

May 20, 1930.

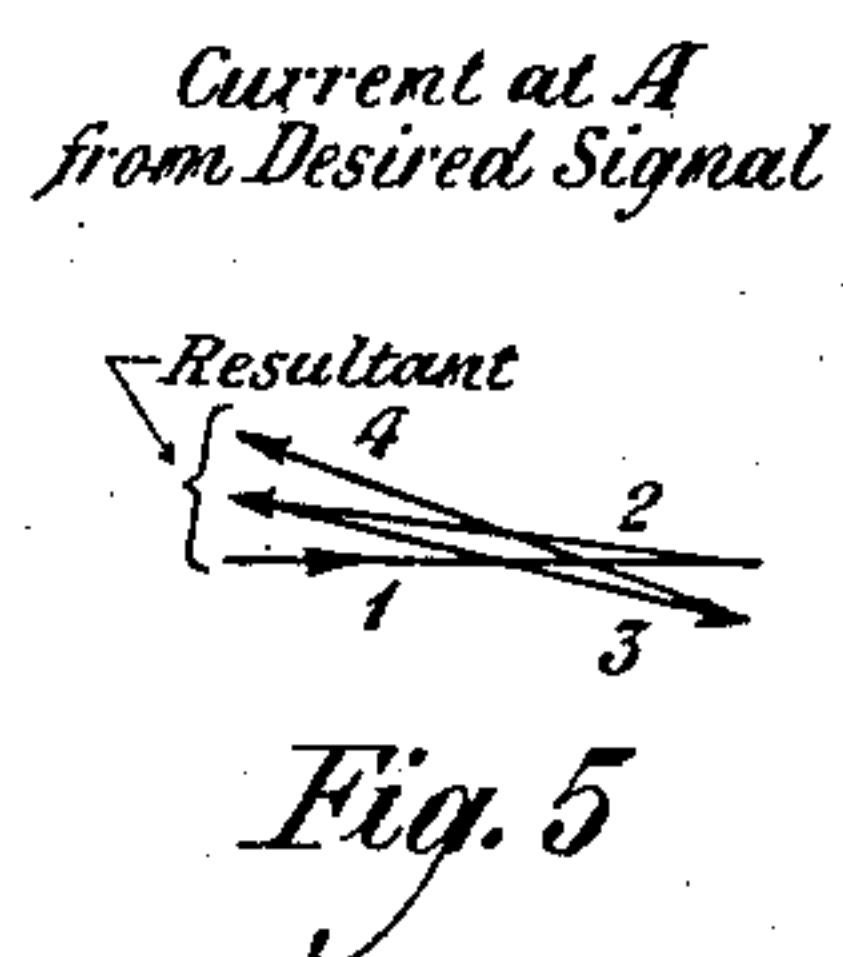
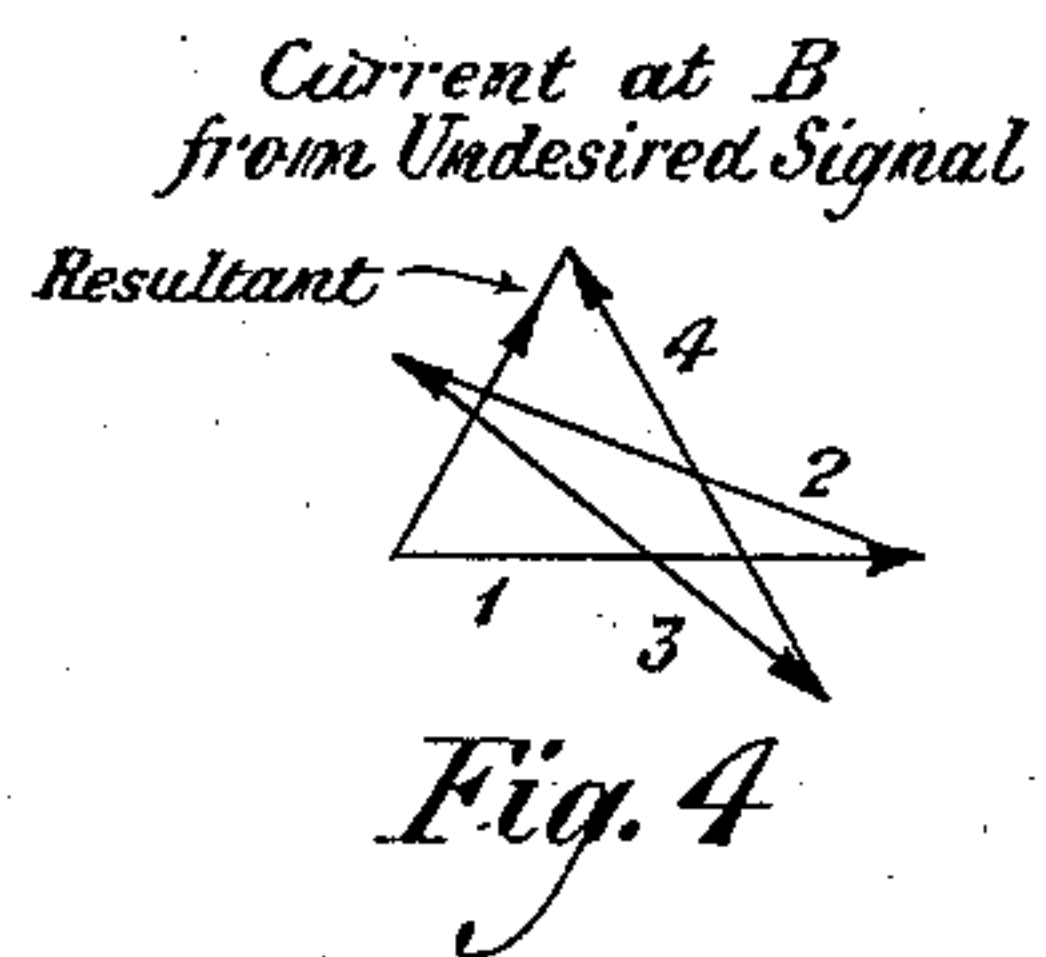
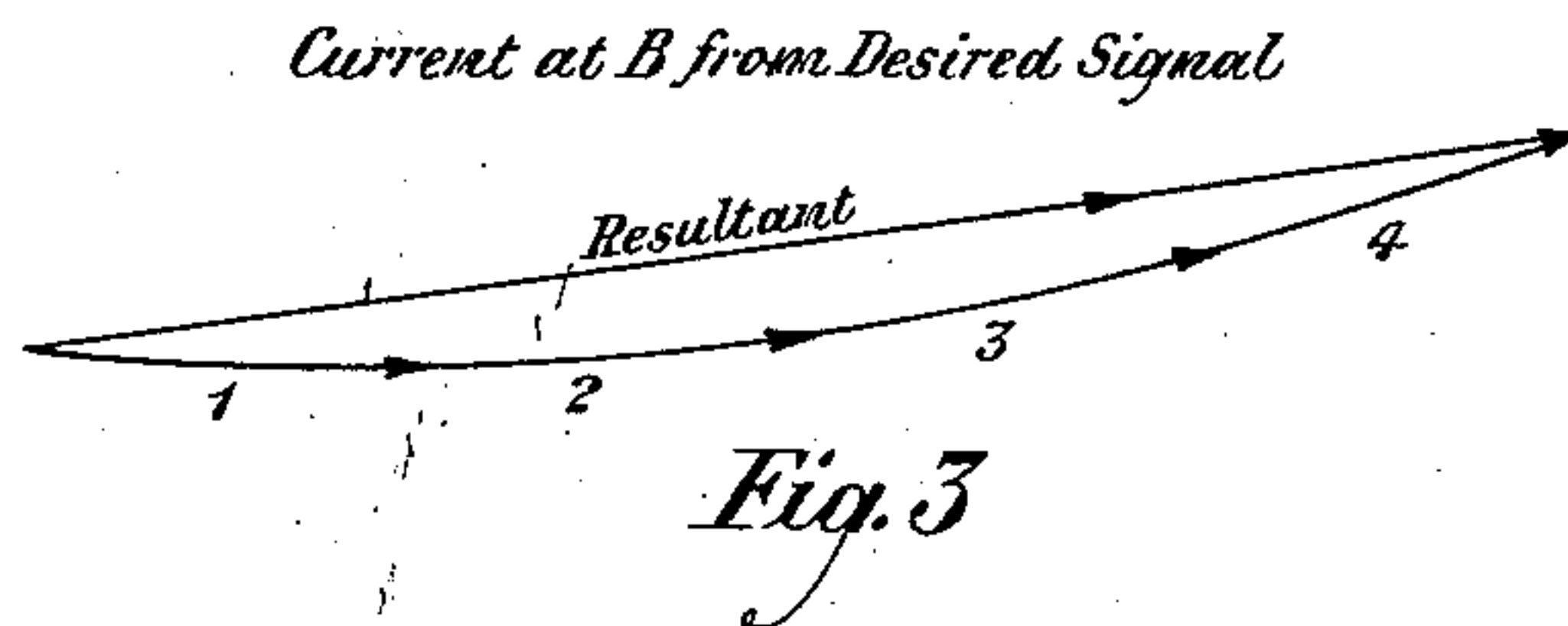
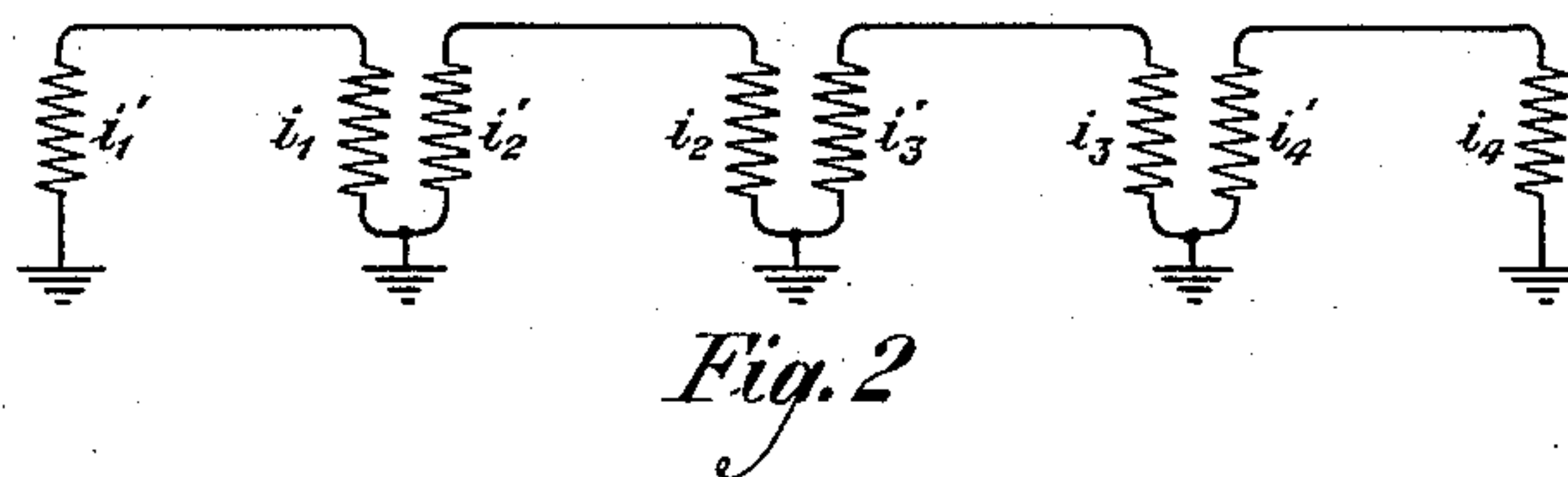
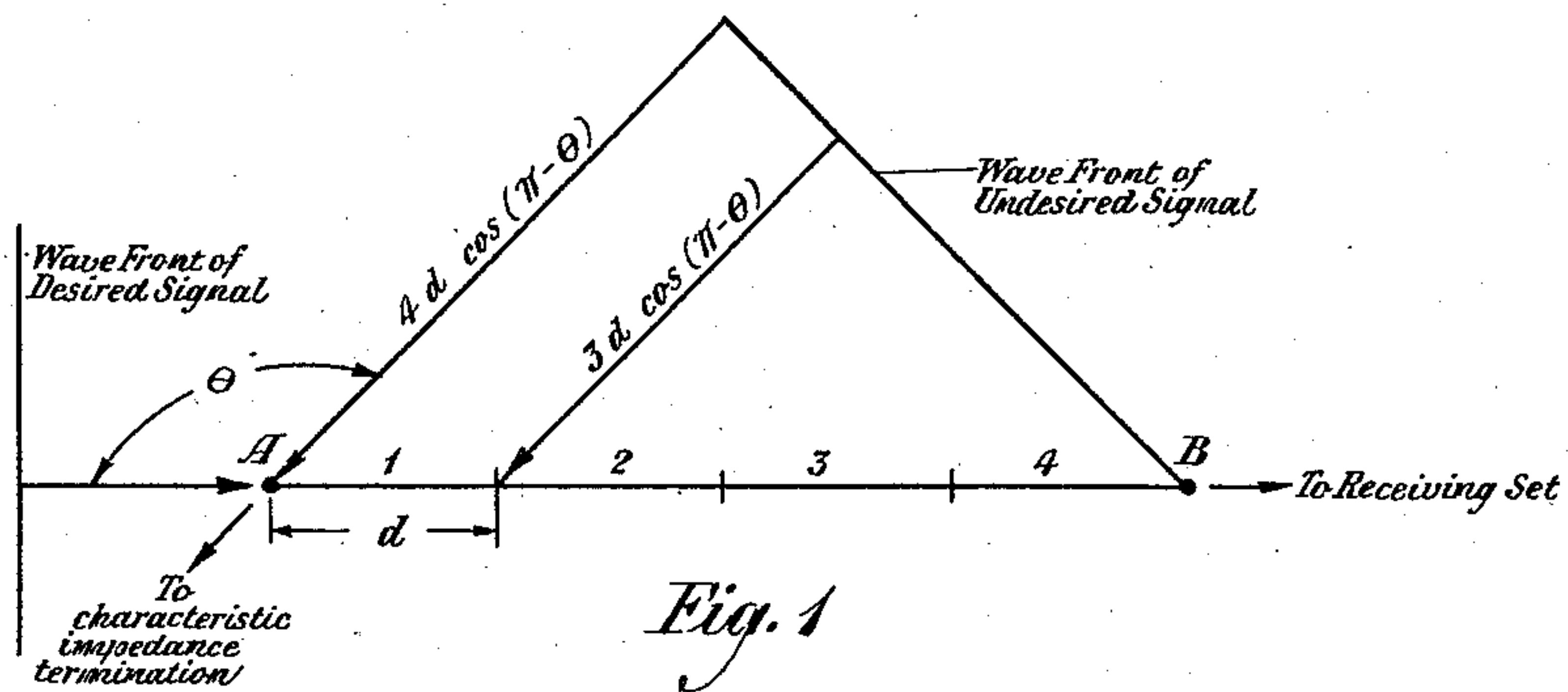
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1,758,933

TRANPOSED AND TAPERED ANTENNA

Filed Aug. 21, 1926

4 Sheets-Sheet 1



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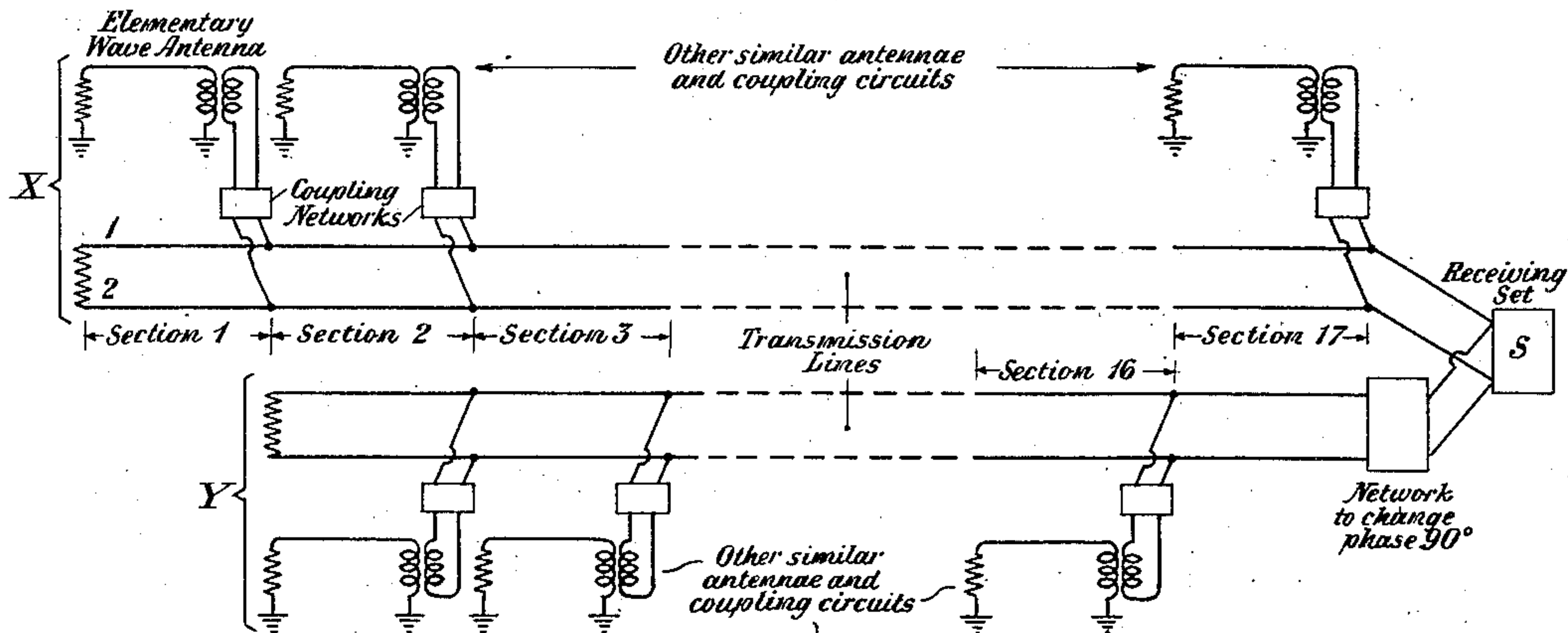
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TRANPOSED AND TAPERED ANTENNA

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4 Sheets-Sheet 2



Relative Strengths of Signals delivered to S by Elementary Wave Antennae

System	Sections Nos.																
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
X	+1	+2	+1	0	-4	-8	-9	-1	-1	-1	-9	-8	-4	0	+1	+2	+1
Y	0	+2	+4	.6	.8	.6	.4	.2	0	-2	-4	-6	-8	-6	-4	-2	0

Note: - sign in above table indicates that signal from coupling network is reversed in phase by means of a transposition.

Fig. 6

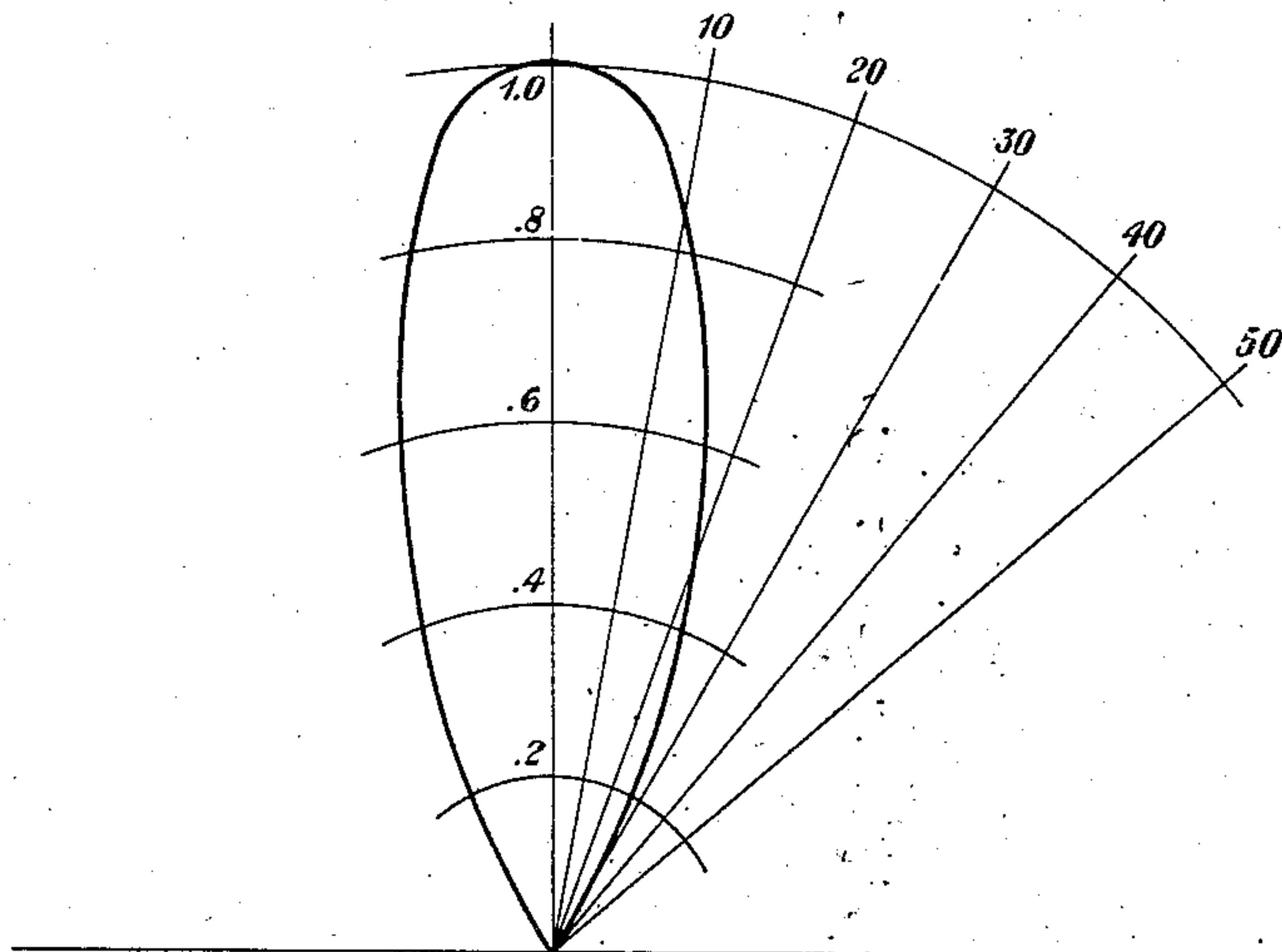


Fig. 6a

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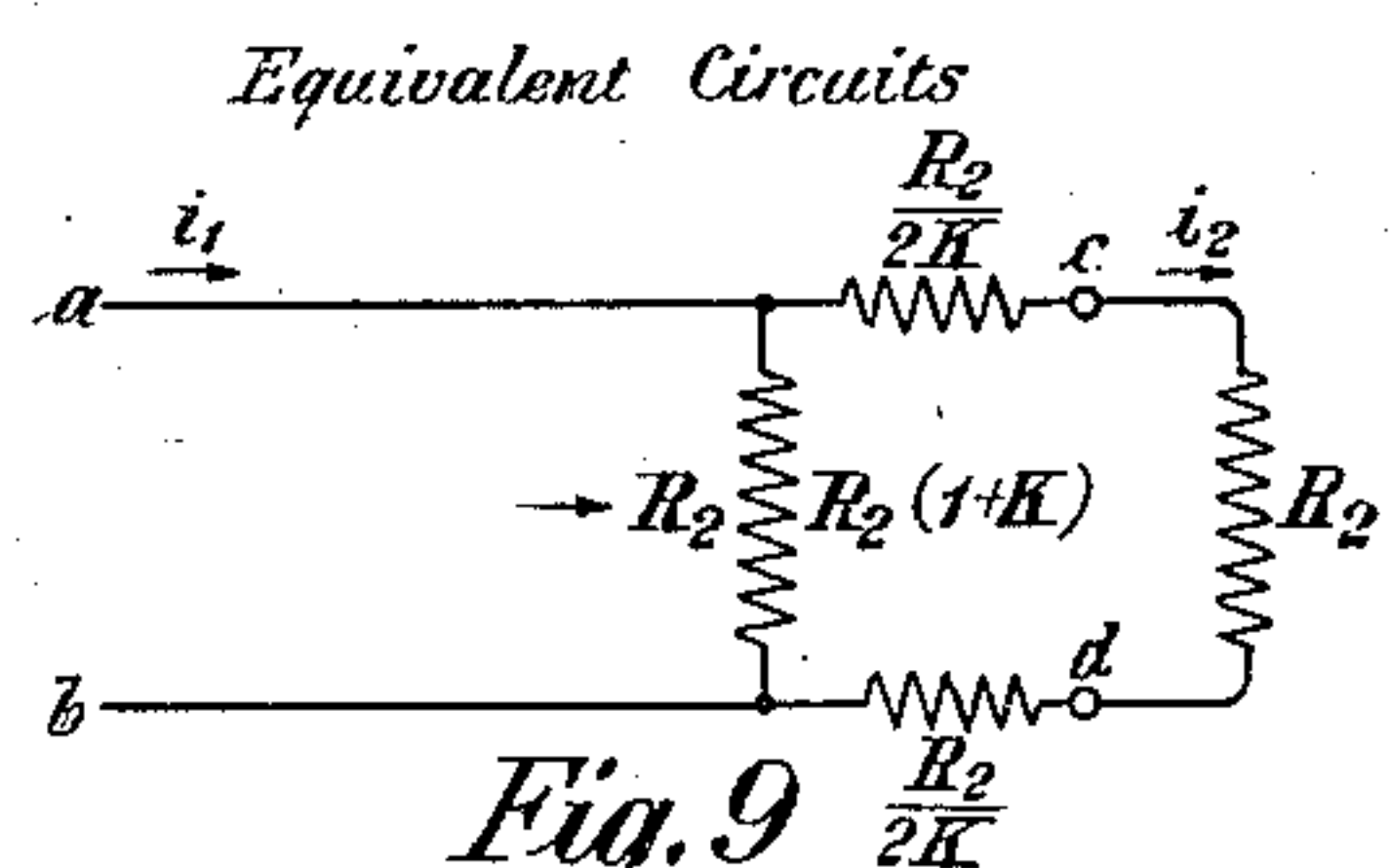
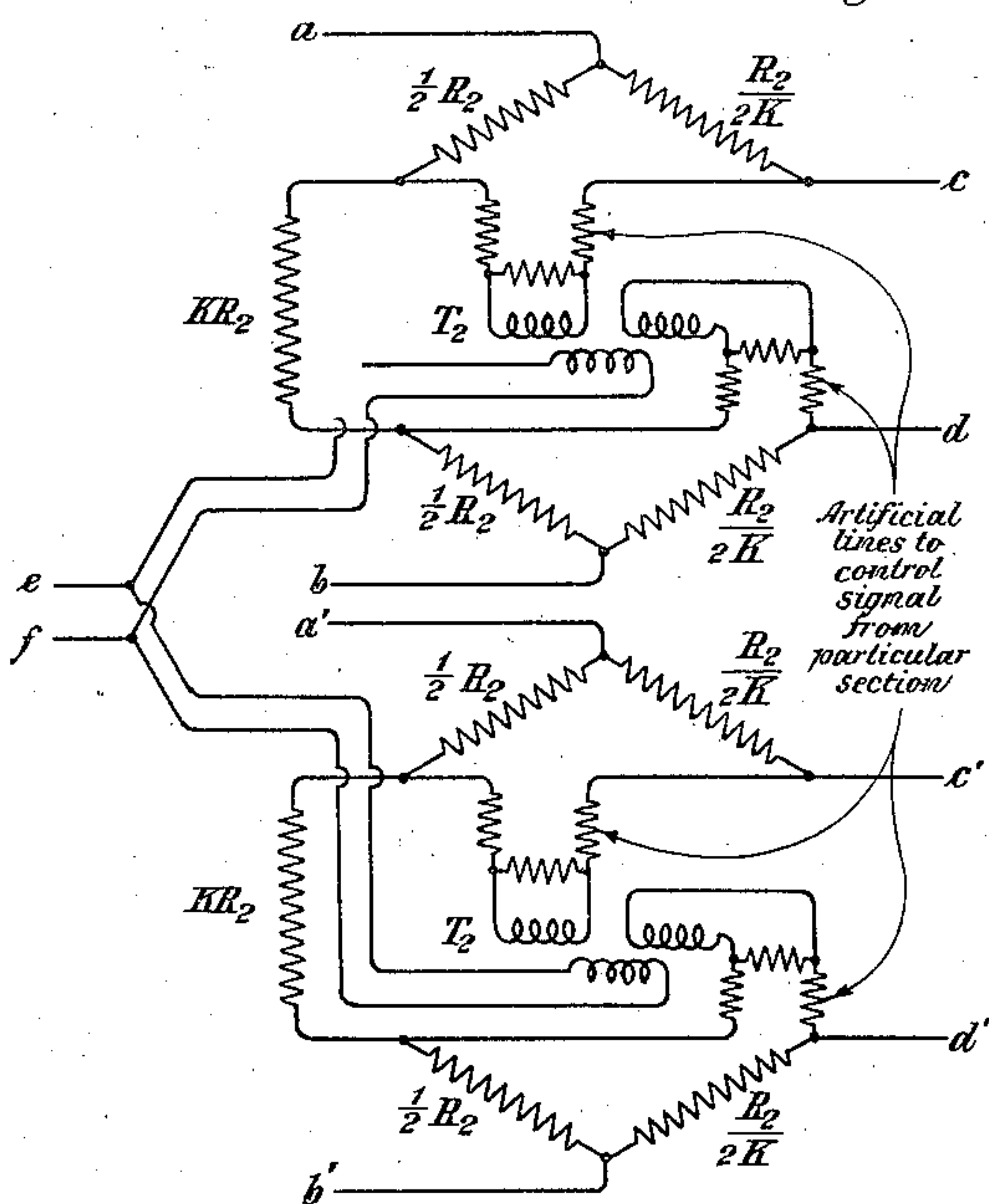
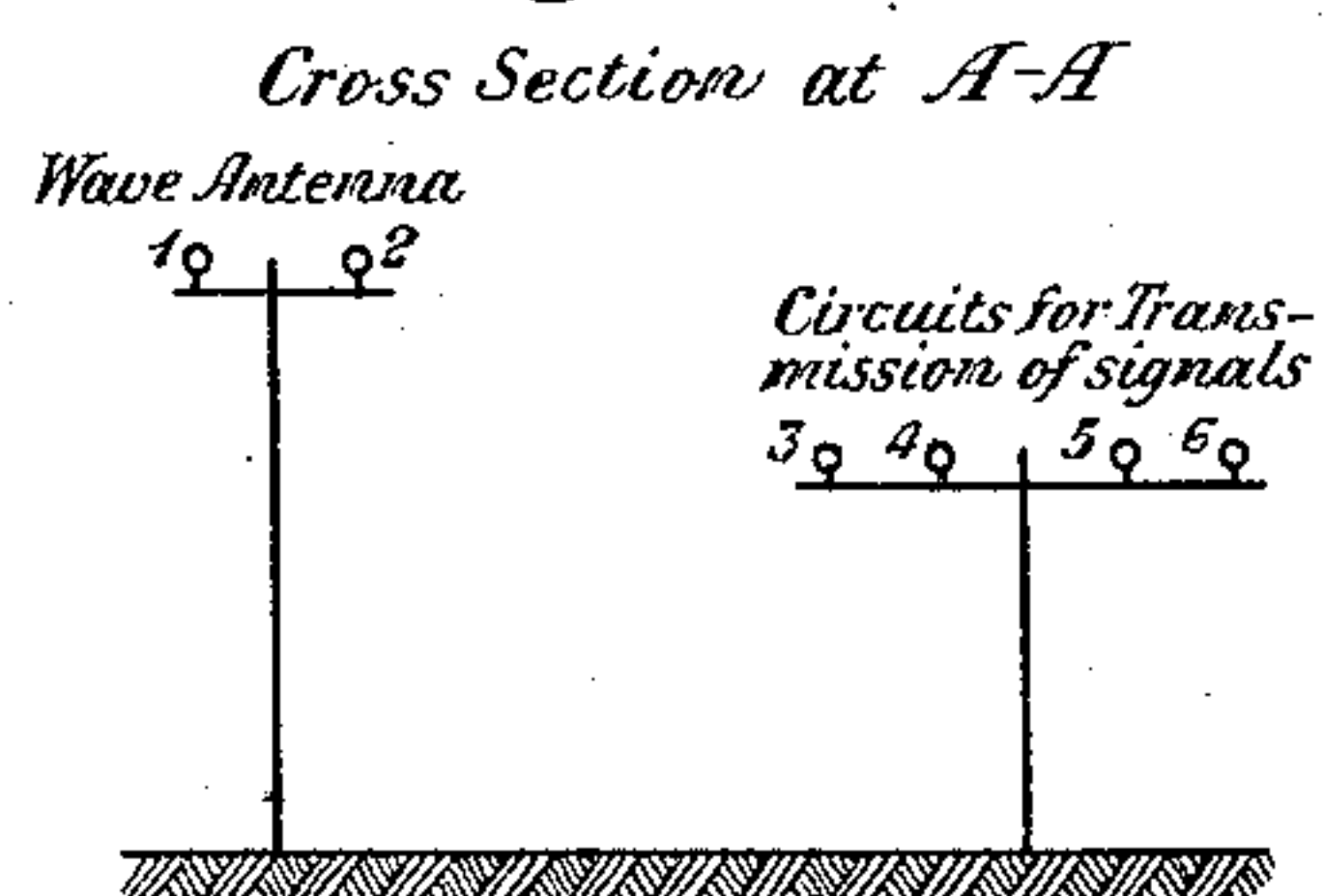
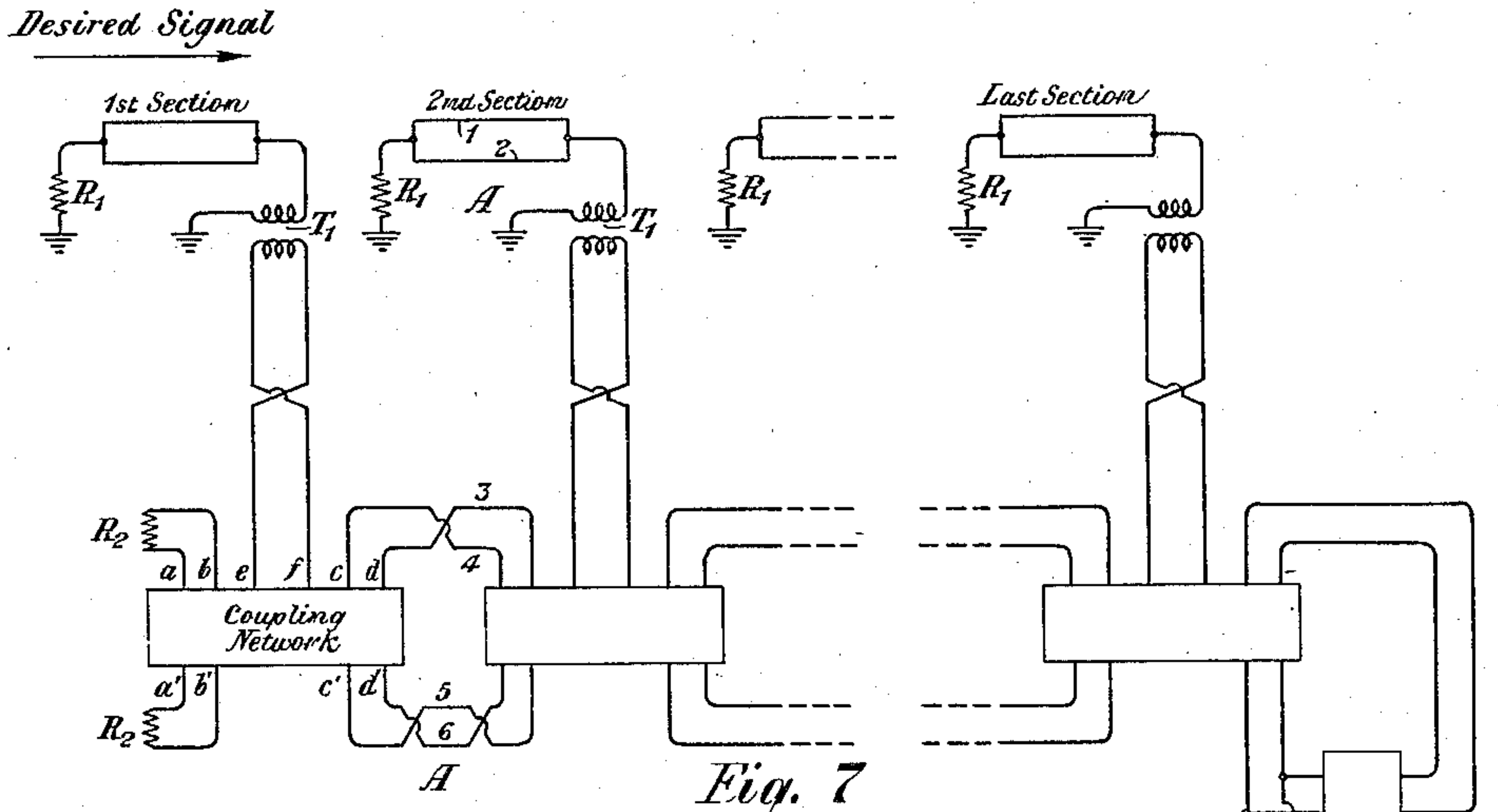
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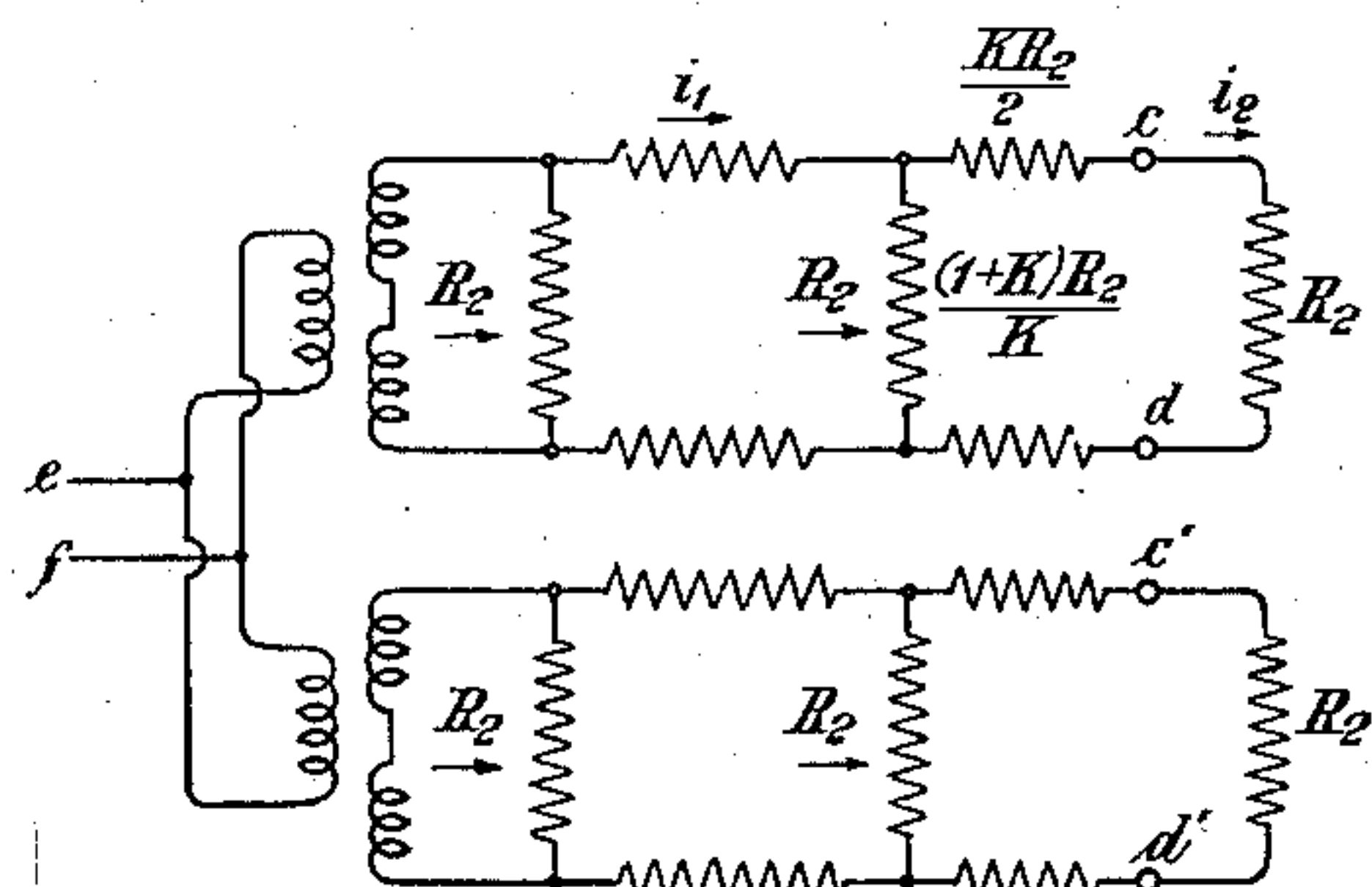
TRANSPOSED AND TAPERED ANTENNA

Filed Aug. 21, 1926

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$$\frac{i_2}{i_1} = \frac{K}{1+K} = .9 \text{ for } K=9$$



$$\frac{i_2}{i_1} = \frac{1}{1+K} = .1 \text{ for } K=9$$

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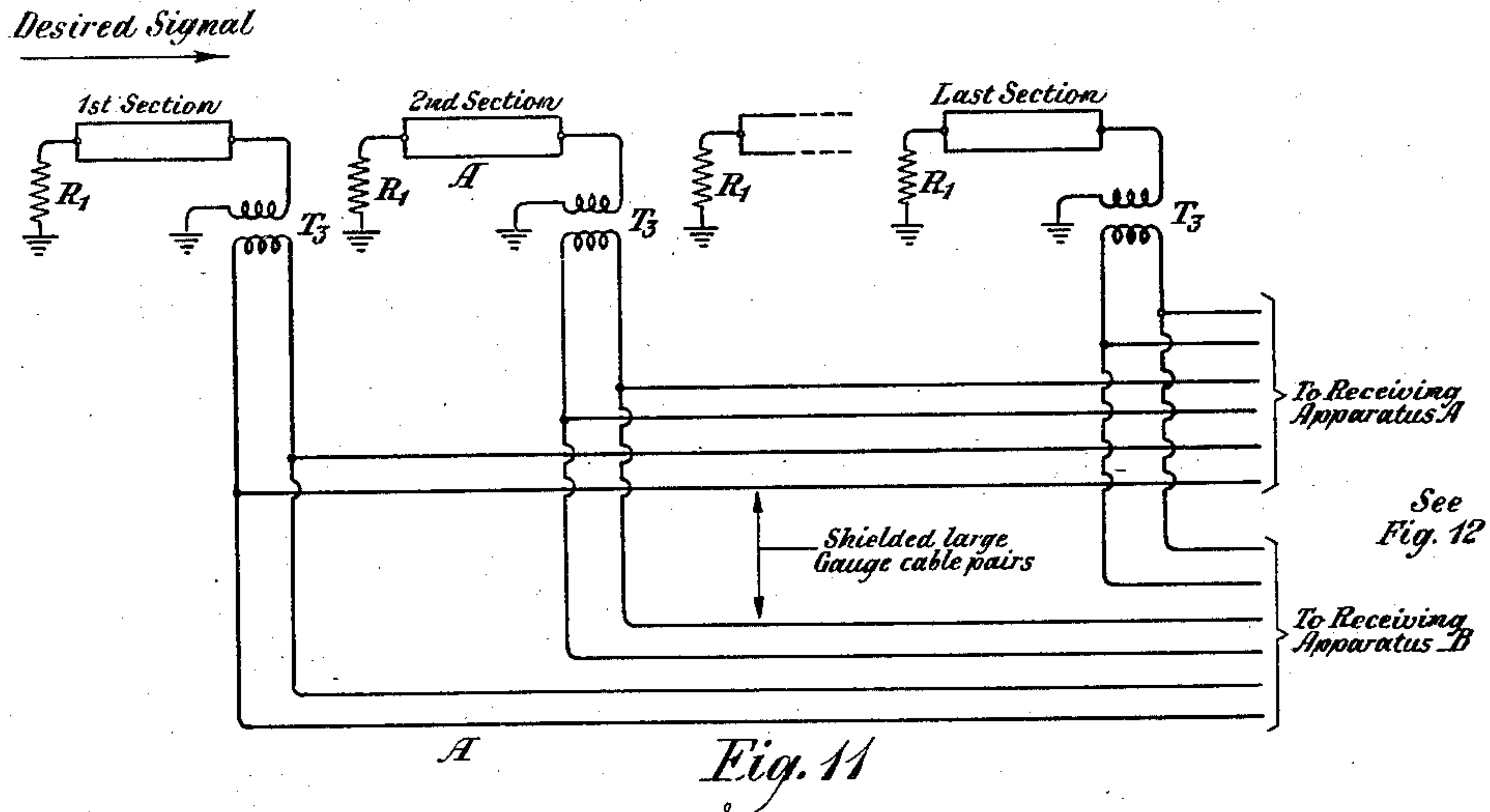
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TRANPOSED AND TAPERED ANTENNA

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4 Sheets-Sheet 4



Cross Section at A-A

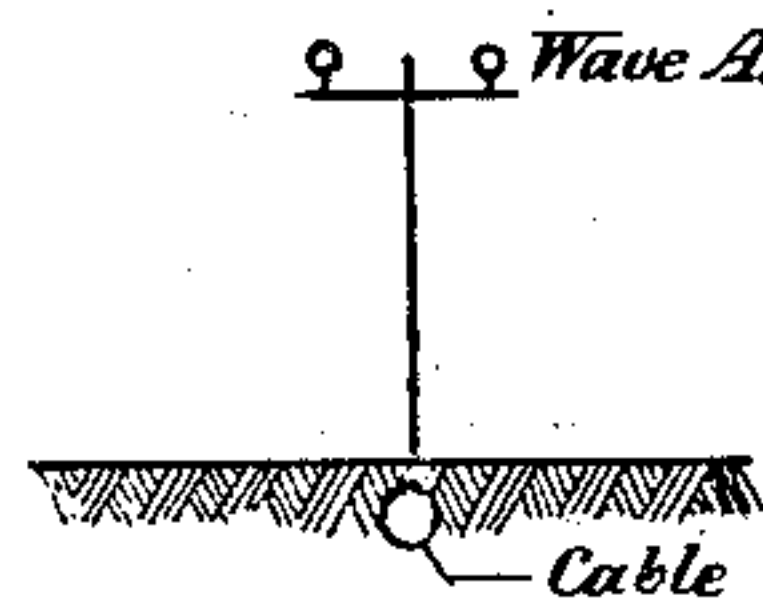
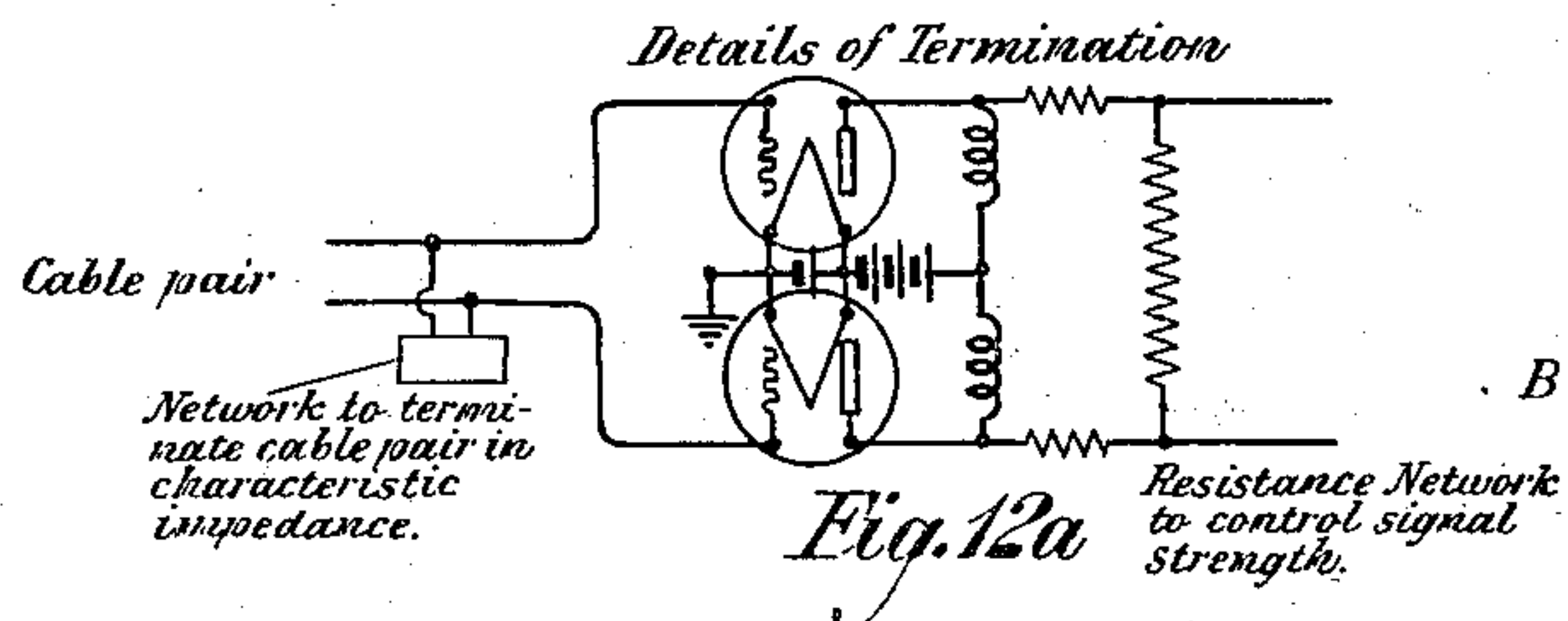
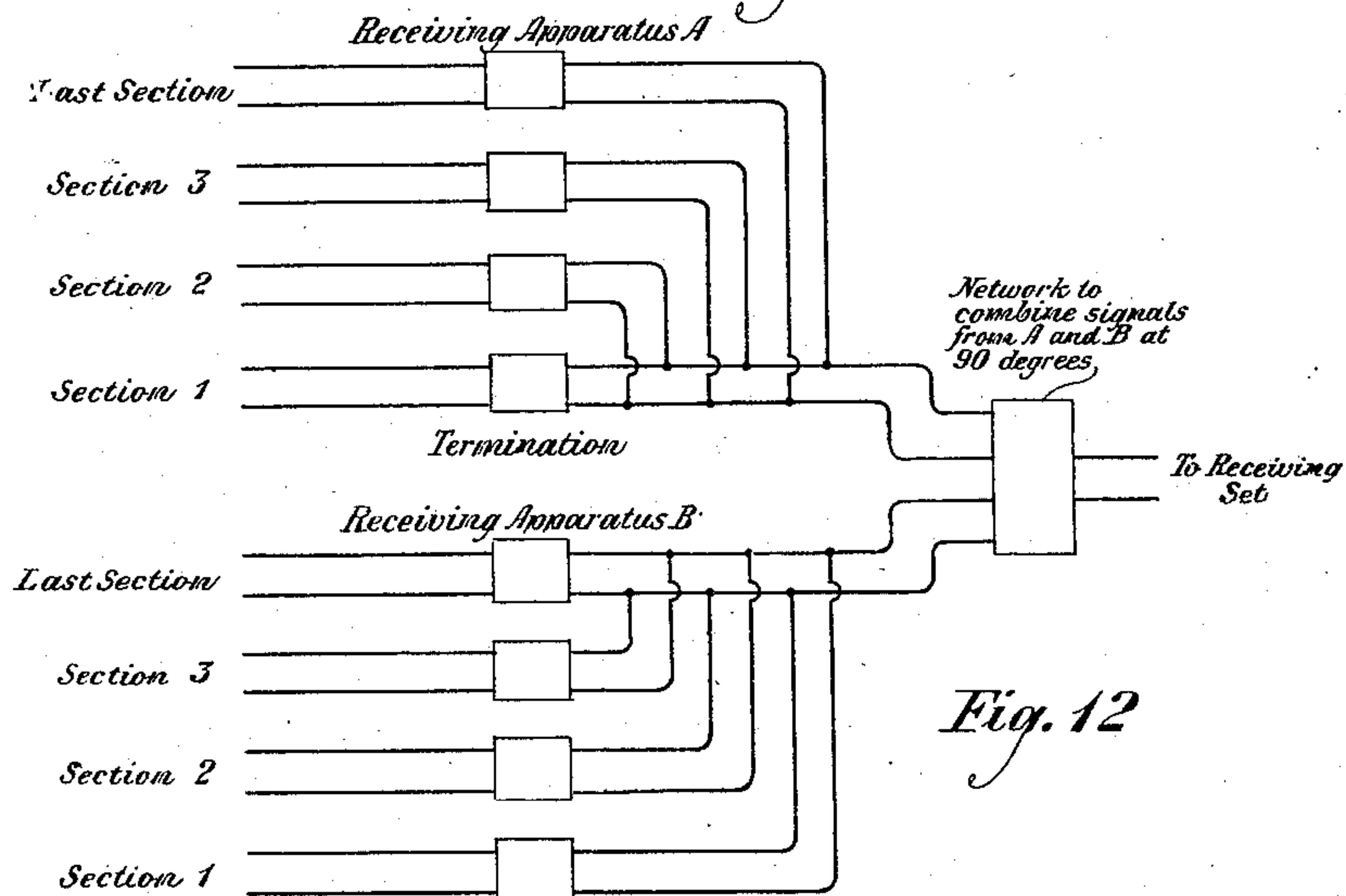


Fig. 11a



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UNITED STATES PATENT OFFICE

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TRANSPosed AND TAPERED ANTENNA

Application filed August 21, 1926. Serial No. 130,637.

This invention relates to wave antennæ, and particularly to one of the tapered and transposed type which is characterized by directional selectivity of a high order.

5 A simple wave antenna such, for example, as shown in the patent to Beverage, No. 1,381,098 may be considered to consist of a succession of similar short finite sections. The current at the receiving end of the an-
10 tenna may be considered to be composed of a number of components, one for each of the finite sections. The individual components received from the various sections are combined at various phase angles depending
15 upon the direction and frequency of the signal, and the length and electrical constants of the antenna. The component currents are very nearly all in phase for the desired signal, and therefore, a large resultant current
20 is obtained. When the components combined are at large angles, such as those produced by undesired signals whose directions of transmission have large angles to that of the desired signal, the resultant received cur-
25 rents produced thereby are relatively small. If transpositions are used at the junctions of the finite sections, the phase angles of some of the component currents may be changed by 180 degrees and by proper design of the
30 transpositions, the directional characteristics of the antenna may be improved. This is the basic principle of the transposed wave antenna.

Furthermore, the resultant received current from the wave antenna may be altered by
35 providing means for adjusting the relative strengths of the currents received from the various sections. It has been found that the adjustment of the relative current strengths combined with the use of transpositions re-
40 sults in improved directional characteristics for the antenna and this is the basic principle of the tapered wave antenna.

In a simple wave antenna the receiving set
45 is connected at the end distant from the station sending the desired signal. The current resulting from the desired signal at the other end of the antenna is relatively small. With transposed and tapered antennæ, this condi-
50 tion may be reversed and the antenna may be

pointed away from the sending station, rather than toward it. As may be readily shown, the best directional characteristics for a transposed wave antenna are obtained with this method of pointing. Furthermore, such
55 an antenna arranged for receiving at the end nearest the sending station has marked frequency selectivity as well as directional selectivity. Such antennæ are, therefore, suitable for rather short wave lengths for which
60 the percentage variation in frequency over a telephone transmission band is relatively small.

In a tapered wave antenna which involves receiving at the end of the antenna distant
65 from the sending station the frequency selectivity is not marked. Such an antenna is, therefore, suitable for relatively long waves.

A combination of tapering and transposing can be worked out for an antenna ar-
70 ranged to receive at the end nearest the sending station. Such an arrangement would probably have better directional selectivity than a simple transposed antenna. Since
75 antennæ arranged for receiving at this end must inherently have marked frequency selectivity, this method of reception is suitable only for relatively short waves.

This invention will be clearly understood from the following description when read in
80 connection with the attached drawing, of which Figures 1 to 5 illustrate the principle underlying the invention; Fig. 6 represents schematically a tapered and transposed antenna in which the invention is embodied,
85 and Fig. 6^a is a polar diagram of such an antenna; Fig. 7 shows the mode of construction of an antenna of the type shown in Fig. 6, and Fig. 7^a is a detail thereof; Fig. 8 shows a coupling network of the type shown sym-
90 bologically in Fig. 7, and Figs. 9 and 10, which are equivalent circuits of those shown in Fig. 7, serve to illustrate the description of the invention; Fig. 11 represents a form of tapered antenna having separate transmission cir-
95 cuits, which feature distinguishes it from Fig. 7; Fig. 11^a is a detail of Fig. 11; Fig. 12 shows the mode of connecting a plurality of antennæ such as are shown in Fig. 11, with a common receiving circuit, and Fig. 12^a is a

detail of the terminating arrangement which is shown symbolically in Fig. 12.

Fig. 1 shows a top view of the antenna which has been assumed to be one wave length long for the frequency under consideration. For the sake of simplicity, only four sections are indicated. The directions of the desired signal and of an undesired signal are indicated. Fig. 2 indicates an imaginary arrangement involving the idea of separately terminating each of the finite sections in characteristic impedance at each end. The currents at each end of each section resulting from any particular signal are indicated. If the individual intermediate terminations are removed and the sections connected together, the normal condition of Fig. 1 is restored. The received current at B in Fig. 1 is evidently the vector sum of the currents i_1 , i_2 , etc., each of these currents being propagated to the point B. Similarly, the current at A is the vector sum of the currents i'_1 , i'_2 , etc., propagated to point A.

If the currents in Fig. 2 result from the desired signal, it is evident that i_2 lags i_1 by the angle $\beta_0 d$ where $\beta_0 = 2\pi f \div$ speed of radio propagation. Since in reaching the terminal B, i_2 is propagated a shorter distance than i_1 , the former will tend to lead the latter by the angle βd where β is the phase change constant of the wave antenna. Considering both effects, i_2 at B will lead i_1 at B by the angle $(\beta - \beta_0)d$; also i_3 at B will lead i_2 at B by the same angle, etc. Fig. 3 indicates graphically the resultant current at B; i. e., the resultant of i_1, i_2 , etc., with the angular relations discussed above. The component at BB due to i_1 will actually be a little smaller than that due to i_2 , because of its greater attenuation in being propagated to point B along the wires of the antenna.

For the undesired signal indicated in Fig. 1, i_2 leads i_1 by the angle $\beta_0 d \cos(\pi - \theta)$ and also by the angle βd when both are propagated to B. The total angle between these two components of the current at B is, therefore, relatively large, since the two angles add rather than subtract as in the case of the desired signal. Fig. 4 indicates the relatively small resultant at B due to the undesired signal. These diagrams do not indicate the effect on the magnitude of the individual currents i_1 , i_2 , etc., due to the direction of the signal.

Fig. 5 indicates the resultant current at A from the desired signal. In this case the angle between the component currents due to i'_1 and i'_2 is large instead of small as in Fig. 3. The component due to i'_2 lags that due to i'_1 by the angle $(\beta_0 + \beta)d$. If the frequency involved is increased by say 10 per cent, the angles between the component vectors will be correspondingly increased. The resultant current of Fig. 3 will evidently be little changed by such a change in frequency, since

the angles are small; i. e., the wave antenna does not have marked frequency selectivity for signals in the direction of the antenna when receiving at end B. The resultants shown in Figs. 4 and 5 will evidently be changed to a marked extent by a 10 per cent change in frequency, since the angles are very large. It is apparent, therefore, that an antenna designed to receive at end A must have marked frequency selectivity and that for an antenna designed to receive at end B, the response to undesired signals will change rapidly with frequency. These same principles apply to tapered and transposed antennae since these modifications simply change the relative angles and magnitudes of the component vectors.

Fig. 6 represents schematically a form of tapered antenna which can be shown to give the directional diagram shown in Fig. 6^a. The system involves schematically two separate wave antenna systems X and Y, each comprising an antenna divided into a plurality of sections connected with a transmission line individual to that system. Thus, one antenna is divided into seventeen equal sections and the other into fifteen equal sections. The length of each section is one quarter of the wave length of the carrier frequency. Each section is terminated to ground at one end in a resistance equal to the characteristic impedance of the wave antenna and at the other end in a transformer and coupling network to couple the section to a metallic transmission line and to properly adjust the magnitude of the signal from the section. Fig. 6 shows only four such sections or elementary wave antennae, but this limitation has been made in order to render the drawing simpler. Since it is necessary to adjust the relative signal strengths of the various sections according to a predetermined plan, such adjustment is made at the terminal of each section by means of a resistance network, and the signal as thus adjusted must be brought to the receiving circuit of the antenna. This may be done by coupling all of the elements associated with one of the series of elementary antennae to a pair of wires such as in indicated by 1—2 of Fig. 6. Likewise, the other series of elementary antennae has its sections coupled with the pair of wires 3—4. The terminals of transmission lines 1—2 and 3—4 are then coupled with the common receiving set S, the connection between 3—4 and S including a network which will change the phase of the current by 90 degrees. The transmission lines must be far enough from the elementary antennae to prevent them from reacting on the current in the antennae. The two transmission lines need only be sufficiently separated to avoid crosstalk between these metallic circuits and this effect may be minimized by the use of

transpositions. Paralleling elementary antennæ may be in close proximity.

The polar diagram of such an antenna is shown in Fig. 6^a. In computing this diagram, 5
attenuation was excluded in order to simplify the computations, but the design of the resistance networks at the terminal of each circuit may be such that the attenuation in the transmission lines or in the elementary antennæ does not appreciably alter the diagram. 10
In designing the tapered antenna described above, effort was made to produce a diagram having practically no area below approximately 30°. A tapered antenna having such 15
a polar diagram will be particularly useful for east and west transmission inasmuch as it would exclude atmospheric interference from the south and southwest.

Fig. 7 shows an improved form of tapered 20
wave antenna such as is shown schematically in Fig. 6. The desirable directional selectivity characteristics shown in Fig. 6^a are obtained with antennæ of reasonable length by using two tapered systems and combining 25
them at the receiving end through a network designed to shift the phase of the signal from one antenna relative to that from the second antenna by an angle of 90° for each frequency in the band transmitted.

In Fig. 7 the improvement resides in the 30
use of a single series of elementary antennæ in place of two antennæ shown in Fig. 6. The signal from each of the elementary antennæ of Fig. 7 is divided into two equal 35
parts, each part being properly attenuated (and in some cases reversed in phase by a transposition) to give the desired tapering effect, and transmitted over an open-wire pair to the receiving station. The use of two separate 40
series of elementary antennæ as indicated in the schematic arrangement of Fig. 6 is unnecessary since the currents at similar ends of two paralleling coterminous closely adjacent elementary antennæ will be alike. A 45
coupling network is necessary at the end of each elementary antenna in order to divide the signal into two equal parts, to properly attenuate each part and connect it to its individual metallic transmission line. A suitable 50
form of coupling network is shown in Fig. 8, in which the same reference characters have been used as in Fig. 7.

Since a single pair of wires transmits half 55
of the signal from each elementary antenna to the receiving set, it is necessary that the coupling network shall not introduce any change in phase in signals transmitted along the metallic circuit and through a series of 60
such coupling networks other than the phase change which would occur if the networks were removed. This condition is satisfied since the network simply inserts in the metallic circuit the equivalent of a resistance artificial line whose input impedance may be 65
made the characteristic impedance of the me-

tallic circuit. This impedance for an open-wire circuit at radio frequencies is practically equal to that of a resistance of about 600 ohms in series with a large capacity. For greater 70
accuracy in preserving normal phase change in the metallic circuits, the five resistances involving R_2 should each have in series a suitably proportioned capacity. This refinement may not be important in practice.

It is also necessary that signals from pre- 75
vious elementary antennæ which are being carried by the metallic circuit shall not be transmitted into the particular section being coupled on, since this would result in transferring a part of the signal from the previous 80
section into the other metallic circuit, thus changing the desired relation between the currents received at the ends of the two metallic circuits. The balance of the bridge circuit prevents this action.

It is also necessary that signals picked up 85
in the grounded phantom of the metallic circuits shall not crosstalk into the elementary wave antenna, since such crosstalk currents 90
would be transmitted down the metallic circuits and interfere with the desired directional characteristics of the antenna. It may be, therefore, necessary to separate the two pole lines shown in Fig. 7^a by a considerable 95
distance. In predetermining the directional characteristics of the wave antenna, it is necessary to allow for the space phase change from the start of the antenna system to the end of any particular elementary antenna and 100
also for the phase change in the wire transmission to the receiving circuit. Phase changes and losses introduced in the coupling network do not affect the computed directional characteristics, provided these effects are involved only in coupling the elementary 105
antennæ to the metallic circuits, and provided all the elementary antennæ are affected alike. For example, the phase changes in transformer T_1 and T_2 do not matter, as long as all similar transformers are exactly 110
alike. In addition, the lengths of the metallic circuits connecting the two pole lines do not matter as long as they are all alike. All the metallic circuits must be transposed. This 115
is indicated in Fig. 7 and is necessary to avoid pick-up of power induction and crosstalk between the various metallic circuits.

As noted, a tapered antenna must necessarily be inefficient due to losses in the coupling networks. With the network described 120
above, it is estimated that the final signal received at the receiving set is down about 30 TU from that which would be obtained if the coupling networks had no losses. The 125
network should be designed to put a small loss in the metallic circuit and a correspondingly large coupling loss between this circuit and the elementary antenna. The signal from any one such antenna is, therefore, down 130
by this large coupling loss plus the sum of the

losses in the metallic circuit caused by all the coupling networks encountered by the signal in being transmitted to the receiving set. The natural attenuation in the metallic circuit will, of course, increase the losses. In this connection it should be noted that the coupling losses may be so adjusted as to compensate for attenuation at the mid-frequency of the band which it is desired to transmit. For example, the coupling losses of the first and last elementary antenna shown in Fig. 6 would not be the same, since the signal from the first antenna is appreciably reduced by the attenuation of the metallic pair. This compensation for attenuation should make the actual directional characteristic of the tapered antenna very nearly the same as the computed characteristic which ignored the natural attenuation.

Fig. 11 shows an alternative method of constructing the tapered wave antenna, using separate transmission circuits for each elementary antenna. Large gauge shielded cable pairs might be used for this purpose. Individual shields will prevent crosstalk between the various transmission circuits and the use of an underground cable would prevent underside signals being picked up by the cable and transmitted by crosstalk to the elementary wave antennae and finally to the transmission circuits. With this method only a single pole line would be necessary, as indicated in Fig. 11^a of the drawing. While the attenuation in the large gauge cable circuits would be much greater than that in open-wire transmission circuits, the efficiency of the system would probably be about equal to that shown in Fig. 7, since the large loss in coupling on elementary antenna to the metallic circuit is avoided. The speed of propagation and, therefore, the phase change constant would be different for the cable pair than for an open-wire pair, but this can be allowed for in designing the antenna system.

Fig. 12 shows a method of coupling together the separate transmission circuits. Since the phase change along a transmission circuit must be taken into account, it is necessary to accurately terminate the distant ends of these circuits in their characteristic impedances. Otherwise, reflections would occur at this point. The reflected currents would travel back to transformers T_3 . A second reflection would occur at this point, since no practical transformer can couple an open-wire circuit of relatively high impedance to a cable circuit of relatively low impedance without introducing appreciable impedance irregularity. The second reflection would result in a reflected current traveling back to the receiving end and, therefore, making the phase of the received current different from that which would be allowed for in the design of the antenna system. Fig. 12^a shows

a tube coupling that may be used in order to insure that the transmission circuits are accurately terminated in their characteristic impedance. The transmission circuits after each is connected to a vacuum tube amplifier are multiplied together, in order to obtain the desired resultant signal. Since the impedances of the transmission circuits looking back into the vacuum tube elements may be made alike, the change in phase and magnitude of the signal from any transmission circuit in being transmitted from the vacuum tube output to the receiving circuit will be the same for all the transmission circuits. Such changes will, therefore, not affect the computed directional characteristics of the antenna system.

The formulæ used for computing the directional characteristic of the particular form of tapered antenna shown in Fig. 6 are as follows:

f_h = horizontal component of electric force at end distant from receiving end.

f_v = corresponding vertical component.

h = height of wave antenna.

l = length of elementary antenna.

Z = characteristic impedance of wave antenna.

θ = angle between direction of signal and direction of antenna.

β_1 = phase change constant for wave antenna.

β_2 = phase change constant for metallic transmission circuit.

$\beta_0 = 2\pi$ divided by speed of radio wave.

$$\phi_1 = \frac{1}{2}(\beta_1 l - \beta_0 l \cos \theta) \quad \phi'_1 = \frac{1}{2}(\beta_1 l + \beta_0 l \cos \theta)$$

$$\phi_2 = \frac{1}{2}(\beta_2 l - \beta_0 l \cos \theta) \quad \phi'_2 = \frac{1}{2}(\beta_2 l + \beta_0 l \cos \theta)$$

Received signal

$$= \frac{3.2 f_h l}{Z} \left[\cos \theta + \frac{j 2 f_v h \phi_1}{l f_h} \right] \left[\frac{\phi_2 \sin \phi_1}{\phi_1 \sin \phi_2} \right. \\ \left. \frac{\sin 8 \phi_2}{8 \phi_2} (1 - \sin 6 \phi_2) (1 - \sin 2 \phi_2) \right.$$

$$\left. \cos \phi_2 \sqrt{16 \phi'_2 + \phi'_1} \right]$$

$$= K (1 - \sin 6 \phi_2) (1 - \sin 2 \phi_2)$$

$$= K (1 + \sin 6 \phi_2 \sin 2 \phi_2) - K (\sin 2 \phi_2 + \sin 6 \phi_2)$$

First term is signal due to upper half of tapered antenna. Second term is signal due to lower half of tapered antenna.

If attenuation is considered β_1 and β_2 should be replaced by γ_1 and γ_2 and the circular trigonometric functions should be replaced by the corresponding hyperbolic functions. Formulæ are given for each half of the antennae system. In practice, the signals from the two halves would be adjusted experimentally in relative phase and magnitude to minimize some particularly objectionable undesired signal and compensate to some extent for irregularities in constructing the antenna system.

As previously noted, the artificial lines in the coupling networks may be adjusted to correct for differences in attenuation in the metallic circuit. If this is done, the formulæ
 5 β_1 with γ_1 . The percentage change in the directional diagram for any particular direction will be the same as that for a single quarter-wave length wave antenna when corrected
 10 for attenuation. This effect is known to be small.

While this invention has been disclosed as embodied in particular forms, it is capable of embodiment in other and different forms
 15 without departing from the spirit and scope of the appended claims.

What is claimed is:

1. A transposed and tapered antenna system comprising two separate aperiodic horizontal antennæ, each antenna being divided
 20 into a plurality of sections, a connecting circuit for each of said antennæ, means to couple each of the sections of each antenna with the connecting circuit individual to the antenna to which the sections belong, means
 25 connected with one of the connecting circuits to change the phase of the currents therein, and a translating circuit common to both connecting circuits.

30 2. In a directional antenna system, the combination with an aperiodic horizontal antenna comprising a plurality of sections of equal length, of a second aperiodic horizontal antenna also comprising a plurality of
 35 sections of equal length, a connecting circuit individual to each of said antennæ, means to transpose certain sections of each antenna with respect to the other sections of the same antenna, and coupling means associated with
 40 each section to connect the said section with the connecting circuit individual to the antenna to which the section belongs, the said coupling means being adapted to control the magnitude of the current applied thereby to
 45 the connecting circuit.

3. In a directional antenna system, the combination with an aperiodic horizontal antenna comprising a plurality of sections of equal length, of a second aperiodic horizontal
 50 antenna also comprising a plurality of sections of equal length, a connecting circuit individual to each of said antennæ, means to transpose certain sections of each antenna with respect to the other sections of the same
 55 antenna, means connected with one of said connecting circuits to change the phase of the current 90 degrees with respect to the current in the other connecting circuit, and a common circuit upon which currents from
 60 both connecting circuits may be impressed.

4. In a directional antenna system, combination with an aperiodic horizontal antenna comprising a plurality of sections, each
 65 of which is an aperiodic antenna, of a second aperiodic horizontal antenna, likewise com-

prising a plurality of sections, each of which is an aperiodic horizontal antenna, a transmission line individual to each antenna, coupling means individual to each section of each
 70 antenna to control the magnitude and phase of the current applied to the transmission line by the section with which the coupling means is connected, a receiving circuit connected with both transmission lines, and
 75 phase changing means connecting between one transmission line and the said receiving circuit.

In testimony whereof, I have signed my name to this specification this 20th day of August, 1926.

ARTHUR G. CHAPMAN.

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