

March 1, 1938.

V. B. BAGNALL

2,109,562

TRANSMISSION SYSTEM

Filed Jan. 2, 1935

4 Sheets-Sheet 1

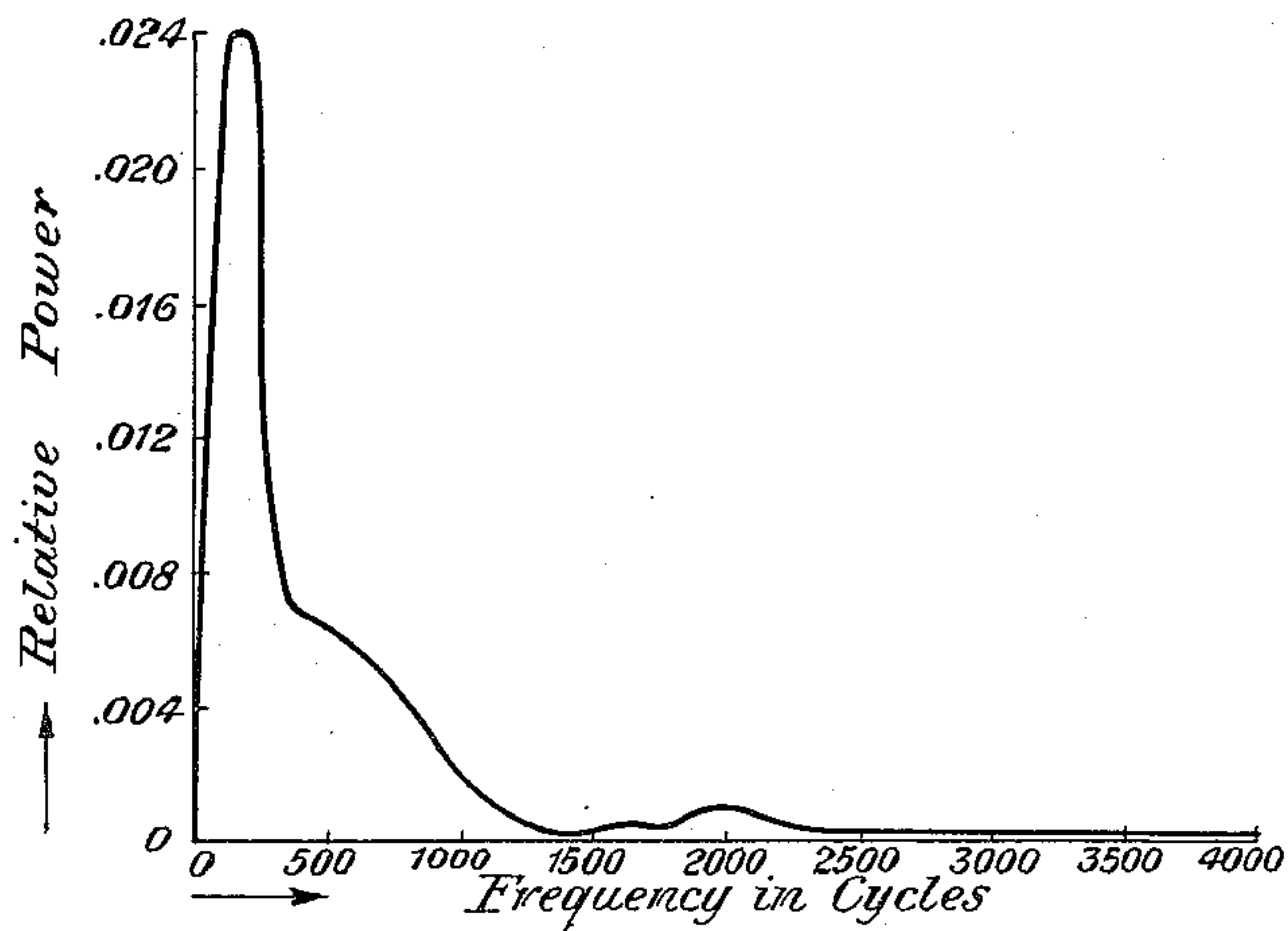


Fig. 1

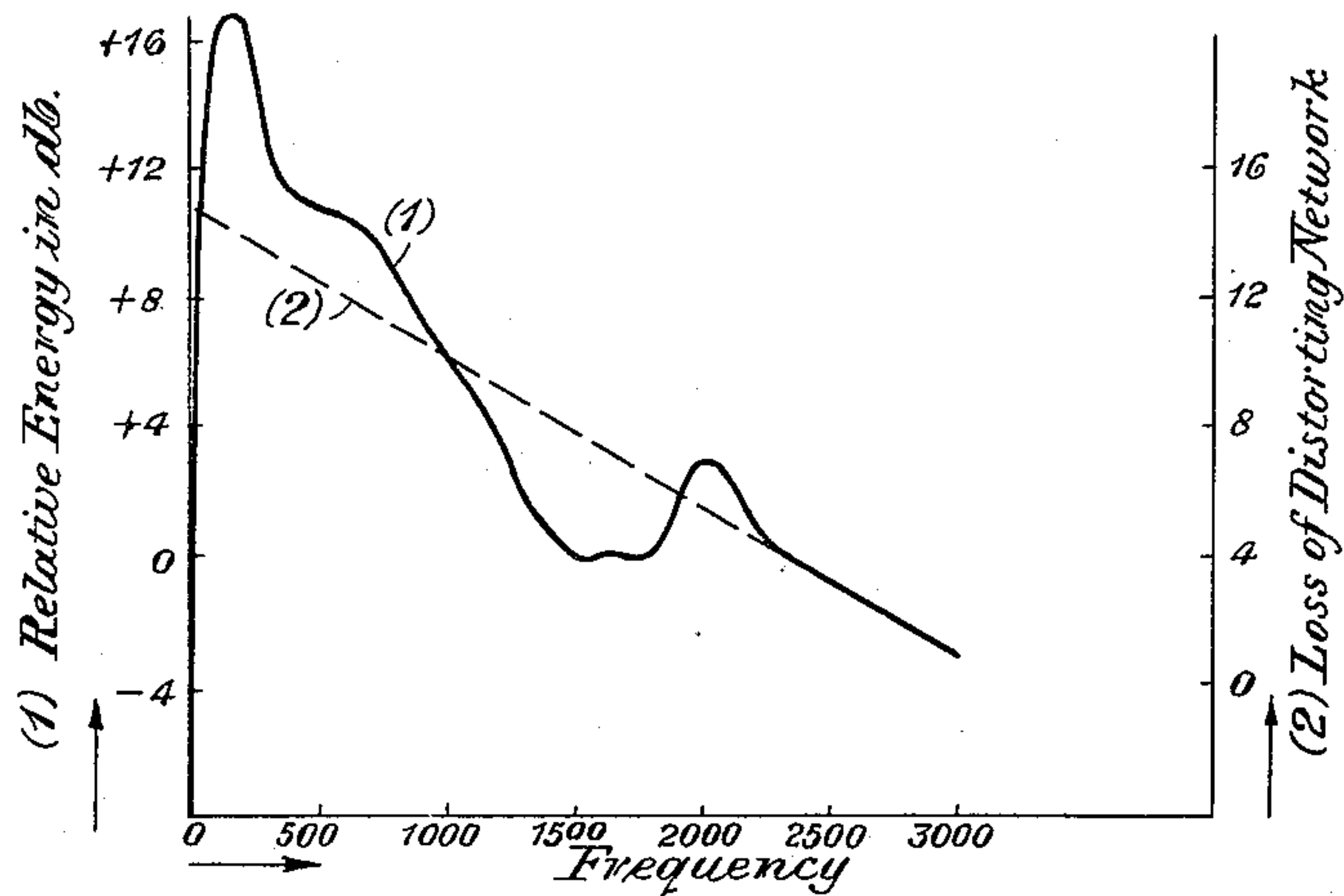


Fig. 2

INVENTOR
V. B. Bagnall
BY *g e f o l e*
ATTORNEY

March 1, 1938.

V. B. BAGNALL

2,109,562

TRANSMISSION SYSTEM

Filed Jan. 2, 1935

4 Sheets-Sheet 2

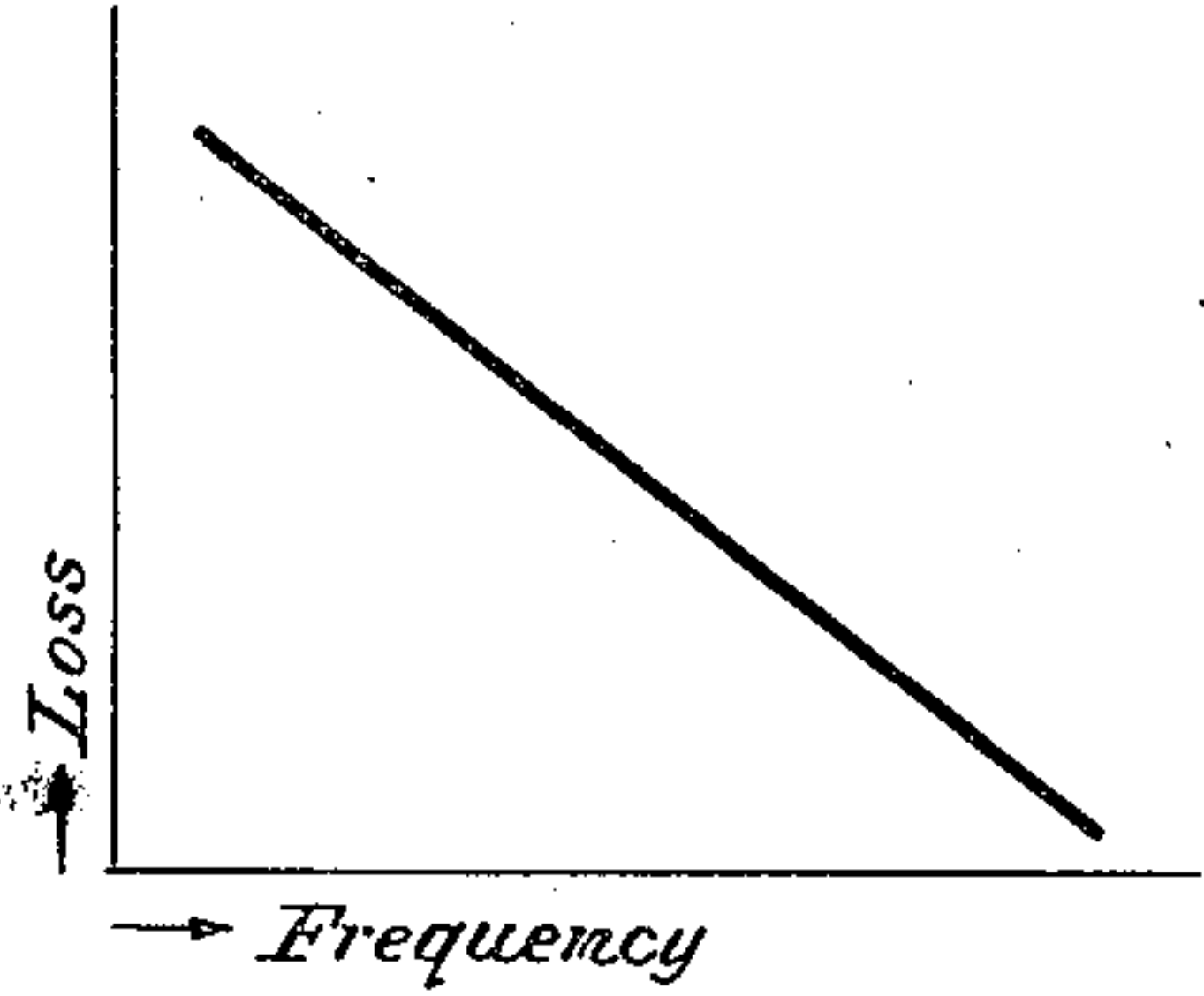
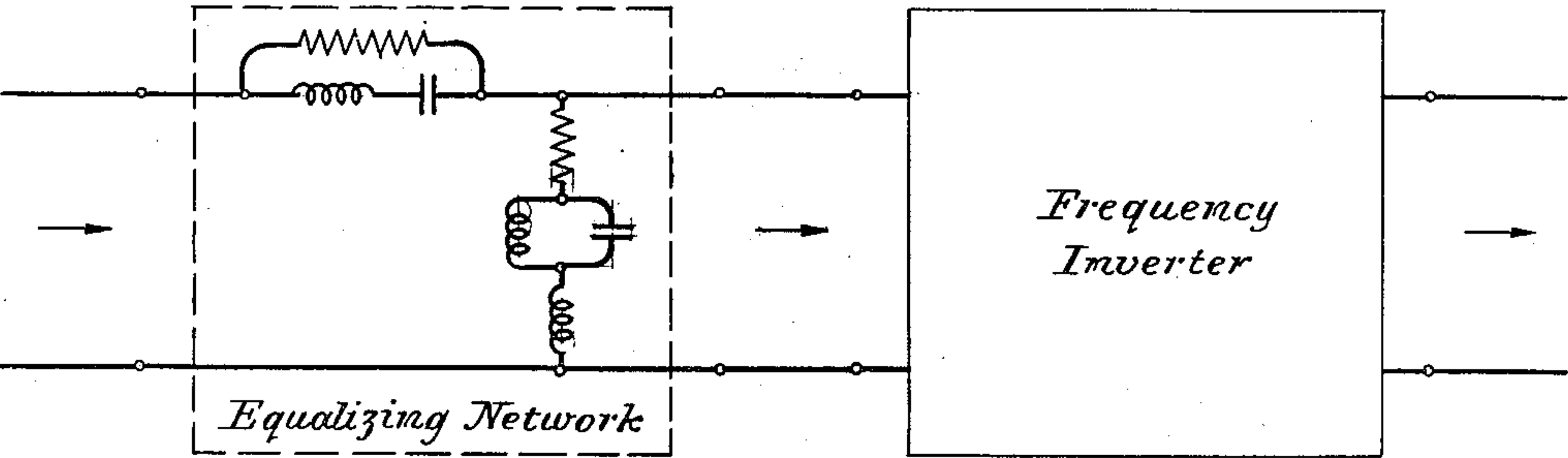


Fig. 3

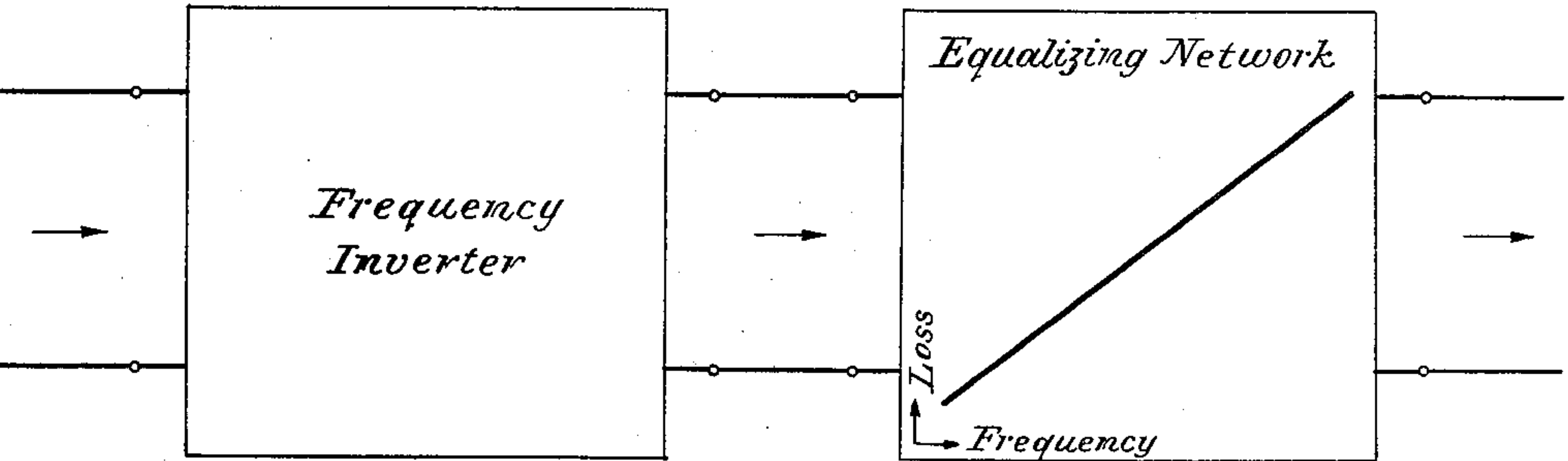


Fig. 4

INVENTOR
V. B. Bagnall
BY *J. H. 402*
ATTORNEY

March 1, 1938.

V. B. BAGNALL
TRANSMISSION SYSTEM
Filed Jan. 2, 1935

2,109,562

4 Sheets-Sheet 3

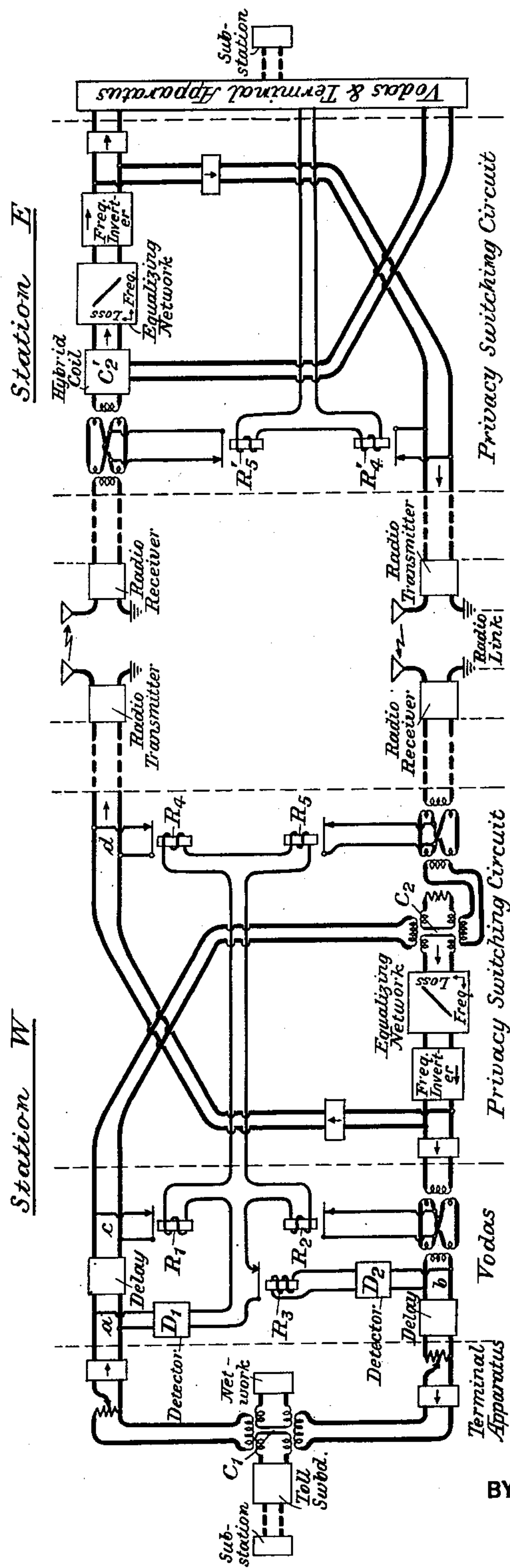


Fig. 5

INVENTOR
V. B. Bagnall
BY *JEH*
ATTORNEY

March 1, 1938.

V. B. BAGNALL

2,109,562

TRANSMISSION SYSTEM

Filed Jan. 2, 1935

4 Sheets-Sheet 4

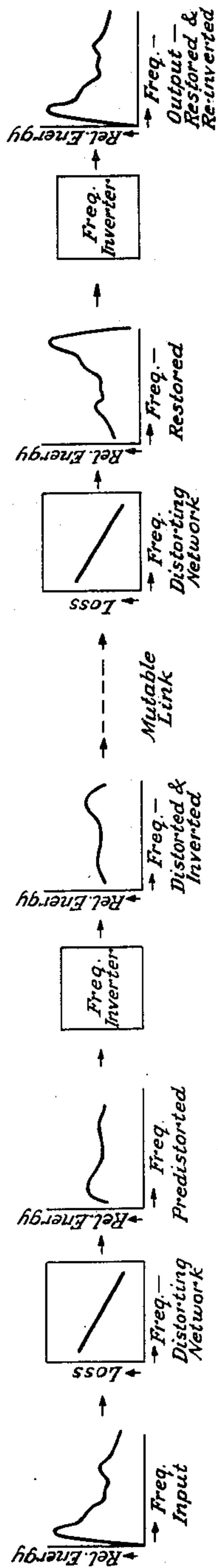


Fig. 6

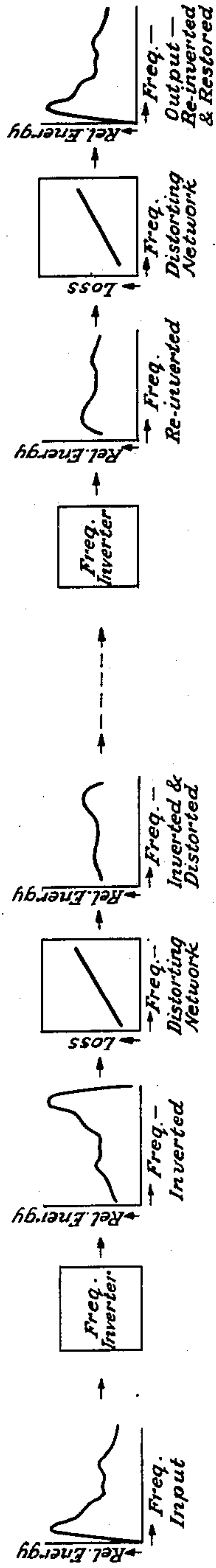


Fig. 7

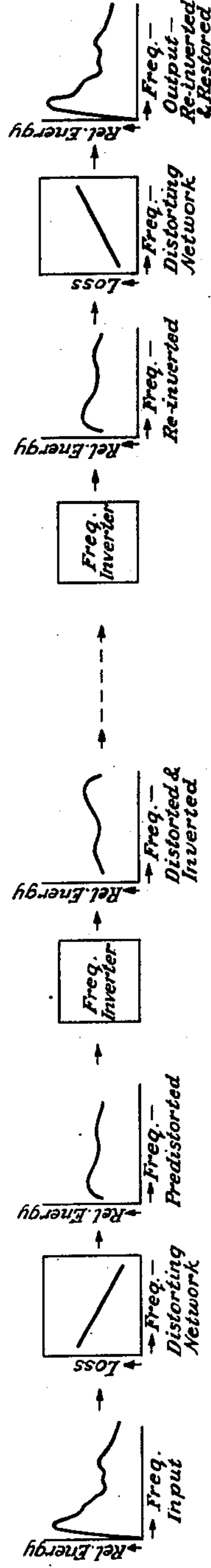


Fig. 8

INVENTOR
V. B. Bagnall
BY *g3402*
ATTORNEY

UNITED STATES PATENT OFFICE

2,109,562

TRANSMISSION SYSTEM

Vernon Barnard Bagnall, East Orange, N. J., assignor to American Telephone and Telegraph Company, a corporation of New York

Application January 2, 1935, Serial No. 162

7 Claims. (Cl. 179-78)

This invention relates to transmission systems, and more particularly to methods of and means for introducing useful distortion—which may in a given instance be predistortion or correction—in signaling systems.

While in certain of its aspects the invention has a wide range of applicability, it is in certain other aspects especially applicable to signaling systems including a mutable link, of which systems an outstanding example is a telephone system including, somewhere between its terminal stations, a radio link.

In using the expression "mutable link" the applicant means a link capable of or liable to change (from internal or external cause) which may give rise to interfering energy, or more specifically, a link specially subject to noise, fading (in the case of radio transmission) or change of impedance.

One of the objects of the invention is the transmission of certain frequencies of a band at a relatively high energy level without overloading the transmission system.

Another object of the invention is the useful predistortion of the frequency-amplitude relation at one end of a transmission system and the complementary correcting distortion at the other end in an efficient and economical manner.

A more specific object of the invention is the predistortion and subsequent restoration of the frequency-amplitude relation in a signaling system in such a way as to overcome the effects of extraneous noise and the like without overloading the system.

In general the invention resides in the method of producing the predistortion or correction, in the arrangement of distorting network and associated apparatus and in methods of and means for producing the predistortion at one end of a signaling system and the correction at the other and in a manner suitable to the elimination or material reduction of the effects of extraneous noise.

As has been stated hereinabove, the invention is especially applicable to a signaling system, such as a telephone system, which includes a mutable link such as a radio link. As is well known in the art, the energy distribution of average speech is not uniform over the range of voice frequencies. The higher frequencies, which provide naturalness in the case of speech and color in the case of music, are relatively of very low amplitude. On the other hand, the energy distribution of noise is comparatively equally distributed over the voice frequency range. Accordingly it is

found that the usefulness of the higher frequencies in the voice range is often nullified by the noise introduced at the receiving end of the system. In other words, because of the fact that the receiving system picks up extraneous noise as well as the signal from the transmitting system, the signal-to-noise ratio for the various frequency components of the received speech will be relatively high for the lower frequencies and relatively low for the higher frequencies, with the result that the higher frequencies may be completely masked while the low frequencies are not appreciably affected.

The applicant makes use of the idea, which is not original with him, of introducing at the transmitting end of the system predistortion of the frequency-amplitude relation over the voice range, for instance, and restoring the original frequency-amplitude relation at the receiving end. It is proposed, however, in accordance with the present invention, to combine the distortion of the frequency-amplitude relation over a given band of frequencies, such as the voice range, with frequency inversion such as that employed for privacy purposes in some telephone systems.

Not only the applicant's methods but also the nature and arrangement of apparatus suitable to the practice of the methods and the manner of applying the invention to telephone systems which include a mutable link will be clearly understood when the following detailed description is read with reference to the accompanying drawings, in which

Fig. 1 presents a curve indicating the energy distribution of average speech over the voice range;

Fig. 2 illustrates by curves the same energy distribution expressed somewhat differently with respect to a base frequency and also indicates the distorting effect of the applicant's predistorting or equalizing network;

Fig. 3 shows diagrammatically and schematically the arrangement in the circuit of the applicant's network and the associated apparatus;

Fig. 4 shows schematically an alternate arrangement of the elements of Fig. 3;

Fig. 5 shows schematically and, in part diagrammatically, the application of the apparatus of the invention to a two-way radio telephone system equipped with the inverter type of privacy apparatus; and

Figs. 6, 7, and 8 indicate schematically the effects of the applicant's methods and means as applied to a signaling system including a mutable link.

The curve of Fig. 1, obtained by plotting power or energy against frequency, shows the energy-frequency distribution of average speech as disclosed by H. Fletcher in his "Speech and hearing" (D. Van Nostrand Company, New York, 1929) at page 79. It will be understood that this curve indicates that approximately 85 per cent of the total speech energy is contained in the frequency range below 1000 cycles, with the remaining 15 per cent in the frequencies above 1000 cycles. Since, as has been pointed out hereinabove, the average random noise energy distribution, for instance the noise picked up at the receiving end of a radio telephone system from the mutable radio link, is more or less uniform over the range of voice frequencies, it will be readily understood that if the signal energy is transmitted to the receiving end without predistortion and if the level of the noise energy is high, the important signal energy in the range of frequencies above 1000 cycles will be of no use or of little use.

In Fig. 2, the energy-frequency distribution of average speech, expressed in decibels and with the use of 1500-cycle energy as the reference, is indicated by the solid line curve (1). The broken line (2) indicates the distortion which may be introduced to produce a more nearly uniform distribution of the energy over the voice range. It will be seen that the useful distorting effect is one in which the loss decreases as the frequency increases. In other words, a distorting network having a linear frequency-loss characteristic such as that represented by the broken line (2), will tend to produce a uniform energy-frequency distribution over the voice range.

The applicant proposes to employ a distorting network in combination with a frequency inverter. For certain particular purposes the network will be included in the circuit ahead of the frequency inverter, while for certain other purposes the order of the elements will be reversed. It is to be understood that the invention is sufficiently broad in scope to include any combination of a frequency inverter and a network having a definite frequency-loss characteristic. For the purpose of illustration there is disclosed in Fig. 3 an arrangement in which an equalizing network of indicated design is placed ahead of a frequency inverter. The network in this particular case has a frequency loss characteristic indicated by the curve placed below the network diagram. This characteristic is linear and involves a loss decreasing with the increase of frequency. The frequency inverter contemplated is one such as that disclosed in United States Patent No. 1,571,010, to B. W. Kendall, in which there is disclosed the method of transmitting a band of audio frequency waves of given frequency range by inverting the frequencies of the components of the band to produce resultant audio frequency waves restricted to a frequency range substantially equal to that of the band of waves to be transmitted, along with suitable apparatus for practicing the method.

Fig. 4 of the drawings indicates schematically the alternate arrangement of the network and inverter, in which the inverter is placed ahead of the network. In this case, for purpose of illustration, the network is schematically disclosed as one in which the loss increases with increase of frequency, the characteristic being linear.

In order to illustrate specifically one application of the applicant's combination of distorting network and frequency-inverter, there is dis-

closed in Fig. 5 by scheme and diagram, a two-way radio telephone circuit which may be a trans-oceanic circuit including a radio link and extended wire links connecting the radio apparatus with the terminal stations. At each terminal station there is a frequency inverter which is used to invert the voice frequencies for the purpose of introducing privacy. For the purpose of economy the system is arranged so that one set of privacy apparatus at each terminal station functions as both predistorter for outgoing energy and corrector for incoming energy. The switching of the privacy apparatus between the two one-way paths of the system at either terminal station is accomplished by relays responsive to the signal energy. The system and the operation of the signal-controlled switches will now be briefly discussed:

At each end of the system of Fig. 5 a substation is shown as connected to a terminal station. At each terminal station there are provided a vodas (voice operated device anti-singing) and a privacy switching circuit. When signal energy travels from the substation connected to the toll switchboard at station W, it is passed on through the hybrid coil C₁, to which is connected, in addition to the two-wire line running to the toll switchboard, a network designed to balance the two-wire line. The useful portion of the energy dividing in the coil C₁ passes over the upper one-way path of the four-wire circuit through an amplifier to the point a. At this point a portion of the energy is diverted to operate the detector D₁, which controls relays R₁, R₂, R₄ and R₅. A relay R₃ responds through the operation of another detector D₂ to energy traveling in the opposite direction over the lower path of the four-wire circuit and reaching point b. Let it be assumed that no energy is reaching point b and that relay R₃ remains unoperated. As a result of the operation of detector D₁, relay R₁ removes a disability normally applied to the upper one-way path at point c, and relay R₂ places a disability on the lower and oppositely directed one-way path at a point ahead of b. It will be understood that one path of the four-wire circuit is normally disabled for the purpose of preventing singing and that the relay operation just described serves to clear the outgoing path in response to the arrival of the outgoing signal energy and at the same time to disable the oppositely-directed path and prevent interference with the outgoing energy by subsequently arriving energy in the incoming path. The position of the frequency inverter is to be noted. It will be seen that by adding relays R₄ and R₅ to the chain of relays controlled by the detector D₁, there is produced the result that signal energy passing out from station W over the upper path of the four-wire circuit, will so connect the privacy inverter that it functions to invert the frequencies of the outgoing energy and is disconnected from the oppositely-directed path.

With the operation of relays R₁, R₂, R₄ and R₅, just described, the energy originating at the west end of the system and passing point a, is delayed sufficiently to permit the operation of the vodas and privacy switches, and then passes through the privacy hybrid coil C₂, the useful energy being subjected to the frequency inversion and passing on through a suitable amplifier to the radio transmitter. At the east end of the radio link the energy passes through the radio receiver and the privacy hybrid coil C'₂ to the frequency inverter, where the frequencies are reinverted and the signals rendered intelligible.

The operation at the receiving end may be discussed in more detail with reference to energy traveling from station E to station W, since the vodas and privacy switching apparatus are merely indicated at station E. When signals pass over the radio link and through the radio receiver at station W (it being assumed that relay R₅ is unoperated), they reach the privacy hybrid coil C₂ and are subjected to frequency inversion in the apparatus schematically shown. It will be understood that in this case of received energy the inverter operates as a reinverter to restore the normal energy-frequency relation originally existing. At the output of the frequency inverter the energy will not travel upward, with reference to the diagram, since the relay R₄, as well as relay R₅, is unoperated and the upper one-way path is disabled at point d. The energy does, however, pass on to point b since relay R₂, along with the other relays controlled by the detector D₁, is unoperated. At point b a portion of the energy is diverted to operate relay R₃ through detector D₂, the result being the maintenance of the normal disability at point c (and also the maintenance of the normal disability at point d) in the upper one-way path. The energy, with the frequencies now reinverted, is free to pass on to the hybrid coil C₁ and through the toll switchboard to the connected substation.

In accordance with the applicant's invention there is associated with the input of the frequency inverter at each of the stations W and E a distorting network which may be termed the "equalizing network", which networks have like characteristics. In the particular case illustrated this characteristic is linear or substantially so and involves a loss which decreases as the frequency increases. With such an arrangement the higher frequencies in the voice range are transmitted from the transmitting station to the receiving station at a relatively high level without overloading the transmitting system, and at the receiving end the original frequency-amplitude relation is restored. Accordingly, the undesirable effect of the masking of the higher frequencies by noise picked up in the radio link is eliminated or substantially reduced, and the energy at the relatively high frequencies in the voice range becomes useful in spite of noise of high energy level. In addition, of course, as has been disclosed hereinabove, the frequencies are inverted at the transmitting end of the system, with the consequent introduction of privacy, and are reinverted at the receiving end, with the consequent restoration of intelligibility.

The effect of the applicant's arrangement of distorting network and frequency inverter (or of correcting network and reinverter) may be more clearly understood from the following discussion. It is to be understood that this particular discussion relates to the case in which the distorting network is connected at the input to the privacy equipment at each terminal station. Let the loss-frequency characteristic of the network at either station be represented by the equation

$$L_F = L_0 - kF,$$

where

L_F = Loss in db of network at any frequency F,
 L_0 = Loss in db of network at zero frequency,
 k = Constant slope of loss-frequency characteristic of predistorting network, and
 F = Frequency.

Assuming a constant loss P through the privacy

device for all frequencies which it is desired to transmit, the overall loss through the network and inverter at the transmitting end of the circuit when the frequency F is impressed on the input is

$$L_T = P + L_0 - kF$$

Now a frequency F' at the input to the inverter type of privacy appears as a frequency F' at the output of the privacy where with the present type of equipment F and F' are related by the equation

$$F' = (3000 - F) \text{ cycles}$$

Hence the overall loss at the transmitting end of the circuit in terms of the frequency appearing at the output of the privacy device is

$$L_T = P + L_0 - k(3000 - F')$$

At the receiving end of the circuit the voice currents go through an identical network and privacy circuit. The input frequency is in this case, however, F'.

Assuming that M represents a constant loss interposed by the intervening medium, the total loss to the output of the receiving network is

$$\begin{aligned} L_R &= M + L_T + L_0 = kF' \\ L_R &= M + 2L_0 + P - k(3000 - F') - kF' \\ L_R &= (M + 2L_0 + P - 3000k), \end{aligned}$$

and the loss including the receiving privacy equipment is

$$L_R = (M + 2L_0 + 2P - 3000k)$$

These equations show that the overall loss is independent of frequency, and, therefore, constant.

It will be understood that the result discussed hereinabove may be produced equally well if there is connected at the output of the privacy equipment at each terminal station a network which has a loss frequency characteristic represented by the equation

$$L_F = L_0 + kF$$

In a manner similar to that employed hereinabove in connection with the discussion of the case of the network connected to the input of the privacy equipment, it can be shown that the overall loss, including the transmitting and receiving networks and privacy systems, is in this new case of the network connected to the output of the privacy equipment, independent of frequency and therefore constant.

Accordingly, with reference to Fig. 5 of the drawings, it is seen that inasmuch as the overall loss for each method discussed hereinabove is independent of frequency, it is feasible to use at each terminal station, in connection with the inverter type of privacy equipment, a single network of the type described to predistort the outgoing speech and to restore the incoming speech.

In Fig. 6 there is presented a schematic disclosure which will enable the reader to understand at a glance the effect of the combination of distorting network and frequency-inverter at each end of the system in the case represented by Fig. 5, in which the network is connected to the input of the frequency inverter. In like manner there is disclosed in Fig. 7 the effect of connecting the distorting network to the output of the frequency-inverter at each end of a system such as that disclosed in Fig. 5.

It will be noted that with predistortion and correction as produced in Figs. 5, 6, and 7, the order of the network and the inverter is the same at each end of the system, and accordingly, a single

set of apparatus may be used at each end of the system, along with suitable switching devices, for switching the input of the inverter-distorter between the outgoing and incoming paths of the four-wire circuit. If, however, two sets of inverter-distorter apparatus are used at each end of the system, the desired result can be accomplished by connecting the predistorting network to the input of the inverter at the transmitting end and connecting the correcting network to the output of the reinverter at the receiving end. The effect of such an arrangement is disclosed graphically in Fig. 8 of the drawings. It will be seen that with the arrangement of Fig. 8, the energy-frequency relation obtaining at the radio transmitter and the radio receiver is the same as in the cases of Figs. 6 and 7 and accordingly, there is equal benefit in overcoming the effect of noise masking the high frequencies at the receiving end.

While somewhat specific disclosure of the invention has been made hereinabove, it is to be understood that such disclosure is for the purpose of illustration and that the true scope of the invention is to be determined from the appended claims.

What is claimed is:

1. In a wave transmission system including a mutable link, means associated with the transmitting end of said mutable link for inverting the frequencies of a given band of frequencies, a network associated with said inverting means and having an approximately linear frequency-loss characteristic such as to produce an alteration of the frequency-amplitude relation over said band of frequencies additional to that produced by the inverting means, and means associated with the receiving end of said mutable link for restoring the original frequency-amplitude relation over said band of frequencies, the inverting and altering means at the one end and the restoring means at the other end being identical.

2. In a two-way telephone system including two terminal stations, oppositely directed transmission paths and an intermediate radio link, means at each terminal station for inverting the frequencies over the speech band, means associated in series with the frequency-inverter at each terminal station for distorting the frequency-amplitude relation of the energy impressed thereon, and means operating in accordance with the direction of transmission over the system for switching the input of the inverter-distorter apparatus at either station between the outgoing and incoming paths.

3. In a two-way signaling system including two terminal stations, oppositely directed transmission paths and an intermediate mutable link, means at each terminal station for inverting the

frequencies over the signal band, means associated in series with the frequency-inverter at each terminal station for distorting the frequency-amplitude relation of the energy impressed thereon, and means operating in accordance with the direction of transmission over the system for switching the input of the inverter-distorter apparatus at either station between the outgoing and incoming paths.

4. In a two-way signaling system including two terminal stations, oppositely directed transmission paths and an intermediate mutable link, means at each terminal station for inverting the frequencies over the signal band, means associated in series with the frequency inverter at each terminal station for distorting the frequency amplitude relation of the energy impressed thereon, said distorting means having an approximately linear frequency-loss characteristic, and means operating in accordance with the direction of transmission over the system for switching the input of the inverter-distorter apparatus at either station between the outgoing and incoming paths.

5. In a two-way signaling system including terminating wire sections and an intermediate mutable link, the method of providing privacy and at the same time improving the signal-to-noise ratio, which consists in introducing at each end of the system distortion of the frequency-amplitude relation over the signal band and inversion of the frequencies of said band, and applying the same distortion and inversion to energy traveling over said end, whether said energy be outgoing from or incoming to said end.

6. In a two-way transmission system including two terminal stations, two paths for transmitting in opposite directions and an intermediate mutable link, means at each terminal station for inverting the frequencies over a given band of frequencies, and means at each station in association with said inverting means for distorting the frequency-amplitude relation of the energy impressed thereon, the inverting and distorting means at one terminal station being identical with said means at the other terminal station.

7. In a two-way telephone system including two terminal stations, two paths for transmitting in opposite directions and an intermediate radio link, means at each terminal station for inverting the frequencies over the speech band, and means associated in series with the frequency-inverter at each terminal station for distorting the frequency-amplitude relation of the energy impressed thereon, the inverting and distorting means at one terminal station being identical with said means at the other terminal station.

VERNON B. BAGNALL.