May 29, 1928. **1,671,143**

G. A. CAMPBELL

WAVE TRANSLATOR

Filed Sept. 24, 1924 4 Sheets-Sheet 1

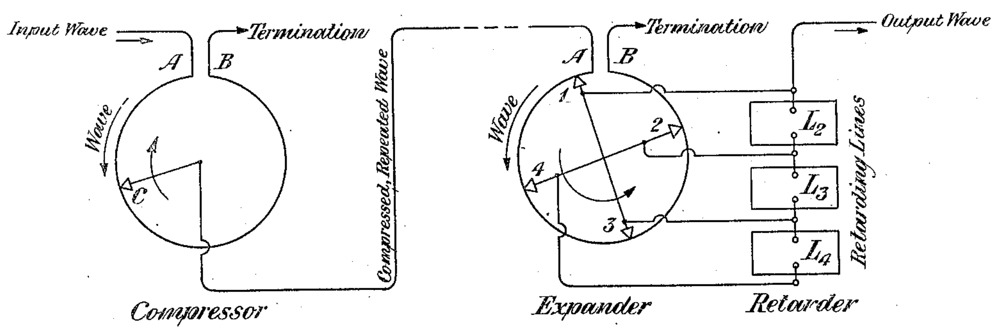

Fig. 1

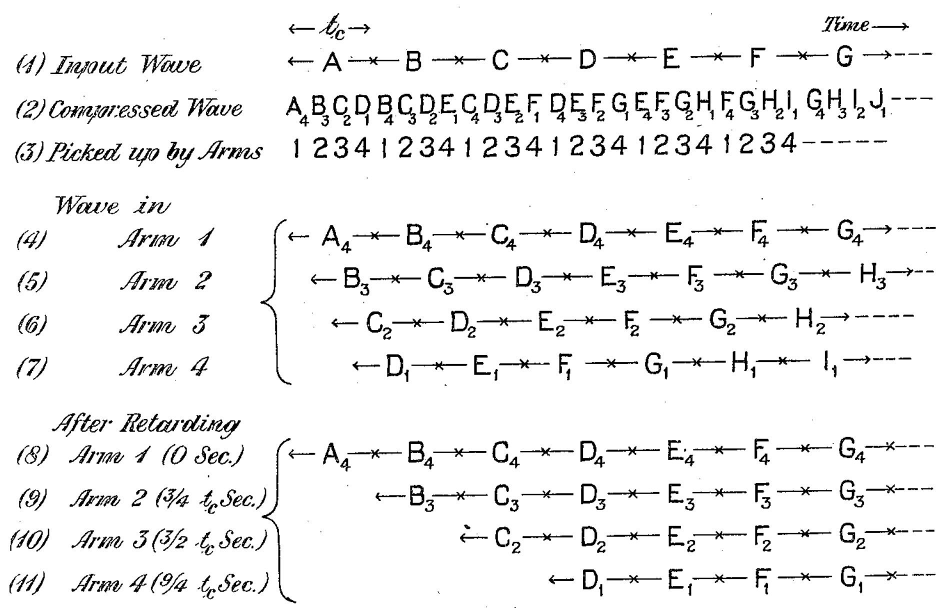

Fig. 2

INVENTOR
G. A. Campbell

BY

ATTORNEY

G. A. CAMPBELL

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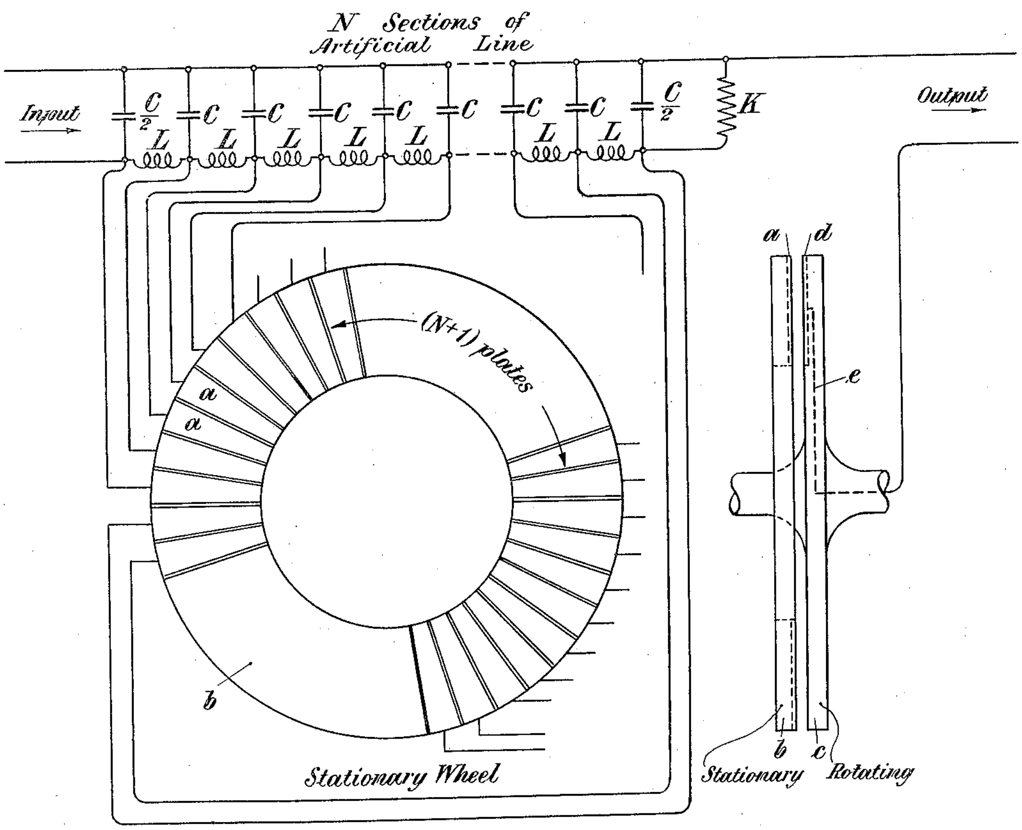

Fig. 3

INVENTOR
G. A. Campbell
BY
[signature]
ATTORNEY

May 29, 1928.

G. A. CAMPBELL

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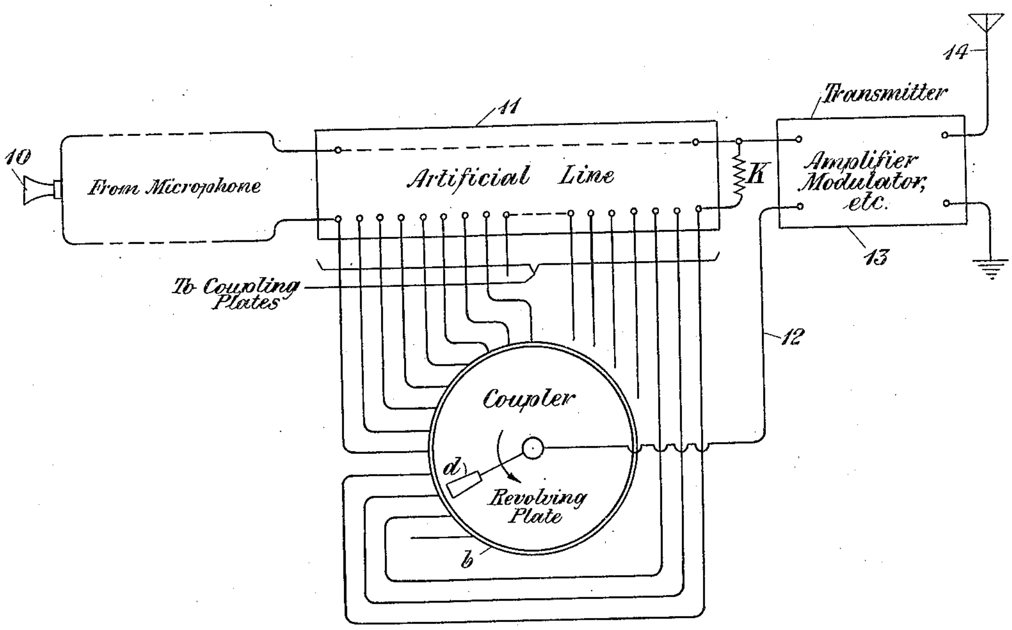

Fig. 4

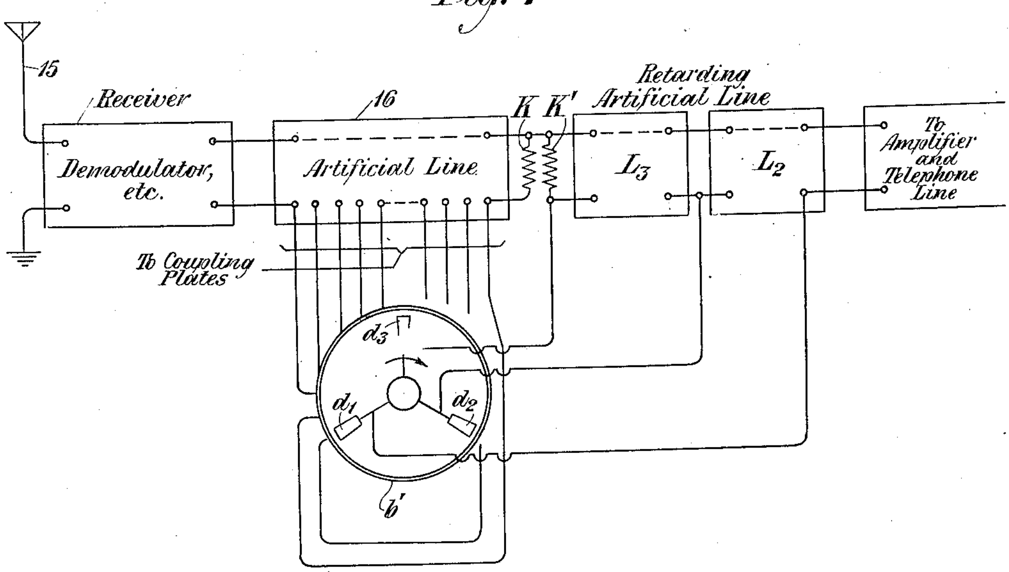

Fig. 5

INVENTOR
G. A. Campbell

BY

ATTORNEY

May 29, 1928.

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G. A. CAMPBELL

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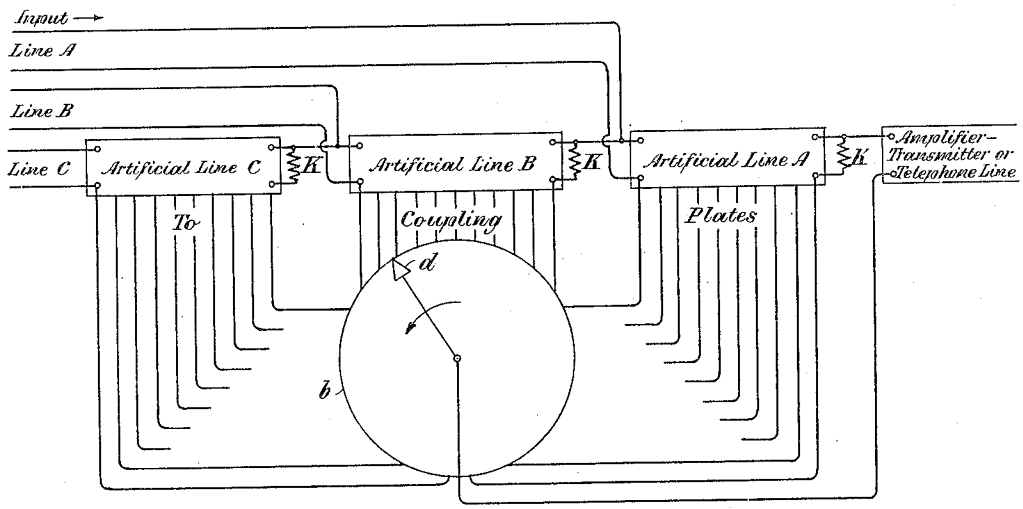

Fig. 6

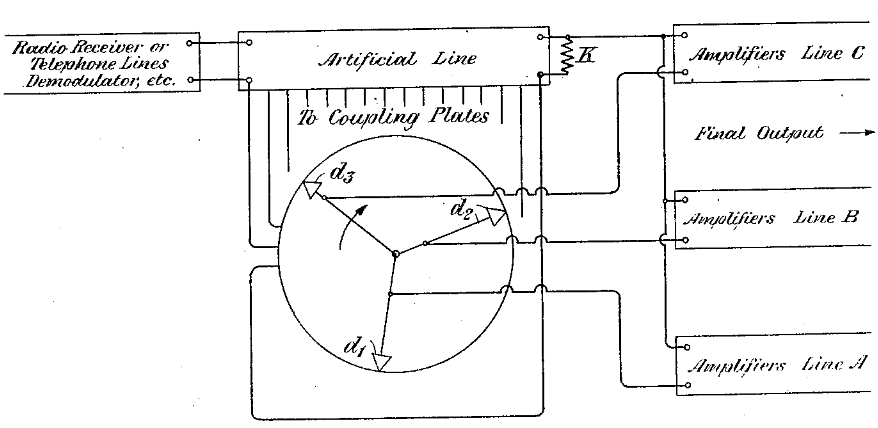

Fig. 7

INVENTOR
G. A. Campbell
BY
[signature]
ATTORNEY

Patented May 29, 1928. **1,671,143**

UNITED STATES PATENT OFFICE.

GEORGE A. CAMPBELL, OF UPPER MONTCLAIR, NEW JERSEY, ASSIGNOR TO AMERICAN TELEPHONE AND TELEGRAPH COMPANY, A CORPORATION OF NEW YORK.

WAVE TRANSLATOR.

Application filed September 24, 1924. Serial No. 739,638.

This invention relates to wave transmission and more particularly to a method of and means for operating upon a wave in such a manner as to change the time required for transmission of short portions of the wave.

The method of transforming the wave is based upon the Doppler principle; the input wave is propagated through a guiding medium with which coupling is made by a device which moves with respect to the medium. The wave thus produced in the coupling device may be transmitted by usual methods to any desired station, there propagated through a second guiding medium and by a second moving coupling device transformed to its original state. The input wave is divided by the mechanism into portions of equal duration. By employing the Doppler principle, motion of the coupling device in the direction of propagation of the input wave, at a velocity less than that of the input wave, will increase the duration in the coupling device of a given portion. The portion, the duration of which has been thus increased, is said to be expanded, and to an amount denoted by the ratio of the duration of the portion in the coupling device to its duration in the guiding medium. This ratio is called the degree of expansion. Similarly, motion of coupling device contrary to the direction of propagation of the input wave will shorten the duration of a portion in the coupling device, or compress it to an amount denoted by the degree of compression, or ratio of the duration of a portion in the guiding medium to its duration in the output of the coupling device. If the wave is periodic, expansion results in reducing the frequency, and compression results in increasing the frequency, of the input wave.

More specifically, the invention contemplates compressing portions of a wave each to $1/n$th its duration and repeating each compressed portion n times. Where the system involves modulation the compression may take place either before or after modulation. The compressed wave is then transmitted by wire or radio to a distant station and, by expansion of compressed portions and superposition of repetitions (either before or after modulation), given its original duration. In a radio system this method of transmission may be used to reduce the effect of static by reason of the fact that each portion of the output signal at the receiving-end will be built up by an n-fold repetition, whereas the static impulse will, in general, not occur in synchronism with the repetitions in the compressed wave and so will not be built up to an n-fold amplitude.

The invention also makes possible the simultaneous transmission in one channel (of n times the normal frequency band-width) of the signals from n channels. The n input waves are compressed portion by portion but not repeated and the compressed portions are so arranged in the single resulting compressed wave that there is one compressed portion from each signal in each sequence of n compressed portions. This multiplex compressed wave is transmitted to a distant station and there expanded in such a way that the n different signals are separated and taken up by n different channels. Such a method of transmission offers a frequency saving over those systems using n channels of normal width in that it eliminates the bands which are necessary in those systems to separate the channels.

The invention also provides means for attaining secrecy in transmission. The input wave is divided into portions, without compression or expansion, but with each portion reversed with respect to time. This transformed wave consisting of successive reversed portions is transmitted to a distant station and there reversed again, portion by portion, reproducing the time relations of the input wave. Furthermore, in the method of compressed, repeated transmission each compressed portion may be reversed with respect to time at the transmitting station and so expanded and reversed at the receiving station as to reproduce the time relations of the input wave, combining the advantages of reversion with those of reducing the effect of static.

The invention may be more fully understood from the following detailed description thereof when read in connection with the accompanying drawings. Figure 1 is a simplified diagram showing how the wave compressor and the wave expander are arranged and combined to cooperate with each other in a signaling system; Fig. 2 is a chart illustrating the states of the wave between the transformations in the apparatus of Fig. 1; Fig. 3 is a diagram showing in some detail the apparatus used either in connection with a wave compressor or with a wave expander; Fig. 4 is a simplified diagram showing how the apparatus of Fig. 3 may be applied as a wave compressor at the transmitting station of a radio system; Fig. 5 is a similar diagram showing how the apparatus of Fig. 4 may be applied as a wave expander at the receiving end of a radio system; Fig. 6 shows how apparatus similar to that of Fig. 4 may be applied to the simultaneous transmission in one channel of input waves from several channels and Fig. 7 shows the apparatus of Fig. 4 used to receive the compressed wave transmitted from the apparatus of Fig. 6.

It is neither practicable nor desirable to transform more than a short portion of a wave as a unit. Compression of a portion of a wave corresponding to a complete message or even a complete sentence would require an inconveniently long guiding medium. It is desirable, furthermore, in two-way communication, that one station be able to interrupt the other at any instant, without waiting for the completion of the message or sentence started. To secure repetitions means must be provided for the coupler to move a given distance back along the guiding medium in a minimum of time. Both these requirements, i. e., division of the input wave into short portions and apparatus permitting the coupling device to move back over a given distance along the guiding medium with sufficient quickness, are met most easily by using a guiding medium which is circular in shape with a coupling device rotating about the center of the circle, the gap between the points where the wave enters and where it leaves the circle being made very small.

The degree of expansion or compression is given directly by the fundamental expression for the Doppler principle (Barton, "Sound", p. 97). In Fig. 1, the incomplete circles represent the guiding mediums: an artificial line in the case of electromagnetic waves, or an air tube for sound waves. The wave enters at A and leaves at B, where there is a suitable termination to avoid reflection. Mounted on an arm which rotates about the center of the circle is a coupling device, C, which is excited by the wave in the artificial line. If the wave and the arm travel around the circle in T seconds and t seconds, respectively, the ratio of their velocities, $\pm t/T$, has the positive or the negative sign if the velocities are in the same or the opposite directions, respectively. Substituting in the equation cited, and noting that a wave portion will be transformed inversely as the frequency of a simple periodic wave, we have

$$\frac{P}{P'}=1-\frac{T}{t} \quad (1)$$

where P is the duration of a wave portion, and P′ the duration of the corresponding transformed portion.

Examination of Equation (1) shows that, depending on the ratio T/t, the input wave is transformed in one of seven ways, which considering only cases in which P/P' is an integer or the reciprocal of an integer, are as follows:

(1) For $T/t<O$, the input wave is compressed and repeated by portions completely.

(2) For $T/t=O$, the input wave suffers no change in time relations.

(3) For $O<T/t<1$, the input wave is expanded by portions, with certain portions omitted.

(4) For $T/t=1$, there is no resulting wave in the coupler.

(5) For $1<T/t<2$, the input wave is expanded by portions, with certain portions omitted, but with the expanded portions reversed with respect to time.

(6) For $T/t=2$, the input wave is reversed by portions completely, but without change in the duration of a portion.

(7) For $T/t>2$, the input wave is compressed and repeated by portions completely, with each compressed portion reversed with respect to time.

The words compression and expansion, unless specifically qualified, will be taken hereinafter to refer to Cases (1) and (3), respectively, that is, to transformation without reversion. Cases (1) and (3) will be considered in detail, information concerning the other cases can be derived by analogous considerations.

For compression, Case (1), the ratio of the velocities of the coupler and the input wave is negative; therefore, using subscript c to denote compression, the degree of compression is

$$n=\frac{P}{P'}=\frac{t_c+T_c}{t_c} \text{ or } T_c=(n-1)t_c. \quad (2)$$

Suppose that, beginning at any instant when the coupler, C, is vertical, the input wave is divided into portions t_c seconds long. By Equation (2) the arm makes contact with n such portions each revolution, and also by Equation (2) the artificial line is of such length as to contain $(n-1)$ portions. Confining our attention to the case where n is an integer, a given portion passes completely through the artificial line in n revolutions. It is consequently repeated in compressed form n times, the first appearance occurring while the portion is in the first nth of the artificial line, the second in the second nth, and so on. At an instant when the arm is vertical it has just made contact for the first time with a certain portion. Since the artificial line contains $(n-1)$ portions, the first of which is the portion in question, the coupler must make contact with $(n-2)$ intervening portions between each repetition in the compressed wave; therefore repetition of identical points occurs at intervals of $t_c(n-1)/n$ seconds.

For example, referring to Fig. 2, if, beginning at any instant when the coupling arm is vertical, the order of portions in the input wave be denoted by letters as in row (1), then for $n=4$ the order of compressed portions in the compressed wave is that shown in row (2), the subscripts denoting the order of appearance of repetitions.

For expansion, Case (3), the velocity of the coupler is positive, that is, the coupler moves in the direction of propagation of the wave. Using subscript e to denote expansion, to attain a degree of expansion n the velocities must be such that

$$n=\frac{P'}{P}=\frac{t_e}{t_e-T_e} \text{ or } T_e=t_e\frac{n-1}{n}. \quad (3)$$

Suppose that beginning at any instant when the coupler is vertical the input wave is divided into portions (t_e-T_e) seconds long. By Equation (3) n such portions enter the artificial line during each revolution, also by Equation (3) the artificial line is of such length as to contain $(n-1)$ such portions. The $(n-1)$ portions in the artificial line at the beginning of a revolution of the coupler are omitted, since the coupler moves more slowly than the wave, and one portion (t_e-T_e) seconds long entering the artificial line as the revolution begins is expanded during each revolution. However, if n equally spaced coupling arms are used, the entire wave will be expanded once and only once, since the arms follow each other by (t_e-T_e) seconds. Successive portions of the input wave are expanded by successive arms.

For example, referring to Fig. 2, if, beginning at any instant when coupling arm 1 is vertical, the order of portions (t_e-T_e) seconds long entering the artificial line be denoted by letters as in row (2), then for $n=4$ the order of portions expanded by the four coupling arms is shown by rows (4) to (7) inclusive.

An input wave which has been compressed and repeated in the manner described for Case (1) is transformed to its original time relations by means of expansion in the manner described for Case (3), subject to the requirements that the degree of expansion equal the degree of compression, the length of the portion (t_e-T_e) seconds long which is expanded equal the length t_c/n seconds of a compressed portion, the length of the portion T_e seconds long which is omitted by the expander equal the length $(n-1)t_c$ seconds of the $(n-1)$ compressed portions which appear in the compressed wave between the compressed portions corresponding to successive portions of the input wave, and the coupling arms of the expander commence a revolution at the instant a compressed portion begins to enter the artificial line of the expander. By means of Equations (2) and (3) the first three requirements become:

$$t_e=t_c \text{ and } nT_e=T_c. \quad (4)$$

Or, the coupling arms of the expander revolve at the same rate as the coupling arm of the compressor, and the wave is propagated through the artificial line of the expander n times as rapidly as through the artificial line of the compressor.

If n equally spaced coupling arms are used in the expansion of a compressed repeated wave each one will reproduce the original input wave, since the length of the portion omitted by each coupling arm of the expander has been made equal to the length of the compressed portions between the same appearances of successive portions. The outputs of the various arms will not, however, be in synchronism, for repetitions of the same point of the wave appear at intervals of $t_c(n-1)/n$ seconds. In order to superpose the outputs, each must be retarded sufficiently to synchronize with that from the arm which expands last appearances of portions in the compressed wave. Calling this arm number 1 and numbering the arms in the order in which they follow this arm, the output from the kth arm must be retarded t_c $(k-1)$ $(n-1)/n$, or $(k-1)$ T_c/n seconds.

Detailed consideration of a special case will make these relations clear. Fig. 1 shows a system using a wave compressor and a wave expander for the case in which $n=4$. The compressor arm carrying the coupler, C, revolves in the direction opposite that of the propogation of the wave and in t_c seconds. The wave travels from A to B in $3t_c$ seconds, where it is dissipated in a non-reflecting termination. The expander has four arms a quarter revolution apart which rotate together in the direction of the wave in t_c seconds. The wave passes through the expander in $3t_c/4$ seconds. The first coupling arm is connected directly to the output circuit, the second to the output circuit through a retarding line or network producing a delay of $3t_c/4$ seconds, the third through, in effect, two such retarding lines, so that the delay is $3t_c/2$ seconds, and the fourth through three retarding lines producing a delay of $9t_c/4$ seconds.

The chart of Fig. 2 illustrates the successive states of an input wave between the various transformations. Each row of the chart is divided into time intervals of the same magnitude, but, unless otherwise noted, each row has a different origin of time. Row (1) shows the division of the input wave, beginning at an instant when the compressor arm is vertical, into portions each t_c seconds long, the portions in order being denoted by the letters A, B, C, D,—etc. Row (2) shows the order and relative duration of compressed portions in the compressed repeated wave. Each portion of the input wave, for example, D, is repeated in compressed form four times, the order of appearance of repetitions being denoted by the subscripts 1, 2, 3 and 4. Successive repetitions of the same compressed portion are separated by two other compressed portions; therefore repetitions of the same point of the input wave, the beginning of portion D, for example, occur at intervals of $3t_c/4$ seconds.

The compressed, repeated wave shown in row (2) is transmitted to the receiving station, where it enters the artificial line of the expander. The rotation of the coupling arms of the expander is so arranged that an arm is in the vertical position at the instant a compressed portion reaches point A of the artificial line. Row (3) of the chart shows the order in which the compressed portions are individually picked up by the several arms of the expander. Arm 1 picks up last appearances in the compressed, repeated wave of successive portions of the input wave; arms 2, 3 and 4 pick up third, second and first appearances, respectively. Each arm accordingly produces a wave having the time relations of the input wave. The waves in the several arms are not synchronous, as shown in rows (4), (5), (6) and (7) of the chart, which are drawn with a common origin of time. The effect of the associated retarding lines, however, is to retard the waves produced by arms 2, 3 and 4 until they synchronize with the wave produced by arm 1, as shown in rows (8), (9), (10) and (11), which have a common origin of time. These synchronous reproductions of the input wave are then superposed to form the output wave.

If the reception of a momentary static impulse should occur during the reception of compressed portion D_2, for instance, the distorting effect of the static impulse will only appear as a distortion of D_2 in row (10) of the chart, consequently in only one of the four-fold repetitions from which the output wave is built up. The ratio of the magnitude of the static effect to the total signal $(D_1+D_2+D_3+D_4)$ is accordingly reduced to 1/4; this reduction increases with the degree of compression used.

It is to be noticed that in expanding a compressed, repeated wave two operations must be performed before the expanded repetitions are superposed: an expansion and a retardation. The case discussed assumes this order; the retardation may, however, be accomplished before the expansion. This is done by using an artificial line in the expander which has the same time of transmission as that of the compressor, and rotating the coupler arms at $1/n$th the rate of the compressor arm. The outputs of the expander arms may then be superposed at once to form the output wave.

It has been pointed out that the successive repetitions of portions in a compressed wave are made in successive arcs $2\pi/n$ of the artificial line of the compressor. If each arc $2\pi/n$ of the artificial line be assigned, each with proper termination, to n different channels of input wave, the compressed wave will consist of sequences of n compressed portions, each one from a different channel. Each portion of each input wave will be compressed and appear once in the compressed wave. If each of the input waves occupies a frequency band of a certain width, the compressed wave, carrying all n signals, will occupy a channel n times as wide. If such a wave be received by an expander of the type illustrated in Fig. 1, each of the n arms will reproduce one of the input waves, since the portion expanded is exactly the length of a compressed portion and the portion omitted is exactly the length of the $(n-1)$ compressed portions belonging to other input waves. Each arm may then be connected to the circuit of a different outgoing channel.

By considerations similar to the foregoing it can be shown that an input wave transformed in the manner of Case (7) of Equation (1), i. e., compressed and repeated by portions, with each portion reversed with respect to time, may be given its original time relations by means of a transformation in the manner of Case (5).

As in the case of unreversed compression and expansion, the expander is provided with n equally spaced coupling arms each of which produces a wave having the time relations of the input wave. The waves from the coupling arms may be superposed, after suitable retardations, to form an output wave having the time relations of the input wave.

Apparatus to accomplish a transformation in the manner of Case (6) is similar to the compressor shown in Fig. (1), except that the coupling arm moves in the direction of propagation of the input wave around the artificial line. If the coupler revolves in t_r seconds the artificial line must be such that the input wave travels around it in $2t_r$ seconds. Beginning at an instant when the coupler is vertical, the input wave is divided into portions t_r seconds long and each portion reversed with respect to time, but without change in the duration of a portion. The resulting reversed wave is transmitted to the receiving station where by means of apparatus identical with the reversing apparatus the reversed wave is given the time relations of the input wave. Such transmitting and receiving apparatus can be used to attain secrecy in transmission.

In any system, involving wave compression followed by expansion, there will be distortion of the signal if the coupling arms vary in speed. This distortion takes the form of over or under compression accompanied by more than n repetitions or less than n repetitions, respectively, of certain fractions of each portion, or too much or too little expansion accompanied by repetitions or omissions, respectively, of certain fractions of each portion. Sufficiently strict synchronism of the compressor and expander arms, both with regard to each other and with regard to the artificial lines, may be attained by well known methods. Another type of distortion will arise if an expanding arm is not commencing a revolution at the instant a compressed portion of signal is entering the artificial line. This type of distortion may be avoided by mounting the artificial line so that it may be turned around its center, the correct position to be found by monitoring either on the signal or a control signal. Precise equations are not given concerning the effect of attenuation, since the method of compensating for it depends on the type of line and the type of coupling employed. In general, attenuation in the artificial line can be compensated for in the compressor by a coupling which decreases exponentially as the arm goes from B to A of Fig. 1; and in the expander by coupling which increases similarly from A to B. If no compensation were provided, and a simple periodic wave entered the compressor artificial line (Fig. 1), the amplitude of the compressed, repeated wave would increase exponentially during the time of each revolution of the coupling arm.

It is apparent that apparatus to accomplish the wave transformations described can be constructed in a variety of ways. To cite only three examples, sound waves may be transformed directly by using a microphone which rotates in a circular air tube; a telegraphone provided with a moving magnet may be used to transform electromagnetic waves; or electromagnetic waves may be transformed by direct coupling.

Details are given here only for one method of accomplishing the last named result. The guiding medium used is an artificial line of the ladder type shown in Fig. 3, with series inductance, L, shunt capacity, C, terminated in mid-shunt by its iterative impedance, K.

Such an artificial line acts as a low-pass filter. From the time of propagation per section, given by the theory of artificial lines, and the total time of propagation needed, which is fixed by the degree of compression used and the rate of revolution chosen for the coupling arm, the number of sections needed for the compressor is:

$$N=\frac{(n-1)pt_o}{2\sin^{-1}(p/p_c)} \quad (5)$$

where $p/2\pi$ and $p_c/2\pi$ are the frequency of the input wave and the cutoff frequency of the artificial line, respectively.

Equation (5) shows that the various frequencies of a band will not be compressed uniformly, the higher frequencies being compressed by a greater amount than the lower ones. Distortion from this cause may be reduced to a negligible amount by choosing the cutoff frequency sufficiently high in comparison with the highest frequency it is desired to reproduce. The expression for the anti-sine may then be replaced by the first term of its series, and, to a degree of accuracy discussed below:

$$N=\frac{n-1}{2}p_ct_o \quad (6)$$

The expander arms, by previous theory, rotate at the same rate as the compressor arm. The cutoff frequency of the expander artificial line must be n times that of the compressor, and its time of propagation must be $1/n$th that of the compressor artificial line. Using the same approximation for anti-sine as in deriving (6), then, the number of sections of artificial line needed for the expander is the same as for the compressor.

The suitable minimum value for the cutoff frequencies may be found by retaining the second term in the series for anti-sine and calculating the change in frequency Δf due to the complete transformation of compression followed by expansion. Dropping terms involving higher powers than the square of f/f_c

$$\Delta f=-\frac{(n-1)^2}{6n}\left(\frac{f}{f_c}\right)^2 f \quad (7)$$

where f is any frequency and f_c the cutoff frequency of the compressor. The effect of the complete transformation is a decrease in all the frequencies. If a variation of 20 cycles at a frequency of 2000 be taken as the maximum permissible, for $n=3$ the cutoff frequency of the compressor must be approximately 9500 cycles, that of the expander 28,500 cycles.

With the cutoff frequencies fixed by (7) and the iterative impedance determined by the apparatus to which the artificial lines are connected, the values of the inductances and capacities required may be computed by well-known formulæ.

The retarding lines for the expander arms can conveniently be made up of lengths of the type of artificial line used for compression. Each length must have N/n sections.

Formula (6) shows the number of sections with which coupling is made each second. This number is large. For instance, if $n=3$ it is approximately 60,000. The values of N and t_c depend, therefore, on a compromise between the cost of building a large number of sections and that of constructing a suitable high-speed coupling device. In the case cited, if 500 sections are used, the arm must run at 7200 revolutions per minute.

Because of the high speeds involved, coupling by direct contact is impracticable. An electrostatic method is shown in Fig. 3. Metal plates, a, connected directly to junction points of the artificial line, are sunk in the face of a stationary wheel, b, and insulated from one another. Coaxial with b, and as near it as possible is a rotating wheel, c, which carries an insulated plate, d, for compressing, or n equally spaced insulated plates for expanding. The plate d is large enough to cover one or several, as may be best, of the plates a. From d runs a conductor, e, to amplifiers, etc. There is some coupling between d and all the plates, a, but coupling is a maximum with the plates directly opposite d. It is desirable to keep the coupling so low as to have a negligible reaction on the wave in the artificial line. Calculation shows that the coupling between adjacent artificial line plates, a, can be neglected.

Figs. 4 and 5 illustrate how the compressor and expander may be applied to the transmitting and receiving stations respectively of a system of radio intercommunication. The particular case illustrated in Figs. 4 and 5 involves a degree of compression $n=3$. In Fig. 4, 10 designates a telephone transmitter which is connected to an artificial line, 11, of the type illustrated in Fig. 3, said line has connections from its various sections to the plates (not illustrated) of the stationary wheel, b. d is the revolving plate of the coupler and is connected by a conductor, 12, to the radio transmitter apparatus, 13, comprising the usual amplifier modulator, etc. The upper terminal of the artificial line, 11, is also connected to the radio transmitter and the transmitter is associated with a radiating antenna, 14, in a well-known manner.

In Fig. 5, 15 designates a receiving antenna having associated therewith the usual radio receiving apparatus comprising a demodulator, etc. One terminal of the radio receiving apparatus is connected to the upper terminal of the artificial line, 16, said artificial line being of the type illustrated in Fig. 3. Connections are made from the various sections of the artificial line to the plates (not shown) of a stationary wheel, b', of the type shown in Fig. 3. The expander is provided with three equally spaced revolving plates d_1, d_2, and d_3, each being similar to the plate d of Fig. 3. The plate d_1 is connected directly to the lower terminal of an outgoing telephone line or an amplifier in said line. The second plate, d_2, is connected to the lower input terminal of a retarding line, L_2, said retarding line being of the same general type as the artificial line illustrated in Fig. 3 and said line being so designed as to produce the necessary retardation of the wave transmitted from the plate d_2. The plate d_3 is connected to the lower input terminal of a similar retarding line, L_3, which is connected in series with the retarding line L_2 so that the wave components picked up by the plate d_3 will be retarded twice as much as those picked up by the plate d_2. A terminating impedance, K′, is connected across the input terminals of retarding line, L_3, the upper one of which is connected directly to the upper terminal of the terminating impedance, K, of the artificial line 16. The operation will be apparent from the theoretical discussion already given.

Figs. 6 and 7 show the application of the compressor and expander to a multiplex system of inter-communication. The particular case illustrated also involves a degree of compression $n=3$ and permits the simultaneous transmission of waves from three channels in one channel three times the normal frequency width and provides means for their separation at the receiving end. Fig. 6 shows the compressing apparatus. The three incoming channels, designated as lines A, B and C are connected to artificial lines A, B and C, respectively. Each of these artificial lines is of the general type shown in Fig. 3 and each is terminated in its iterative impedance, K. The section points of each line are connected to the plates (not illustrated) of the stationary wheel, b, in such a way that the wave in each artificial line travels along a third of the circumference of b. d is the revolving plate of the coupler, moving in a direction opposite that of the waves. d is connected to an amplifier which in turn actuates radio transmitting apparatus or a telephone line in the usual manner. The upper terminals of the artificial lines and the amplifier are connected in series.

In Fig. 7 is shown the expander to be used at the receiving end with the output of the compressor in Fig. 6. It is essentially the same as the apparatus shown in Fig. 5, except that no retarding networks are needed and the output from each arm is connected to the lower terminals of amplifiers associated with channels A, B and C, respectively. The upper terminals of these amplifiers are connected to the upper terminal of the terminating impedance, K. The operation of this system is evident from the discussion previously given.

Systems of intercommunication involving reversion by portions of the transmitted wave need not be shown in detail, since the method of construction of the apparatus and the inter-relations between the transmitting and the receiving elements are apparent from the principles and apparatus heretofore described.

It will be obvious that the general principles herein disclosed may be embodied in many other organizations widely different from those illustrated without departing from the spirit and scope of the invention as defined in the appended claims.

What is claimed is:

1. The method of wave transmission which consists in progressively producing upon successive elements of a transmission medium effects corresponding to the progressive variation of a wave with time so that the wave is in effect propagated from element to element along the medium, producing in a conductor a wave having variations corresponding to said successive effects, and moving said conductor with respect to said medium during the propagation of a wave along the medium to change the time relations of the variations of the produced wave as compared with the time relations of the corresponding variations of the original wave.

2. The method of wave transmission which consists in transmitting a wave through an artificial line, producing in a conductor a wave having variations corresponding to the successive effects in the sections of said artificial line, and moving said conductor with respect to the elements of said artificial line to change the time relations of the variations of the produced wave as compared with the time relations of the corresponding variations of the original wave.

3. The method of compressing a wave which consists in progressively producing upon successive elements of a transmission medium effects corresponding to the progressive variations of the wave with time so that the wave is in effect propagated from element to element along the medium, producing in a conductor a wave having variations corresponding to said successive effects, and moving said conductor with respect to said medium in a direction opposite to that in which the wave is being propagated along said medium, thereby reducing the time relations of the variations of the produced wave as compared with the time relations of the corresponding variations of the original wave.

4. The method of compressing a wave which consists in propagating a wave from section to section of an artificial line, producing in a conductor a wave having variations corresponding to the variations in the wave propagated along the artificial line, and moving said conductor with respect to said artificial line in a direction opposite to the direction of propagation over the line, thereby reducing the time relations of the variations of the produced wave as compared with the time relations of the corresponding variations of the original wave.

5. The method of increasing the frequency of a wave which consists in progressively producing upon successive elements of a transmitting medium effects corresponding to the progressive variations of the wave with time so that the wave is in effect propagated from element to element along the medium, producing in a conductor a wave having variations corresponding to said successive effects, and moving said conductor with respect to said medium in a direction opposite to that in which the wave is propagated over the medium, thereby increasing the frequency at which succeeding elements of the wave follow each other as compared with the frequency at which similar elements of the original wave recur.

6. The method of increasing the frequency of a wave which consists in propagating said wave from section to section of an artificial line to produce in each section effects corresponding to the progressive variations of the wave with time, producing in a conductor a wave having variations corresponding to said successive effects, and moving said conductor with respect to said artificial line in a direction opposite to that in which the wave is propagated along said artificial line, thereby increasing the frequency at which succeeding elements of the wave follow each other as compared with the frequency at which similar elements of the original wave recur.

7. The method of expanding a wave which consists in progressively producing upon successive elements of a transmitting medium effects corresponding to the progressive variations of the wave with time so that the wave is in effect propagated from element to element along the medium, producing in a conductor a wave having variations corresponding to said successive effects, and moving said conductor with respect to said medium in the same direction as the direction of propagation of the wave along said medium and at a rate slower than the rate of propagation of the wave along the medium, thereby increasing the time relations of the variations of the produced wave as compared with the time relations of the corresponding variations of the original wave.

8. The method of expanding a wave which consists in propagating said wave from section to section of an artificial line to produce effects in each section correspond-

ing to the progressive variations of the wave with time, producing in a conductor a wave having variations corresponding to said successive effects, and moving said conductor with respect to said artificial line in the same direction as the direction of propagation of the wave over said line and at a rate slower than the rate of propagation over said line, thereby increasing the time relations of the variations of the produced wave as compared with the time relations of the corresponding variations of the original wave.

9. The method of decreasing the frequency of a wave which consists in progressively producing upon successive elements of the transmitting medium effects corresponding to the progressive variations of the wave with time so that the wave is in effect propagated from element to element along the medium, producing in a conductor a wave having variations corresponding to said successive effects, and moving said conductor along said medium in the same direction as the direction of propagation of the wave along said medium and at a rate slower than the rate of propagation along said medium, thereby decreasing the frequency at which succeeding elements of the wave follow each other as compared with the frequency at which similar elements of the original wave recur.

10. The method of decreasing the frequency of a wave which consists in propagating said wave from section to section of an artificial line to produce effects in each section corresponding to the progressive variations of the wave with time, producing in a conductor a wave having variations corresponding to said successive effects, and moving said conductor along said artificial line in the same direction as the direction of propagation of the wave along said line and at a rate slower than the rate of propagation of said wave over said line, thereby decreasing the frequency at which succeeding elements of the wave follow each other as compared with the frequency at which similar elements of the original wave recur.

11. The method of wave transmission which consists in compressing a wave by successive portions each to a fraction of its original length, and repeating each compressed portion a number of times equal to the ratio of the original length of the wave to its compressed length.

12. The method of wave transmission which consists in compressing a wave by successive portions each to a fraction of its original length and repeating each compressed portion at separated intervals a number of times corresponding to the ratio of the original length of the wave to its compressed length, the intervals between successive repetitions of a given portion of the wave being sufficiently great to enable other compressed portions to be repeated during said intervals.

13. The method of wave transmission which consists in increasing the frequency of successive portions of a wave, portion by portion, and repeating each portion at an increased frequency a number of times corresponding to the ratio of its increased frequency to its original frequency.

14. The method of wave transmission which consists in increasing the frequency of successive portions of a wave, portion by portion, and repeating each portion at an increased frequency during separated intervals a number of times corresponding to the ratio of the increased frequency of the wave to its original frequency, the separation between successive repetitions of a given wave portion being sufficiently great to permit of the repetition of other portions of the wave during said intervals.

15. The method of wave transmission which consists in compressing a wave by successive portions to a fraction of its original length, repeating each compressed portion a number of times equal to the ratio of the original length of the wave to its compressed length, transmitting the wave thus translated, and expanding each compressed portion to its original form.

16. The method of wave transmission which consists in compressing a wave by successive portions to a fraction of its original length, repeating each compressed portion a number of times equal to the ratio of the original length of the wave to its compressed length, transmitting the wave as thus translated, expanding each compressed portion to its original form, and changing the time relation of the several expanded repeated portions so as to bring the components corresponding to the same portion into synchronism with each other.

17. The method of wave transmission which consists in increasing the frequency of successive portions of a wave, portion by portion, repeating each portion at an increased frequency a number of times corresponding to the ratio of its increased frequency to its original frequency, transmitting the portions thus translated, and expanding each portion to its original form.

18. The method of wave transmission which consists in increasing the frequency of successive portions of a wave, portion by portion, repeating each portion at an increased frequency a number of times corresponding to the ratio of its increased frequency to its original frequency, transmitting the wave portions thus translated, expanding each portion to its original form, and changing the time relation of repeated components of the same portion so as to

bring the several components corresponding to the same portion into synchronism with each other.

19. In a signaling system, a transmission medium upon the successive elements of which effects may be impressed corresponding to the progressive variation of a wave with time so that the wave is in effect propagated from element to element along the medium, a conductor inductively related to said medium so that variations corresponding to said successive effects may be impressed thereon, and means to move said conductor with respect to said medium during the propagation of a wave along the medium to change the time relations of the variations of the produced wave as compared with the time relations of the corresponding variations of the original wave.

20. In a signaling system, an artificial line comprising a succession of sections upon which may be impressed effects corresponding to the progressive variation of a wave with time, a conductor inductively related to said artificial line so that the successive effects in the sections of said artificial line may be induced therein, and means to move said conductor with respect to the sections of said artificial line to change the time relations of the variations of the produced wave as compared with the time relations of the corresponding variations of the original wave.

21. In a signaling system, a transmission medium upon the successive elements of which effects may be impressed corresponding to the progressive variation of a wave with time so that the wave is in effect propagated from element to element along the medium, a conductor inductively related to said medium so that variations corresponding to said successive effects may be impressed thereon, and means for moving said conductor with respect to said medium in a direction opposite to that in which the wave is being propagated along said medium, thereby reducing the time relations of the corresponding variations of the original wave.

22. In a signaling system, an artificial line comprising a succession of sections upon which may be impressed effects corresponding to the progressive variation of a wave with time, a conductor inductively related to said artificial line so that the successive effects in the sections of said artificial line may be induced therein, and means to move said conductor with respect to said artificial line in a direction opposite to the direction of propagation over the line, thereby increasing the frequency at which succeeding elements of the wave follow each other as compared with the frequency at which similar elements of the original wave recur.

23. In a signaling system, a transmission medium upon the successive elements of which effects may be impressed corresponding to the progressive variation of a wave with time so that the wave is in effect propagated from element to element along the medium, a conductor inductively related to said medium so that variations corresponding to said successive effects may be impressed thereon, and means for moving said conductor with respect to said medium in the same direction as the direction of propagation of the wave along said medium and at a rate slower than the rate of propagation of the wave along the medium, thereby increasing the time relations of the variations of the produced wave as compared with the time relations of the corresponding variations of the original wave.

24. In a signaling system, an artificial line comprising a succession of sections upon which may be impressed effects corresponding to the progressive variation of a wave with time, a conductor inductively related to said artificial line so that the successive effects in the sections of said artificial line may be induced therein, and means to move said conductor along said artificial line in the same direction as the propagation of the wave along said line and at a rate slower than the rate of propagation of said wave over said line, thereby decreasing the frequency at which succeeding elements of the wave follow each other as compared with the frequency at which similar elements of the original wave recur.

25. In a signaling system, a wave compressor comprising a transmission medium having a high time constant arranged in the form of an open circle, means to impress a wave upon said transmission medium at one terminal, and means to take off the wave at the other terminal after propagation over the medium, a rotating coupler adapted to be continuously rotated along said medium in a direction opposite to the direction of transmission through said medium, thereby producing in the coupler successive wave portions, each corresponding to portions of the wave transmitted through said medium, each a fraction of the length of the original portion, and each portion thus compressed being repeated a number of times equal to the ratio of the original length of the portion to its compressed length.

26. In a signaling system, a wave compressor comprising an artificial line having a number of sections arranged in the form of an open circle, means to impress a wave upon said artificial line at one end thereof, means at the other end for taking off said wave after propagation through said artificial line, a rotating coupler inductively related to said line and adapted to be rotated in a direction opposite to the direction of propagation along said line, thereby produc-

ing in the coupler successive wave portions, each corresponding to portions of the wave transmitted through said artificial line, each a fraction of the length of the original portion, and each portion thus compressed being repeated a number of times equal to the ratio of the original length of the portion to its compressed length.

27. In a signaling system, a wave compressor comprising a transmission medium having a high time constant arranged in the form of an open circle, means to impress a wave upon said transmission medium at one terminal, and means to take off the wave at the other terminal after propagation over the medium, a rotating coupler adapted to be continuously rotated along said medium in a direction opposite to the direction of transmission through said medium, thereby producing in the coupler successive wave portions, each corresponding to portions of the wave transmitted through said medium, each a fraction of the length of the original portion, each portion thus compressed being repeated a number of times equal to the ratio of the original length of the portion to its compressed length, means to transmit the wave as thus translated, a wave expander, said wave expander comprising a transmitting medium having a high time constant arranged in the form of an open circle, means to impress the translated waves upon one end of said medium, means to take off said waves from the other end of said medium after propagation along said medium, and a rotating coupler rotating in synchronism with the coupler of said compressor and in the same direction as the direction of propagation along the transmitting medium of said expander, whereby each compressed portion will be expanded to its original length.

28. In a signaling system, a wave compressor comprising an artificial line having a number of sections arranged in the form of an open circle, means to impress a wave upon said artificial line at one end thereof, means at the other end for taking off said wave after propagation through said artificial line, a rotating coupler inductively related to said line and adapted to be rotated in a direction opposite to the direction of propagation along said line, thereby producing in the coupler successive wave portions, each corresponding to portions of the wave transmitted through said artificial line, each a fraction of the length of the original portion, each portion thus compressed being repeated a number of times equal to the ratio of the original length of the portion to its compressed length, means to transmit the wave portions thus translated, a wave expander comprising an artificial line having a plurality of sections arranged in the form of an open circle, means to impress the translated waves upon one end of said artificial line, means to take off said waves after propagation over said artificial line, a rotating coupler associated with said line and adapted to rotate at the same rate of speed as the coupler of said compressor and in the same direction as the direction of propagation along the artificial line of said expander whereby each compressed portion will be expanded to its original length.

In testimony whereof, I have signed my name to this specification this 22nd day of September, 1924.

GEORGE A. CAMPBELL.