

Aug. 30, 1938.

YUK-WING LEE ET AL

2,128,257

ELECTRICAL NETWORK SYSTEM

Filed July 7, 1936

6 Sheets-Sheet 1

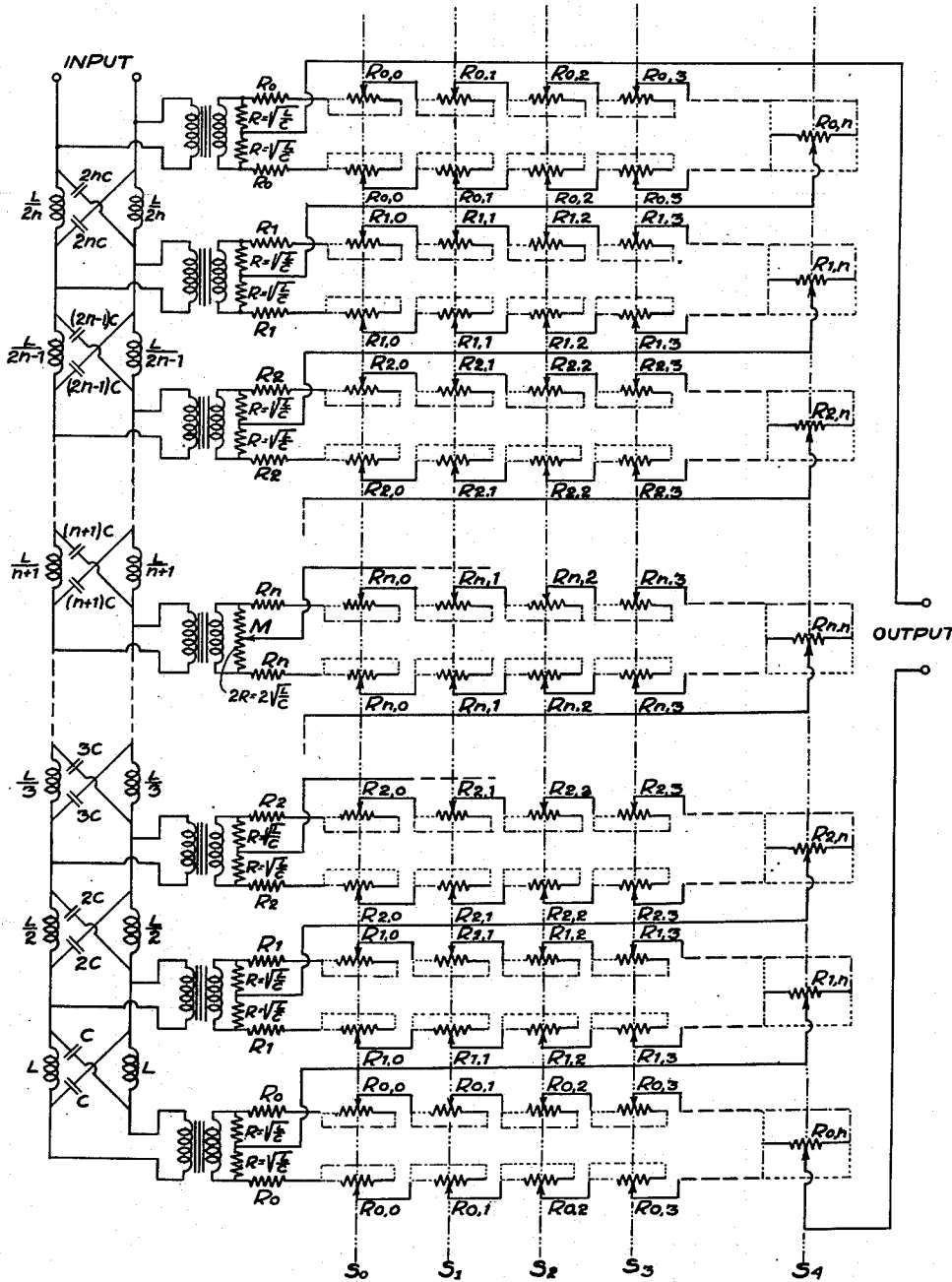


FIG. 1.

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6 Sheets-Sheet 2

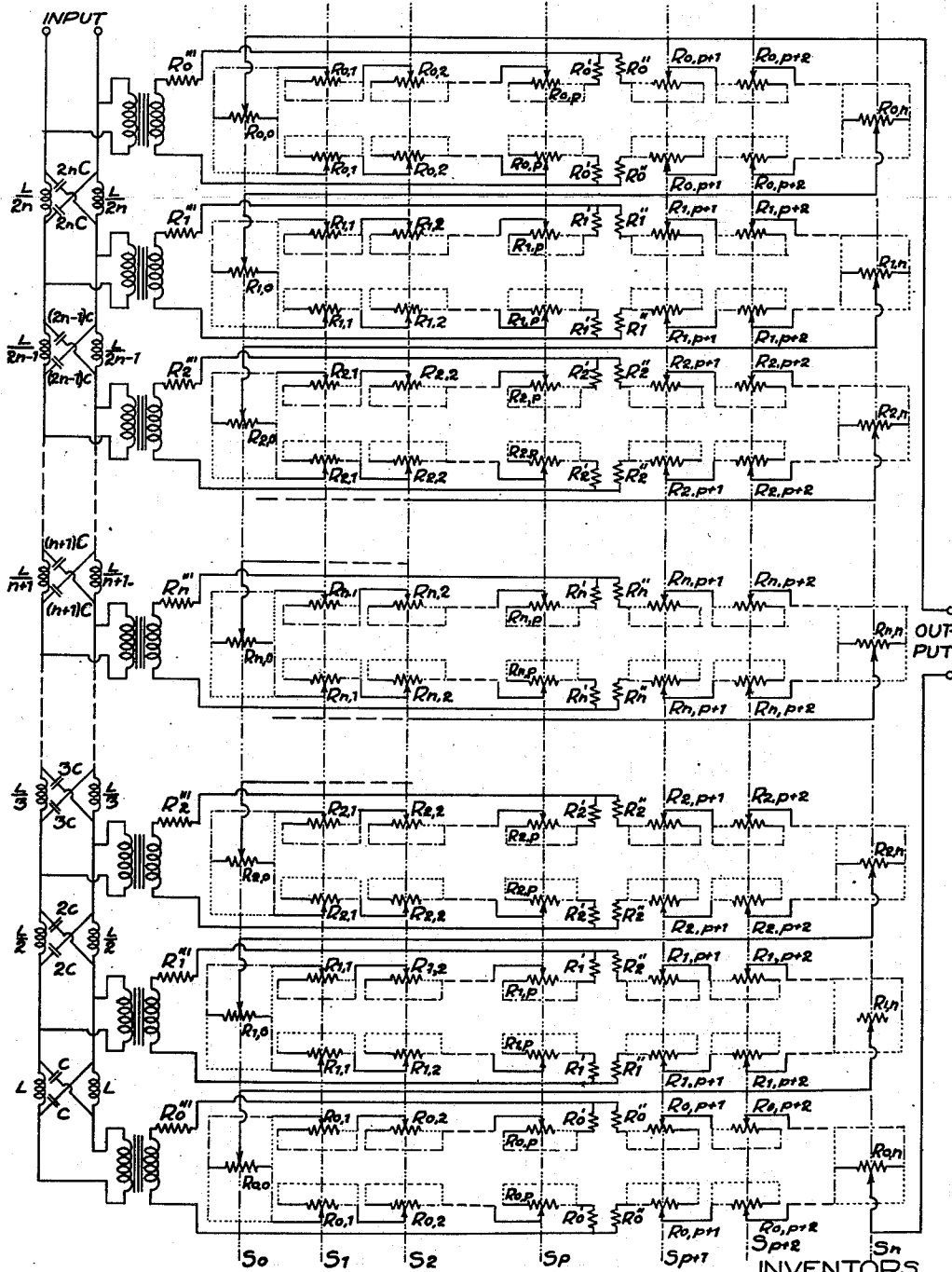


FIG. 2.

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6 Sheets-Sheet 3

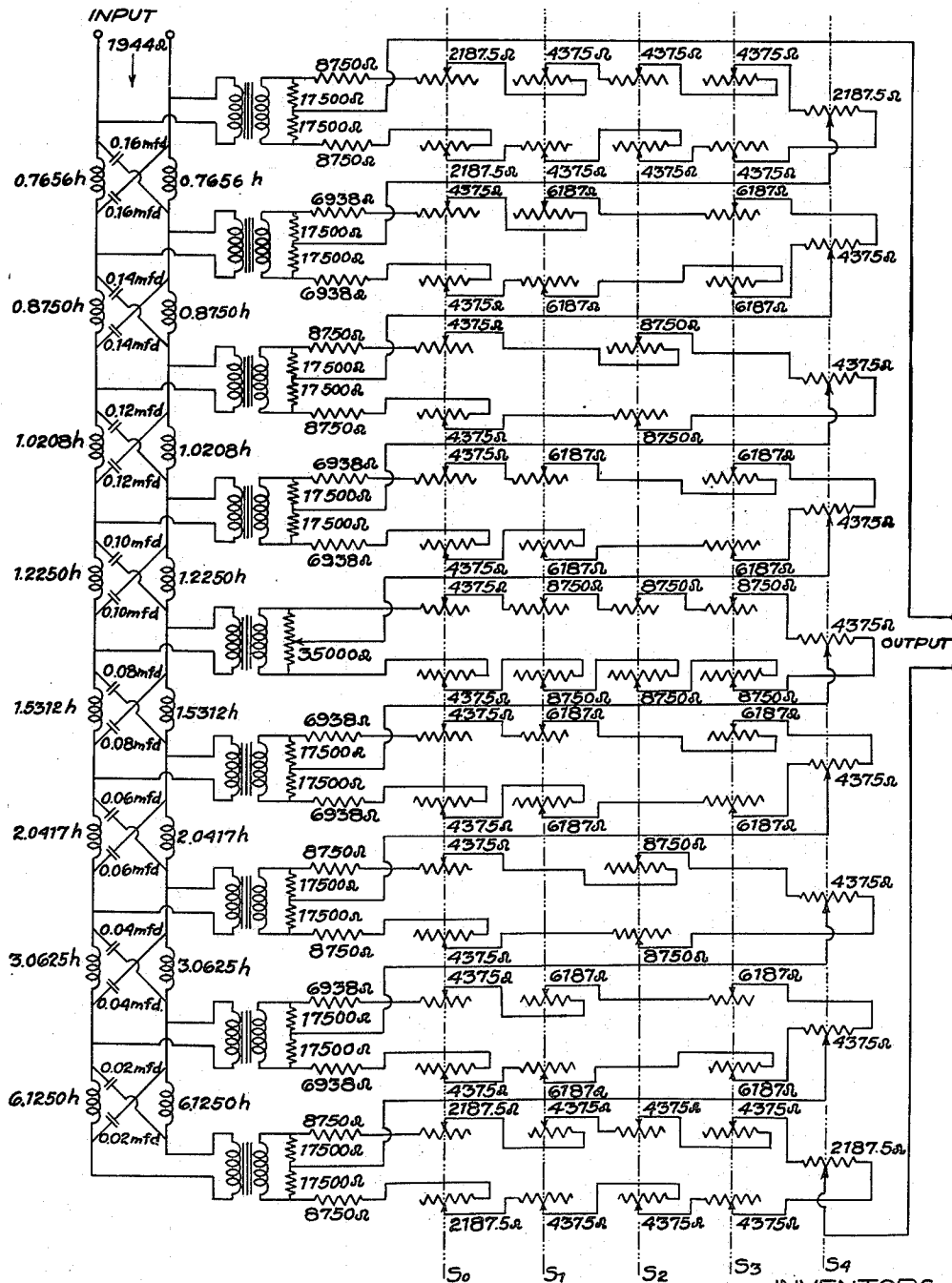


FIG. 3.

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6 Sheets-Sheet 4

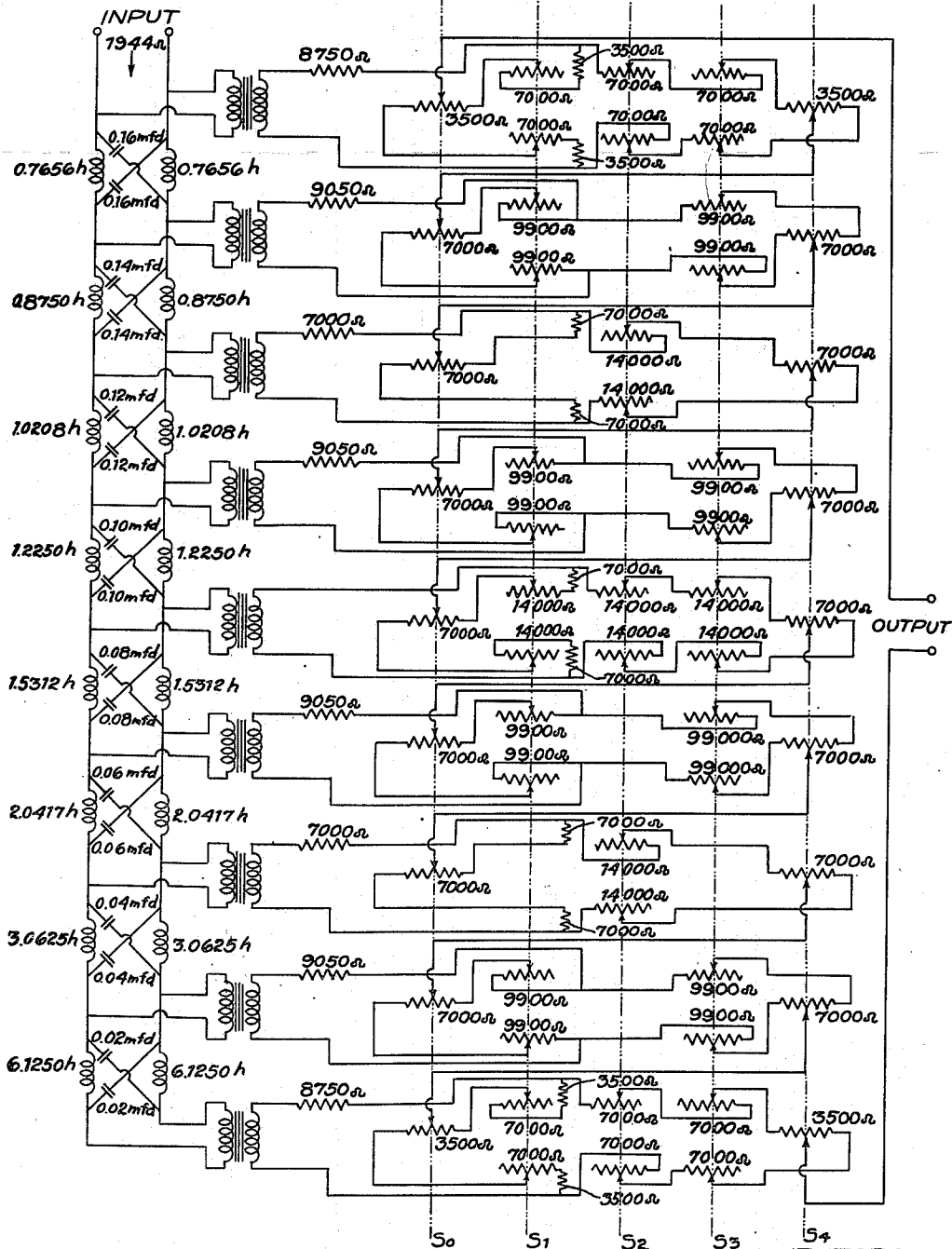


FIG. 4.

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6 Sheets-Sheet 5

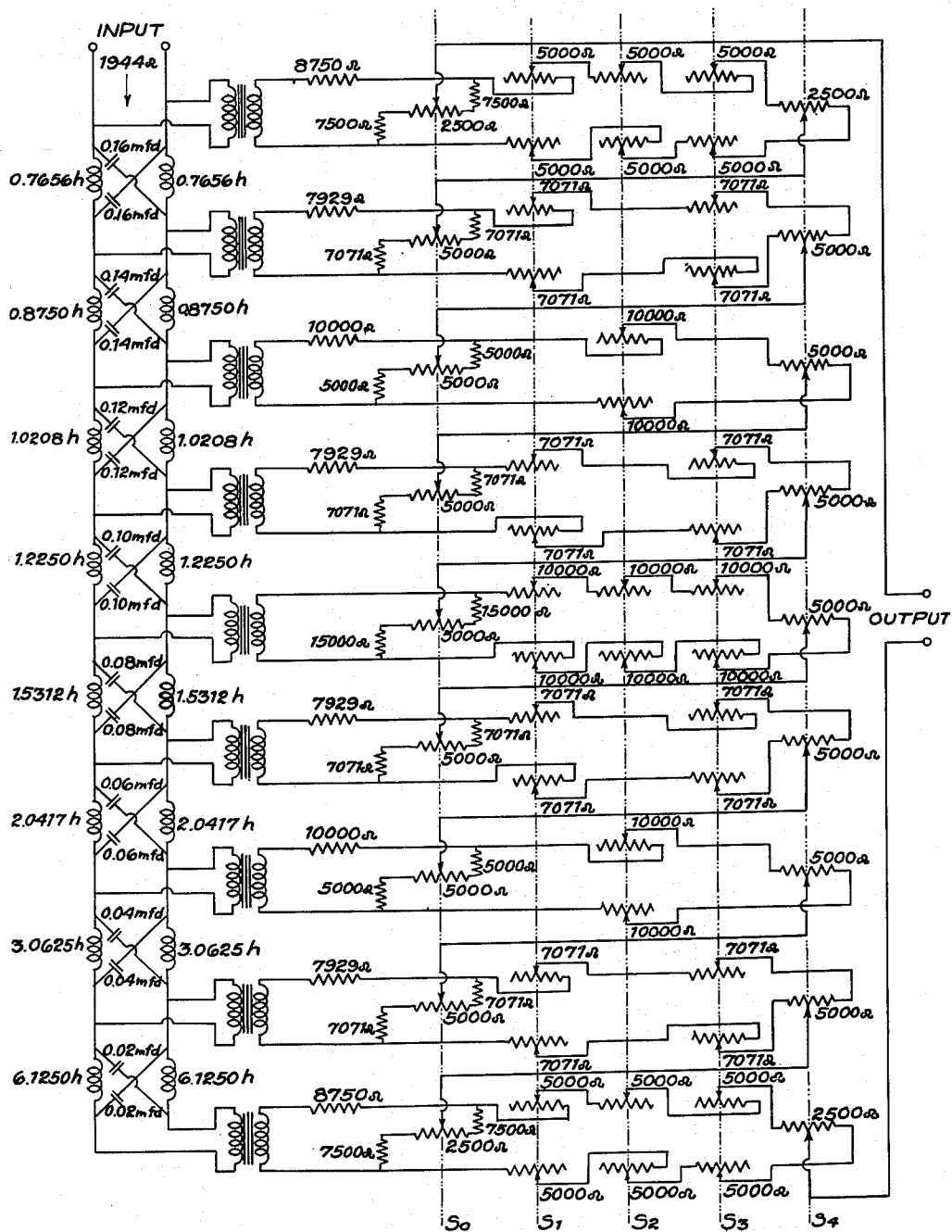


FIG. 5.

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6 Sheets-Sheet 6

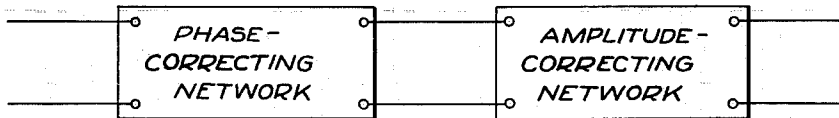


FIG. 6.



FIG. 7.

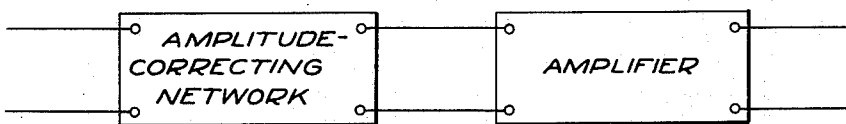


FIG. 8.

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2,128,257

ELECTRICAL NETWORK SYSTEM

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Application July 7, 1936, Serial No. 89,336

17 Claims. (Cl. 178-44)

This invention relates to electrical corrective network systems, and particularly to a new type of electrical network, and to a new method of computing the constants and values of the respective elements of a network system.

In electrical communication systems, and in other systems where vibrations of different frequencies undergo an electrical transformation, it is desirable to have corrective networks to correct the distortion in the electrical vibrations due to the inherent properties of or imperfections in the parts of the systems. The corrective network may also serve to control electrical vibrations in accordance with specifications required for a special purpose which may or may not be corrective, or may be partially corrective.

Distortion in electrical vibrations may be in amplitude or in phase or in both amplitude and phase. Amplitude distortion is the unequal change in amplitude of vibrations of different frequencies; and phase distortion is the unequal change in phase relations of the vibrations of different frequencies. Generally, an amplitude-correcting network serves to equalize the amplitude change, and a phase-correcting network serves to bring the vibrations into the same phase relations as those existing in the original vibrations. These conditions are necessary for the true reproduction of vibrations of different frequencies. Various networks have been invented for such corrections, but they are not subject to adjustment or conveniently adapted to preliminary computations.

An object of this invention is to correct distortion in electrical transmission systems and in other similar systems.

Another object is to incorporate in a single network system adjustable members adapted to produce any attainable amplitude-frequency characteristic, the adjustment for any characteristic to be done with the aid of simple computations, or in accordance with calibrations, or rapidly by experiment.

Still another object is to provide a network system having any desired attainable amplitude-frequency characteristic, and whose design requires only simple calculations.

A still further object is to correct both amplitude and phase distortions in electrical transmission and other similar systems by the insertion into such systems of two different but supplementary corrective networks having adjustable or non-adjustable members.

A further object of this invention is to provide an electrical network system having any de-

sired attainable amplitude-frequency and phase-frequency characteristics.

According to this invention, a network system having an adjustable amplitude-frequency characteristic but a fixed phase-frequency characteristic is obtained by the construction of a network system in accordance with a Fourier series and the provision of means by which the circuit elements representing the coefficients of the series may be varied in such a manner that any amplitude-frequency characteristic may be simulated. A part of this network system is a lattice network of a number of sections which are similar in structure, but different in value. The lattice network is combined with a system of variable and fixed resistances through a set of transformers. The system of resistances is connected mechanically in such a manner that each of a number of separate mechanical connections may be assigned to control independently the amplitude of electrical vibrations of a particular frequency. The amplitude-frequency characteristic of the whole system is a smooth curve passing through all the values at the particular frequencies.

Other objects and structural details of this invention will be apparent from the following description when read in connection with the accompanying figures, wherein:

Fig. 1 illustrates an electrical network system of this invention;

Fig. 2 illustrates a modified form of the electrical network system of Fig. 1;

Figs. 3 to 5 illustrate sample network systems of this invention with specific values of the network elements;

Fig. 6 illustrates a phase-correcting network system directly in combination with a network system of this invention;

Fig. 7 illustrates a phase-correcting network system in combination with a network system of this invention through amplifier means; and

Fig. 8 illustrates a network system of this invention in combination with amplifier means.

It has been shown in U. S. Patent No. 2,024,900, issued December 17, 1935, to N. Wiener and Y. W. Lee, that a network characteristic $Y(\theta)$, having been expanded into a Fourier series of the form

$$Y(\theta) = a_0 + a_1 e^{-j\theta} + a_2 e^{-j2\theta} + a_3 e^{-j3\theta} + \dots \quad (1)$$

wherein $a_0, a_1, a_2, a_3 \dots$ are constants,

$$j = \sqrt{-1}$$

and $\theta = 2 \tan^{-1} k\omega$, k being a positive constant, and ω being 2π times the frequency, may be

(7). The output side of each transformer is shunted by a resistance of value

$$2R = 2\sqrt{\frac{L}{C}}$$

5 and a connection is made at the middle except
at M where a sliding contact may take the place
of a fixed connection. The point M determines
the zero position of the shafts. The movement
10 of this point from top to bottom corresponds to
the displacement of the zero point from the ex-
treme left to the extreme right of the columns of
resistances. The portion of each column to the
right of the zero position may be taken to rep-
15 resent the positive values of the network char-
acteristic, and the portion to the left, the nega-
tive values. Although an amplitude-frequency
characteristic is always positive, it is sometimes
easier to produce a required characteristic of
20 certain irregularities by considering portions
of it as negative. While the amplitude of the
network characteristic may be adjusted as de-
scribed, the phase characteristic is unaffected by
the adjustment so long as no positive coefficient
25 is replaced by a negative one, and has the value
given by Equation (5).

30 A modified form of the network of Fig. 1 is shown in Fig. 2. Here the transformers are connected to the system of resistances through resistances R' and R'' . The resistances R' and R'' are such that

$$(11) \quad \begin{array}{l} 2R'_0 + R_{0,0} + R_{0,1} + R_{0,2} + \dots + R_{0,p} = 2R''_0 + R_{0,p+1} + R_{0,p+2} + \dots + R_{0,n}; \\ 2R'_1 + R_{1,0} + R_{1,1} + R_{1,2} + \dots + R_{1,p} = 2R''_1 + R_{1,p+1} + R_{1,p+2} + \dots + R_{1,n}; \\ 2R'_2 + R_{2,0} + R_{2,1} + R_{2,2} + \dots + R_{2,p} = 2R''_2 + R_{2,p+1} + R_{2,p+2} + \dots + R_{2,n}; \\ \vdots \\ 2R'_n + R_{n,0} + R_{n,1} + R_{n,2} + \dots + R_{n,p} = 2R''_n + R_{n,p+1} + R_{n,p+2} + \dots + R_{n,n}. \end{array}$$

and R''' is added so that

$$(12) \quad R''_0 + 2(2R'_0 + R_{0,0} + R_{0,1} + R_{0,2} + \dots + R_{0,n}) = \sqrt{\frac{L}{C}};$$

$$R''_1 + 2(2R'_1 + R_{1,0} + R_{1,1} + R_{1,2} + \dots + R_{1,p}) = \sqrt{\frac{L}{C}};$$

$$R''_2 + 2(2R'_2 + R_{2,0} + R_{2,1} + R_{2,2} + \dots + R_{2,p}) = \sqrt{\frac{L}{C}};$$

$$R''_n + 2(2R'_n + R_{n,0} + R_{n,1} + R_{n,2} + \dots + R_{n,p}) = \sqrt{\frac{L}{C}}$$

The zero point of each column of resistances is at the middle position. Other features of this network system are essentially the same as those described hereinbefore.

55 Fig. 3 shows a sample network system designed in accordance with the principles of this invention described above. This is an example of the general network system of Fig. 1. Shafts S_0 , S_1 , S_2 , S_3 and S_4 are designed to control the network
60 characteristic at frequencies of zero, 188, 454, 1097, and infinite cycles per second. Although the first and last shafts theoretically control vibrations at zero, and infinite cycles per second, they may be utilized to adjust vibrations at any
65 frequency between zero and 188 cycles per second, and any frequency between 1097 and infinite cycles per second, respectively. The extreme values are used here as a matter of convenience in computations. According to the theory of this
70 invention, other values may be used instead. The transformers of this network are to operate between impedances of 17,500 ohms. The input impedance is 1944 ohms of pure resistance.

Figs. 4 and 5 show sample networks of the
75 general network of Fig. 2. These networks are

designed so that the shafts S_0 , S_1 , S_2 , S_3 , and S_4 control the network characteristic at the same frequencies as those in the previous case. The input impedance remains as 1944 ohms of pure resistance.

A distinguishing feature of the network systems herein described is that they have a fixed phase characteristic independent of the variations in the systems of resistances. This property of the network systems is a very useful one. In an electric network, a change in the amplitude characteristic is usually accompanied by a change in the phase characteristic and vice versa. These changes are related to each other, and although the relation is important in the study of network behavior, its existence is often an obstacle in engineering design problems. In a great many electrical problems, the separate control of amplitude characteristic and phase characteristic is much desired.

A particular merit of this network system is that, when viewed from the input end, as usually operated, it has the impedance characteristic of a pure resistance, and that when the network is adjustable, the value of this resistance is unaffected by the adjustment. This greatly facilitates the computation of the characteristic which the network must have to produce a desired effect, and minimizes the deleterious effect of reflection of oscillations at the network, which makes the problem of matching characteristics

very critical in wave filters of most previous types.

A suitable type of phase-correcting network system, for example, one of those disclosed and claimed in the aforementioned patent, may be combined directly as shown in Fig. 6, or indirectly through an amplifier as shown in Fig. 7, with a network system of this invention thereby providing a new network system capable of producing any desired amplitude-frequency and phase-frequency characteristics. The network system of this invention controls the amplitude-frequency characteristic, and, having a fixed phase-frequency characteristic itself, allows the phase-correcting network system to control the phase-frequency characteristic.

The device of this invention thus produces a single electrical network system having adjustable members by means of which any desired network characteristics can be produced, thereby enabling a single corrective system to be used for any purpose. Such a system is to be distinguished from the prior art, in which a given network was adaptable only to a single amplitude characteristic curve, and was adapted to other

characteristic curves only after complete rebuilding and reconstruction of the values of all the component parts.

The invention does not, however, necessarily reside in the adjustable features as above-mentioned, since it is possible by the computation process of this invention to produce a network having non-adjustable elements, which can be computed and constructed in size according to the desired characteristic curve of the network. When so constructed, the system, although non-adjustable without partially rebuilding, nevertheless produces a simple, convenient network system of high efficiency which stimulates with a high degree of accuracy the characteristic curve obtainable from computation.

The system of the invention may be used to feed directly into a repeater or other amplifying device, as shown in Fig. 8, or may be interpolated between the stages of an amplifier. It may also be used to feed directly or indirectly into a phonograph cutter or other instrument transforming electrical vibrations into a mechanical form. Among its applications, but not exhausting them, are a use in connection with communication circuits for filtering, balancing, or compensating purposes; a use, when in combination with a phase-correcting network, in connection with television circuits, to which the combination is peculiarly adapted, owing to the fact that it gives a ready control over phase distortion as well as amplitude distortion; a use in the production of tones or noises of predetermined distribution of energy in frequency; a use in the recording and reproducing of sound; a use as an instrument in the calibration of electrical and acoustical systems, for laboratory, medical and other purposes; and a use in the determination of what quality of response in a sound reproducing device is most desirable or pleasing to the human ear. It is possible to embody the principles of this device in mechanical or acoustical form, in accordance with the well-known analogies between electrical vibrating systems and mechanical or acoustical vibrating systems.

While the above description discloses a limited number of embodiments of the device of this invention, it is possible to produce still other embodiments without departing from the spirit thereof, and it is desired, therefore, that only such limitations shall be imposed upon the appended claims as are stated therein or required by the prior art.

What is claimed is:

1. An electrical network system with adjustable amplitude-frequency characteristic, and with phase-frequency characteristic independent of adjustment, said system comprising means for progressively shifting the phase of an input signal, a plurality of pairs of electrical paths for withdrawing therefrom voltages differing in phase, means for combining said voltages, and means including variable impedances for adjusting the relative amplitudes of said voltages.
2. An electrical network system with adjustable amplitude-frequency characteristic, phase-frequency characteristic independent of adjustment, and input impedance that of a constant resistance, said system comprising means for progressively shifting the phase of an input signal, a plurality of pairs of electrical paths for withdrawing therefrom voltages differing in phase, means for combining said voltages, and means

including variable impedances for adjusting the relative amplitudes of said voltages.

3. An electrical network system with adjustable amplitude-frequency characteristic, and with phase-frequency characteristic and input impedance both independent of adjustment, said system comprising means for progressively shifting the phase of an input signal, a plurality of pairs of electrical paths for withdrawing therefrom voltages differing in phase, means for combining said voltages, and means including variable impedances for adjusting the relative amplitudes of said voltages.

4. An electrical network system comprising means for progressively shifting the phase of an input signal, a plurality of electrical paths for withdrawing therefrom voltages differing in phase, means for combining said voltages, a plurality of variable impedances, and a series of controls for adjusting said variable impedances, whereby the output to input voltage ratio of the system may be controlled over a portion of the frequency spectrum without substantially influencing said voltage ratio at certain other specific frequencies.

5. An amplitude-correcting network having a constant, non-reactive input impedance, said network comprising means for progressively shifting the phase of an input signal, a plurality of electrical paths for withdrawing therefrom voltages differing in phase, means for combining said voltages, a plurality of variable impedances, and a plurality of controls for adjusting said variable impedances, whereby the absolute value of the ratio of the input to the output voltage may be independently adjusted at any one of a plurality of fixed frequencies without affecting either the phase-frequency characteristic or said input impedance.

6. An amplitude-correcting network comprising a plurality of tandem connected four-terminal transducers for progressively shifting the phase of an input signal, a plurality of electrical paths for tapping off voltages from said transducers, means for combining said voltages, and a plurality of variable resistances associated with said paths by means of which the amplitude-frequency characteristic may be adjusted without affecting the phase-frequency characteristic of said network.

7. An amplitude-correcting network having a constant, non-reactive input impedance and comprising means for progressively shifting the phase of an input signal, a plurality of electrical paths for withdrawing therefrom voltages differing in phase, means for combining said voltages, and a plurality of variable resistances for adjusting the relative amplitudes of said voltages, whereby the amplitude-frequency characteristic of said network may be adjusted without affecting its phase-frequency characteristic.

8. An amplitude-correcting network comprising means for progressively shifting the phase of an input signal, means for extracting therefrom phase-shifted voltages at a plurality of points, means for combining said voltages, and means comprising a plurality of variable resistances for individually controlling the amplitudes of said voltages whereby the amplitude-frequency characteristic of said network may be adjusted without affecting either its phase-frequency characteristic or its input impedance.

9. An amplitude-correcting network having a constant, non-reactive input impedance and comprising means for progressively shifting the phase

of an input signal, a plurality of electrical paths for tapping off phase-shifted voltages, means for combining said voltages, a plurality of variable resistances in each of said paths, and a plurality of controls associated with said variable resistances by mean of which the amplitude-frequency characteristic may be adjusted without affecting either the phase-frequency characteristic or the input impedance of said network.

10 10. A variable amplitude-correcting network comprising means for progressively shifting the phase of an input signal, a plurality of electrical paths for withdrawing phase-shifted voltages therefrom, means for combining said voltages, and a plurality of controls for regulating the relative amplitudes of said voltages, whereby the amplitude-frequency characteristic of said network may be adjusted independently at any one of a plurality of frequencies without affecting the
20 amplitude-frequency characteristic at any of the other of said frequencies.

11. A network comprising a plurality of connected transducer sections for progressively shifting the phase of an input signal, a plurality of electrical paths connected to said sections at different points, means for tapping off voltages from said paths, and means for combining said voltages, the magnitudes of said voltages corresponding to the coefficients $a_0, a_1, a_2, a_3, \dots, a_n$
30 of the expansion of the amplitude-frequency characteristic to be simulated into a series of the form

$$a_n + 2a_{n-1} \cos \theta + 2a_{n-2} \cos 2\theta + 2a_{n-3} \cos 3\theta + \dots + 2a_0 \cos n\theta$$

35 wherein $\theta = 2 \tan^{-1} k\omega$, k being a positive constant, and ω being 2π times the frequency.

12. A network comprising a plurality of connected transducer sections for progressively shifting the phase of an input signal, a plurality of electrical paths connected to said sections at different points, means for tapping off voltages from said paths, and means for combining said voltages, the magnitudes of said voltages corresponding to the coefficients $a_0, a_1, a_2, a_3, \dots, a_n$
45 of the series.

$$a_0 + a_1 e^{-j\theta} + a_2 e^{-j2\theta} + a_3 e^{-j3\theta} + \dots + a_n e^{-jn\theta} + a_{n-1} e^{-j(n+1)\theta} + a_{n-2} e^{-j(n+2)\theta} + \dots + a_0 e^{-j2n\theta}$$

50 wherein $j = \sqrt{-1}$, $\theta = 2 \tan^{-1} k\omega$, k being a positive constant, and ω being 2π times the frequency.

13. An electrical network system comprising a plurality of tandem connected transducers for subjecting the signal voltage to progressive phase shift, means comprising variable impedances for tapping off voltages at a plurality of junction points of said transducers, means for combining said voltages, and a plurality of controls for adjusting said variable impedances whereby the
60 amplitude frequency characteristic of said sys-

tem may be independently adjusted at any one of a plurality of frequencies without materially affecting its phase frequency characteristic.

14. An electrical network system comprising means for subjecting a signal voltage to progressive phase shift, a plurality of electrical paths for tapping off phase-shifted voltages at a plurality of points, means for combining said voltages, a plurality of pairs of variable impedances associated with said paths, and a unitary control for said variable impedances whereby the magnitude of each of said impedances may be varied without changing the total impedance of each of said pairs.

15. An electrical network system comprising a plurality of transducers for progressively shifting the phase of an input signal, a plurality of electrical paths for tapping off phase-shifted voltages from said transducers, means for combining said voltages, a plurality of pairs of variable impedances in each of said paths, and a plurality of controls, each of said controls being associated with a plurality of said pairs of variable impedances in a plurality of said paths, and the adjustment of each of said controls operating to increase the magnitude of one of the impedances of each of said pairs with which said control is associated while at the same time decreasing by a like amount the magnitude of the other variable impedance forming said pair.

16. An electrical network system comprising a plurality of transducers for progressively shifting the phase of an input signal, a plurality of similar pairs of electrical paths leading from said transducers, means for combining the output voltages of said paths, a plurality of pairs of variable impedances in each of said paths, and a plurality of controls, each of said controls being associated with a pair of said impedances in each of said paths and operating to adjust the amplitude-frequency characteristic of said system over a portion of the frequency spectrum without substantially altering said characteristic at certain other specific frequencies.

17. An electrical network system comprising a plurality of transducers for progressively shifting the phase of an electrical vibration, a plurality of electrical paths for tapping off phase-shifted vibrations from said transducers, means for combining said phase-shifted vibrations, a plurality of pairs of variable impedances in each of said paths, and a unitary control operative to adjust each of said variable impedances of a pair in each of said paths, whereby the amplitude-frequency characteristic of said system may be adjusted without materially affecting its phase-frequency characteristic.

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