

Dec. 10, 1935.

J. S. STONE

2,023,556

FREQUENCY SELECTIVE COMMUNICATION SYSTEM

Filed Oct. 3, 1931

4 Sheets-Sheet 1

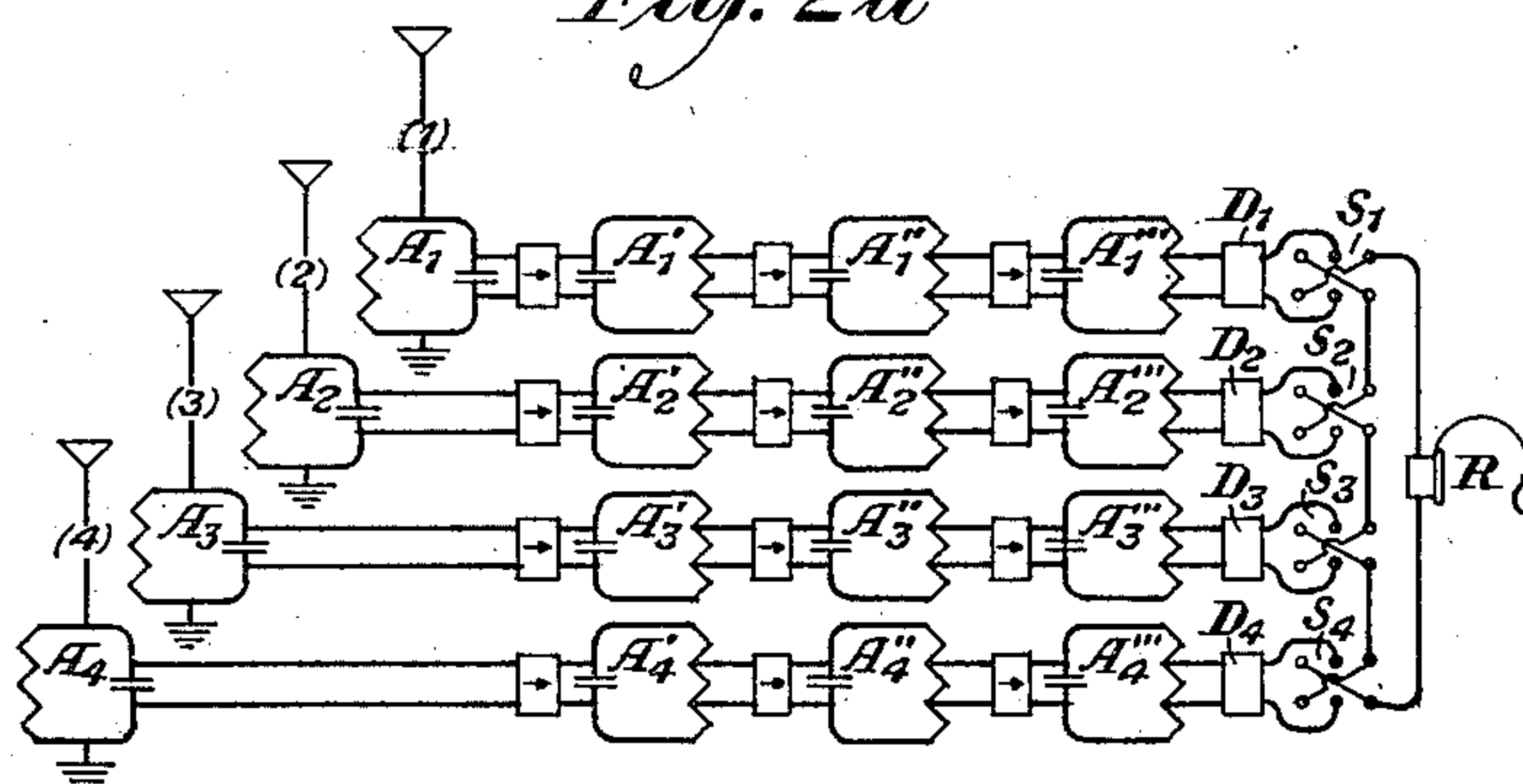
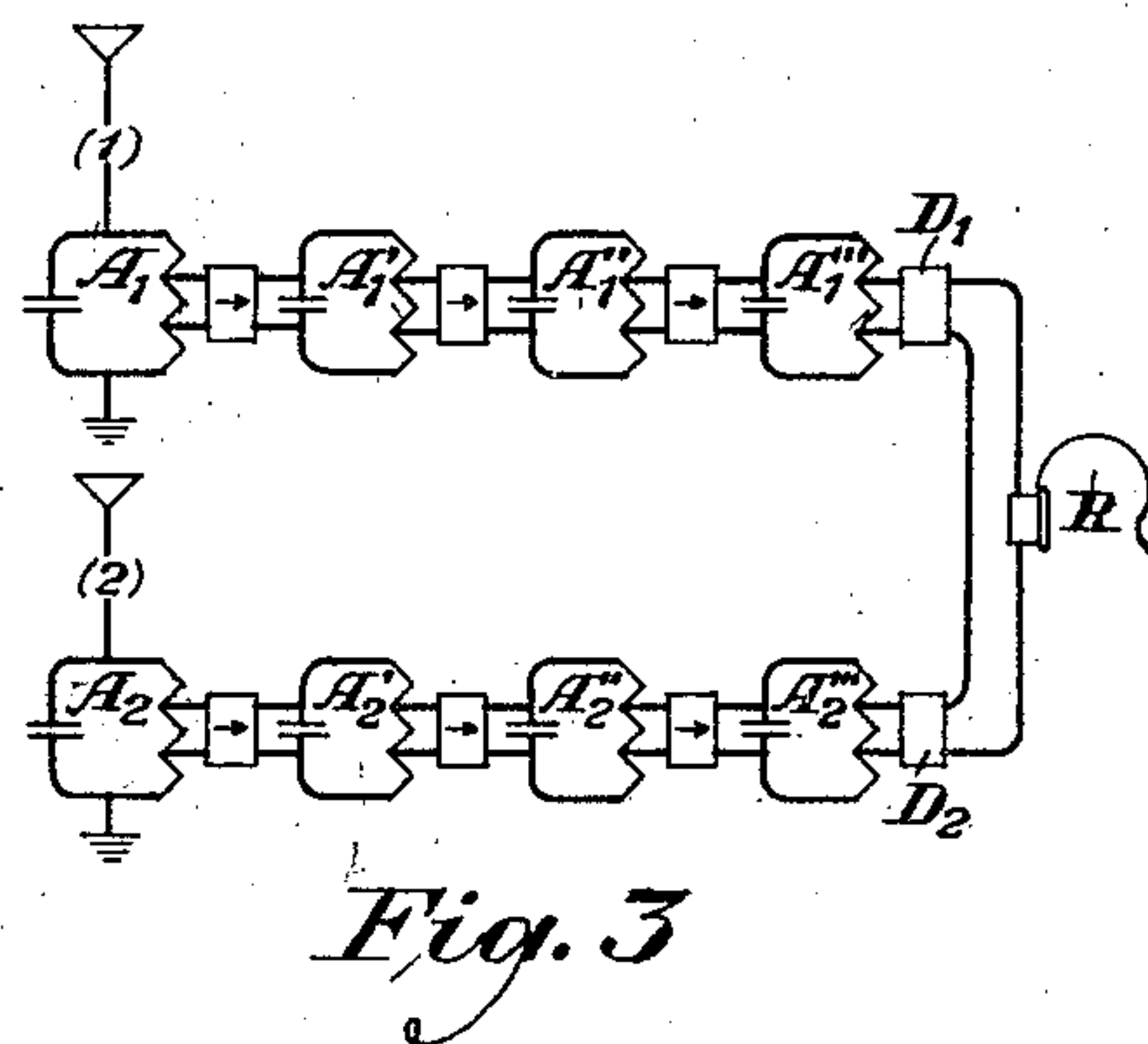
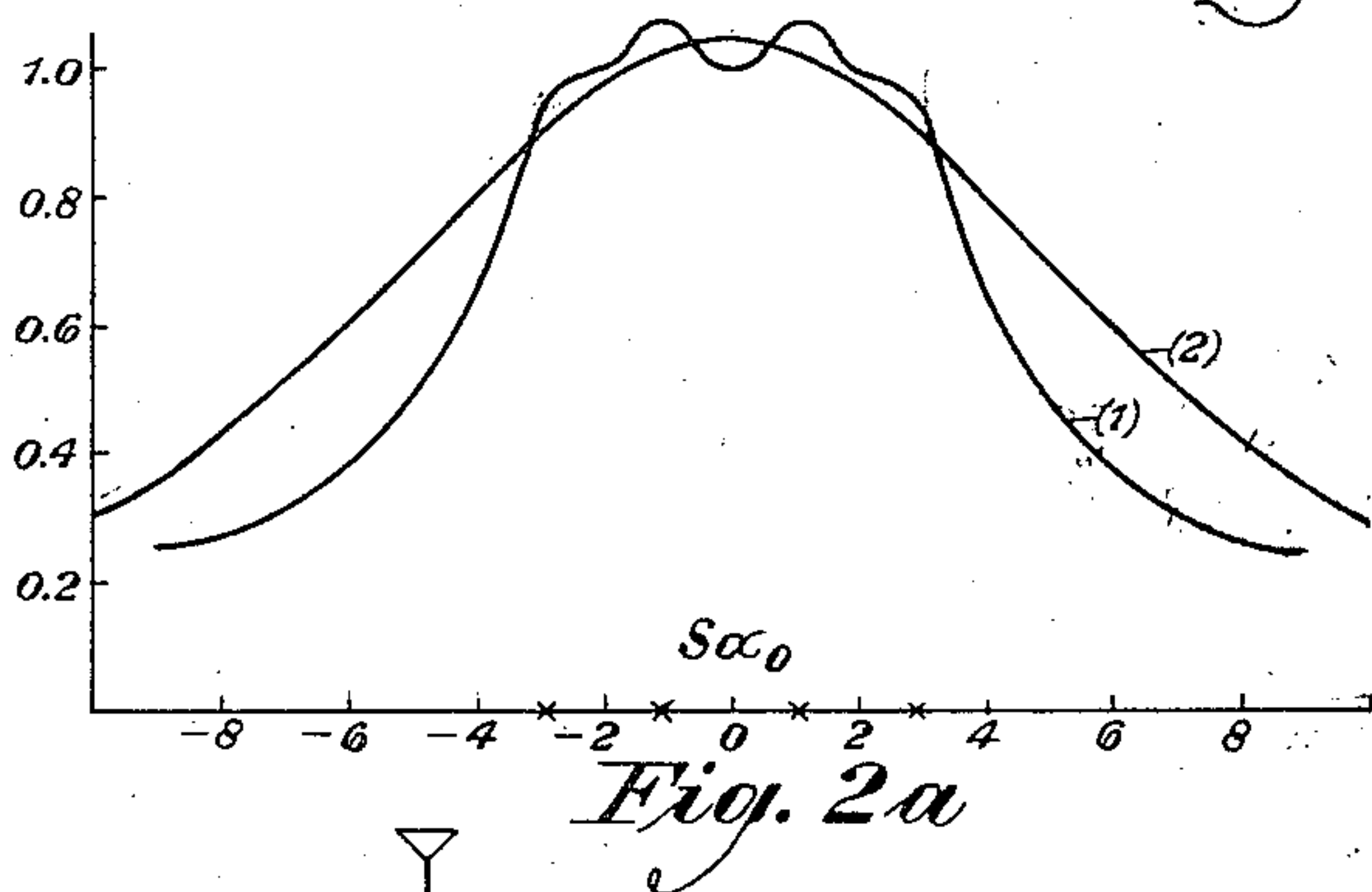
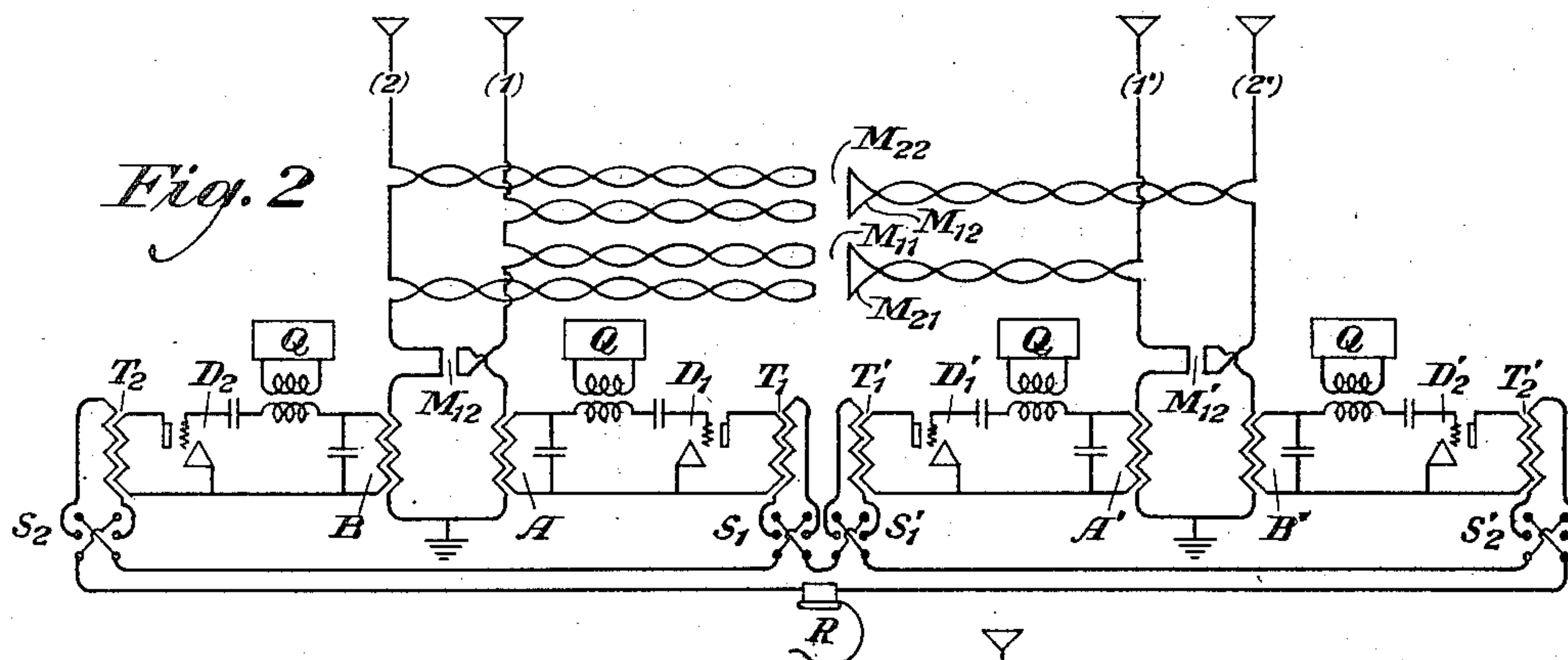
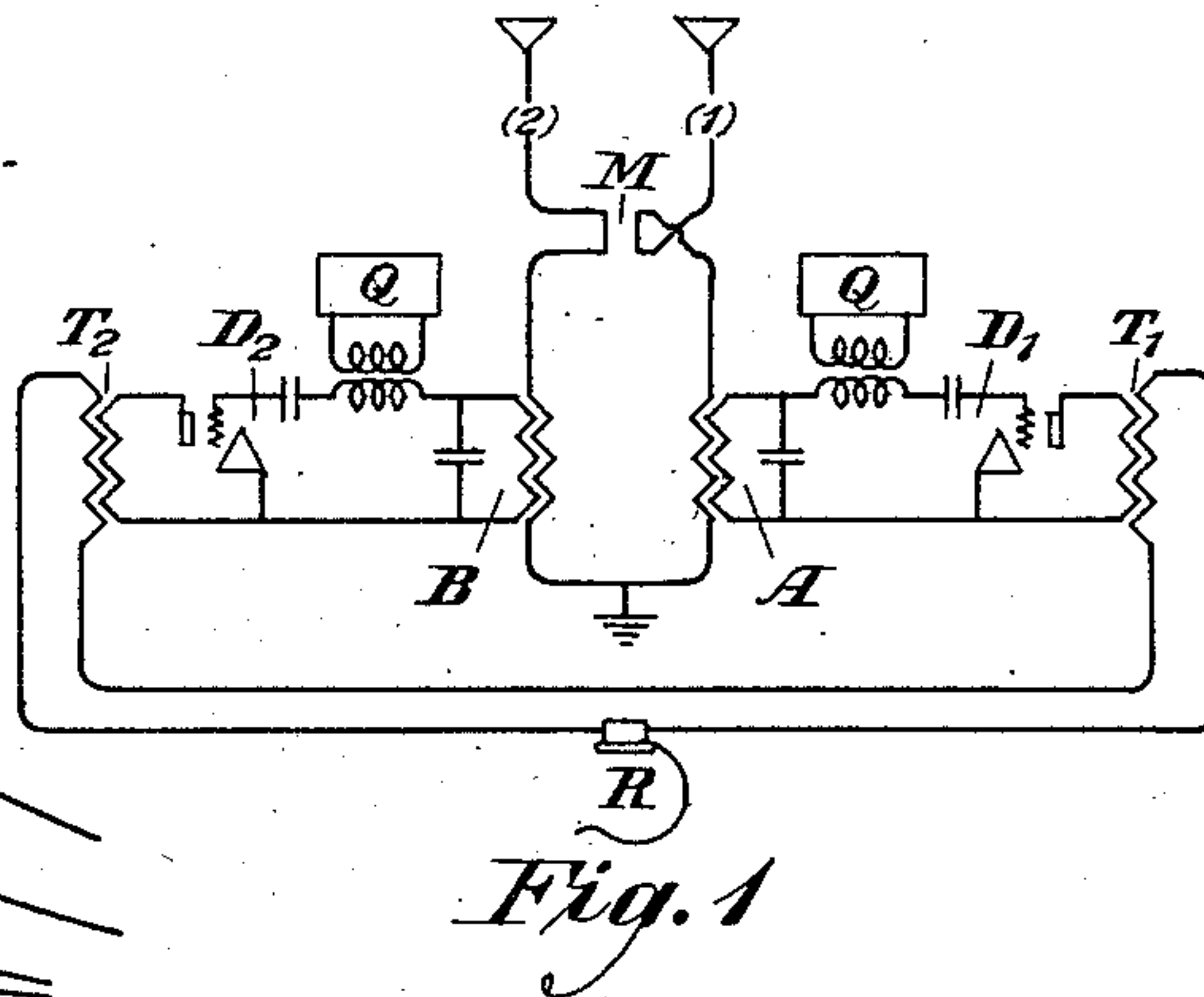
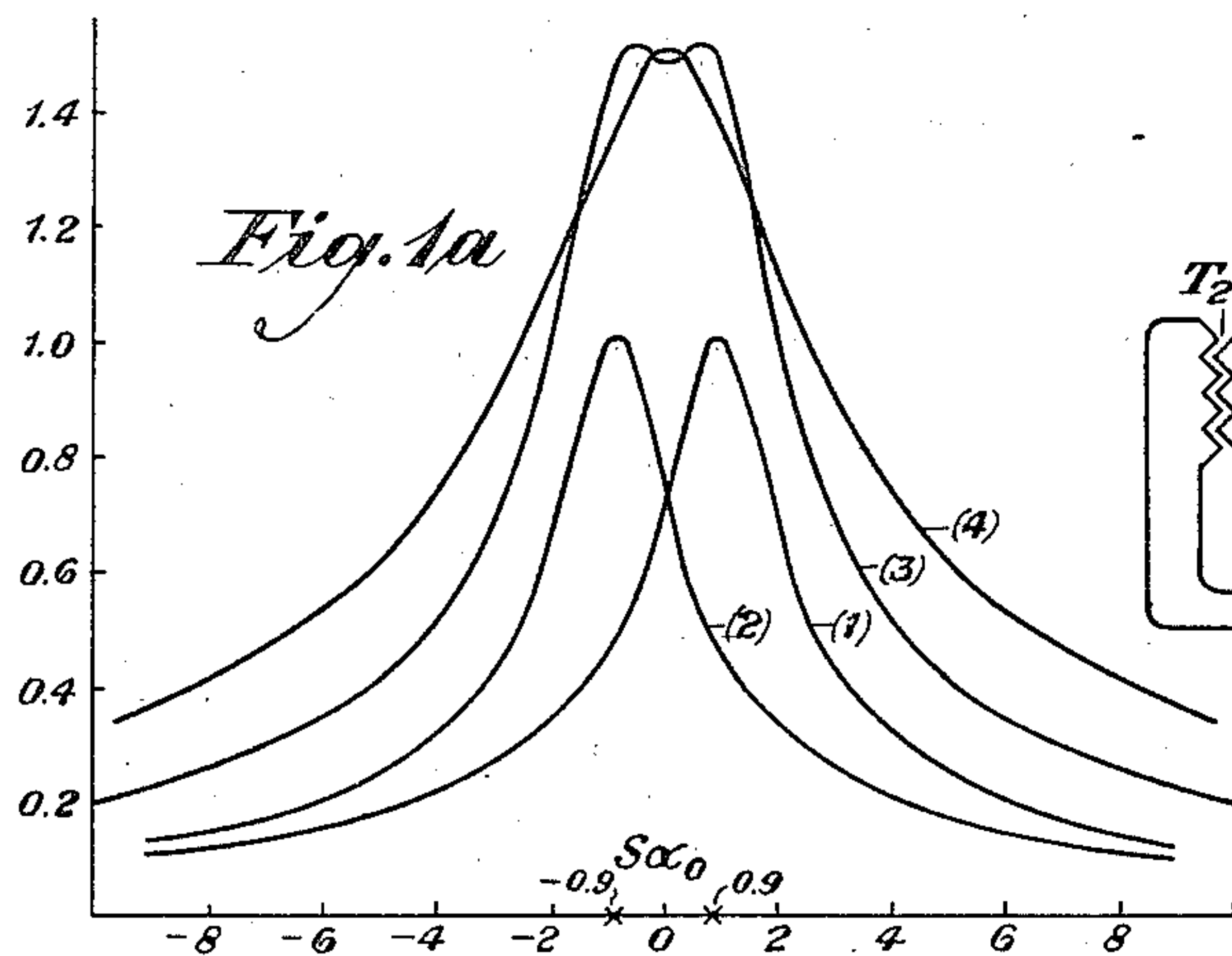


Fig. 4

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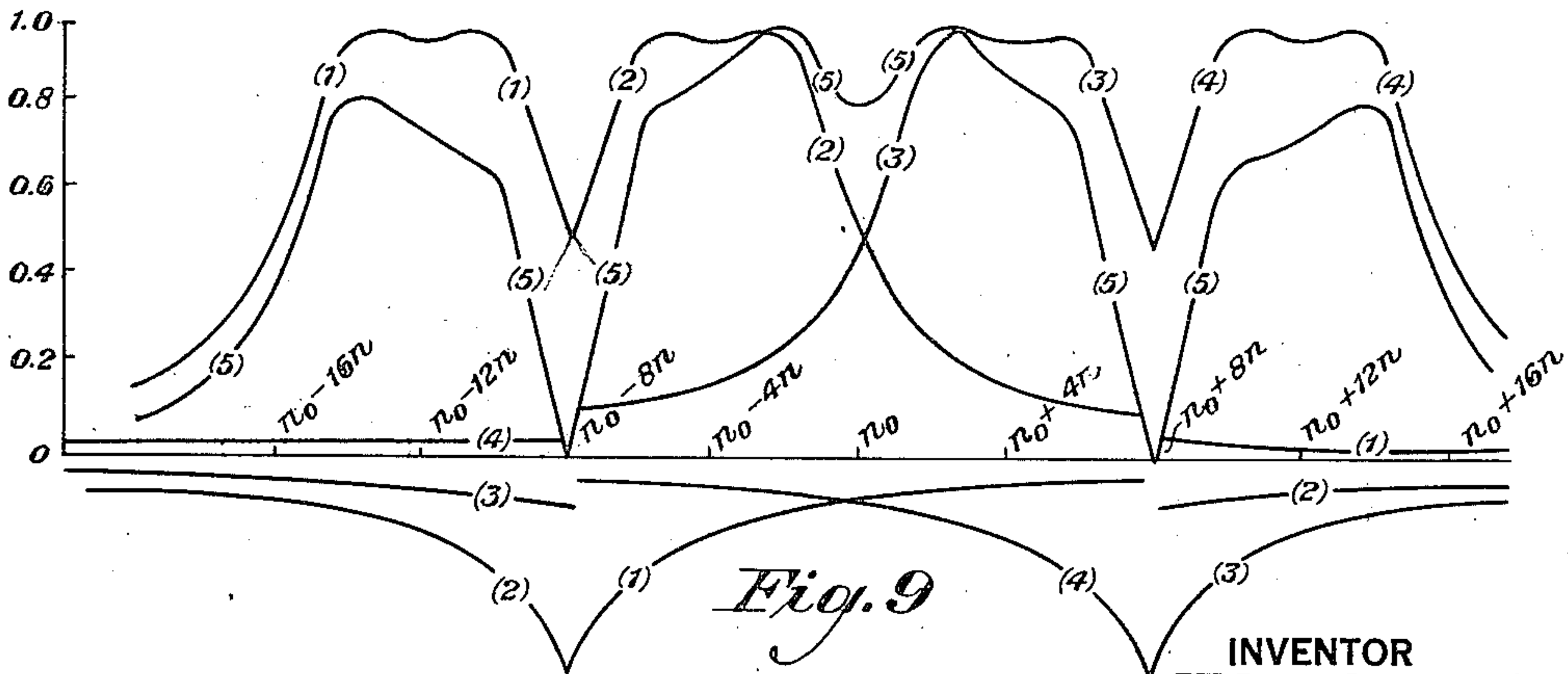
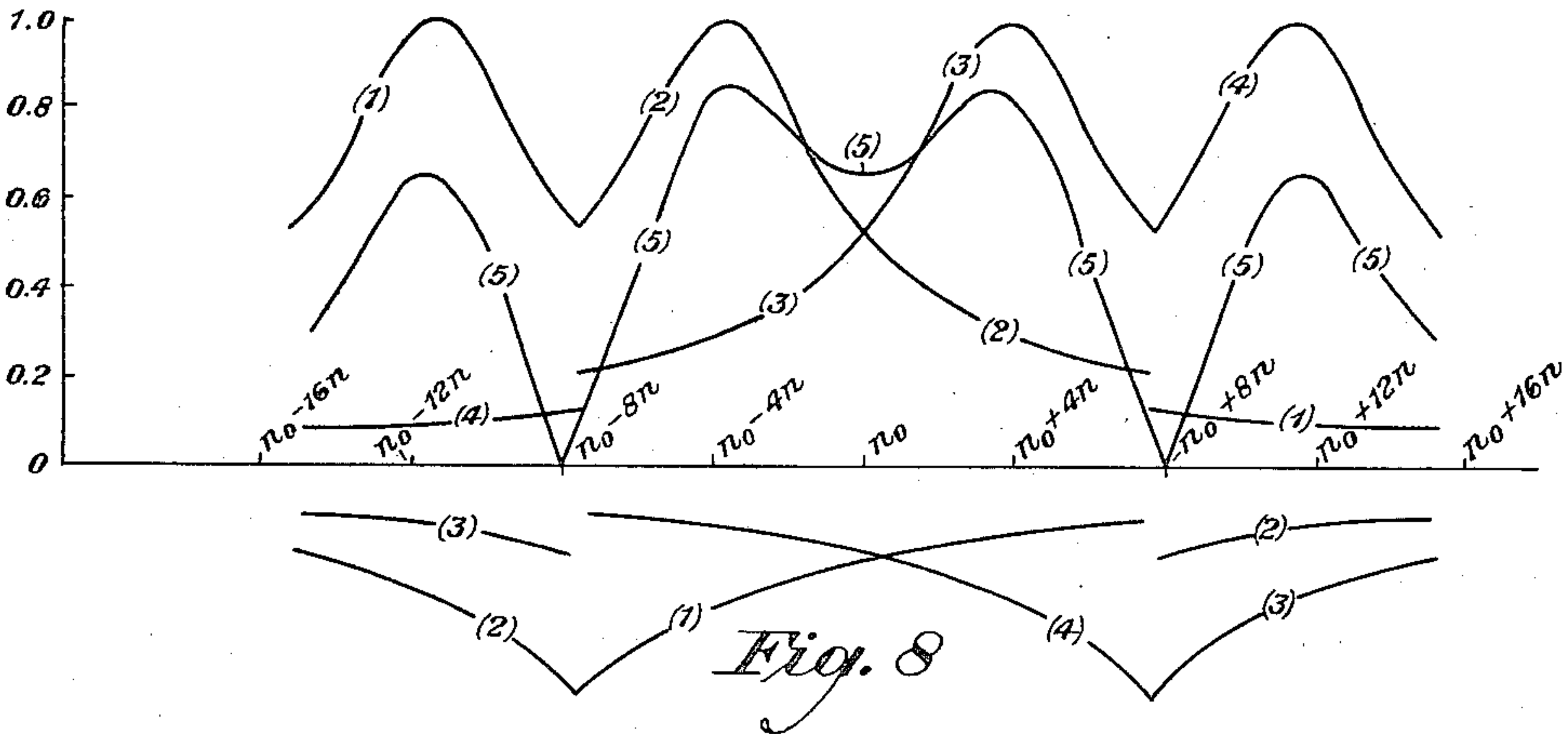
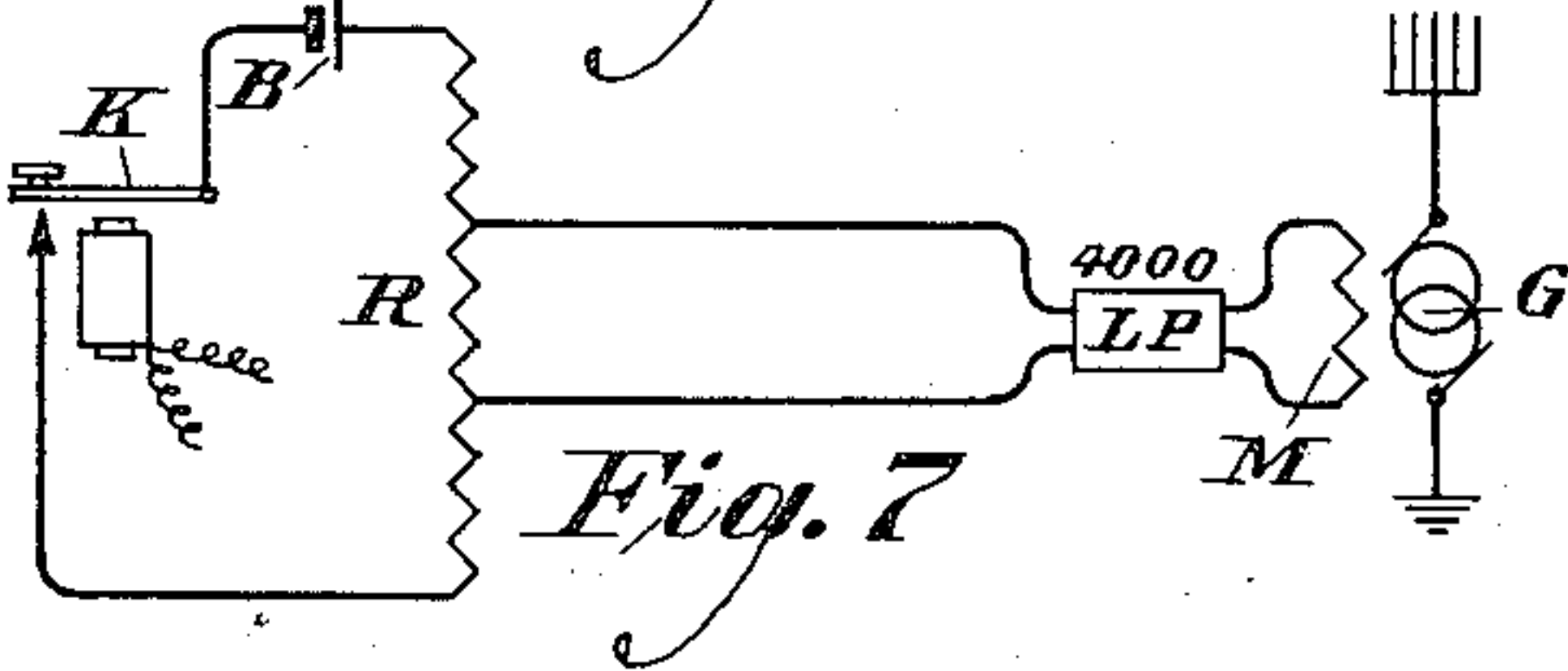
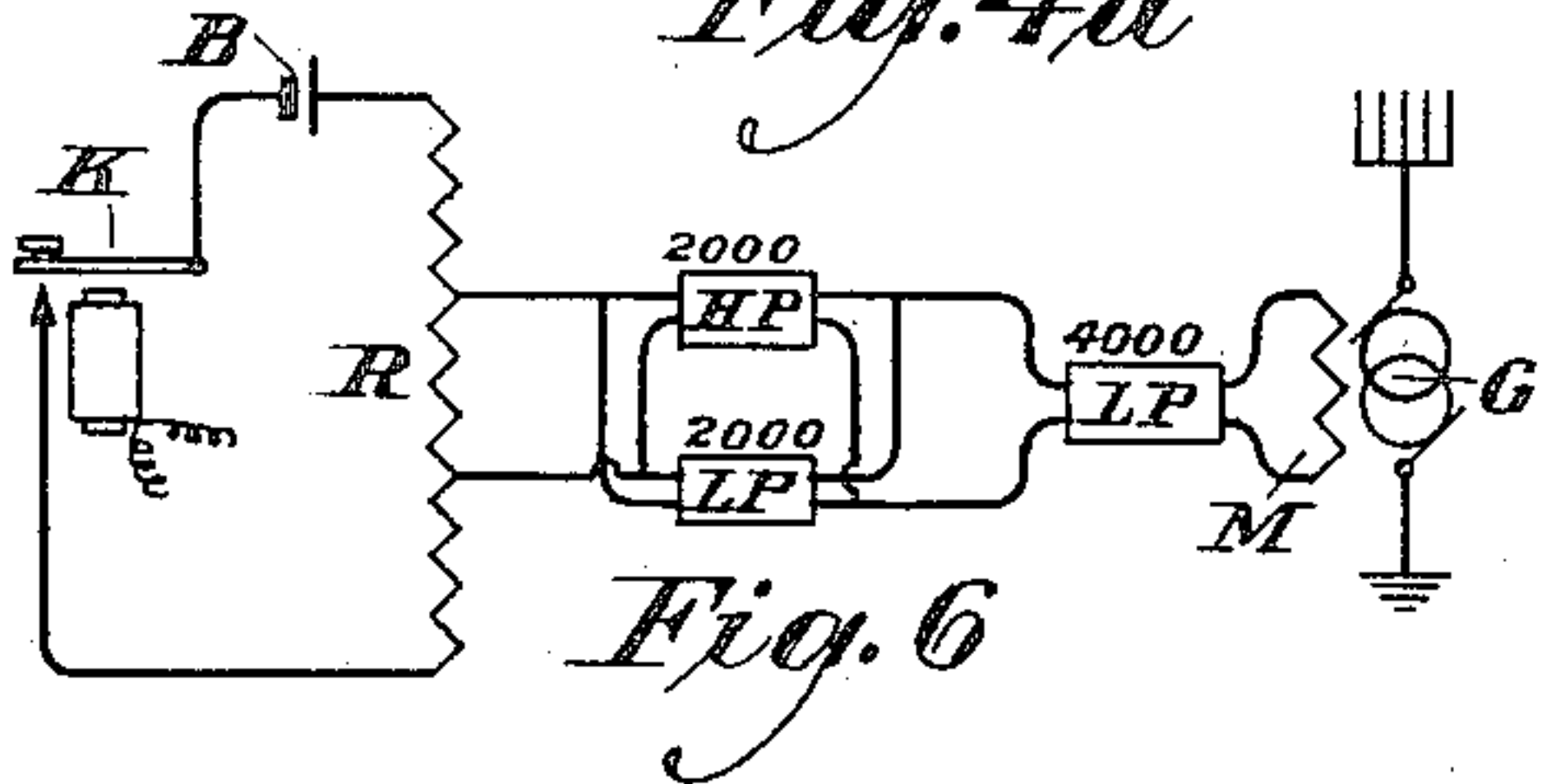
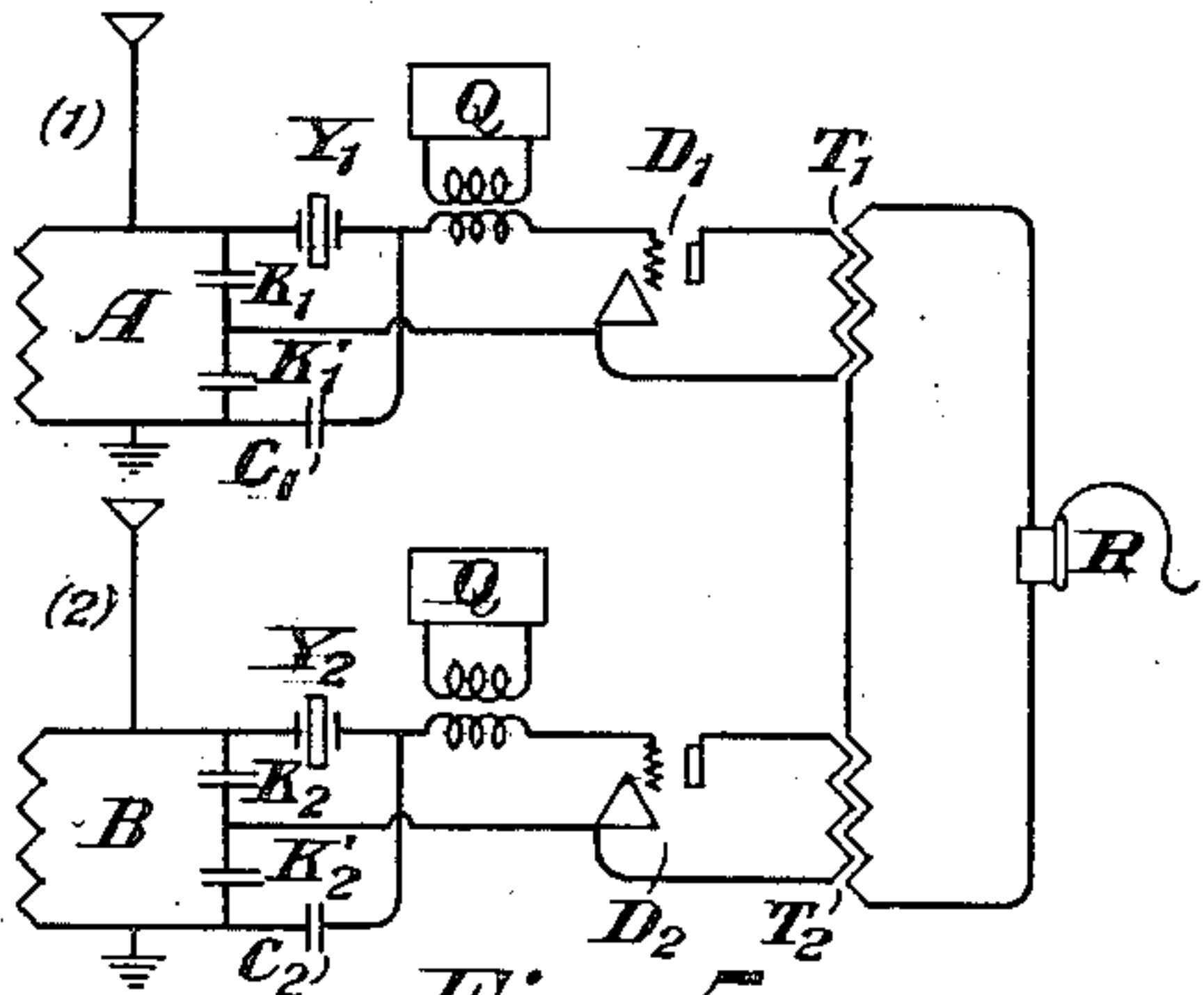
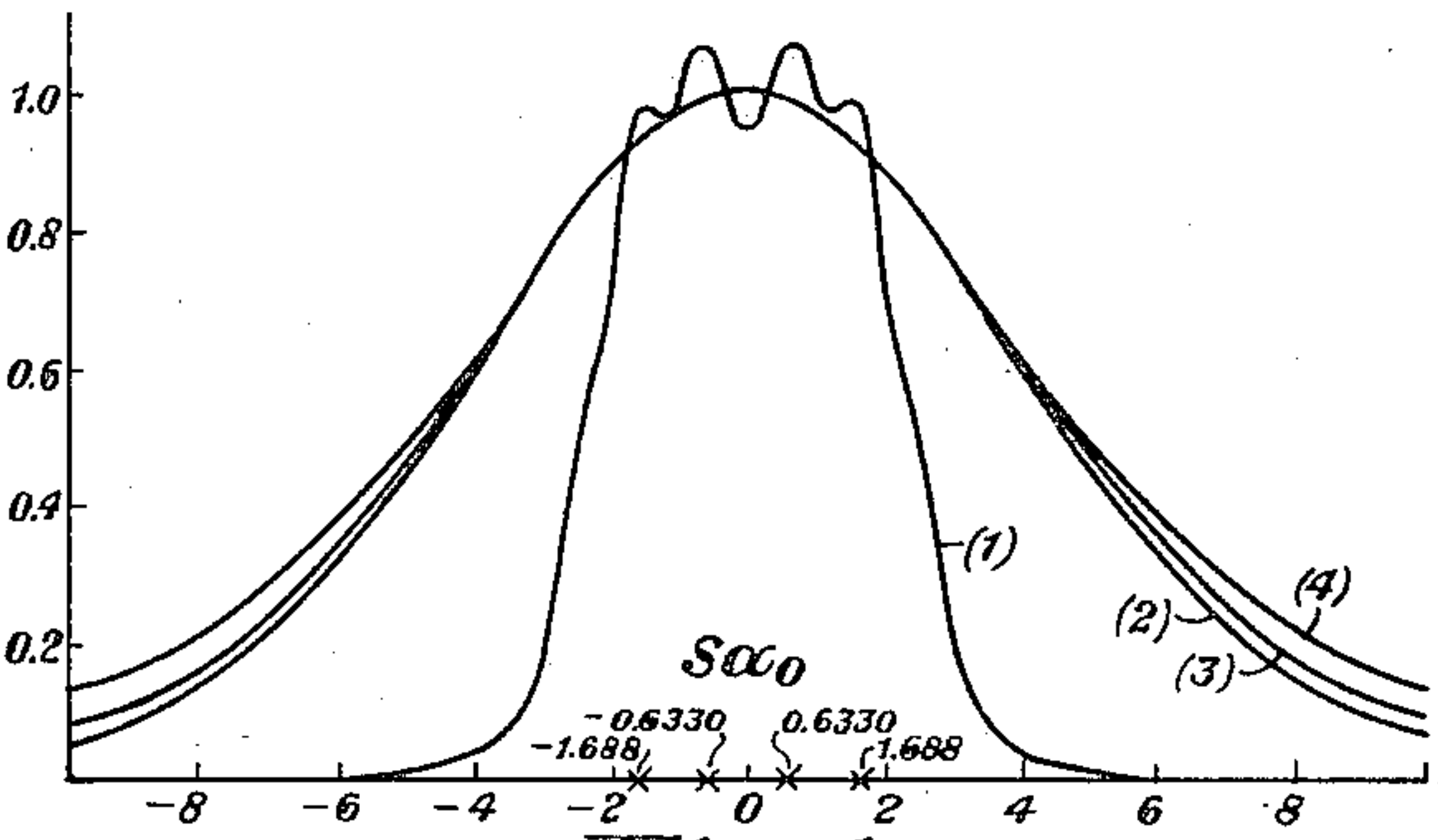
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FREQUENCY SELECTIVE COMMUNICATION SYSTEM

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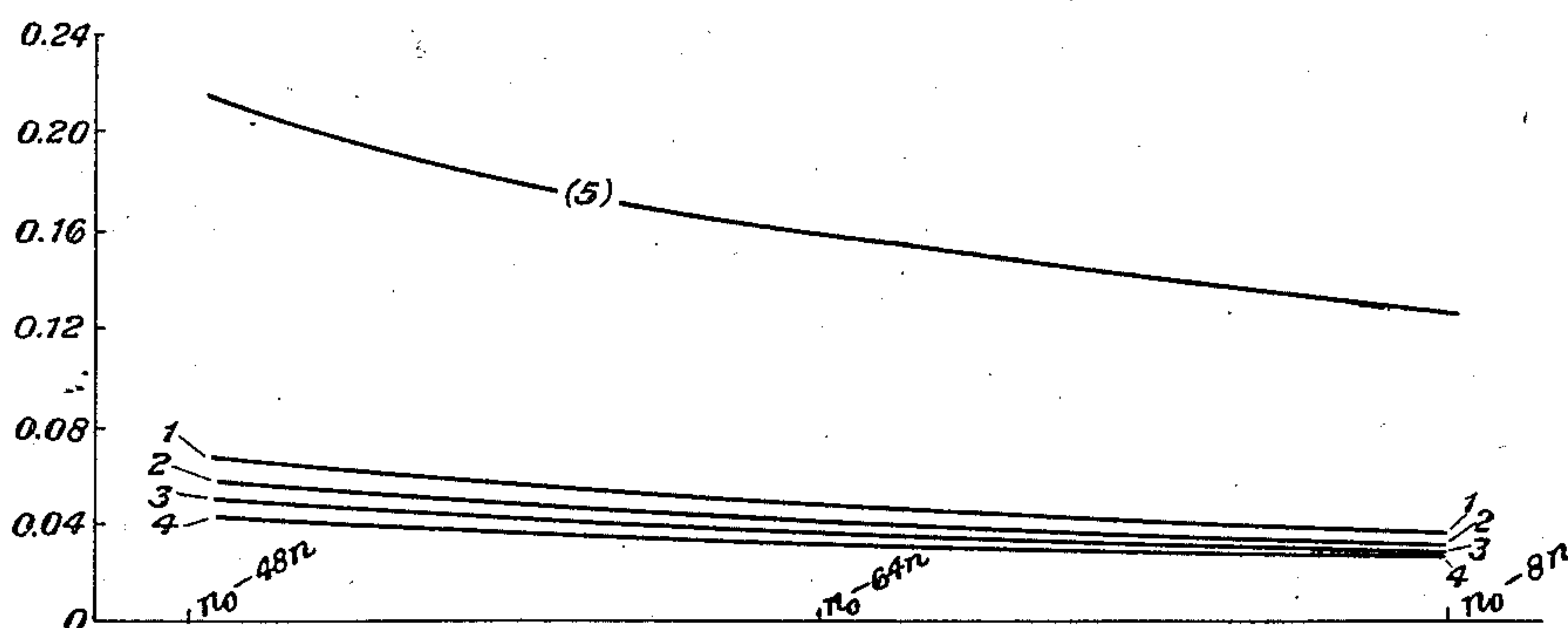
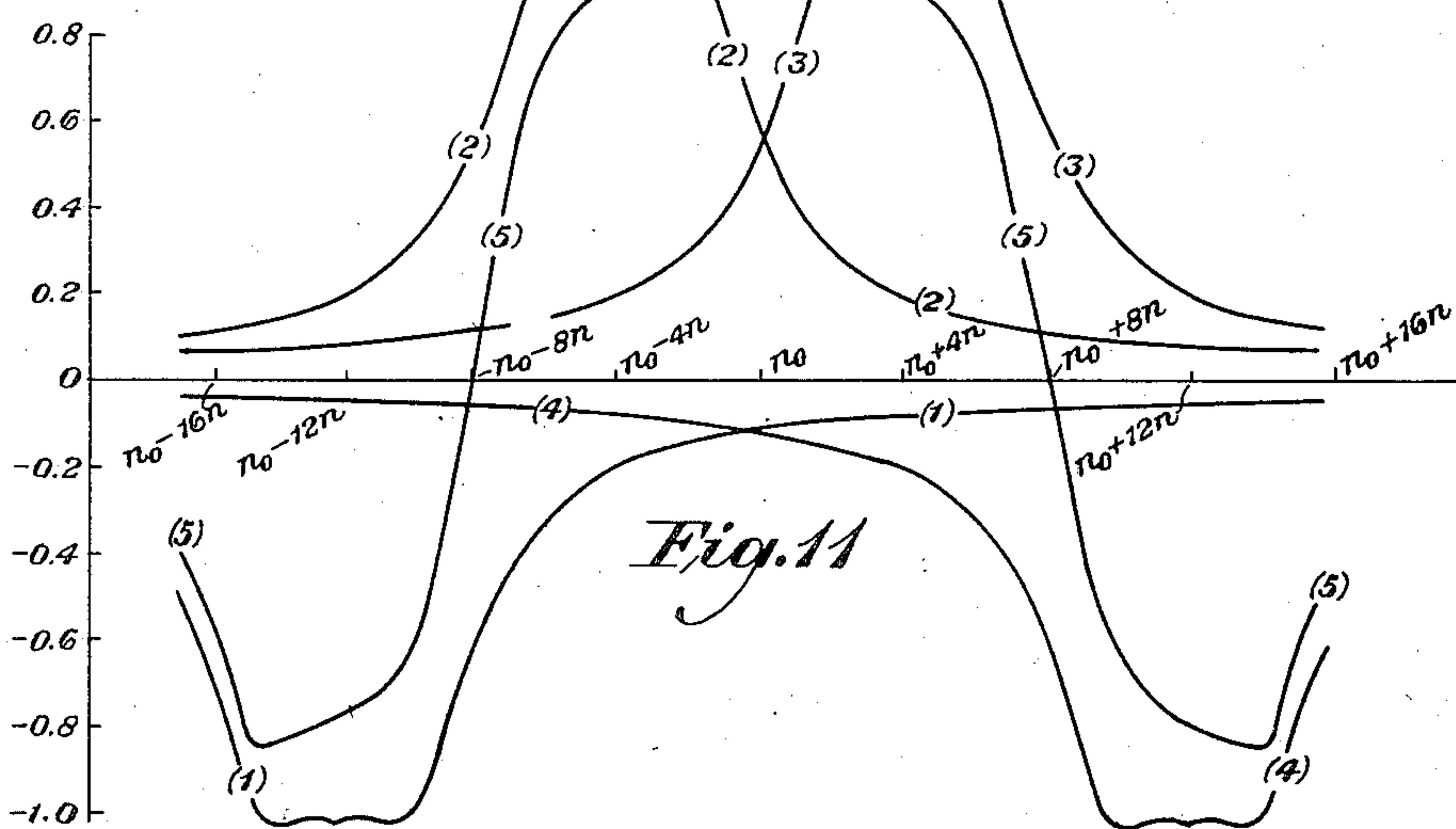
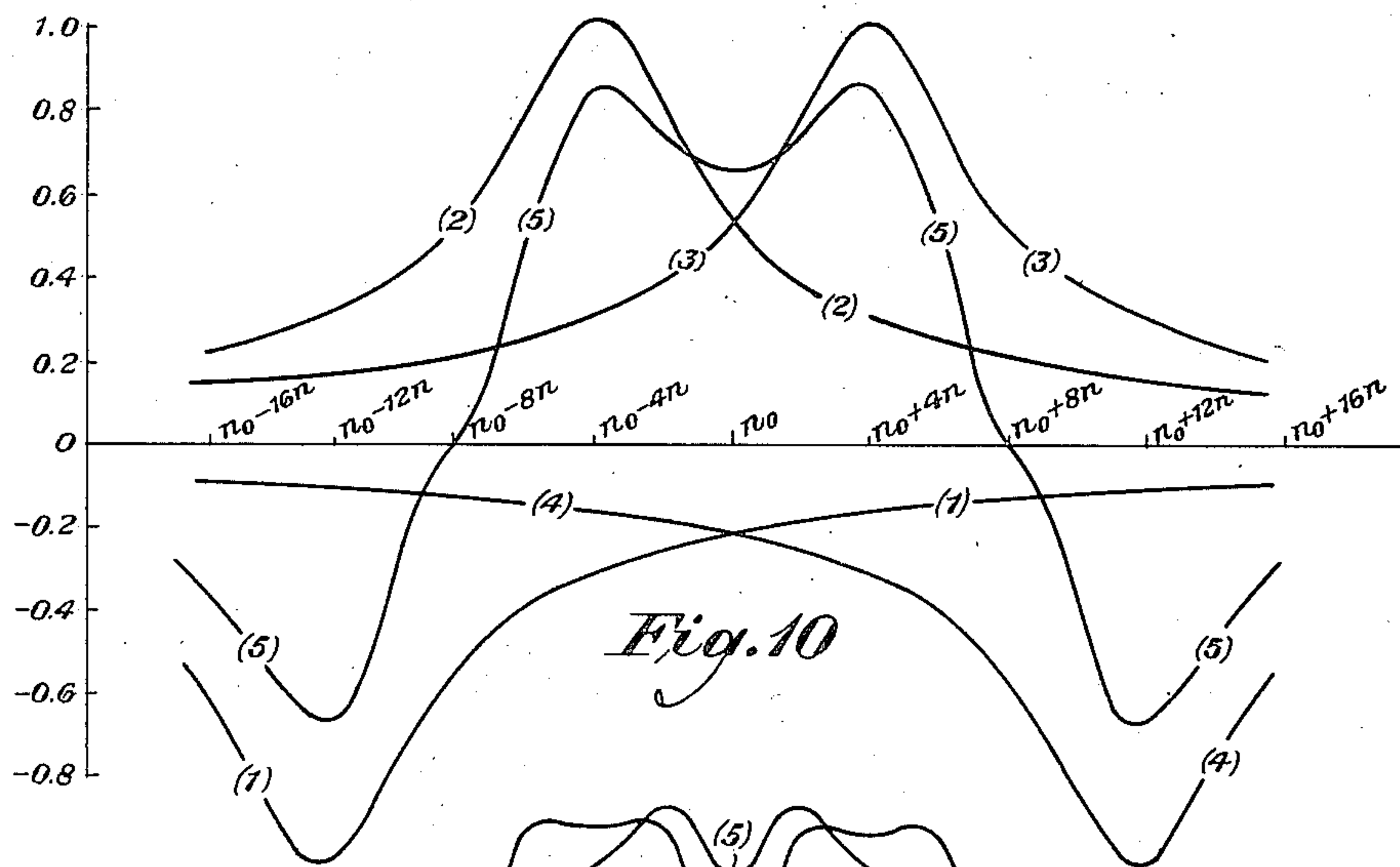


Fig. 12

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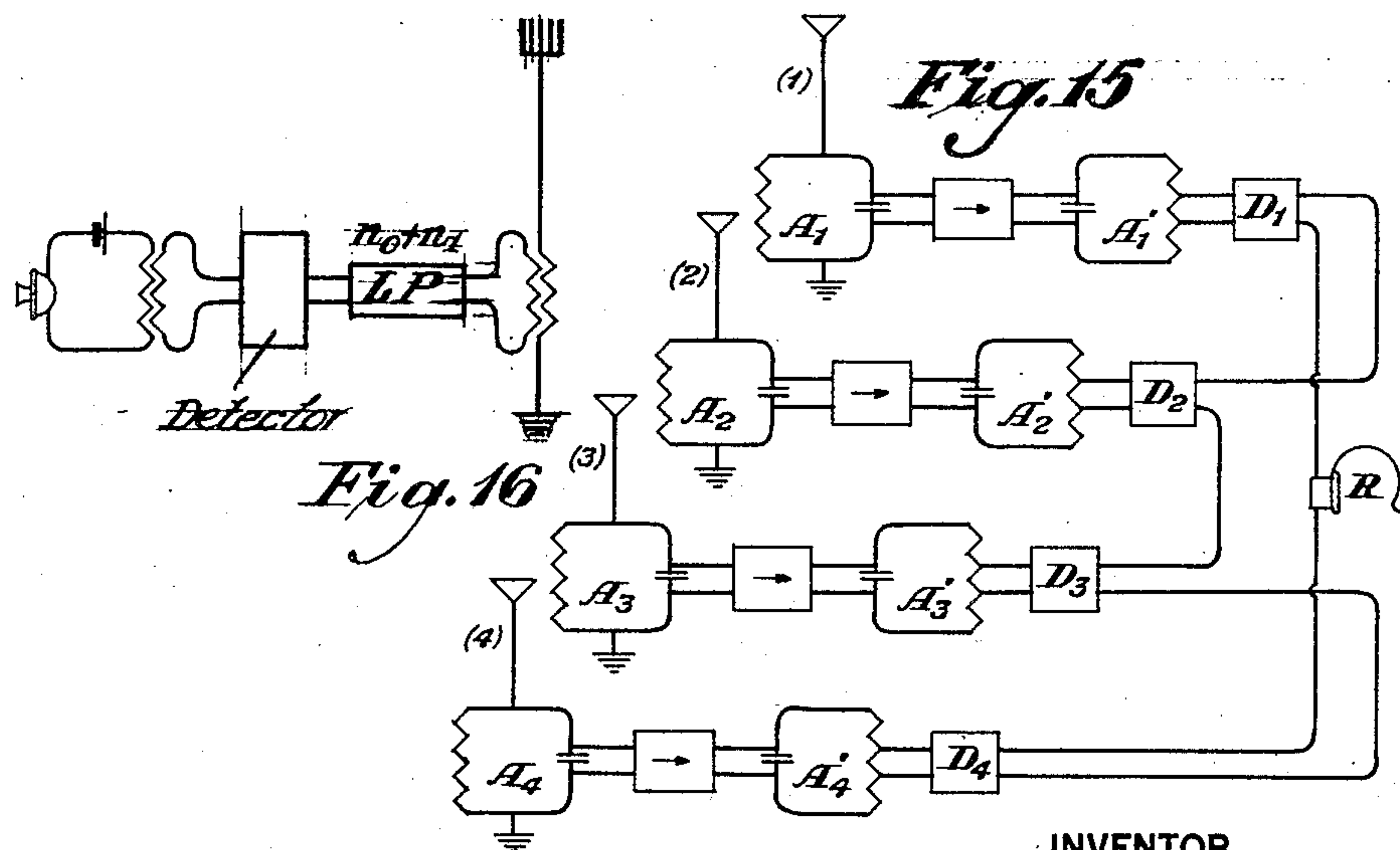
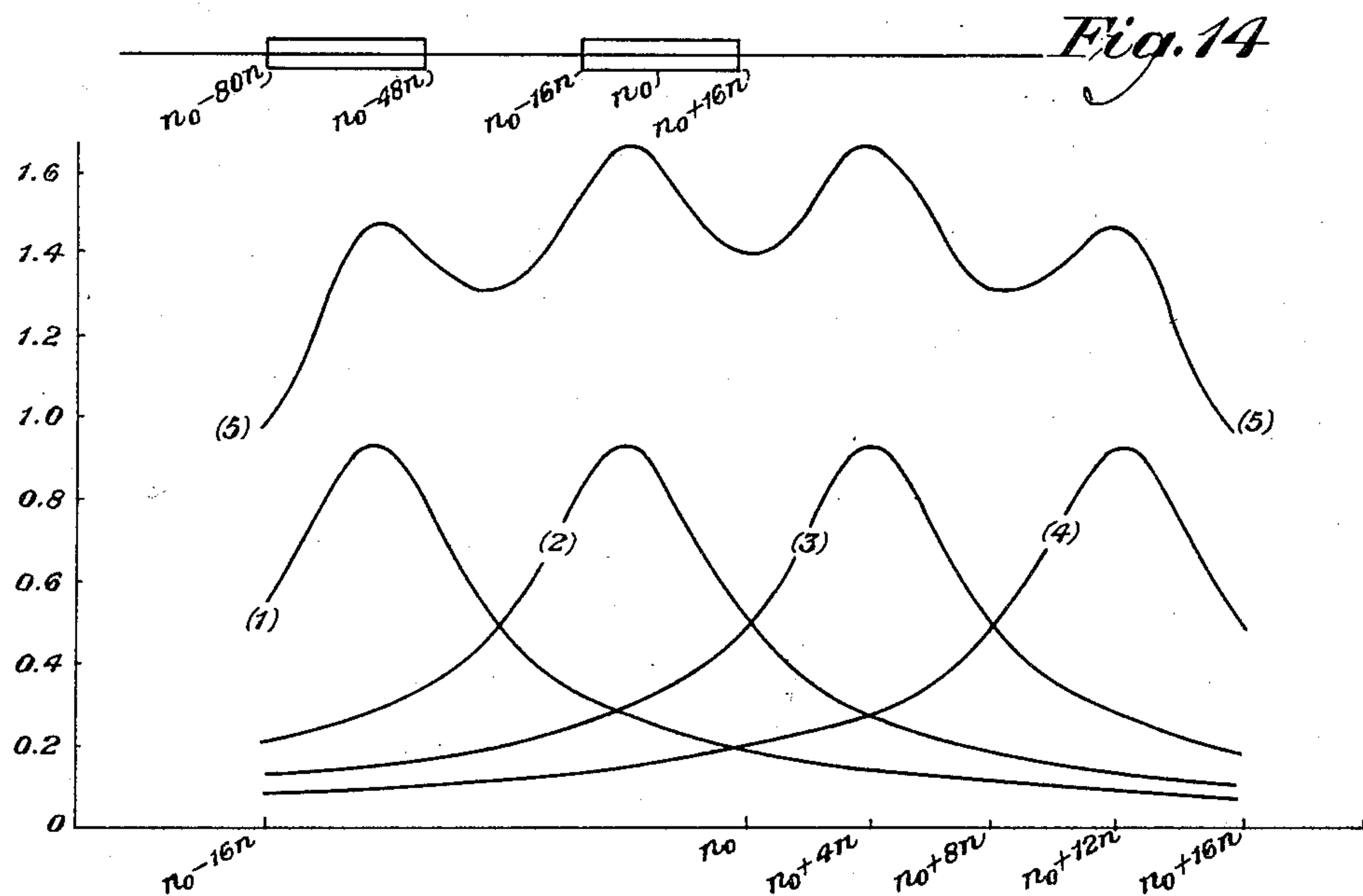
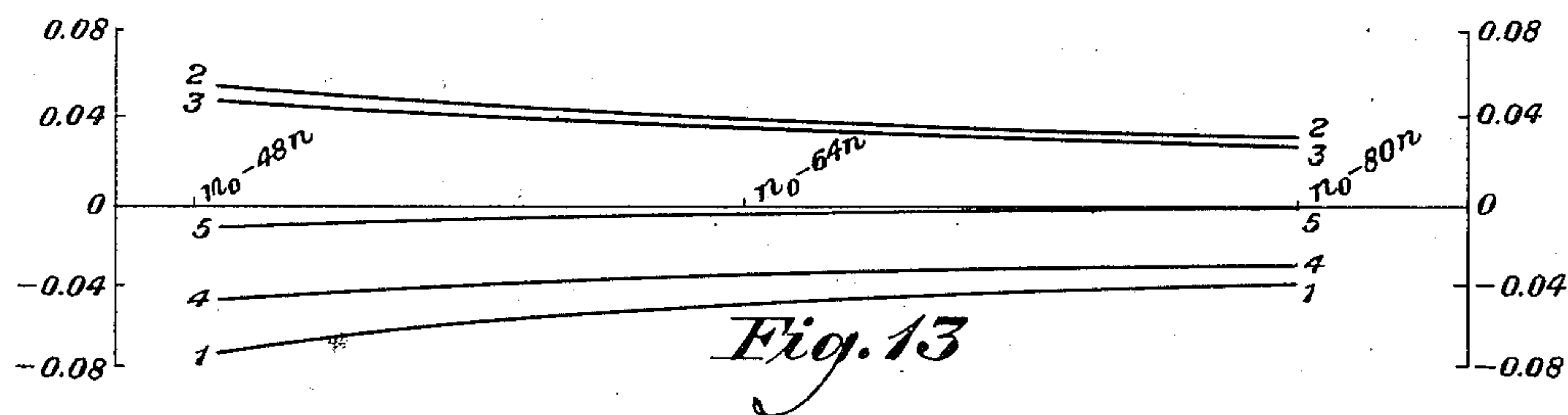
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FREQUENCY SELECTIVE COMMUNICATION SYSTEM

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4 Sheets-Sheet 4



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UNITED STATES PATENT OFFICE

2,023,556

FREQUENCY SELECTIVE COMMUNICATION
SYSTEMJohn Stone Stone, San Diego, Calif., assignor to
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a corporation of New York

Application October 3, 1931, Serial No. 566,741

14 Claims. (Cl. 250—6)

An object of my invention is to provide a system of communication by means of electric waves with economy of the frequency range of the waves. Another object is to provide a highly selective electric wave signaling system with substantially undistorted operation within a certain range of wave frequency and with substantial exclusion of effects outside that range. In the following specification I disclose a limited number of ways in which my invention may be practiced. It will be understood that the following text relates principally to these specific examples of procedure under the invention and that the scope of the invention will be indicated in the appended claims.

Referring to the drawings, Figure 1 is a diagram of a receiving system with two frequency maxima, Fig. 1a is a corresponding curve diagram, Fig. 2 is a diagram of a receiving system with four frequency maxima, Fig. 2a is a corresponding curve diagram, Fig. 3 is a diagram of a receiving system with two frequency maxima and with four stages of tuning and intermediate amplification for each of the two frequencies, Fig. 4 is a diagram of a receiving system with four frequency maxima and with four stages of tuning and intermediate amplification for each of the four frequencies, Fig. 4a is a corresponding curve diagram, Fig. 5 is a diagram which may be compared with Fig. 3 by stating that crystal circuits have been substituted for the four stages of tuning and intermediate amplification of Fig. 3, Fig. 6 is a diagram of a transmitting station having certain advantages, Fig. 7 is a diagram of a more usual type of transmitting station for comparison with Fig. 6; Fig. 8 is a curve sheet of operation for a receiver like Fig. 2 or Fig. 4 receiving from a transmitter like Fig. 6, Fig. 9 is a similar curve sheet for a system involving a certain simple modification of Fig. 2; Figs. 10 and 11 correspond respectively with Figs. 8 and 9, but are for speech and music instead of telegraphic signals, Figs. 12 and 13 are performance curves for the receiver of Fig. 2 respectively without and with alternately reversed connections in its audio output circuit, Fig. 14 is a detail scale notation diagram, Fig. 15 is a curve diagram further illustrating the performance shown in Fig. 12, and Fig. 16 is a diagram of a complete transmitting and receiving system involving certain principles discussed in connection with the preceding figures.

The number of channels of radio communication securable within a given range of frequencies is ultimately limited by the width of the band of frequencies which have to be transmitted in order to secure the requisite clarity of the signals re-

ceived. This is because the selectivity of the receiver may only be pushed to a point beyond which the extreme frequencies of this band of essential frequencies are suppressed or materially discriminated against in the receiver. This fact is so well understood that it need not be further elaborated here.

It is also well known that the band of essential frequencies consists of two "side bands", one of which may be suppressed and transmission of the signals effected with the remaining "side band", thus halving the width of the band of frequencies essential to transmission and so doubling the ultimate possible number of channels which may be successfully used.

It is further well known that the selectivities of the receivers may be increased through the use at the receiver of a succession or chain of similarly tuned resonant circuits, each such circuit being coupled with the next preceding circuit through a one-way relay, and each successive circuit being carefully screened against inductive action from without itself.

Under all circumstances, it is necessary, in order to make full use of the radio frequency range, that transmitters radiate bands of frequencies only wide enough to secure clarity of reception of the transmitted signals in adequate receivers, and to secure this desideratum band filters are used at the transmitter which preclude the radiation of any but the desired band of frequencies. In the discussion which follows, it will be assumed that the transmitters used are so equipped.

It is my purpose to disclose a radio receiver which shall exhibit a great power of excluding frequencies in the vicinity of those of the band to be received, as well as a great power of excluding frequencies remote from those of that band. It is also my purpose to disclose means which will not only permit of the use in radio receivers of a cooperative chain of selective unit circuits of the maximum selectivity heretofore attained in such unit circuits, irrespective of the frequency of the carrier waves employed, thus obviating the serious limitations to the selectivity of the unit circuits of a chain of such unit circuits; but also to disclose how such improved means may be employed to permit of the use at radio receivers of selective units of far greater selectivity than that attainable in resonant electric circuits. Reference is here had to crystal resonators.

My invention may be realized by a procedure which consists in the use of independent and differently attuned selective units for the recep-

tion of different parts of the signal frequency band; in combining the audio frequency output currents of these several receiving units in the circuit of the ultimate receiving telephone; and in
 5 so choosing the relative frequencies, selectivities, and receptivities of the independent selective units that the arithmetical sum of the audio frequency responses of the several selective unit or component receivers is such as to insure a sub-
 10 stantially uniform characteristic for the composite receiver over the full signal band to be received. The "independent and differently at-tuned selective units" will in general consist of chains of selective circuits or of individual reso-
 15 nant crystals.

It will be convenient here to explain certain terms that will be employed in the following discussion. In a tuned circuit designated by the subscript 0, let the frequency of maximum re-
 20 sponse be f_0 and let f be any other frequency. Then the frequency function α_0 is defined by the equation

$$\alpha_0 = \frac{f^2 - f_0^2}{ff_0}$$

25 Similarly for any other tuned circuit designated say by the subscript 1; in this case

$$\alpha_1 = \frac{f^2 - f_1^2}{ff_1}$$

30 The current intensity at various frequencies in a tuned circuit designated by subscript 0 will be given by an equation of the form $I_0 = F(f)$ and therefore by an equation of the form $I_0 = F'(\alpha_0)$. The function F' may be transformed so that

$$35 \quad I_0 = K(1 + S_0^2 \alpha_0^2)^{-1/2}$$

and this equation defines S_0 , which is called the selectivity of the circuit designated by the sub-
 script 0.

40 A simple form of receiver is shown in Fig. 1, but it cannot be completely illustrated in a circuit diagram, the receiver involving as it does the precise proportionment of the several selective parts in accordance with the principle of the invention.

45 In this diagram (1) and (2) are two equal antennas whose only direct association is the coupling M which is carefully designed to neutralize the mutual inductive effects of the antennas and so render them mutually independent of each
 50 other or conjugate, in order that a current in one will not engender a current in the other. This element permits the plural antennas of the receiving stations disclosed in this specification to be juxtaposed without engendering mutual inter-
 55 ference. Circuits A and B are two resonant loop circuits attuned to frequencies f_1 and f_2 respectively. D_1 and D_2 are detectors which translate the radio frequency currents of the loops A and B into audio frequency currents corresponding to the fluctuations of amplitude of these radio fre-
 60 quency currents. The devices marked Q are sources for supplying current of carrier frequency to the detectors. R is a telephone receiver so associated with the audio frequency side of the
 65 detectors D_1 and D_2 that it responds to the arithmetical sum of the output currents of these detectors.

The antennas (1) and (2) are of equal recep-
 70 tivity to waves of their respective frequencies f_1 and f_2 , as are also the selective circuits A and B. The detectors D_1 and D_2 are equally responsive to the E. M. F.'s impressed upon them by the loop circuits A and B respectively. The trans-
 75 formers T_1 and T_2 are connected in such senses as to cause the equally intense audio frequency

currents delivered by the detectors D_1 and D_2 to be arithmetically additive in their effects upon the ultimate telephone receiver R.

The mode of operation of this organization will be best understood by having reference to the
 5 curves of Fig. 1a. Curves 1 and 2 have intensities of direct current developed in the output circuits D_1 and D_2 respectively, for ordinates, and for the abscissas they have the values of $S\alpha_0$, where S is the common selectivity of the resonant
 10 loop circuits A and B, while α_0 is the frequency function of the carrier frequency.

Curves 1 and 2 are the receiving characteristics of component receivers $1AD_1T_1$ and $2BD_2T_2$ re-
 15 spectively, i. e., they represent the intensities of the direct current outputs of these two component receivers for varying frequency functions of the received waves over the frequency func-
 20 tion range of $\alpha_0 = \pm 9/S$, and for varying frequencies of these received waves over the frequency range given by the expression

$$f \approx f_0 \left(1 + \frac{81}{8S^2} \pm \frac{9}{2S} \right).$$

When $S=200$, which is its most usual approxi-
 25 mate value in tuned radio circuits, this frequency range extends from $f=1.02275f_0$ to $f=0.97775f_0$. When S is smaller or larger than 200, the frequency range is correspondingly larger or smaller,
 30 respectively.

The direct currents corresponding to curves 1 and 2, Fig. 1a, are arithmetically added in the circuit of the common or ultimate telephone re-
 ceiver R, so that the receiving characteristic of the complete receiver is given by the sum of these
 35 curves, that is, by curve 3, Fig. 1a.

It will be observed that the receiving characteristic is substantially flat over the range
 $S\alpha_0 = \pm 0.9$. Over this range the characteristic does not differ by quite 1% from the mean. For
 40 a selectivity of 200, this corresponds to a frequency function range of $\alpha = \pm 0.0045$, or a frequency range of $f = (1.0000025303 \pm 0.00225)f_0$. If this band is to be 10,000 cycles wide with a selec-
 45 tivity of 200, the carrier frequency must be about two and a fifth megacycles.

If the extreme frequencies of the band may be permitted a loss of 17%, then the width of the band becomes $S\alpha = \pm 1.5$, which gives a frequency
 50 range of $0.00750f_0$. When this band is 10,000 cycles wide, the carrier frequency is one and a third megacycles.

The amplitude curve of a simple resonant circuit that gives a characteristic in which the ex-
 55 treme frequencies of the signal band of 10,000 cycles are 17% less intense than the central or carrier frequency is plotted for comparison in curve 4, Fig. 1a. In this curve 4, the selectivity is less than 45% of that of curves 1 and 2. Be-
 60 sides giving a less favorable receiving characteristic than that of curve 3 over the signal frequency band to be received, the circuit of curve 4 is not nearly so exclusive of frequencies beyond this band and is not therefore so economical of
 65 the frequency range.

The next step in the development of the idea involved in the structure of Fig. 1 is to mul-
 70 tiply the number of equal and independent component receiving units whose output currents are combined to actuate a common or ultimate tele-
 75 phone receiver. Thus Fig. 2 illustrates the case of four equal component receivers combined to form a single receiver with a favorable receiving characteristic over more than double the width of frequency band received by the receiver of Fig. 1

1. In this diagram all of the resonant receiving units or component receivers have the same selectivity and receptivity and their equal intensity outputs are additive in their effects upon the common and ultimate telephone receiver R. The reversing switches S_1, S_1', S_2 and S_2' are for a use that will be mentioned in connection with Fig. 6. The four equal antennas are so associated, through the intermediary of the mutual inductances designated by the M's, as to neutralize any natural inductive effects between them.

The theory of operation of this organization is illustrated in curve 1, Fig. 2a. This curve is obtained as the sum of four curves equally spaced along the axis abscissas, each of the character of curves 1 and 2 of Fig. 1a. They are separated by the interval $S_{\alpha 0}=4$, which when $S=200$ corresponds to a frequency function interval of 0.08, and which in turn corresponds to a frequency interval $0.01f_0$.

Curve 1 on Figs. 2a has the scale of the ordinates so reduced as to give a receiving characteristic of approximately unity maximum intensity. This curve gives the receiving characteristic of the organization of Fig. 2. It varies over a range of about 7% in a range of $S_{\alpha 0}=\pm 3$. For $S=200$, this corresponds to a frequency function range of 0.03 or a frequency range of $0.015f_0$. If this range is 10,000 cycles, then the carrier frequency f_0 is about 670,000.

In the curves of Figs. 1a, 2a and 4a the position on the $S_{\alpha 0}$ scale of the resonant units or component receivers is marked by an x on the scale of abscissas. Curve 2 on Fig. 2a shows the receiving characteristic secured by a chain of four resonant circuits alternately disposed with amplifiers, each such circuit being of selectivity $S_1=0.9435S$, and having a receiving frequency band of about the same width as that of the receiver of Fig. 2. Two such chains are shown in Fig. 3, one from A_1 to A_1''' and another from A_2 to A_2''' .

An inspection of the receiving characteristics shown in curve 3, Fig. 1a and curve 1, Fig. 2a shows that the parallel resonant unit receiver is capable of giving a flat top receiving characteristic with very definite "cut-offs", so that this type of receiver tends to exclude nearby frequencies to a degree not shared by the series resonant unit receivers of the chain type, though the latter tend to give a much better exclusion of remote frequencies. This latter advantage of the series unit receivers is very marked. The four resonant unit series receiver which has nearly as good a receiving characteristic as curve 1, Fig. 2a, over a band of width $S_{\alpha 0}=\pm 3.5$ is one in which the resonant units have the common selectivity $S_1=0.0943536S$ and a receptivity of 1.01227. Such a chain has a receiving characteristic given by curve 2, Fig. 2a. This curve has a maximum intensity of 1.05 at $S_{\alpha 0}=0$, an intensity of 0.9 at $S_{\alpha 0}=\pm 3$, an intensity of $0.602+$ at $S_{\alpha 0}=\pm 6$, and an intensity of $0.354+$ at $S_{\alpha 0}=\pm 9$. However, at the remote frequency corresponding to $S_{\alpha 0}=100$, the parallel arrangement of curve 1, Fig. 2a, has an intensity of about 0.0201, while the series arrangement of curve 2, Fig. 2a, has an intensity of but about 0.0013.

A careful study of these two systems of combining resonant units shows that they are complementary, each possessing in the greater degree the advantages possessed in the lesser degree by the other. I propose their combination as a possible means of producing the ideal type

of receiver having a flat-topped receiving characteristic with sharp cutoffs and great powers of excluding not only remote, but also nearby frequencies.

Such suggested combinations are illustrated in Figs. 3 and 4. In Fig. 3 is illustrated a system composed of two chains, each consisting of four resonant circuits disposed alternately with amplifiers, these two chains combined in parallel so as to act additively on the ultimate receiver R. In this diagram, we have the equal antennas 1 and 2 and the chains of equal resonant circuits A_1, A_1', A_1'', A_1''' and A_2, A_2', A_2'', A_2''' in which the elements are associated together through one way relays designated by small squares each enclosing an arrow which indicates the direction of action of the relay.

Without further discussion of this case, we may pass to that of the organization of Fig. 4. Here we have four chains of equal resonant circuits and alternately disposed amplifiers combined in parallel so as to cooperate in actuating the ultimate telephone receiver R. The reversing switches S_1, S_2, S_3 and S_4 are for a use that will be mentioned in connection with Fig. 6. The receiving characteristic of this organization is illustrated in curve 1 on Fig. 4a. Here we have a very favorable characteristic over the band of width $S_{\alpha 0}=\pm 1.75$. This receiving characteristic is compared with curve 2, Fig. 4a, which is that of a receiver consisting of a chain comprising 16 resonant circuits, each of which has a selectivity of $S_1=0.065794S$. This chain receiver has about the same width of band as that of Fig. 4 but is far from having the power to exclude nearby frequencies possessed by the latter.

It is seen from the foregoing that the combination of the parallel and series chain of resonant units overcomes the disadvantages of those types of chains as well as combining their advantages.

The system of Fig. 3 has 2 chains of 4 stages each, 8 resonant units in all. Similarly, the system of Fig. 4 has 16 such units. It will be instructive to show what advantage there might be in putting all these 8 or 16 units in a single chain.

If the resonance characteristic of each tuned circuit of the series of such circuits be expressible as $(1+S^2\alpha^2)^{-1/2}$, where S is the common selectivity of the several circuits and α is their frequency function, and if the intercircuit screening be assumed to be perfect, then the resonance characteristic of the receiver, when n such circuits are used, will be expressible as $(1+S^2\alpha^2)^{-n/2}$. If the receiving characteristic of the receiver is to be such that the intensities of the extremes of the receiver band are to be

$$\frac{1}{m}$$

of the intensity of the central of carrier frequency, then we have $(1+S^2\alpha_1^2)^{-n/2}=1/m$, where $\pm\alpha_1$ are the values of the frequency function α for the extreme frequencies of the transmitted band. This gives $S=(m^{2/n}-1)^{-1/2}/\alpha_1$, from which it is seen that the selectivity of the component circuits is strictly limited by the width of the band to be received without excessive distortion. For purposes of illustration we may consider the case in which the frequency of the transmitter is 10^5 , corresponding to a wave length of 3000 meters. Then if the signal band transmitted be 10,000 cycles wide, we get $\alpha_1=0.09762$. If we permit $1/m$ to be as small as 0.80, and if we take $n=2$, then $S=5.122$. This illustrates

the case of a chain of two equal resonant circuits receiving a signal band 10,000 cycles wide on a carrier frequency of 100,000 cycles, when the characteristic of the receiver is such that the extreme frequencies of the band may be permitted to have but 80% of the intensity of the central or carrier frequency. It shows that the common selectivity of the two resonant circuits may not exceed 5.122 or about 2.5% of the most usual selectivity of a tuned radio circuit and about 1.25% of that of the highest attainable selectivity of such circuits. If the chain in this case consisted of four equal resonant circuits instead of two such circuits, then $n=4$, and we get from our expression $S=3.519$ or about 1.75% of the usual selectivity of tuned radio circuits and about 0.88% of the best attainable selectivity of such circuits.

In order that the chain of n equal resonant circuits may make use of the most selective possible circuits of the type used in radio, the relation $\alpha_1^2(m^{2/n}-1)/1.6 \times 10^5$ must subsist. Again taking $1/m$ as of the value 0.8, and the width of the signal band as 10,000 cycles, we find, for a chain of two circuits that the carrier frequency must be about 8×10^6 , which corresponds to a wave length of 37.5 meters. Taking the same values of m and of the width of the signal band, but assuming that there are four equal resonant circuits in the chain, then the carrier frequency must be about 11.5×10^6 , corresponding to a wave length of about 26.1 meters, in order that the most selective circuit may be made use of.

In these examples the width of the signal band is excessive from the point of view of the more usual modern practice, but the width of the effective signal band in radio has been progressively broadened in the past and will doubtless be still further broadened in the near future, particularly in specialized uses of radio. However, the prime reason for using a wide signal band in these examples is to bring out most clearly the effect of the width of this band on the selectiveness of the receivers and their component circuits.

Further to illustrate the point of the foregoing remarks, curves 3 and 4 have been added on Fig. 4a. In each of the cases represented by curves 2, 3 and 4, the equal and effective reception of a frequency band whose width is given as

$$S_{\alpha 0} \approx \pm 1.75$$

is predicted. These curves permit the comparison between the receiving characteristics of chains having respectively 4, 8 and 16 equal resonant units.

Individually these curves show that the chain does not exclude nearby frequencies, though it is exceedingly effective in excluding remote frequencies. But a comparison of these three curves shows that after four units have been used, there is little gain in using a greater number of units, so far as exclusion of frequencies within the limits given by $S_{\alpha 0} = \pm 10$ is concerned.

We have already seen how the use of parallel associated receivers permits of the use of very much more selective units than would otherwise be possible. Though resonant circuits attuned to radio frequencies may, through the exercise of great care, in their construction, attain a selectivity of about 400, a far greater degree of selectivity, in fact a selectivity of a higher order is attainable through the use of suitably cut crystals such as are used in stabilizing the frequency of transmitters.

Ordinarily the use of so high an order of selec-

tivity as is provided by the resonant crystal would give the receiver an impracticably narrow band of received frequencies, but through the use of parallel associated receivers of the type illustrated in Figs. 1 and 2, the width of the received band of frequencies can be made as great as desired.

Fig. 5 illustrates a mode of connection by which crystals may be used with the receiver of Fig. 1. In Fig. 5 the letters of reference which are the same as those in Fig. 1 refer to the same elements as they do in Fig. 1. The condensers K_1 and K_1' are preferably equal, as are also the condensers K_2 and K_2' . The capacity of the condenser C_1 is preferably equal to the effective capacity γ_1 of the crystal Y_1 for frequencies remote from that of the crystal, and the capacity of the condenser C_2 is preferably equal to the effective capacity γ_2 of the crystal Y_2 for frequencies remote from that of the crystal. But, whether or not these specific relations be established, we should have approximately the relations $\gamma_1 K_1' = C_1 K_1$ and $\gamma_2 K_2' = C_2 K_2$, wherein C_1 , C_2 , K_1 , K_1' , K_2 , and K_2' are taken as capacities of the condensers C_1 , C_2 , K_1 , K_1' , K_2 , and K_2' respectively. Other types of balanced bridges than that here shown may be used. For frequencies different from that to which the crystal is resonant, these bridges will cause the detector branch to be conjugate to the loop resonant circuit so that there will be no tendency to develop a current in the detector, but when the frequency of the received waves is that to which the crystal is resonant, the crystal branch presents a relatively low resistance instead of a very large capacity reactance. The balance of the bridge is thereby upset, and the detector is energized.

A sufficient number of parallel resonant units must be used in each receiver to secure for it the requisite width of received frequency band. The principle involved is illustrated by Fig. 5 in which the number of such parallel resonant units is only two.

In all the cases considered heretofore the improvement has resided in the receiver, and transmission has been according to the simple, familiar, single band system with the use of a band-pass filter at the transmitter. I will now disclose a modified transmitter capable of advantageous use with receivers like those described heretofore, or only slightly modified therefrom.

The fundamental distinction between the transmitter hereinafter to be described and those ordinarily in use is that it transmits consecutive parts of the signal frequency band in opposite phases. Thus, if it be elected to divide the signal frequency band into two equal parts, half of the band is subjected to phase reversal and transmitted, whereas the other half is not so reversed before transmittal. If it be elected to separate the signal frequency band into three equal divisions, then either the central division is reversed or the other two thirds are reversed before transmittal.

This distinctive feature is illustrated in Fig. 6, which depicts in a purely conventional manner, a radio transmitter in which the signal frequency is divided into two equal parts transmitted in opposite phase. In this diagram, K formally represents a high speed automatically driven circuit control device, B represents a battery, R is a coupling resistance, the symbols "HP" and "LP" represent respectively high pass and low pass filters, and the numerals above these, such as 2000 and 4000, give their cutoff frequencies. The frequency

range indicated in Fig. 6 is chosen arbitrarily for purposes of illustration. G represents a high frequency generator whose modulating field coils are designated by M.

Of course, any suitable means may be used for subdividing the signal band into consecutive sections with reversed phase, and any suitable means may be used to generate the carrier frequency and to modulate it by the resulting signal frequency band with alternately opposed phases.

We may assume that the generator G, under unit excitation, gives an output represented by $\sin 2\pi n_0 t$, and that the key k is opened and closed regularly, the durations of opening and closing being equal and there being n complete periods per second. An analytical study of the output from the generator G under these conditions may be made. When this output is resolved into its components according to frequency and these components are compared with the corresponding components of the output from a transmitter of the kind shown in Fig. 7, it will be found that the radio signal band from the system of Fig. 6 shows a natural division into three parts A, B and C, in order of increasing frequency. In the following discussion we shall refer to these several parts or bands A, B and C. The central division B is the same in phase as the corresponding part of the radio frequency band developed by the transmitter of Fig. 7, while the extreme divisions A and C are of opposite sign or phase to the corresponding divisions of the band radiated by the transmitter of Fig. 7. It will also be noted that the central division B of the radio signal frequency band is twice as broad as either of the end divisions A and C.

The types of receiver adapted to utilize the radiation from the transmitter of Fig. 6 to the best advantage are those illustrated in Figs. 2 and 4. These receivers have four separate selective units in operative parallelism and might therefore seem best adapted to reception from a transmitter radiating four instead of three band divisions, but in this respect the appearances are deceptive as will become apparent later.

In the receivers of Figs. 2 and 4, the output terminals of the four detectors or demodulators are so connected in the circuit of the receiving device R as to produce in that device an arithmetically additive effect when, as is the case of the transmitter of Fig. 7, the signal band impressed upon the modulator of the transmitter is of normal phase throughout, i. e., not subdivided into band divisions of opposing phase. But when these receivers are used to receive signals from a transmitter such as that of Fig. 6, in which the radiated signal band is divided into parts, the consecutive divisions of the band having opposite phases, then the connection of the output terminals of the four detectors must be so changed as still to produce an arithmetically additive effect upon the receiving device R. Such change may be effected by the use of the switches S_1, S_1', S_2 and S_2' in Fig. 2 and S_1, S_2, S_3 and S_4 in Fig. 4.

Since the band division B radiated from the transmitter of Fig. 6 is of double the width of the individual band divisions A and C, two selective units of the receivers of Figs. 2 and 4 are assigned to the reception of this band division, while single selective units are assigned to the reception of the band divisions A and C. Thus, in the case of the receiver of Fig. 2, antennas 2 and 2', and their associated selective circuits are respectively tuned to the central frequencies n_0-12n and

n_0+12n of band divisions A and C respectively, while antennas 1 and 1' and their associated selective circuits are respectively tuned to the symmetrically disposed frequencies n_0-4n and n_0+4n of the broad central band division B. Similarly, in the case of the receiver of Fig. 4 receiving from the transmitter of Fig. 6, the antennas 1 and 4 their associated selective circuits are respectively tuned to the central frequencies n_0-12n and n_0+12n of band divisions A and C respectively, while antennas 2 and 3 and their associated selective circuits are respectively tuned to the symmetrically situated frequencies n_0-4n and n_0+4n of the central band division B.

Fig. 8 illustrates the mode of operation of a receiver having four selective units in effective parallelism when receiving from the transmitter of Fig. 6. In this diagram the selectivity of each unit or component receiver is assumed to be that of a simple resonant circuit. These units are equally spaced in the frequency scale and the receiving characteristic of the receiver as a whole is given by curve 5 which is seen to be not very uniform. The individual effects of the four selective units or component receivers upon the circuit of the ultimate receiving device R, are illustrated respectively by curves 1, 2, 3 and 4, of which the characteristic curve 5 is the algebraic sum. In this diagram the abscissas are values of the frequency and the ordinates are intensities of the current components in the circuit of the ultimate receiving device R.

Fig. 9 illustrates the mode of operation of a receiver having four pairs of selective units or component receivers in effective parallelism when receiving from the transmitter of Fig. 6. In this diagram the selective units in effective parallelism are assumed to be simple resonant circuits, but they are grouped in pairs along the frequency scale, each pair taking the place on the frequency scale of one of the selective units of the organization whose mode of operation is illustrated in Fig. 8. The individual effects of the four pairs of selective units upon the circuit of the ultimate receiving device R are given by the curves 1, 2, 3 and 4 respectively, while curve 5, which is the algebraic sum of these curves, is the receiving characteristic of the station as a whole.

The receiving characteristic of Fig. 9 is an improvement on that of Fig. 8, but both are characterized by the elimination of the frequency corresponding to that at which the phase reversal took place at the transmitter, and a partial suppression of the frequencies in the immediate vicinity of this frequency. The receiver having the receiving characteristic given in appended Fig. 9 gives a very adequate reproduction of the signal sequence assumed for Fig. 6, namely a succession of closures of key K with the same duration for all the closures and for all the alternate openings of the key.

In the foregoing, I have described the invention entirely with reference to the high speed telegraphic signal transmitters of Figs. 6 and 7. This was done in order to make the disclosure as complete and clear as possible, but by far the most important and at the same time the simplest application of the principles involved is in connection with the transmission of speech and music.

The simplicity in these latter applications of the invention arises from the fact that the clarity and quality of transmitted speech and music are not affected by a reversal of phase of a portion or of portions of the signal frequency band. It

follows from this that receivers of the types whose characteristics are given in Figs. 8 and 9, may be used to receive speech and music from the usual radio transmitter without material loss of clarity and quality.

When the receiver, whose mode of operation has been illustrated by Fig. 8, is used to receive speech or music from the usual radio transmitter, in which of course there are no imposed reversals of phase, then its mode of operation will be illustrated by Fig. 10. When the receiver whose mode of operation has been illustrated by Fig. 9 is used to receive speech or music from the usual radio transmitter, then its mode of operation will be illustrated by Fig. 11. In the diagrams of Figs. 10 and 11, the abscissas are frequencies in the radio signal scale and the ordinates are intensities of effects induced in the circuit of the ultimate receiving device R of the station as a whole.

In Fig. 10, curves 1, 2, 3 and 4 represent respectively the individual effects produced in the circuit of the ultimate receiving device R by the four selective receiving units in effective parallelism, while curve 5, which is the algebraic sum of curves 1, 2, 3, and 4, represents the characteristic of the resulting receiving station. Similarly, in Fig. 11, curves 1, 2, 3, and 4 represent respectively the individual effects produced in the circuit of the ultimate receiving device R by the four pairs of selective receiving units in effective parallelism, while curve 5, which is the algebraic sum of the curves 1, 2, 3, and 4, represents the characteristic of the receiving station.

From an inspection of the curves 5 of these diagrams, we again note the suppression of the frequency at which the reversal of the phase takes place, and the partial suppression of a narrow band of contiguous frequencies. The measure which may be taken to prevent this feature of the characteristic from materially affecting the clarity and quality of the reception will be considered after I have discussed the question of the immunity from interference secured by the reversed phase receiver.

The advantages to be gained through the use of the reversed phase receiver over that secured through the use of the otherwise identical receiver disclosed in connection with Figs. 2 and 4 is best exhibited by the two diagrams of Figs. 12 and 13.

In the construction of these diagrams, I have assumed that the receiver of Fig. 12 is of the four selective unit type illustrated in Fig. 2, while that of Fig. 13 is an identical receiver except for the fact that it has the reversed phase feature. In other words, the receivers contemplated in Figs. 12 and 13 consist of four equal resonant units in effective parallelism. In the receiver contemplated in Fig. 12, the output terminals of the four demodulators are connected together in the same sense so as to produce arithmetically additive effects upon the receiving device R of the station, while in the otherwise identical receiver contemplated in Fig. 13, the output terminals of the demodulators of resonant units 1 and 4 are connected in the reverse sense to the terminals of the demodulators of resonant units 2 and 3, so that the joint effects of these two pairs of resonant units upon the receiving device R is equal to the arithmetical difference of their individual effects.

The effect of reversing the phase in a multiple selective unit receiver is to greatly reduce its response to sources of interference such as radio transmitters whose frequency bands are too close

to be effectively excluded by the usual selective methods.

In Figs. 12 and 13 I have, for purposes of illustration, assumed that the receivers are acted upon by a transmitter radiating a band of frequencies equal to that normal to the receivers, i. e., $32n$, and separated from the receiver's frequency band by a frequency interval equal in width to the width of the bands in question. The relation in the frequency scale of the interval between the interfering frequency band and the band normal to the receivers is illustrated on a small scale in Fig. 14. The interfering transmitter is assumed to be of the usual type, but radiating a band of frequencies having uniform intensity.

In Figs. 12 and 13, curves 1, 2, 3, and 4 indicate the individual responses of the four selective units in effective parallelism as impressed upon the receiving device R of the station, while curves 5, which are the algebraic sum of their respective curves 1, 2, 3, and 4 show, in each case, the resultant of the response of the four selective units as impressed on the ultimate receiving device R of the station.

A comparison of the curves 5 of these two diagrams serves to show the great disparity in the intensity of the response of the two stations in question to the interfering transmitter. We see that the response of the receiver having the reversed phase feature is but about 0.5% of that of the receiver, with which it is otherwise identical.

The mode of operation of the receiver contemplated in Fig. 12 when receiving from the transmitter proper to it, is illustrated in Fig. 15. Here, as before, curves 1, 2, 3 and 4 represent the individual responses of the selective units in effective parallelism as impressed upon the ultimate receiving device R of the station, and curve 5, which is the sum of these curves, represents the response of the station. In this diagram the assumed intensity of the waves received from the transmitter proper to the station is but one-fifth the assumed intensity of the waves from the interfering transmitter in Figs. 12 and 13. The mode of operation of the receiver contemplated in Fig. 13, when receiving from the transmitter proper to it and to the receiver contemplated in Fig. 12, is illustrated in Fig. 10.

We have seen that in the reception by a reversed phase receiver, the frequency at which the phase reversal takes place is suppressed and a narrow band of frequencies contiguous thereto is partially suppressed. This characteristic of the receiver is more or less detrimental to the clarity and quality of the transmission, depending respectively on how low or high the frequency of reversal is in the scale of signal frequencies. If the frequency of reversal be so chosen as to lie in the extreme upper range of the signal frequency band, little detriment to the clarity or quality of speech or musical transmission need be apprehended. When, moreover, the frequency of phase reversal is pushed to the extreme upper limit of the transmitted signal frequency band, then the phase reversal at the receiver exerts but a negligible effect upon the character of the transmission.

It must be remembered that the purpose of the phase reversal at the receiver is solely to minimize interference, and that this purpose can be effected whether or not the phase reversal occurs within the signal frequency band. In the preferred form of the contrivance, therefore, the transmitter is equipped with a low-pass filter

which cuts out all frequencies above the upper limit of the required frequencies, and the phase reversal at the receiver takes place at this frequency or even at a somewhat higher frequency.

5 This preferred form of the invention is illustrated in a strictly formal manner in Fig. 16. Here the transmitter has a low pass filter which confines the radiation to frequencies below the upper limit of the desired band, which may be
10 represented as $n_0 \pm n_1$. Here n_0 is the mid frequency of the band and $n_0 - n_1$ and $n_0 + n_1$ are respectively the lowest and highest frequencies of the band which it is desired to transmit. At the receiver, the component receivers 1 and 4 are at-
15 tuned to the frequencies $n_0 \pm \frac{1}{2}n_1$ respectively, while component receivers 2 and 3 are attuned to frequencies $n_0 \pm \frac{1}{4}n_1$ respectively. The output terminals of the detectors D₁, D₂, D₃ and D₄ are so relatively connected to the ultimate receiving
20 device R of the station that D₁ and D₄ act in one sense, while D₂ and D₃ act in the opposite sense. It should be observed that in such an organization, component receivers 1 and 4 serve no useful purpose in the reception of the signals,
25 their function being solely to neutralize cross-talk and other interference.

I claim:

1. In a system of signaling by waves of various frequencies within a certain complete frequency
30 band of substantially uniform average intensity, receiving means comprising means to separate such band into respective parts having considerable overlap each with consecutively adjacent parts, respective means for selectively amplifying
35 these parts so as to enhance intensity at and near the main frequency of each part but not at overlapping frequencies, and means to combine the outputs of the said last mentioned means.

2. The method of selectively receiving single
40 band electric wave signals which consists in receiving them in separated parts at several different frequencies within such band and with considerable overlap of frequency between successive parts, selectively amplifying these parts while
45 separated so as relatively to enhance the intensity of each such part at and near its main frequency relatively to its overlapping frequencies and then combining them for ultimate reception.

3. In a system of signaling by waves of various frequencies within a certain single carrier frequency band, a plurality of separate receivers for
50 respective parts of said band, said receivers having respective frequency maxima along said band with considerable overlap into successively adjacent bands, respective selective amplifiers therefor adapted to enhance the intensity at the central frequency of each said receiver relatively to
55 its overlapping frequencies, and a common ultimate receiver associated with said amplifiers.

4. In a system of signaling by waves of various frequencies within a certain single carrier frequency band, a plurality of separate receivers for
60 respective parts of said band, said receivers having respective frequency maxima along said band with considerable overlap into successively adjacent bands, respective selective amplifiers therefor adapted to enhance the intensity at and near
65 the said frequency maxima relatively to the overlapping frequencies, respective detectors associated with said selective amplifiers, and a common receiver for the detector outputs.

5. A radio receiving system adapted to receive
75 signals on waves lying at any and all frequencies within a certain frequency band comprising a

plurality of receiving antennae, respective selective amplifying units each adapted to enhance the intensity of its main frequency relatively to frequencies remote therefrom, the frequency
5 range of each such unit overlapping with diminishing intensity into the ranges of successively adjacent units, the main frequencies of these units being distributed along the said band, respective detectors with said units, and a common
10 audio frequency receiver associated with said detectors.

6. The method of selectively receiving radio signals carried at any and all frequencies within a definite limited band of frequencies which consists in receiving them separately at different fre-
15 quencies within the said band with considerable overlap into successively adjacent frequencies, selectively amplifying at these different frequencies so as to enhance the main frequencies relatively to the overlapping frequencies, separately
20 detecting the signal elements at each such frequency and reducing them all to audio frequency, and combining the audio frequency outputs to get the signals.

7. The method of selectively receiving electric
25 wave signals lying within a certain complete frequency band of substantially uniform average intensity, which consists in receiving them separately at several different frequencies distributed within that band with considerable overlap be-
30 tween consecutively adjacent frequencies, selectively amplifying these respective separated frequencies so as to enhance intensity at and near the central frequency of each separated part of the band but not at its overlapping frequencies,
35 then detecting them, and then combining the detected outputs for ultimate reception of the signal.

8. In a system of signaling by waves of various frequencies within a certain complete frequency
40 band of substantially uniform average intensity, means at the transmitting end alternately to reverse the phase of the waves for consecutive intervals of said band, separate receiving means at the receiving end corresponding to these intervals,
45 each such receiving means permitting some overlap, respective selective amplifiers adapted to reduce the relative intensity of the overlapping parts, and means to combine the outputs of said
50 amplifiers.

9. In a system of signalling by waves of various frequencies within a certain frequency band on a single carrier, means at the transmitting end to separate the said band into parts with
55 alternate phase reversal along these parts, separate receiving means at the receiving end corresponding to these transmitted frequency intervals, each receiving means permitting some overlap, respective selective amplifiers therefor adapted to reduce the relative intensity of the over-
60 lapping parts, respective detectors, and a common receiving circuit connected on the output side of said detectors.

10. The method of electric wave signaling which consists in generating the signal as a re-
65 stricted single carrier band of frequencies, separating this band into parts, reversing alternate parts in phase, receiving these parts separately with some overlap selectively amplifying them so as to reduce the relative intensity of the over-
70 lapping parts, detecting them, and combining the detected outputs additively for reception of the signal.

11. In a system of signaling by waves of various frequencies within a certain frequency band, 75

a receiver adapted to receive over a wider frequency band to which the first mentioned band is intermediate, said receiver comprising means to receive parts of its band separately and in alternately opposite phase, an ultimate receiver, and means to combine said parts and apply them to said receiver.

12. The method of reducing interference in electric wave signaling which consists in receiving a frequency band of a certain width, separating the received waves into consecutive narrow smaller bands according to frequency, reversing the phase in alternate narrow bands over an entire frequency band wider than the band intended to be received, said band to be received being intermediately located in the frequency scale with respect to said wider band, and combining the effects of all of said narrow bands.

13. A radio receiving system adapted to receive signals on waves lying within a certain major frequency band on a single carrier current comprising a plurality of receiving antennæ, respective chains of tuned circuits and alternately dis-

posed intermediate amplifiers, the circuits of each chain tuned alike and differently from other chains so that each chain will pass a minor band of frequencies, the different central frequencies of the respective minor bands for the different chains lying at regular intervals along the said major frequency band with considerable overlap between the minor bands, respective detectors with said chains, and a common audio frequency receiver associated with said detectors.

14. In a system of signaling by waves of various frequencies within a certain frequency band, receiving means comprising means to separate such band into respective narrower bands having considerable overlap each with consecutively adjacent narrower bands, respective selective means for reducing the relative intensity of the overlapping parts of these narrower bands, respective amplifying means for these narrower bands, and means to combine the narrower bands after such relative reduction of intensity and such amplification.

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