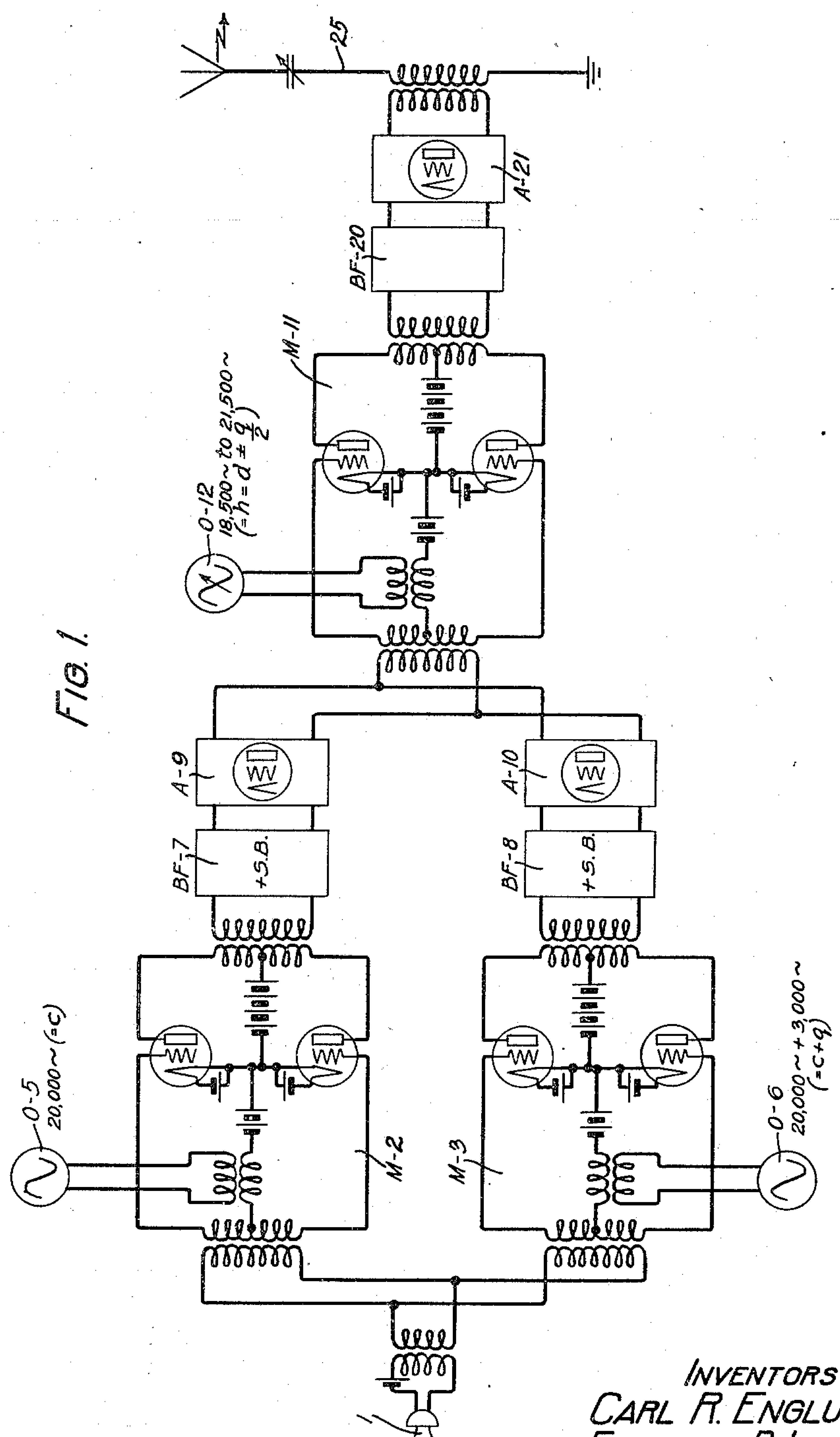
Jan. 14, 1930. C. R. ENGLUND ET AL 1,743,710

SECRECY SYSTEM FOR SIGNALING

Filed Nov. 1, 1927 2 Sheets-Sheet 1

FIG. 1.



INVENTORS:
CARL R. ENGLUND
FREDERICK B. LLEWELLYN
BY H. A. Burgess
ATTORNEY

SECRECY SYSTEM FOR SIGNALING

Filed Nov. 1, 1927 2 Sheets-Sheet 2

FIG. 2.

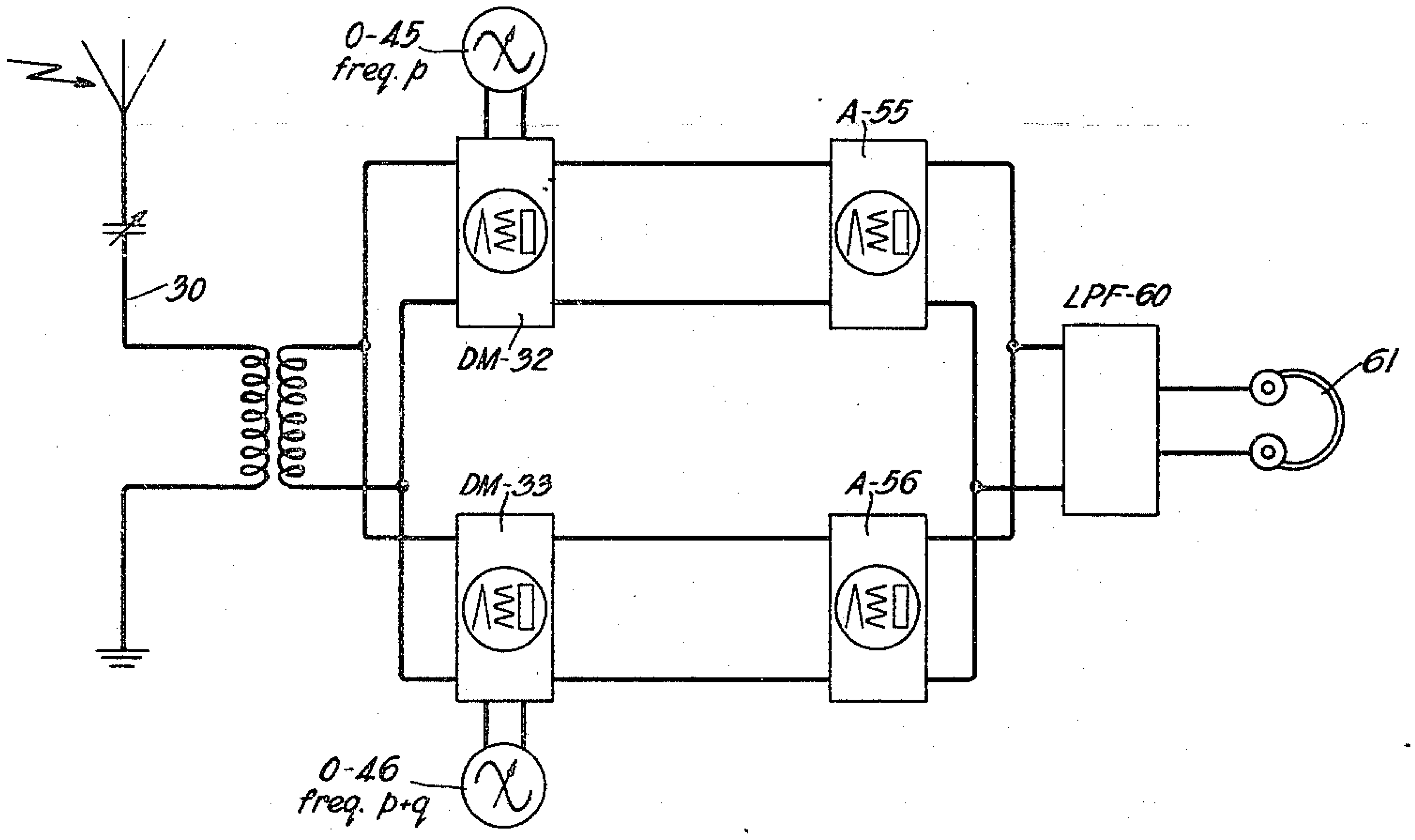
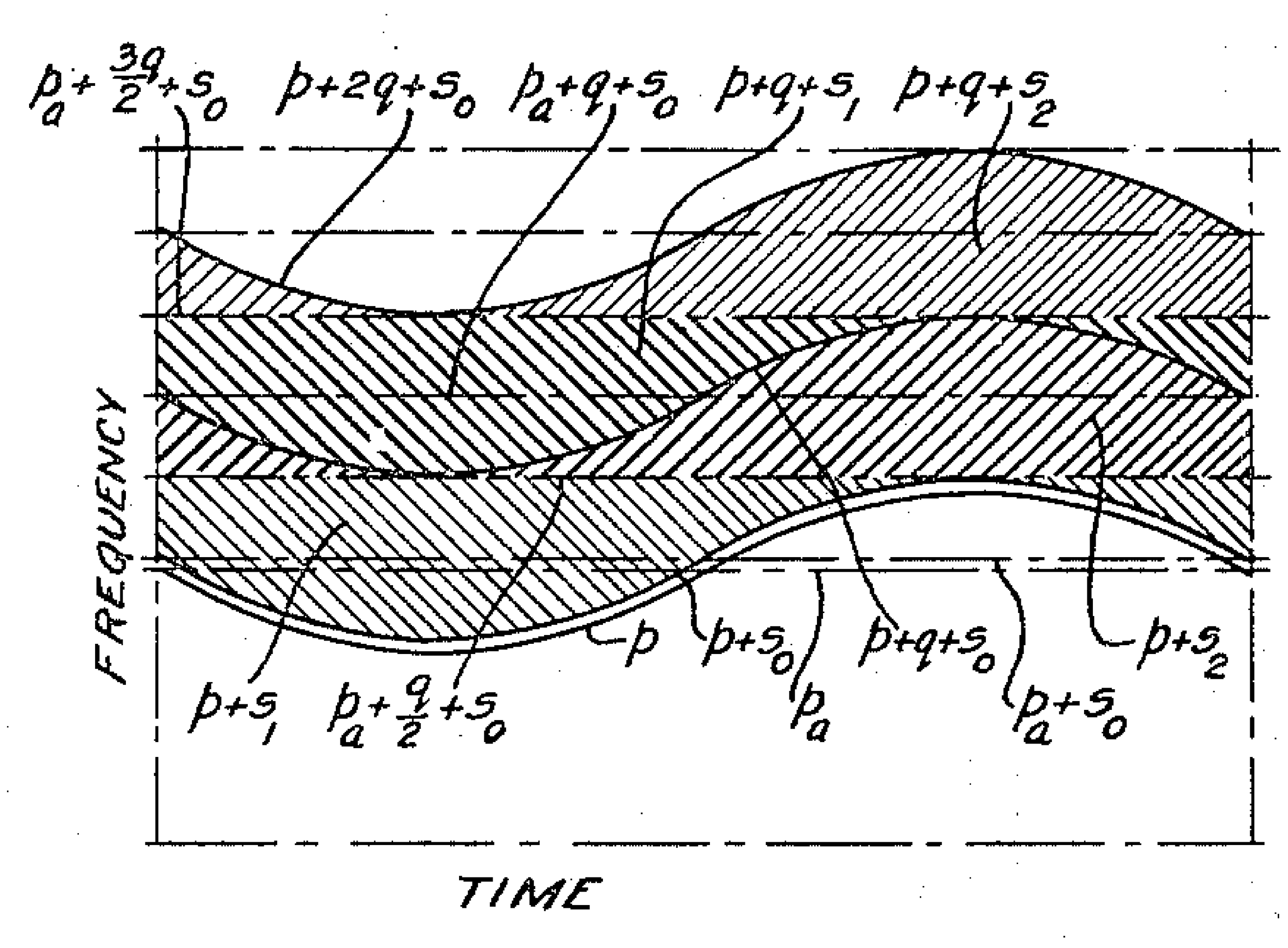


FIG. 3.



INVENTORS:
CARL R. ENGLUND
FREDERICK B. LLEWELLYN
BY H. A. Burgess
ATTORNEY

Patented Jan. 14, 1930

1,743,710

UNITED STATES PATENT OFFICE

CARL R. ENGLUND, OF FREEHOLD, AND FREDERICK B. LLEWELLYN, OF MONTCLAIR, NEW JERSEY, ASSIGNORS TO BELL TELEPHONE LABORATORIES, INCORPORATED, OF NEW YORK, N. Y., A CORPORATION OF NEW YORK

SECRECY SYSTEM FOR SIGNALING

Continuation of application Serial No. 217,130, filed September 2, 1927. This application filed November 1, 1927. Serial No. 230,222.

This invention relates to wave transmission, especially signaling by electric waves.

An object is to prevent unauthorized obtaining of information carried by transmitted waves.

A further object is to obtain such secrecy without unduly broadening the requisite width of the frequency band comprising the frequencies which the components of a wave transmitting information have in the transmission medium.

In one specific aspect the invention is a radio telephone system in which a speech wave separately modulates two carrier waves of such frequencies that the resulting upper side bands for example, are contiguous and when selected and added form a band of frequencies double the width of the speech band, the carrier waves being suppressed in the modulators.

This band of double the speech band width is caused to modulate a variable frequency carrier wave, which is suppressed in the modulator. The resulting upper side band, for example, is a "wobbling" band, its width in the frequency scale being twice the width of the speech frequency band at each instant, and its position in the frequency scale varying in synchronism with the variation of the frequency of the carrier wave, through a frequency range of variation equal to that of the carrier wave.

This "wobbling" band is impressed on a filter which passes only a frequency band of the speech band width having its center somewhere between the frequency limits of the wobbling band, as for example, midway between the frequency limits of the wobbling band. The passed band is radiated from a transmitting antenna and received by a distant receiving antenna. The pass band of the filter is of constant width, and at each instant the radiated band contains components representing all of the components of the speech wave, with their identity preserved. However, the components representing speech components are permuted in a cyclic order in this radiated band. The band consists of two contiguous sub-bands each of varying width, the upper one containing components representing the components of a variable portion of the speech band extending upward from the lower limit of the speech band, and the lower of the two sub-bands containing components representing the remaining components of the speech band. The information carried by the radiated band cannot be obtained from the band without knowledge of various factors, including the frequency of the variable frequency carrier wave.

The band incident on the receiving antenna is demodulated separately by two waves of variable frequencies, the frequency of one of these waves being the algebraic sum of the variable carrier frequency and the lower of the two fixed carrier frequencies employed at the transmitter, and the frequency of the other variable carrier wave employed at the receiver being the algebraic sum of the variable carrier frequency and the higher of the two fixed carrier frequencies employed at the sending station. This demodulation yields the two above mentioned variable portions of the speech band, which together comprise at each instant all of the components of the speech wave. The demodulations also yield distortion components, but certain of these are filtered out, and the remainder do not render the received speech unintelligible.

Other objects and aspects of the invention will be apparent from the following description and claims.

Fig. 1 of the drawing is a circuit diagram of the sending station referred to above; Fig. 2 is a similar diagram of the receiving station referred to above; and Fig. 3 is a set of graphs for facilitating explanation of the invention.

In the following description, frequencies are given in terms of radians per second, except when otherwise indicated, and in symbolical expressions for current or voltage waves, coefficients indicating amplitudes are omitteid, only quantities that indicate frequency being given. Specific values of quantities such as frequencies, speeds, etc., are mentioned merely by way of example, and the invention is not limited thereto.

In Fig. 1 a signal wave, for example a speech wave from telephone transmitter 1, is introduced into the speech or signal frequency input circuit of each of two modulators M—2 and M—3. Each of the modulators may be, for example, of the usual type of balanced vacuum tube modulator arranged for carrier wave suppression.

The carrier wave for modulator M—2 may be obtained from an oscillator O—5 of a frequency c which may be, for example, $2\pi\times20{,}000$.

The carrier wave for modulator M—3 may be obtained from an oscillator O—6 of a frequency $c+q$, where q is the difference between the highest and the lowest frequencies of the speech wave that is to be transmitted. Thus, if q is $2\pi\times3{,}000$, then the frequency of oscillator O—6 may be $2\pi(20{,}000+3{,}000)$. The lowest frequency of the speech band that is to be transmitted may be designated s_o.

The upper side bands, for example, from modulators M—2 and M—3 are selected by filters BF—7 and BF—8 respectively, and amplified by amplifiers A—9 and A—10 respectively, and applied as a modulating wave to a modulator M—11, which may be, for example, of the usual type of balanced vacuum tube modulator arranged for suppression of the carrier wave. The filter BF—7 may be, for example, a band filter passing only frequencies between $c+s_o$ and $c+s_o+q$. The filter BF—8 may be, for example, a band filter passing only frequencies between $c+s_o+q$ and $c+s_o+2q$. The modulating wave supplied to modulator M—11 from amplifiers A—9 and A—10 is then two identical speech side bands one immediately above the other, the two occupying the frequency range from $c+s_o$ to $c+s_o+2q$.

In modulator M—11 this wave modulates a variable frequency carrier wave supplied from source O—12. The frequency of this carrier wave may vary in any suitable manner, as for example sinusoidally, ten times per second, between a lower limiting frequency $d-\frac{q}{2}$ and an upper limiting frequency $d+\frac{q}{2}$. Then, designating the value of this variable carrier frequency h, the frequency h will vary about an average value d through a range q. The source O—12 may be, for example, a variable frequency oscillator of any suitable type. A suitable type is disclosed in Kendall Patent 1,571,010, January 26, 1926, or 1,592,940, July 20, 1926. The frequency d may be, for example $2\pi\times20{,}000$.

The speech wave that is to be transmitted is assumed, as indicated above, to have a frequency spectrum extending from a frequency s_o up to frequency $q+s_o$, and is assumed to consist of two contiguous subbands or portions, s_1 being taken as representative of those frequencies between s_o and $\frac{1}{x}(q+s_o)$ where x may be a variable number and is never less than 1, and s_2 being taken as representative of the remaining frequencies; which are those between $\frac{1}{x}(q+s_o)$ and $q+s_o$. The speech may then be symbolically written $\cos s_1t+\cos s_2t$, where, for generality, s_1 and s_2 may exist either simultaneously or one at a time.

The output wave from modulator M—11 is applied to band pass filter BF—20. Letting $h+c=p$, the upper side band in this output wave consists of $\cos(p+s_1)t$ and $\cos(p+s_2)t$, both due to the modulating wave from aplifier A—9, and $\cos(p+q+s_1)t$ and $\cos(p+q+s_2)t$, both due to the modulating wave from amplifier A—10. As indicated in Fig. 3, this side band represents two variable frequency or "wobbling" side bands exactly alike except relatively displaced in the frequency scale so that the lowest frequency of the side band (extending from $p+q+s_o$ up to $p+2q+s_o$) due to the modulating wave from amplifier A—10 is equal to the highest frequency of the side band (extending from $p+s_o$ up to $p+q+s_o$) due to the modulating wave from amplifier A—9.

The average value of frequency p will be designated p_a. The band pass filter BF—20 passes only the frequencies between

$$p_a+\frac{q}{2}+s_o, \text{ and } p_a+\frac{3q}{2}+s_o.$$

That is, it passes only the frequencies lying $\frac{q}{2}$ radians per second on either side of its center frequency, p_a+q+s_o. The frequency p may take on any values between

$$p_a-\frac{q}{2} \text{ and } p_a+\frac{q}{2},$$

and still all frequencies of the speech spectrum be transmitted, although, to be sure, in cyclically varying order. In Fig. 3 p is indicated as varying over a frequency range of width equal to that of the range s_o to $q+s_o$.

The output wave from band pass filter BF—20 consists of components which may be symbolically written

$$\cos(p+s_2)t \text{ and } \cos(p+q+s_1)t.$$

This output wave is amplified in any desired number of amplifiers A—21, radiated from the sending antenna 25 and received by the receiving antenna 30 at the distant receiving station, shown in Fig. 2. Although the wave contains components representing all of the speech components, with the identity of each preserved, the information which it carries can not be obtained from it without knowledge of various factors, including the variable frequency p, which is not transmitted.

From the antenna 30 the received wave is impressed on the input circuits of each of two demodulators DM—32 and DM—33, which may be for example, like modulators M—2 and M—3.

The carrier or demodulating wave for demodulator DM—32 has the variable frequency p, and the demodulating wave for demodulator DM—33 has the variable frequency $p+q$. In the system of the drawing, these demodulating waves are obtained from variable frequency oscillators O—45 and O—46 like the oscillator O—12 at the sending station.

The low frequency output wave from demodulator DM—32 may be symbolically written

$$\cos s_2t+\cos (q+s_1)t+\cos (q+s_1-s_2)t,$$

and the low frequency output wave from demodulator DM—33 may be symbolically written,

$$\cos (q-s_2)t+\cos s_1t+\cos (q+s_1-s_2)t.$$

These waves, after amplification by amplifiers A—55 and A—56 respectively, are impressed on low pass filter LPF—60, which has its output side connected to telephone receiver 61, and which has a cut-off frequency $q+s_0$. The component $\cos (q+s_1)t$ is suppressed by the filter. The components s_1t and $\cos s_2t$ constitute all of the components of the original speech wave, at their original speech frequencies, and reproduce the signal intelligibly in receiver 61, although the component $\cos (q-s_2)$ and the two components of frequency $q+s_1-s_2$ are distortion components. The two latter components are customarily present in speech demodulators.

It will be apparent that the invention is not limited to radio transmission but is applicable, for example, to wire carrier systems and to systems in which the frequencies employed for transmitting speech or other signals between two stations are within the frequency limits of the original frequencies of the signal components, the radio transmission channel between the stations being representative of any suitable type of transmission channel such as a voice frequency or wire carrier frequency channel.

Although in the system shown in the drawing the waves of the frequencies c and $c+q$ are generated by separate oscillators, it will be apparent that, if desired, suitable means, as disclosed in Fig. 3 of H. W. Nichols Patent 1,545,270, July 7, 1925, may be employed for deriving the second wave from the first by modulating the first with a wave of frequency equal to the difference between the desired frequency of the second wave and the frequency of the first wave, and selecting the upper side frequency from the modulation products. The wave of frequency $p+q$ for use as the demodulating wave in demodulator DM—33 may be derived from the wave of frequency p generated at the receiving station in a similar manner.

It will be apparent that the frequencies of the carrier waves at the transmitting station and the demodulating waves at the receiving station may be kept in proper relation by suitable electrical means, as for example, in the manner indicated in the above mentioned Kendall patents, or in the manner in which television transmitting apparatus and receiving apparatus has been synchronized. Means which have been employed for synchronizing such television apparatus are disclosed for example in the copending applicatiton of H. M. Stoller and E. R. Morton, Serial No. 200,799, June 23, 1927.

If desired, oscillator O—45 can be a vacuum tube oscillator carefully constructed to have the same frequency variations as oscillator O—12, although in a different frequency range; or if preferred, the demodulating wave of frequency p for demodulator DM—32 may be obtained by having two oscillators (not shown) at the receiving station, identical with the oscillators O—5 and O—12 respectively at the sending station, and a modulator (not shown) for producing the frequency p from the waves of such two oscillators. Similarly, the oscillator O—46 can be constructed to have the same frequency variations as oscillator O—12, in a different range; or the demodulating wave of frequency $p+q$ can be obtained as a side band resulting from intermodulation of waves of two oscillators (not shown) identical with oscillators O—6 and O—12 respectively.

As indicated above, it is not necessary that the frequency of oscillators O—12, O—45 and O—46 vary throughout a frequency range equal in width to that from s_0 to $q+s_0$. With any smaller variation, if still of considerable magnitude, the system will still afford a large element of secrecy, because all components of the signal undergo variation in frequency, in the wave transmitted between the sending station and the receiving station. If the frequencies of oscillators O—12, O—45 and O—46 vary less than q radians, then the pass band of filter BF—20 does not have to be located exactly midway in the extreme side band variation range but may be in any position in that range, such that the speech side bands do not materially slide off the characteristic selective range of the filter. The rate of variation of the frequencies of oscillators O—12, O—45 and O—46 preferably should be sufficiently high to prevent syllable reception with use of a constant beating frequency.

Preferably the frequency of variation is between about 5 cycles per second and about 15 cycles per second. As indicated above, 10 cycles a second is a very satisfactory frequency of variation. It will be apparent that the variation need not be sinusoidal, and that if desired it may be intermittent rather than continuous, and moreover, that the mode of the variation of frequency may be changed, in any suitable manner agreed upon between the operators at the two stations, to still further increase the secrecy of transmission. For simplicity the drawing shows the variation as sinusoidal; but for greater secrecy it is preferable to have the variation irregular within each cycle of variation.

Although the specific value of frequency d mentioned above by way of example is equal to the value mentioned for frequency c, such equality is not necessary. Frequency d may have any suitable value. However, its value is preferably such that the pass band of filter BF—20 does not in any way overlap the frequency range covered by the output waves from amplifiers A—9 and A—10 (that is, the frequency range extending from $c+s_o$ to $c+s_o+2_q$), so that the components of the output waves of amplifiers A—9 and A—10 do not pass through the filter BF—20.

It will be apparent to those skilled in the art that various modifications may be made in the system shown in the drawing, without departing from the invention. Thus, for example, the filter BF—20 may be omitted if the antenna 25 is tuned sufficiently sharply to suppress the frequencies outside of the band which it is desired to radiate.

This application is a continuation of our application Serial No. 217,130, filed September 2, 1927, entitled "Secrecy systems for signaling."

What is claimed is:

1. The method of operating on a wave having components of different frequencies, which comprises relatively displacing groups of said components in the frequency scale and progressively varying the width of the frequency band formed by the frequencies of the components that form one of the relatively displaced groups.

2. The method which comprises changing the order of sequence of portions of a band of frequencies in the frequency scale and varying the widths of said portions.

3. The method which comprises transposing portions of a band of frequencies and cyclically and continuously varying the width of each of said portions while maintaining their combined width constant.

4. The method which comprises so variably permuting, in the frequency scale, currents having frequencies forming sub-bands that form a frequency band, as to vary the widths of the sub-bands and maintain all of the permuted currents within a frequency band width equal to that of the first mentioned band at each instant.

5. The method which comprises so varying the frequency of each of the components of a band of signal components of different frequencies as to produce from the first mentioned band a frequency band of the signal components which has the same width as the first mentioned band, and which contains the signal components of the first mentioned band variably permuted in the frequency scale but at each instant all present that are present in the first mentioned band at a corresponding instant, and which is composed of variable width sub-bands of the signal components throughout each of which the signal components have their original order of sequence in the frequency scale.

6. The method which comprises relatively displacing, in the frequency scale, groups of wave components that form portions of a band of frequencies and gradually varying the width of one of the relatively displaced portions, transmitting the relatively displaced portions to a distant point, and at that point varying the frequencies of the components transmitted and restoring the portions to their initial relation.

7. The method of transmitting signal components of different frequencies comprised in a frequency band, which comprises transposing groups of the components that form portions of the band in the frequency scale and repeatedly varying the width of certain of the frequency bands formed by the transposed groups, for transmission of the signal components, and, for reception of the signal components, restoring the transposed groups to their initial relative positions in the frequency scale.

8. The method of operating on a plurality of frequency bands of components, each band varying in width but all of the bands forming during said variation a band of constant width, which comprises varying the frequency of each of the components of the first mentioned bands and transposing the first mentioned bands in the frequency scale.

9. In combination, means for producing two contiguous frequency bands of signal components with each band representing the same signal, and means for varying the frequencies of certain of the components of each band.

10. In combination, means for producing two contiguous frequency bands of signal components with each band representing the same signal and with the signal components of each band varying in frequency, and means for selecting two such contiguous, variable width, frequency groups of the components, one group from each band, as to thereby form a frequency band of the components that is constant in width and that has constant frequency limits.

11. In a method of radio signaling in which secrecy is obtained by varying the frequency of carrier waves which carry the signal, the step of causing the signal components at the upper end of the frequency spectrum of the signal to take the place of those at the lower end when the frequency of the carrier waves increases, and vice versa.

12. In combination, means for producing two contiguous frequency bands of signal components with each band representing the same signal and with the signal components of each band varying in frequency, and means for selecting two contiguous frequency groups of the components, one group from each of the two bands.

13. In combination, means for producing two contiguous frequency bands of signal components with each band representing the same signal and with the signal components of each band varying in frequency, and means for selecting two such contiguous frequency groups of the components, one group from each band, as to thereby form a frequency band of the components that is constant in width.

14. In combination, means for producing two contiguous frequency bands of signal components with each band representing the same signal and with the signal components of each band varying in frequency, and means for selecting two contiguous frequency groups of the components, with the components of each group forming a frequency band of varying width.

15. A secrecy signaling system comprising a transmitting station having means for producing from the signal to be transmitted a wave in which complementary portions of the signal frequency band each of which varies in width are reversed as to their order of sequence in the frequency scale, and a receiving station having means for restoring the portions to their original positions in the frequency scale.

16. Apparatus for receiving signal wave components forming a plurality of frequency bands each varying cyclically in width, said apparatus comprising means for cyclically varying the frequency of each of the components at the frequency of said cyclical variation of band width and transposing the bands of variable width in the frequency scale to form a resulting wave, and means for selecting from the resulting wave a frequency group of wave components and reproducing the signal therefrom in a form intelligible to one of the senses.

17. In a method of receiving a plurality of frequency bands each varying cyclically in width, cyclically varying the frequencies of the components at the frequency of said cyclical variations of band width and transposing the bands of variable width in the frequency scale.

18. A method of operating on mutually exclusive portions of a band of signal components of various frequencies, which portions are variable in width in the frequency scale in such a manner that the respective frequency ranges over which said portions extend, at least partly overlap, said method comprising varying the frequencies of the components, synchronously with the first mentioned variations and through a frequency range of variation equal to the range of the first mentioned variations, and transposing the bands of variable width in the frequency scale.

19. In combination, means for producing two contiguous frequency bands of signal components with each band representing the same signal and with the signal components of each band varying in frequency, and means for selecting two contiguous frequency groups of the components, one group from each of the two bands, and each group of variable width in the frequency scale.

20. In combination, means for producing two contiguous frequency bands of signal components with each band representing the same signal, means for selecting two contiguous frequency groups of the components, one group from each of the two bands, and means for varying the frequencies of the components of each group.

In witness whereof, we hereunto subscribe our names this 31st day of October, A. D. 1927.

CARL R. ENGLUND.
FREDERICK B. LLEWELLYN.