

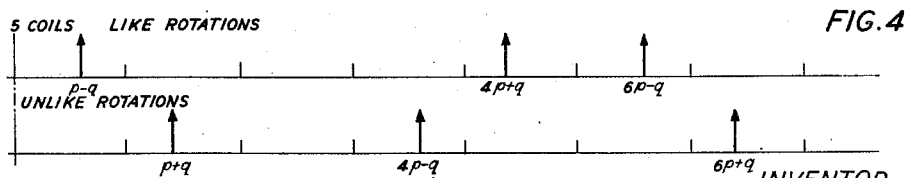
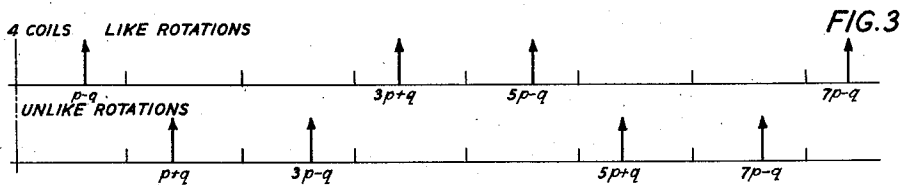
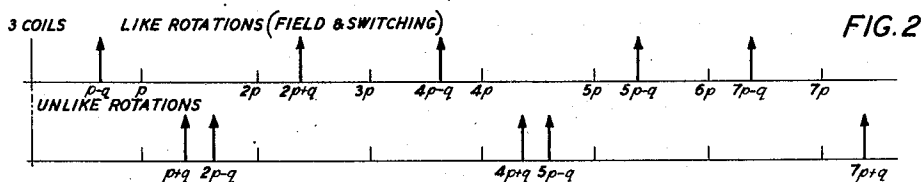
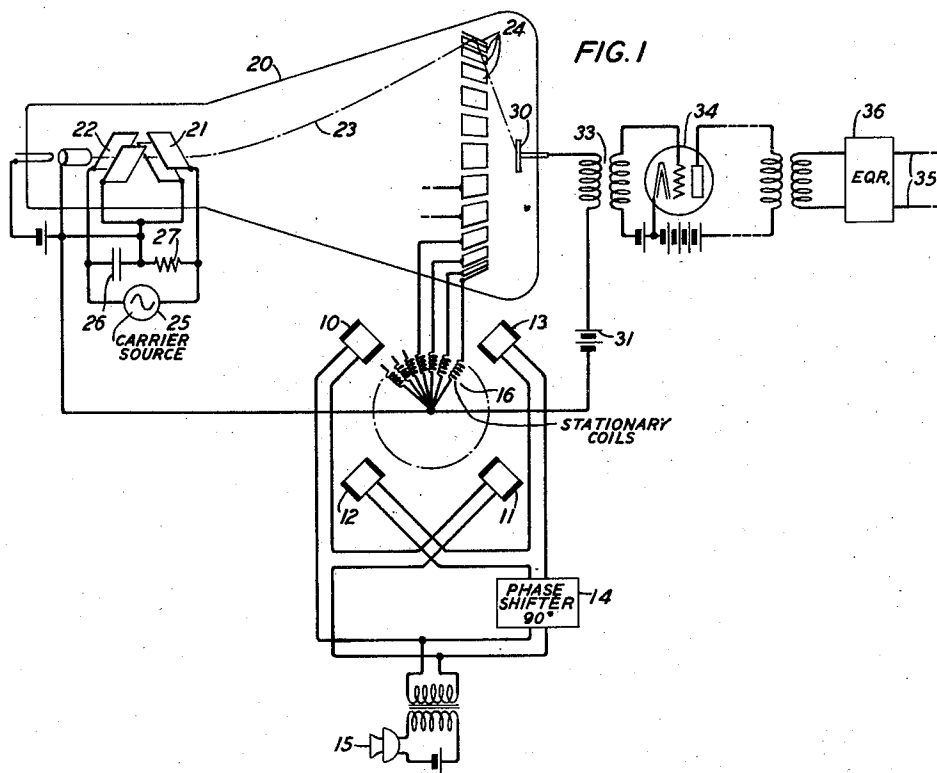
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SIGNAL WAVE MODULATION

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SIGNAL WAVE MODULATION

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The present invention relates to electrical wave modulation for purposes of intelligence transmission, and more specifically to the production of a single side-band of a modulated wave.

Direct production of a single side-band in order to avoid having to filter out the unwanted side-band from a double side-band wave has been proposed heretofore. As far as applicant is aware such direct production of a single side-band has really involved the production of pairs of side-bands in a circuit so constructed as to cause one side-band of one pair to cancel out one side-band of the other pair leaving the other two side-bands to reinforce each other in the final output. Such method requires phase shifting and circuit balancing operations of a rather critical character.

In accordance with the present invention such phase shifting circuits and circuit balances are obviated and direct production of but a single side-band based upon a required carrier frequency is achieved.

In a specific form of the invention to be disclosed in detail herein, the signal is applied to sets of field coils, arranged in a circle, to produce a rotating magnetic field, within which are placed stationary secondary windings with equal angular displacements relative to one another. The circuit of utilization is switched from one secondary coil to the next at a rate widely different from the highest signal frequency and, in general, at a rate which is high compared with the highest signal frequency. The use of a plurality of secondary coils arranged in this manner and switched into the outgoing circuit in rapid succession avoids the difficulty that would be involved in using a single rotating coil rotating at the excessively high speed that would be necessary in the case, for example, of a speech signal. The method of the invention secures results which are not entirely similar to the effects that would be obtained with a rotating coil but which yield as one resultant component wave a single side-band which is unaccompanied by the usual opposite side-band and which is easily separable from other output components.

The various features and objects of the invention will be made more apparent from the following detailed description of a preferred embodiment as illustrated in the accompanying drawing.

In the drawing:

Fig. 1 is a schematic diagram of a preferred type of the apparatus for practicing the inven-

tion involving the use of a cathode ray tube with a rotating beam as the switching means;

Figs. 2, 3 and 4 are diagrams representing carrier and side-band relations on the assumption of different numbers of secondary coils.

Referring to Fig. 1, field coils 10, 11, 12 and 13 produce a rotating magnetic field having the frequency and amplitude characteristics of the speech or other signal, by virtue of the phase quadrature relations between the currents in the respective pairs of coils caused by use of 90-degree phase shifter 14. The signal may be of any desired type but is illustrated as originating in microphone 15. The phase shifter 14 may be, for example, a network such as shown in Hartley Patent 1,666,206, April 17, 1928, or a double modulating system making use of a carrier wave shifted 90 degrees for one of the modulations, as disclosed in Carpe Patent 1,747,160, February 18, 1930.

In the field of the coils 10, 11, 12, 13 are positioned a number of stationary coils 16 with equal angular spacing. In the drawing only a few of these coils are shown but it will be understood that the coils actually extend entirely around the circle indicated. The number of coils used may be varied as will appear later on. The terminals of coils 16 are brought to the electrodes 24 of a cathode ray tube 20 provided with the usual cathode and beam forming electrodes and with two pairs of deflecting plates 21, 22 for causing the beam 23 to rotate over the fixed electrodes 24. The beam is rotated at the carrier frequency. The carrier generator 25 is connected to the usual phase-splitting circuit 26, 27 for producing phase quadrature voltages on plates 21, 22 to rotate the beam.

The electrodes 24 are preferably coated to make them good emitters of secondary electrons. The secondarily emitted electrons are collected by central electrode 30 which is at positive potential with respect to electrodes 24 due to battery 31. The collector electrode 30 leads to the primary of an output transformer 33 which may couple the modulating system to any desired type of load circuit 35 through suitable amplifier stages indicated at 34.

As mentioned above, a rotating coil could be placed in the field of the coils 10, 11, 12, 13 and rotated at the carrier frequency and would produce at its output terminals directly a single side-band, an upper or lower side-band, depending on the direction of coil rotation with respect to the direction of field rotation. In the case of speech the frequency of rotation would need to be ex-

cessively high and would involve mechanical difficulties considering that leads would have to be brought out from the coil terminals. With such a moving coil, the side-band amplitude would be proportional to the side-band frequency since the electromotive force developed is a function of rate of change of flux. This would produce distortion which could be compensated by a suitable equalizer.

In accordance with this invention the "rotation" is transferred from the coil to the switching mechanism. The rotating field induces voltages in the stationary coils 16 which are a function of the signal amplitude and frequency. These are sampled in rotation by the switching mechanism. The coil whose voltage is utilized may be considered as occupying at succeeding instants of time the same positions that the moving coil would occupy at the same instants but without having to move in order to reach those positions. The resulting side-band amplitude is proportional to the signal frequency rather than to the side-band frequency as in the case of the moving coil. This distortion can be compensated for by a suitable equalizer shown at 36, which may precede amplifier 34 if desired.

To obtain a quantitative theory taking into account departures from ideal conditions, let us assume that the rotating field vector is represented by

$$H = Q(i \cos qt + j \sin qt) \quad (1)$$

where i, j, k are the unit vectors along the axes of a rectangular coordinate system. Let the axis of a coil in the field make an angle α with the horizontal. Then a unit vector along the coil axis may be represented in vector notation by

$$a = a(i \cos \alpha + j \sin \alpha) \quad (2)$$

The voltage induced across the terminals of the coil is

$$E = -N10^{-8} \frac{d\phi}{dt} \quad (3)$$

where N is the number of turns and ϕ is the component of magnetic flux parallel to the axis of the coil. If A is the cross-sectional area of the coil,

$$\phi = AH \cdot a = AQ \cos(qt - \alpha) \quad (4)$$

Therefore,

$$E = NAQ10^{-8}(q - d\alpha/dt) \sin(qt - \alpha) \quad (5)$$

In the moving coil modulator, $\alpha = \pm pt$, and $d\alpha/dt = \pm p$. In the stationary coil modulator with external switching, $d\alpha/dt = 0$, and the voltage applied across the amplifier terminals may be expressed as

$$E_o = hqQ \sum_{k=1}^n f_k(pt) \sin(qt - \alpha_k) \quad (6)$$

where $h = NA10^{-8}$, $\alpha_k = 2\pi(k-1)/n$ is the angle which the axis of the k^{th} coil makes with that of the first coil, $f_k(pt)$ is a "switching function" expressing the constant of proportionality between the voltage across the amplifier input and the voltage induced across the k^{th} coil as a function of time, and n is the total number of stationary coils. The properties of this system as a single side-band modulator may be exhibited by making the assumption that the contacts are identical and uniformly traversed with angular velocity p . Assumptions concerning infinitely rapid changes from zero to finite conductance

in the switching process are thereby avoided. In mathematical language, we require

$$f_k(pt) = f_1 \left[pt - \frac{(k-1)2\pi}{n} \right], \quad k = 1, 2, \dots, n \quad (7)$$

It follows that

$$f_k(pt) = \frac{c_o}{2} + \sum_{m=1}^{\infty} c_m \cos \left(m \left[pt - \frac{(k-1)2\pi}{n} \right] + \theta_m \right) \quad (8)$$

where

$$\left. \begin{aligned} c_m^2 &= a_m^2 + b_m^2; \quad a_m = \frac{1}{\pi} \int_0^{2\pi} f_1(x) \cos mx dx \\ \tan \theta_m &= -b_m/a_m; \quad b_m = \frac{1}{\pi} \int_0^{2\pi} f_1(x) \sin mx dx \end{aligned} \right\} \quad (9)$$

Substituting Equation 8 in Equation 6

$$E_o = \frac{hqQ}{2} c_o \sum_{k=1}^n \sin \left[qt - \frac{2\pi}{n}(k-1) \right] +$$

$$\sum_{m=1}^{\infty} c_m \sum_{k=1}^n \sin \left[(mp+q)t + \theta_m - \frac{2\pi(m+1)(k-1)}{n} \right] -$$

$$\sum_{m=1}^{\infty} c_m \sum_{k=1}^n \sin \left[(mp-q)t + \theta_m - \frac{2\pi(m-1)(k-1)}{n} \right] \quad (10)$$

The first sum, which represents the signal, is zero except when $n=1$. The second sum, which represents the upper side-bands, is zero except when $m+1$ is zero or a multiple of n . The last sum, which represents the lower side-bands, is zero except when $m-1$ is zero or a multiple of n . We thus have upper side-bands on only the $(rn-1)st$ harmonics of the switching frequency, $r=1, 2, \dots$, and lower side-bands on only the $(rn+1)st$ harmonics of the switching frequency, $r=0, 1, 2, \dots$. The general form for E_o is thus found to be:

$$E_o = \frac{nhqQ}{2} \sum_{r=1}^{\infty} c_{rn-1} \sin [(rn-1)p + q]t + \theta_{rn-1} -$$

$$\frac{nhqQ}{2} \sum_{r=0}^{\infty} c_{rn+1} \sin [(rn+1)p - q]t + \theta_{rn+1} \quad (11)$$

The frequency spacing between the single side-band on the fundamental and the next higher side-band is $(n+1)$ times the switching frequency. For rectangular switching with no lost time,

$$c_m = \frac{2 \sin \frac{m\pi}{n}}{m\pi} \quad (12)$$

The solution 11 holds for like directions of rotation of field and switching. If the field and the switching process move in opposite directions, the positions of upper and lower side-bands are interchanged, the effect being shown by changing the sign of q in 11. A less favorable separation of fundamental side-band and the next higher one is thereby obtained.

To illustrate for particular values of n , we note that with three stationary coils, it is possible to get an output wave containing a lower side-band on p , an upper on $2p$, lower on $4p$, upper on $5p$, etc. Or, by reversing one direction of rotation, we get upper side-bands on $p, 4p, 7p, \dots$ and lower side-bands on $2p, 5p, 8p, \dots$. With four stationary coils, lower side-bands on $p, 5p, 9p, \dots$ and upper side-bands on $3p, 7p, 11p, \dots$ may be produced.

These relations are shown graphically in Figs. 2, 3 and 4 which are self-explanatory.

While the type of switching or commutating circuit shown is the preferred type, the invention is not in any wise limited in its broader aspects to the use of this or any specific type. Any suitable arrangement for connecting the coils 16 into the outgoing circuit in sufficiently rapid succession may be used. A ring of gas tubes arranged to fire in succession as disclosed in King-Ohl Patent No. 2,136,621, dated November 15, 1938 may be used. Another type of commutation using a succession of biased rectifiers having periodic impulses supplied to them to counteract the bias voltages at proper time displacements as disclosed in E. Peterson application Serial No. 221,297, filed July 26, 1938, may be used. The scope of the invention is indicated in the claims which follow.

What is claimed is:

1. The method of producing a signal modulated wave comprising producing a rotating field represented by a vector having an amplitude proportional to the maximum amplitude of the signal and rotating at signal frequency, producing a response proportional to the component of such vector along each of a succession of angular directions, detecting these responses successively at a rate different from the frequency of rotation and combining the detected responses in a common circuit.

2. The method of producing a signal modulated wave in the case of a signal comprised of a band of frequency components comprising producing from the signal a rotating field in space having frequency components each of which may be represented by a vector proportional to the maximum amplitude of a corresponding frequency component of the signal rotating at the frequency of the corresponding signal component, producing from each frequency component of the field a response proportional to the component of the corresponding field vector along each of a succession of angular directions, detecting these responses successively at a rate high in comparison with the highest signal frequency and combining the detected responses in a common circuit.

3. The method of producing a single side-band of a modulated wave from a signal having a band of frequencies comprising producing a rotating magnetic field having the same band of frequency components as the signal, inducing voltages in coils at a succession of angular positions in said field, switching said coils successively into connection with a circuit of utilization at a rate high in comparison with the highest signal fre-

quency whereby side-bands are produced at frequency levels spaced apart by at least the frequency of switching, and selecting the desired side-band by filtering.

4. In a signaling system, a source of signal waves, magnetic coils arranged in a circle and so connected to said source as to produce rotating magnetic fields of the signal frequencies, stationary coils at equally spaced angular positions in said fields, a circuit of utilization, and means of rapidly switching said coils into connection with said circuit in rotation.

5. In a signaling system, a source of signal waves, means comprising field coils and connections thereto from said source for producing a rotating field having frequency and amplitude vectors determined by the signal, stationary coils in said field, a cathode ray tube having control electrodes, connections from said stationary coils to respective control electrodes, means for sweeping a cathode beam over said electrodes at a frequency high in comparison with the highest signal frequency, and an output circuit operatively related to said electrodes.

6. In a signaling system, means including a source of signal waves and field windings for producing a rotating magnetic field having frequency and amplitude characteristics determined by the signal, a plurality of stationary windings inductively related to said rotating field, a circuit of utilization, and electrical commutating means for successively establishing operative connection between each of said stationary windings and said circuit of utilization at a rate high in comparison with the highest signal frequency component.

7. In a signaling system, a cathode ray tube including means for producing a rotating beam rotating at a frequency higher than the highest signal frequency component to be transmitted, a plurality of emitter electrodes positioned to be scanned by said beam, a collector electrode positioned to receive secondarily emitted electrons from said emitter electrodes, a source of signal waves, means including angularly positioned coils and phase shifting means for producing a rotating magnetic field under control of said signal waves, secondary coils angularly displaced from one another in said rotating field, individual connections from said secondary coils to said emitter electrodes, and a circuit of utilization connected between said collector electrode and a common terminal of said secondary coils.

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