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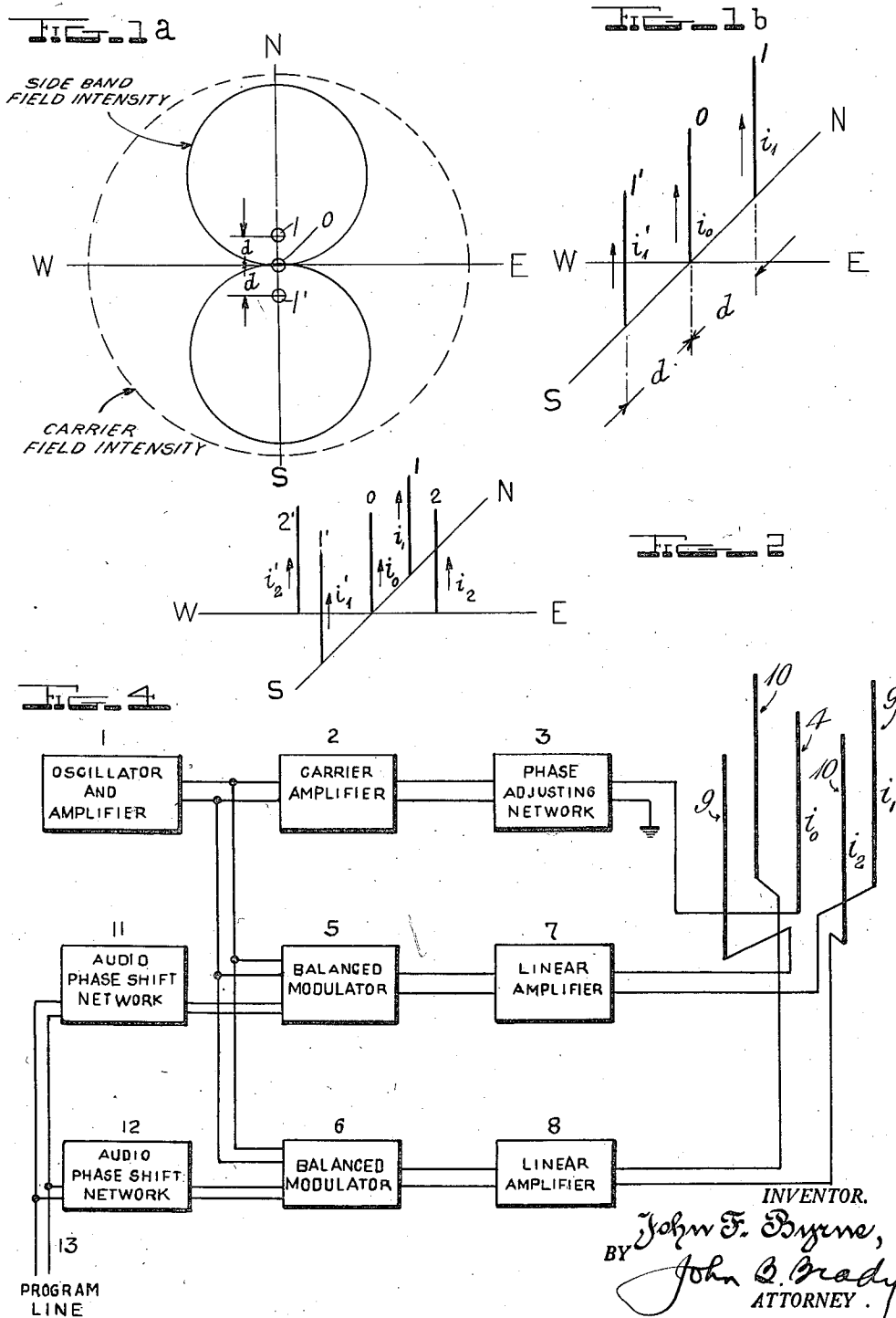
J. F. BYRNE

2,313,048

BROADCASTING SYSTEM

Filed June 23, 1938

5 Sheets-Sheet 1



March 9, 1943.

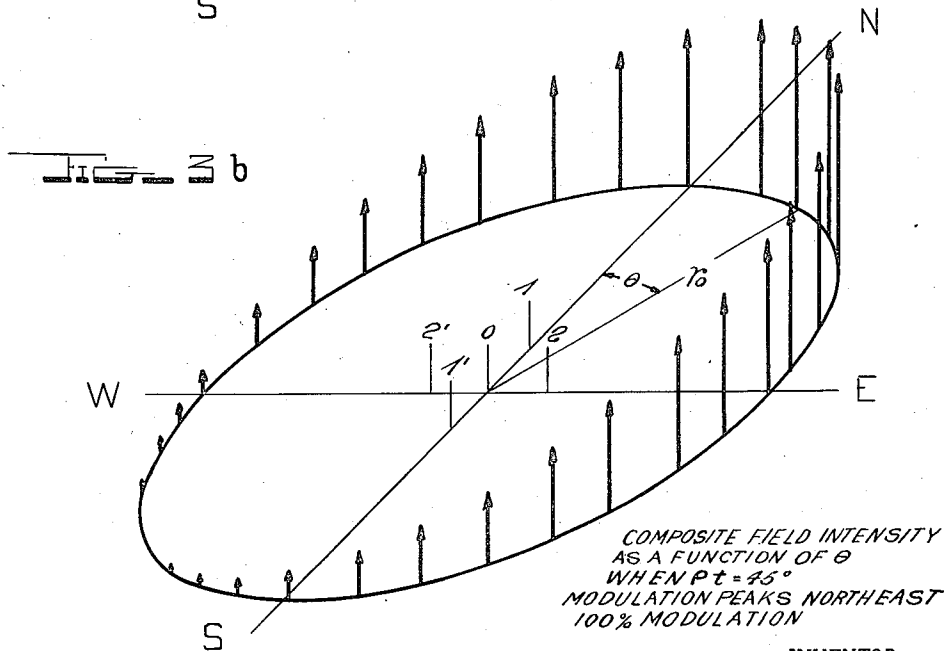
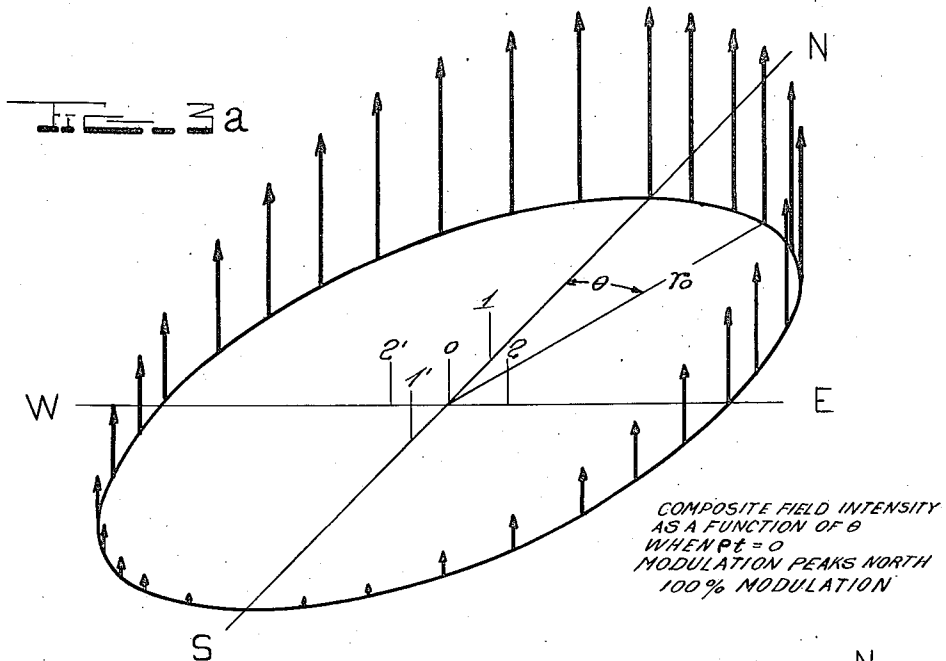
J. F. BYRNE

2,313,048

BROADCASTING SYSTEM

Filed June 23, 1938

5 Sheets-Sheet 2



INVENTOR.
John F. Byrne,
BY John C. Brady
ATTORNEY.

March 9, 1943.

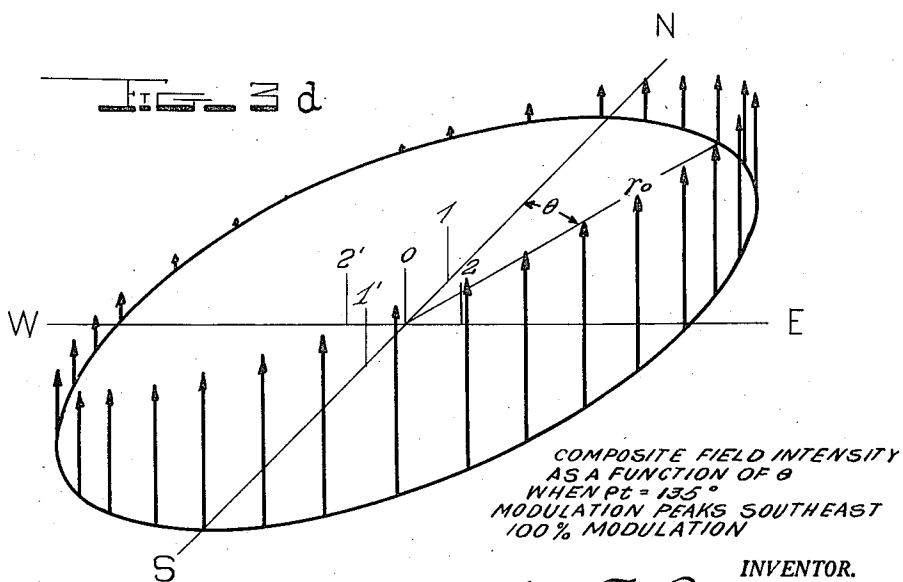
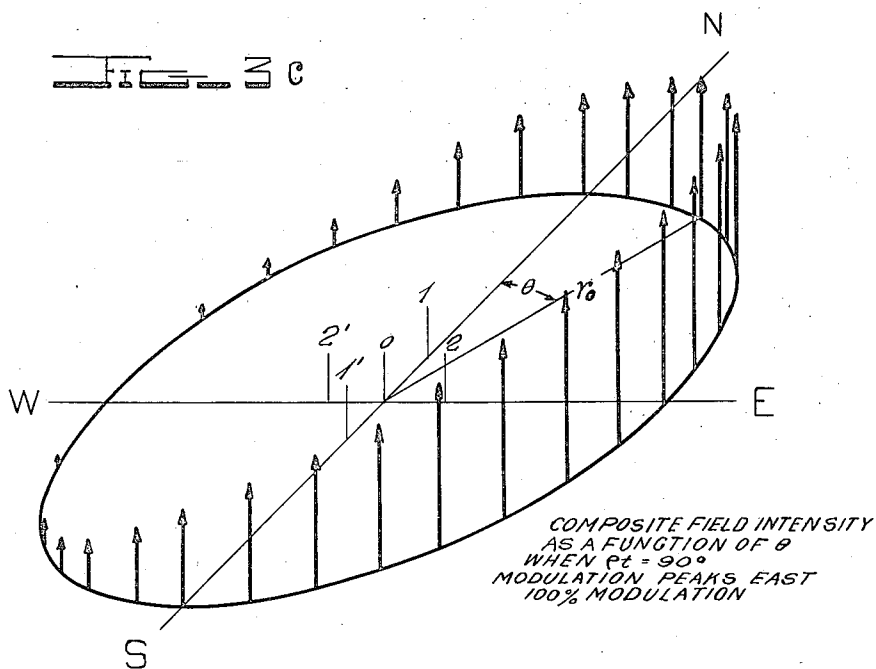
J. F. BYRNE

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BROADCASTING SYSTEM

Filed June 23, 1938

5 Sheets-Sheet 3



INVENTOR.

John F. Byrne,
BY John C. Brady
ATTORNEY.

March 9, 1943.

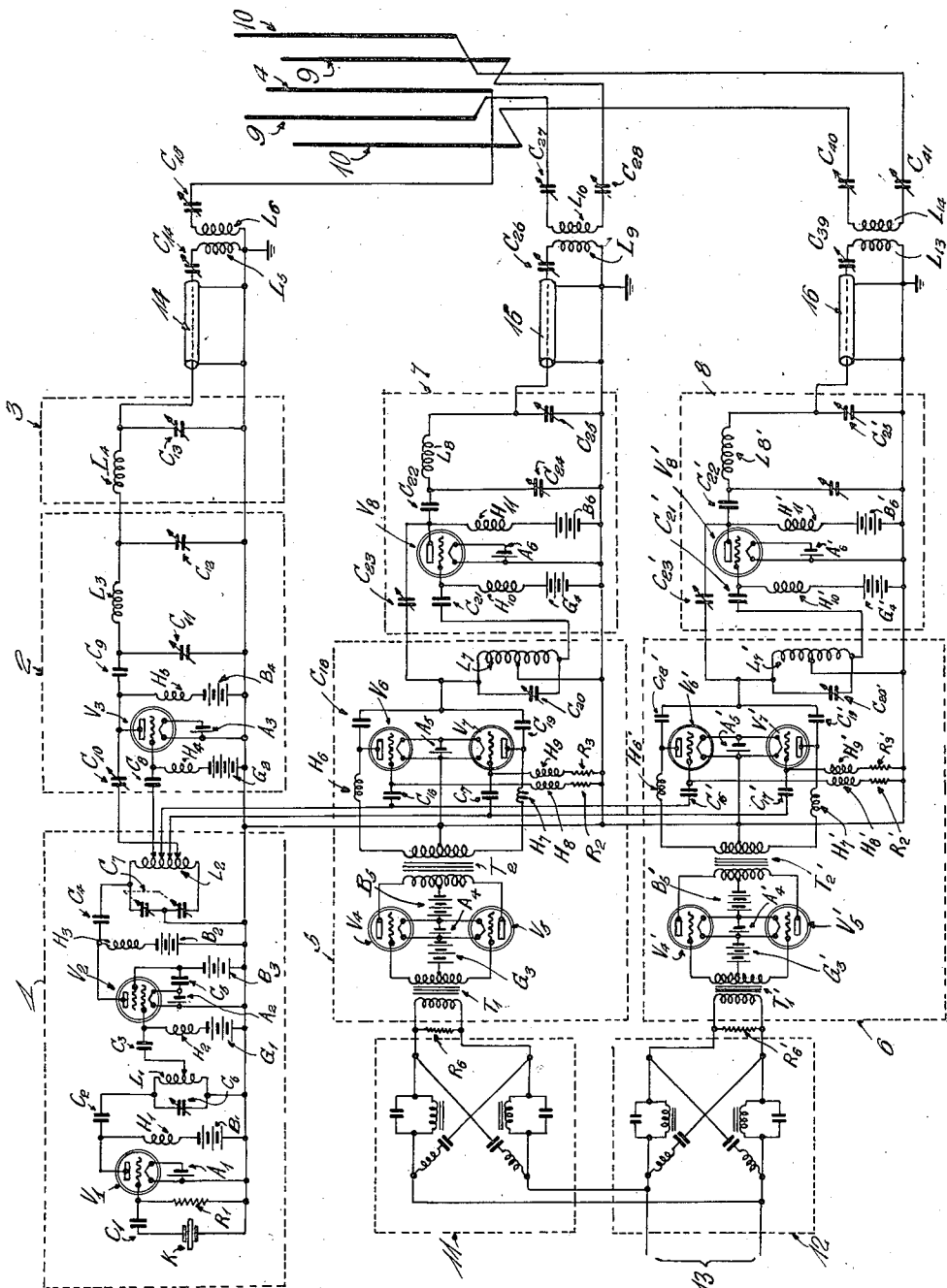
J. F. BYRNE

2,313,048

BROADCASTING SYSTEM

Filed June 23, 1938

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INVENTOR.

John F. Byrne,
BY

BY

BY *John Q. Brady*
ATTORNEY.

ATTORNEY

March 9, 1943.

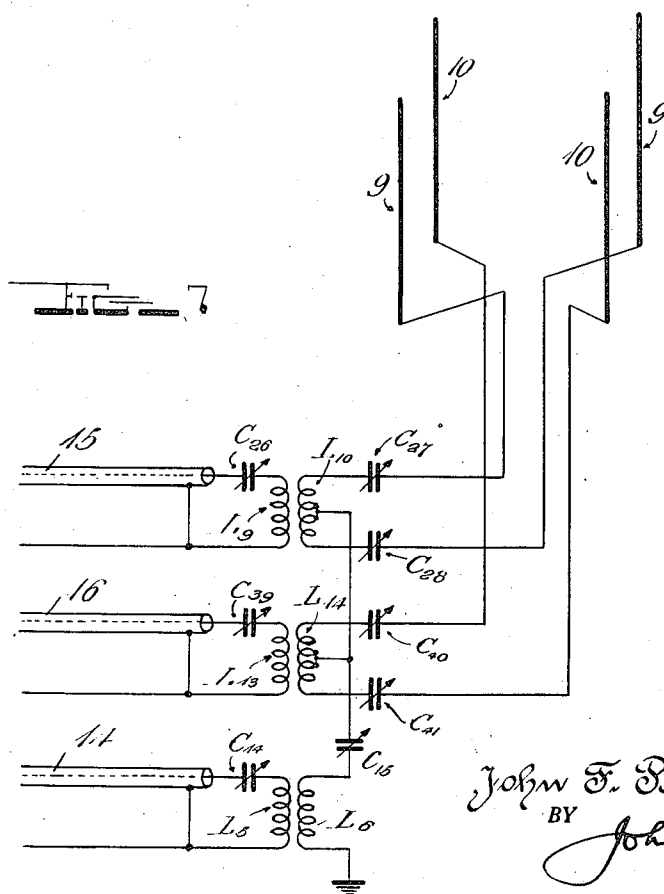
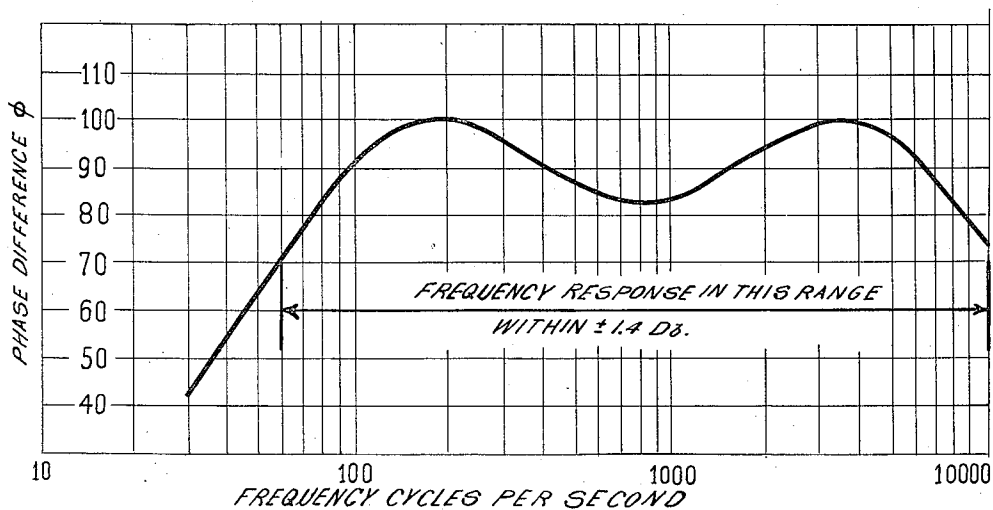
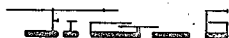
J. F. BYRNE

2,313,048

BROADCASTING SYSTEM

Filed June 23, 1938

5 Sheets-Sheet 5



INVENTOR.
John F. Byrne,
BY
John C. Brady
ATTORNEY

UNITED STATES PATENT OFFICE

2,313,048

BROADCASTING SYSTEM

John F. Byrne, Cedar Rapids, Iowa, assignor to
Collins Radio Company, Cedar Rapids, Iowa, a
corporation of Iowa

Application June 23, 1938, Serial No. 215,465

26 Claims. (Cl. 250—17)

My invention relates broadly to high frequency signal transmission systems and more particularly to a transmitting system in which the total power output of the system is substantially constant throughout the cycle of modulation.

One of the most important objects of my invention is to provide a means for signalling, using amplitude modulated waves in which the efficiency of power conversion is exceptionally high.

Another object of my invention is to provide a system of signalling by means of amplitude modulated waves in which the vacuum tube utilization is of a high degree. For example, in the system to be described, the peak power output is one and one-half times the carrier power of the transmitter as contrasted with conventional systems where the peak power output is necessarily four times the carrier power of the transmitter.

Still another object of my invention is to provide a system of radio transmission in which the percent amplitude modulation is the same in all directions, but in which the phase of the modulation varies in a prescribed manner; that is, the phase angle is an integral multiple of the space angle in the ground plane.

A further object of my invention is to provide a means for transmission of double side band signal components to produce amplitude modulation of a transmitted carrier using a system in which the mutual coupling of the carrier transmitter and the side band transmitter is zero.

A still further object of my invention is to provide a means for the transmission of double side band signal components which are the result of modulation using N phase audio frequency current, from N transmitters and antenna systems which are so arranged that the mutual coupling of the N transmitting systems is zero.

Another object of my invention is to provide a system of radio transmission wherein the root-mean-square radio frequency power output is constant throughout the modulation cycle.

Still another object of my invention is to provide a polyphase radio broadcasting system wherein the radio frequency carrier energy is single phase and modulated by polyphase signal energy coordinated with spacial sectors in accordance with the number of phases of the modulation energy.

A further object of my invention is to provide a system of radio transmission of double side band signal components wherein carrier and side band components are separately generated and combined in space by radiation from coordinated

antenna systems, the side band components being polyphase in character and cooperable, and the carrier component single phase for obtaining high efficiency in transmission.

5 A still further object of my invention is to provide a system of radio transmission including the propagation of an unmodulated carrier wave and the modulation thereof in space by the addition of side band components separately generated and propagated and of polyphase character to obtain broadcast coverage.

10 Another object of my invention is to provide a polyphase radio broadcasting system wherein the phase of an amplitude modulation is a function of the azimuth angle while the carrier energy is independent of such modulation.

Other and further objects of my invention reside in the combination and arrangement of apparatus and the operation thereof as hereinafter set forth more particularly with reference to the accompanying drawings in which:

Figures 1a and 1b are theoretical and diagrammatic showings, respectively of a fundamental radiating arrangement illustrative of the basic features of my invention; Fig. 2 is a diagram of the arrangement of antennas in a simple polyphase broadcasting system in accordance with my invention; Figs. 3a, b, c and d are spacial diagrams of the magnitude of the field intensities in different phases of the modulation cycle, the relation to the azimuth angle being apparent; Fig. 4 is a block diagram of the system of my invention; Fig. 5 is a schematic diagram of a transmitter for supplying energy of the proper character to the antennas in accordance with the system of my invention; Fig. 6 is a graph showing calculated performance data relative to the audio phase shifting networks shown in Figs. 4 and 5; and Fig. 7 is a schematic diagram showing a modified form of antenna arrangement and one manner of coupling the same to the transmitter shown in Fig. 5.

In the conventional system of amplitude modulation, the final amplifier tubes must be of sufficient rating to supply peak power equal to four times carrier power of the transmitter. In the system to be described, the maximum power output of the transmitter is equal to one and one-half times the carrier power and the final amplifier tubes have a maximum capability which is two times the carrier power. Under any condition of sustained modulation, the power output of the transmitter is constant throughout the audio cycle. This latter feature is of particular importance, as it results not only in high effi-

ciency, but in a tube economy of considerable magnitude in high power transmitters.

The polyphase nature of the system is the result of using directional radiating elements to produce an essentially "rotating modulation field" in which, at a particular instant, modulation peaks occur in the north direction, carrier values occur to the east, modulation minima to the south, carrier values to the west. One quarter of the modulation cycle later, modulation peaks occur to the east, carrier values to the south, minima to the west, and carrier values to the north. As the modulation progresses through the cycle, the peaks of modulation rotate about the transmitting system at the modulating frequency.

In the discussion of the various features of the system of broadcasting covered in this invention, attention will be entirely directed to what might be termed a two-pole four-phase system. By carrying out certain generalizations, one can easily arrive at a system described as an n -pole N -phase case.

Inasmuch as the system to be described is one in which modulation is a function of the azimuth angle, several simple systems will be reviewed, which will readily lead up to the polyphase system of my invention.

A system in which the percent modulation is a function of the azimuth angle

The most commonplace of these systems is the ordinary radio range beacon used in this country. In the newer of these systems, carrier energy is supplied to a nondirectional radiator, indicated at o in the diagram Fig. 1a, and a single frequency single side band current is supplied to a figure-of-8 directional system consisting of the

A system in which the phase of a modulation of the pure amplitude type is a function of the azimuth angle

Consider the system of three antennas as before and, with reference to Fig. 1b, let the following currents be established in them:

$$\begin{aligned} i_0 &= I_0 \cos \omega t \\ i_1 &= I_1 \sin \omega t \cos \rho t \\ i_1' &= -I_1 \sin \omega t \cos \rho t \end{aligned}$$

Where

$\omega/2\pi$ is the carrier frequency

$\rho/2\pi$ is the modulation frequency

I_0 is the maximum value of current in the carrier antenna

I_1 is the maximum value of current in the side band antenna

The field intensities due to these radiators (assumed identical) at a distance r_0 , where r_0 is at least ten wavelengths, may be written:

$$\begin{aligned} e_0 &= \frac{KI_0}{r_0} \cos \omega \left(t - \frac{r_0}{c} \right) \\ e_1 &= \frac{KI_1}{r_0} \sin \omega \left(t - \frac{r_0 - d \cos \theta}{c} \right) \cos \rho t \\ e_1' &= \frac{-KI_1}{r_0} \sin \omega \left(t - \frac{r_0 + d \cos \theta}{c} \right) \cos \rho t \end{aligned}$$

Where

K =antenna performance constant

r_0 =distance to receiving point, meters

d =antenna spacing, meters

c =velocity of light, meters/sec.

The sum $e_1 + e_1'$ becomes

$$\begin{aligned} e_1 + e_1' &= \frac{KI_1}{r_0} \left\{ \sin \omega \left(t - \frac{r_0}{c} + \frac{d \cos \theta}{c} \right) - \sin \omega \left(t - \frac{r_0}{c} - \frac{d \cos \theta}{c} \right) \right\} \cos \rho t \\ &= \frac{2KI_1}{r_0} \cos \omega \left(t - \frac{r_0}{c} \right) \sin \omega \left(\frac{d \cos \theta}{c} \right) \cos \rho t \end{aligned}$$

two antennas, 1 and 1' of Fig. 1a. These antennas are placed in the same straight line with radiator o and with equal spacing. If we imagine the antennas to be placed in a north and south line, and we measure an angle θ clockwise from north, the ratio of the side band field intensity to the carrier field intensity will be proportional to the absolute value of the cosine of this azimuth angle. In the conventional beacon system the antennas of Fig. 1a are supplemented by two

Now, if $\omega d/c$, the spacing in electrical degrees, is less than 30° ,

$$\sin \frac{\omega d}{c} \cos \theta = \frac{\omega d}{c} \cos \theta, \text{ very nearly.}$$

Hence

$$e_1 + e_1' = \frac{4\pi d}{r_0 \lambda} KI_1 \cos \omega \left(t - \frac{r_0}{c} \right) \cos \theta \cos \rho t$$

The complete field is

$$e_0 + e_1 + e_1' = \frac{KI_0}{r_0} \cos \omega \left(t - \frac{r_0}{c} \right) \left[1 + \frac{4\pi d}{\lambda} \frac{I_1}{I_0} \cos \theta \cos \rho t \right] \quad (1)$$

more antennas placed in line with the carrier antenna and at right angles to the first directional pair. These antennas produce a figure-of-8 pattern at right angles to the first pair and the modulation thus produced is proportional to the absolute value of the sine of the azimuth angle. The on-course indication is given when the percent modulation is the same for both directional pairs. It should be pointed out that the resulting signal is one consisting of carrier and a single side band, and would not be suitable for conventional broadcast transmission using conventional receivers.

The factor

$$\frac{4\pi d (\cos \theta)}{\lambda} \frac{I_1}{I_0}$$

is the familiar modulation factor m and it is thus seen that the resultant field is an amplitude modulated one, and that the percent modulation varies as the cosine of the azimuth angle.

It should further be noted that the carrier system and the side band system are uncoupled electrically; the side band system consisting of two antennas having equal and opposite mutual effects upon the carrier antenna.

If, as in the beacon system, we add another directional pair of antennas, 2 and 2' of Fig. 2, and establish currents

$$\begin{aligned} i_2 &= I_1 \sin \omega t \sin \rho t \\ i_2' &= -I_1 \sin \omega t \sin \rho t \end{aligned}$$

(Where I_1 , ω , and ρ have the same meaning as before) in the antennas 2 and 2', a system will be obtained in which the magnitude of the amplitude modulation is independent of the azimuth angle, and the phase of the modulation is equal to the azimuth angle. Mathematically the result is as follows:

The antenna currents are:

$$\begin{aligned} i_0 &= I_0 \cos \omega t \\ i_1 &= I_1 \sin \omega t \cos \rho t \\ i_1' &= -I_1 \sin \omega t \cos \rho t \\ i_2 &= I_1 \sin \omega t \sin \rho t \\ i_2' &= -I_1 \sin \omega t \sin \rho t \end{aligned}$$

The field intensities become

$$\begin{aligned} e_0 &= \frac{KI_0}{r_0} \cos \omega \left(t - \frac{r_0}{c} \right) \\ e_1 &= \frac{KI_1}{r_0} \sin \omega \left(t - \frac{r_0 - d \cos \theta}{c} \right) \cos \rho t \\ e_1' &= -\frac{KI_1}{r_0} \sin \omega \left(t - \frac{r_0 + d \cos \theta}{c} \right) \cos \rho t \\ e_2 &= \frac{KI_1}{r_0} \sin \omega \left(t - \frac{r_0 - d \sin \theta}{c} \right) \sin \rho t \\ e_2' &= -\frac{KI_1}{r_0} \sin \omega \left(t - \frac{r_0 + d \sin \theta}{c} \right) \sin \rho t \end{aligned}$$

$$e_0 + e_1 + e_1' + e_2 + e_2' = \frac{KI_0}{r_0} \cos \omega \left(t - \frac{r_0}{c} \right) \left\{ 1 + \frac{4\pi d I_1}{I_0 \lambda} (\cos \theta \cos \rho t + \sin \theta \sin \rho t) \right\}$$

which becomes

$$E \text{ total RMS} = \frac{KI_0 \text{ rms}}{r_0} \left[1 + \frac{4\pi d I_1}{I_0 \lambda} \cos (\rho t - \theta) \right] \quad (2)$$

This Equation 2 shows that the audio phase is dependent upon the azimuth angle. Further, the modulation factor

$$\frac{4\pi d I_1}{I_0 \lambda}$$

is independent of the azimuth angle, and only depends upon the relative magnitudes of I_1 and I_0 .

Figures 3a, 3b, 3c and 3d are a pictorial representation of Equation 2 and the vectors show the magnitude of the field intensities in the different directions noted as the modulation cycle progresses.

The transmitting equipment used to generate the currents i_0 , i_1 , and i_2 is shown in the schematic diagram of Fig. 4. Fig. 5 is a wiring diagram of a transmitter embodying the form of my invention shown schematically in Fig. 4.

In Fig. 4, element 1 is a source of carrier frequency energy consisting of the conventional master oscillator and radio frequency amplifier used to provide radio frequency excitation to the following amplifier stages. Element 2 is a radio frequency power amplifier supplying the carrier frequency energy transmitted to the central radiator, 4, of the antenna system, through radio frequency phase adjusting network 3, which provides the proper phase relation between the carrier current in antenna 4 and the side band currents in antennas 9 and 10. Elements 5 and 6 are balanced modulators supplied with carrier

frequency excitation from source 1 and audio modulation frequencies from networks 11 and 12. The audio components applied to balanced modulators 5 and 6 are substantially 90 electrical degrees out of phase with respect to each other by reason of the difference in delay of the two audio frequency phase-shifting networks 11 and 12, both of which are connected to the same source of audio frequency current, program line 13. Balanced modulators 5 and 6 generate side band frequencies corresponding to the sum and difference of the carrier frequency and the audio modulation frequencies, but suppress the original carrier frequency. These double side band components are amplified by linear amplifiers 7 and 8 to the power level required in the two side band antenna systems consisting respectively of antennas 9 and 10.

Let

- 20 i_0 = the instantaneous carrier frequency current in antenna 4
- I_0 = the maximum instantaneous amplitude of the current in antenna 4
- $\omega = 2\pi$ times the carrier frequency in cycles per second
- 25 t = the time in seconds
- i_1 = the current in side band antennas 9
- i_2 = the current in side band antennas 10
- I_1 = maximum instantaneous amplitude of the side band currents in antennas 9 and 10
- 30 $\rho = 2\pi$ times the audio modulation frequency in cycles per second
- $i_0 = I_0 \cos \omega t$ (3)
- $i_1 = I_1 (\sin \omega t) \cos \rho t$ (4)
- 35 $i_2 = I_1 (\sin \omega t) (\sin \rho t)$ (5)

Equation 3 shows the carrier current in antenna 4 as a function of only the carrier frequency ω . Side band currents i_1 and i_2 in Equations 4 and 5 have the factor $\cos \omega t$ replaced by $\sin \omega t$, indicating a 90 degree phase difference between the carrier current i_0 and the suppressed carrier current in antennas 9 and 10. The factors $\cos \rho t$ and $\sin \rho t$ in Equations 4 and 5 indicate balanced modulation by audio frequency currents which are 90 degrees different in phase for balanced modulators 5 and 6.

In the wiring diagram of the transmitter shown in Fig. 5, the portions of the circuit enclosed by dotted lines and labeled 1 to 13 inclusive represent the corresponding elements of Fig. 4. In the oscillator-amplifier element 1, V_1 is a conventional crystal controlled oscillator tube, and V_2 a radio frequency amplifier tube. A_1 and A_2 represent the filament current sources of V_1 and V_2 respectively, B_1 is the plate current source of V_1 and B_2 that of V_2 . G_1 is a source of negative D.-C. grid bias, and B_3 is a source of positive screen potential, for amplifier V_2 . Condensers C_1 to C_5 are D.-C. blocking condensers. H_1 , H_2 , and H_3 are radio frequency choke coils. R_1 is the grid leak resistor for oscillator tube V_1 , and K is a piezo-electric crystal for determining the frequency of oscillation. The tuned circuit consisting of condenser C_6 and coil L_1 supplies carrier frequency excitation from the oscillator circuit to the grid of the amplifier circuit through blocking condenser C_3 . The amplifier tuned circuit consisting of condenser C_7 and coil L_2 supplies radio frequency excitation to the carrier amplifier in element 2 and the

balanced modulator tubes in elements 5 and 6.

The element 2, V_3 , is a carrier power amplifier tube of sufficient power to amplify the carrier energy to the power level required in antenna 4. A_3 is the filament current source for V_3 , and G_2 and B_4 are the grid bias and plate voltage sources, respectively. Condensers C_8 and C_9 are blocking condensers. H_4 and H_5 are radio frequency choke coils. Condenser C_{10} is a neutralizing condenser for neutralizing radio frequency feedback from the plate circuit to the grid circuit of tube V_3 . Condensers C_{11} , C_{12} , and coil L_3 constitute the output plate circuit of V_3 and serve to match the radio frequency load impedance of the tube to the input impedance of phase adjusting network 3. The bias voltage, radio frequency excitation voltage, plate voltage and radio frequency load impedance of tube V_3 are adjusted for high efficiency, high power output condition, since this stage operates as an unmodulated carrier amplifier and can be considered comparable to the output amplifier stage of a radio-telegraph transmitter.

In element 3, coil L_4 and condenser C_{13} serve as a radio frequency phase shift network which is adjusted so that the total radio frequency phase shift between amplifier V_3 and antenna 4 is correct with respect to the radio frequency phase shift between balanced modulators 5 and 6 and antennas 9 and 10; that is, so that there is a phase difference of 90 electrical degrees between the carrier current in antenna 4 and the suppressed carrier currents in side band antennas 9 and 10. Radio frequency carrier output from phase adjusting network 3 is transmitted through a concentric tube transmission line 14 to the coupling network, consisting of condensers C_{14} and C_{15} and coils L_5 and L_6 , which is installed at the base of antenna 4.

In balanced modulator 5, V_4 and V_5 are the tubes of a conventional push-pull audio amplifier stage whose grids are coupled to phase shift network 11 through input transformer T_1 and whose plates are coupled to the plate circuit of balanced modulator tubes V_6 and V_7 through output transformer T_2 . A_4 and A_5 are the filament current sources of the audio amplifier and the balanced modulator tubes respectively. G_3 and B_5 are the grid bias and plate voltage sources respectively of the audio amplifier stage. The balanced modulators consist of two radio frequency amplifier tubes V_6 and V_7 whose grids receive radio frequency excitation voltage from element 1 through blocking condensers C_{16} and C_{17} . The connection is such that radio frequency voltage on the grid of V_6 is 180 electrical degrees out of phase with that of the grid of V_7 . H_3 and H_9 are radio frequency choke coils and R_2 and R_3 are grid leak resistors for the grids of V_6 and V_7 .

The plates of V_6 and V_7 are connected through blocking condensers C_{18} and C_{19} to the tuned circuit consisting of coil L_7 and condenser C_{20} . This connection effectively places the two plates in parallel to radio frequency voltage. There is no direct current source in the plate circuit of V_6 and V_7 , but the plates are connected through radio frequency chokes H_6 and H_7 in a push-pull or opposed sense to the output transformer T_2 of the audio frequency amplifier stage. Hence the plate circuit of the balanced modulator tubes is inactive except when audio modulation voltage is applied and only one of the tubes V_6 — V_7 passes plate current at any given instant. For example, V_6 would be active during the positive half of the audio frequency cycle and V_7 during the negative half. The result is that the output circuit C_{20} — L_7

receives only the two side band frequencies corresponding to the sum and difference of the carrier frequency and the audio frequency, and that the carrier frequency is suppressed.

Element 7 is a conventional class B linear radio frequency amplifier including V_8 the function of which is to amplify the double side band output of balanced modulator 5 to the power level required in antennas 10. A_6 is the filament current source, B_6 the plate potential source, and G_4 the grid bias source for this amplifier stage. Grid bias voltage is so adjusted as to produce essentially zero plate current in the absence of radio frequency excitation in accordance with conventional practice for linear amplifier stages. H_{10} and H_{11} are radio frequency chokes, C_{21} and C_{22} are blocking condensers, and C_{23} is the neutralizing condenser for this stage. Condensers C_{24} and C_{25} and coil L_8 constitute the radio frequency output circuit for this stage and function to match the plate load impedance to the impedance of the concentric tube transmission line 15 following. Condensers C_{26} , C_{27} and C_{28} and coils L_9 and L_{10} constitute the coupling network between the bases of antennas 9 for coupling the transmission line to this antenna circuit.

It is seen that elements 6 and 8 are identical with elements 5 and 7 respectively and serve to supply the required side band current to antennas 10 in the same fashion. For convenience, therefore, I have shown primed reference characters in elements 6 and 8 to indicate corresponding parts. The radio frequency excitation to balanced modulator element 6 is the same as that supplied to element 5. The audio frequency voltages to these two elements, however, are supplied by two different audio phase shift networks 11 and 12. The input circuits of these two networks are connected in parallel to a source of audio frequency voltage such as the program line 13, or the output of a microphone or microphone amplifier. These networks are designed so that the difference in the phase shift through the networks is substantially ninety electrical degrees throughout the useful audio frequency range. In network 11, for example, the coils and condenser are constructed to have reasonably small losses, so that the attenuation is negligible when the network is terminated in its characteristic impedance. Resistor R_6 , connected across the input winding of transformer T_1 , is of such value that the effective parallel impedance of said resistor and transformer provides the proper termination for network 11.

The outlet of amplifier 8 is conducted through concentric tube transmission line 16 and applied to antennas 10 through a coupling network, including coils L_{13} and L_{14} and condensers C_{39} , C_{40} and C_{41} , which is similar to that in connection with antennas 9.

Fig. 6 shows the characteristics of a sample design of audio frequency phase shifting network. The deviation in phase difference from 90 degrees is seen to be within plus or minus 15 degrees over the frequency range of 65 to 10,000 c. p. s. The following considerations will show the effect of small deviations from the required phase shift of 90 degrees.

Returning to Equation 2, the total field intensity is proportional to

$$\cos \omega t [1 + m \{ \cos \theta \cos \rho t + \sin \theta \sin (\rho t - \varphi) \}]$$

where φ is the phase deviation in degrees.

The term: $m [\cos \theta \cos \rho t + \sin \theta \sin (\rho t - \varphi)]$ for any particular value of θ has two conventional

vector components. They are displaced in phase by an angle $\pi/2 + \varphi$. Consider the case when θ is 45 degrees. At this point the vectors are equal in length. Their sum, $.707m (1/\sqrt{2} + 1/\sqrt{2} + \varphi)$ is the percentage of modulation existing at an angle of 45 degrees with the meridian. At an angle of 135 degrees the sum becomes $(-1/\sqrt{2} + 1/\sqrt{2} + \varphi)$ ($.707m$) and so on. These values of θ are used for illustrative purposes because the percentage of modulation is most sensitive to phase deviations in these directions. The following table shows the change in percent modulation in decibels as a function of the phase deviation in degrees for the most sensitive directions:

Phase deviation	-45°	-135°
5° -----	- .38 db.	+ .36 db.
10° -----	- .82 db.	+ .68 db.
15° -----	- 1.30 db.	+ .99 db.
20° -----	- 1.84 db.	+ 1.16 db.
30° -----	- 3.00 db.	+ 1.76 db.

The table shows that the system is not particularly critical as to audio phase balance, as a deviation as much as plus or minus 20 degrees only produces a maximum variation of 3 decibels in the frequency response, and this only occurs at the diagonal angles. It is, of course, clear that in the north and south, and east and west directions, no change in the transmitted frequency response occurs. This simple requirement, of course, means that a satisfactory polyphase audio source can readily be set up.

Fig. 7 shows an alternative to the antenna system shown in Fig. 5, in which the carrier antenna 4 has been eliminated. The coils and condensers in the coupling circuits of Fig. 7 are identical to and numbered to correspond with those of Fig. 5. Condenser C_{15} of the carrier coupling circuit instead of being connected to a separate carrier antenna is connected to center taps on coils L_{10} and L_{14} of the side band coupling circuits. The result is that the carrier current is divided into four portions which flow in the four antennas 9 and 10, producing, at any point at least ten wavelengths from the antenna system, virtually the same field intensity as would be produced by the separate carrier antenna 4 of Fig. 5. The center tap connections to L_{10} and L_{14} result in a balanced or bridge circuit involving the carrier and the side band circuits, so that there is no coupling between them.

Instead of four or five separate antenna structures as shown in Figs. 5 and 7, a more economical arrangement consists of a central structure for the carrier with the four side band antennas suspended therefrom. That this is entirely feasible is shown from a consideration of the dimensions involved. In the development of Equation 2 it was assumed that the spacing of the directional elements was small in comparison with a wavelength. This small spacing is desirable not only from the point of view of the directional characteristic in the ground plane, but also in order that the distribution of the figure-of-8 directional system in the vertical plane (as a function of the vertical angle) be as nearly as possible similar to the vertical distribution of the carrier antenna. Using the ratio of d , the spacing, to λ , the wavelength of one to thirty, consider the following example:

Frequency 1000 KC.

Halfwave antenna----- 493. feet high
Spacing of elements----- 32.8 feet

It would hardly be out of line to assume that the side band antenna systems could be suspended from the center carrier antenna structure, without greatly increasing the cost of the antenna system. Electrical desirability and mechanical convenience are fortunately concurrent.

Practical aspects of the system

Although the system of my invention introduces certain additional structural and control factors not found in conventional transmission systems, the following outstanding advantages of this polyphase modulation system are obtained.

1. The carrier amplifier 2 operates under class C telegraph conditions. It always supplies carrier energy only.

2. The high power tube complement must be capable of supplying peak power as follows:

Carrier amplifier----- Carrier power
Each side band amplifier----- $\frac{1}{2}$ carrier power

This should be contrasted with the conventional system which requires that the final amplifier be capable of supplying four times carrier.

3. The class C telegraph operation of the carrier amplifier reduces the hum problem to a minimum.

4. The minimum audio frequency load on the filter system is four times the lowest desired audio frequency.

5. Slight maladjustment of the system does not seriously impair fidelity.

6. High overall operating efficiency is realized for the complete transmitter.

The following is an example of the economy of the polyphase system as applied to a proposed 50 kw. transmitter. This transmitter would utilize four water-cooled vacuum tubes, two of which are in the carrier amplifier and one in each of the side band amplifiers. These tubes would be driven by six type 849A vacuum tubes, two for the carrier amplifier and two modulators for each of the side band amplifiers. These tubes in turn can be driven from a single source of radio frequency voltage and a pair of 803 vacuum tubes would provide sufficient power for driving purposes. The following table outlines the probable power consumption and tube expense of this transmitter:

50 kw. transmitter

Plate input, carrier-----	72 kw.
Plate voltage-----	18 kv.
Plate current-----	4.0 amp.
Plate current per tube-----	2.0 amp.
Peak current per tube-----	6.6 amp.
Plate current each side band amplifier at 100% modulation-----	1.27 amp.
Plate current each side band amplifier at 30% modulation-----	.382 amp.
Plate input, two side band amplifiers at 30% modulation-----	13.75 kw.
Filament power 4 tubes, 61 ampere at 22 V.-----	5.37 kw.
Plate input carrier amplifier-----	72.0 kw.
Plate input side band amplifiers-----	13.75 kw.
	91.12 kw.
Allow 20 kw. for exciter and amplifiers-----	20.00
Total-----	111.12 kw.

To further emphasize the importance of the system as applied to high power broadcasting,

owing data have been compiled concerning possible layout for a 500 kw. transmitter. Transmitter would utilize four type 898 tubes in the carrier amplifier and two of the side band amplifiers. The magnitude of the saving is such as to shed possibly light on the economies of 500 kw. operation.

500 kw. transmitter

input carrier amplifier-----	720.0 kw.
input side band amplifiers-----	137.5 kw.
total power, 8 tubes, 207A at 38-----	54.7 kw.
and auxiliaries-----	150.0 kw.
total-----	1062.2 kw.

As shown in the drawings and specification I referred to specific elements, such as batteries of power and bias potential, particularly controlling circuits and the like; I have used such devices to be illustrative only and employ in lieu thereof any suitable means in the art or as yet undisclosed. It is to be understood that where batteries are shown alternating current, or rectified alternating may be employed as in conventional systems.

The system of my invention is particularly adapted to commercial broadcasting of high power. The use of the great savings in initial cost, operation and maintenance effected, especially in the long hours of operation daily. As a result of the savings accomplished by the system of my invention, I cite the following:

500 kw. transmitter

300 kw. at \$.008 for 19 hours=\$45.50 per day, 365 days per year=\$16,500 per year.

12 tubes eliminated—life, 10,000 hours,
 $\frac{\times 19}{1000} \times \frac{12 \times 1600}{1} = \$13,350$ per year

Saving: \$16,500 + \$13,350 = \$29,850 per year.

50 kw. transmitter

60 kw. at 1.2¢ for 19 hours/days=\$13.68 per day
 $165 \times \$13.68 = \$5,000$ per year.

12 tubes at \$425.00—life 6500 hours against 2 tubes \$1600.00—life 10,000 hours

$\frac{425 \times 19 \times 365}{6500} = \$1,810$ per year

$\frac{1600 \times 19 \times 365}{10,000} = \$2,210$ per year

10—\$1,810=\$300

100 + \$300 = \$5,300.00 total annual saving

Frequency stability and fidelity of signal are not affected in the system of my invention; rather, because of the reduced power output of the transmitter and signals of given intensity, control factors are greatly simplified and generally improved results are achieved.

It is disclosed only a particular embodiment of my invention for clarity, but it will be readily understood that the system may be modified for other polyphase relations and by the substitution of equivalent means in the apparatus for transmission. The system of my invention is applicable not only to broadcast transmission, as shown, but by virtue of the relation of the phase

of modulation to azimuth angle is adaptable also to a variety of applications where such relation may be useful, such as in radio compass systems, synchronizing systems, duplex signal transmission, and other fields as will be apparent to those skilled in the art. Thus, I desire it understood that no limitations upon my invention are intended except as may be imposed by the scope of the appended claims.

What I claim as new and desire to secure by Letters Patent of the United States is as follows:

1. A high frequency signalling transmission system comprising means for broadcasting unmodulated carrier energy, directional means for propagating modulation side band signal energy of the type covering simultaneously a band of frequencies, and means for timing the energization of said directional means according to the frequency of said modulation side band signal energy for effecting radiation, the phase of which is a function of the azimuth angle.

2. A high frequency signalling transmission system comprising means for broadcasting unmodulated carrier energy, directional means for propagating polyphase modulation side band signal energy of the type covering simultaneously a band of frequencies, and means for timing the energization of said directional means according to the frequency of said modulation side band signal energy for effecting radiation, the phase of the composite field of said modulation side band signal energy being a function of the azimuth angle.

3. A high frequency signalling transmission system comprising separate means for propagating radio frequency carrier energy and modulation side band radio frequency energy of the type covering simultaneously a band of frequencies, means for timing the radiation of the modulation side band signal energy according to the frequency of the modulation side band signal energy, and means for controlling the space phase of the composite field intensity produced by said separate means so that the root-mean-square radio frequency power output of said separate means is constant throughout the modulation cycle.

4. A high frequency signalling transmission system comprising separate means for propagating carrier energy and modulation side band signal energy of the type covering simultaneously a band of frequencies, the output of said means for propagating carrier energy being substantially constant, and means for controlling the phase of the modulation side band signal energy as a function of the azimuth angle at a rate dependent upon the frequency of the modulation side band signal energy so that the root-mean-square output of said means for propagating modulation side band signal energy is constant throughout the modulation cycle.

5. A high frequency signalling transmission system comprising nondirectional radiating means and means for individually supplying carrier energy thereto, polyphase directional radiating means and means for supplying polyphase modulation side band signal energy of the type covering simultaneously a band of frequencies thereto at a rate dependent upon the frequency of the modulation side band signal energy, the phase of the modulation in the composite field intensity being a function of the azimuth angle.

6. A high frequency signalling transmission system comprising nondirectional radiating means and means for individually supplying carrier energy thereto for establishing a uniform field of carrier energy about said radiating means, multi-

ple radiating means within said field and means for supplying modulation side band signal energy of the type covering simultaneously a band of frequencies thereto for establishing separate restricted fields of modulation side band signal energy superimposed on said field of carrier energy at a rate dependent upon the frequency of the modulation side band signal energy, the phase of the modulation side band signal energy in the respective restricted fields being a function of the azimuth angle.

7. The method of high frequency transmission which consists in establishing in space separate fields of carrier energy and modulation side band signal energy of the type covering simultaneously a band of frequencies, controlling the transmission of the modulation side band signal energy in proportion to the frequency of the modulation side band signal energy and varying the phase of the modulation in the composite field as a function of the azimuth angle.

8. The method of high frequency transmission which consists in establishing a composite field of carrier energy and modulation side band signal energy of the type covering simultaneously a band of frequencies in space, and separately controlling the phase of the modulation as a function of the azimuth angle at a rate dependent upon the frequency of the modulation side band signal energy.

9. The method of broadcasting high frequency signal energy which consists in establishing in space a field of high frequency energy of substantially constant power input modulating said field by a signal of the type covering simultaneously a band of frequencies, controlling the phase of the maximum intensity of said field as a function of the azimuth angle at a rate proportional to the modulating frequency, and varying the intensity of said field in accordance with the modulating signal.

10. The method of broadcasting high frequency signal energy which consists in uniformly propagating in all directions in the ground plane an amplitude modulated signal wave of the type covering simultaneously a band of frequencies and having uniform amplitude of modulation in all directions and controlling the rate of propagation according to the frequency of modulation of the modulated signal wave with the phase of the modulation varying as a function of the azimuth angle.

11. The method of high frequency signalling which includes transmitting high frequency amplitude modulated signal waves of the type covering simultaneously a band of frequencies along different azimuths and controlling the space phase of the amplitude modulated signal waves as a function of the azimuth angle at a rate dependent upon the modulation frequency of the amplitude modulated signal waves.

12. The method of broadcasting high frequency signal energy with substantially constant power consumption throughout the modulation cycle which includes controlling the space phase of an amplitude modulated signal wave of the type covering simultaneously a band of frequencies as a function of the azimuth angle so that instantaneous field intensities at points of 180° displacement in the ground plane are 180° out of phase at a rate dependent upon the modulation frequency of the amplitude modulated signal wave.

13. The method of broadcasting high frequency signal energy with substantially constant power consumption throughout the modulation cycle

which consists in broadcasting an amplitude modulated signal wave of the type covering simultaneously a band of frequencies, and controlling the space phase of the modulation energy as a function of the azimuth angle so that instantaneous field intensities are 180° out of phase at points of 180° displacement in the ground plane, power maxima in one phase being accompanied by power minima in the opposite phase to preserve constancy in the power input throughout the modulation cycle at a rate dependent upon the modulation frequency of the amplitude modulated signal wave.

14. A high frequency signalling transmission system comprising a source of unmodulated carrier energy, separate sources of polyphase modulation side band signal energy of the type covering simultaneously a band of frequencies, and an antenna system including radiators coupled with each phase of said polyphase modulation signal energy and mounted relative to each other about a central point in accordance with the phase of the signal energy to be radiated therefrom, said antenna system including means separately connected with the first said source for independently radiating said unmodulated carrier energy.

15. A high frequency signalling transmission system as set forth in claim 14 and wherein the last said means comprises a nondirectional radiator disposed at the central point in said system and separately coupled with said source of unmodulated carrier energy.

16. A high frequency signalling transmission system as set forth in claim 14 and wherein the last said means comprises a balanced circuit interconnecting the said radiators and said source of carrier energy for radiating unmodulated carrier energy from said radiators, said balanced circuit operating to annul coupling between the separate radiators and the polyphase signal energy supplied thereto.

17. A high frequency signalling transmission system comprising a source of unmodulated carrier energy, a source of modulation signal energy of the type covering simultaneously a band of frequencies, phase splitting means coupled with said source of signal energy, separate means for modulating carrier energy from said source thereof by each phase of said signal energy, means for suppressing the carrier energy in each phase of the signal modulated energy, means for separately and independently radiating unmodulated carrier energy derived from said source thereof and each phase of the signal modulated energy, the radiating means for each phase of said signal modulated energy being disposed relative to each other about a central point in accordance with the phase of the energy to be radiated therefrom and means for controlling the rate of radiation of each phase of the signal modulated energy according to the frequency of said source of modulation signal energy.

18. A high frequency signalling transmission system comprising a source of unmodulated carrier energy, a source of modulation signal energy of the type covering simultaneously a band of frequencies, phase splitting means coupled with said source of signal energy, separate modulating means coupled with said source of carrier energy and each phase of said phase splitting means and operative to produce suppressed carrier polyphase double side band signal modulated energy, means for radiating unmodulated carrier energy derived from said source of carrier energy, and separate

liating each phase of said polyphase modulated energy at a rate dependent upon said modulating means, the rates for each phase of said signal modulating means being disposed in space in accordance with the relations of the energy to be radiated.

A frequency signalling transmission system comprising a source of unmodulated carrier energy, a source of modulation signal energy, means for producing simultaneously a band of frequencies, separate circuits coupled with the carrier energy, phase shifting means in at least one of said circuits to produce signal currents in phase in the separate circuits, balancer means in each of said circuits to balance said source of carrier energy and a divider double side band signal modulator means for separately and independently modulating carrier energy derived from said source thereof and each phase of said band signal modulated energy, the modulated energy being disposed in quadrature phase, and means for controlling the radiation of each phase of the signal modulated energy according to the frequency of said modulation signal energy.

A method of broadcasting high frequency signals which includes directing and successively in space an amplitude modulated signal of the type covering simultaneously a band of frequencies, maintaining the percent modulation hereof the same in all directions, and controlling the phase of the modulation with direction proportional to the modulation frequency of the amplitude modulated signal wave.

A broadcasting system comprising non-directional means for radiating unmodulated carrier energy characterized by the function $\cos \rho t$, directional means for radiating suppressed carrier energy of the type covering simultaneously a band of frequencies characterized by $\sin \omega t \cos \rho t$, other directional means for radiating suppressed carrier energy in 90° relation to the first said means for radiating suppressed carrier energy characterized by the function $\sin \omega t \sin \rho t$, where ω represents the carrier frequency, ρ the signal frequency, and means

for controlling the radiation of the suppressed carrier signal in proportion to the value of ρ .

22. A broadcasting system comprising non-directional means for radiating unmodulated carrier energy, multiple directional means for radiating polyphase suppressed carrier signal energy of the type covering simultaneously a band of frequencies, with the radiating components of said multiple directional means disposed in space in relation to the polyphase energy radiated thereby for producing in cooperation with said non-directional means a composite field characterized by the function $\cos (\rho t - \theta)$, where ρ represents the signal frequency and θ the azimuth angle, and means for controlling the radiation of the suppressed carrier signal in proportion to the value of ρ .

23. An antenna modulation system including means for generating carrier frequency current, a source of modulation current of the characteristics required for the transmission of signals covering simultaneously a band of frequencies, means for applying one of said currents to create an omni-directional field, and means for applying the other of said currents to create a field rotating at the frequencies of said band of frequencies.

24. An antenna modulation system including means for generating carrier frequency currents, a source of modulation currents of the characteristics required for the transmission of signals covering simultaneously a band of frequencies, means for applying one of said currents to create an omni-directional field, and means for applying the other of said currents to create a field rotating at the frequency of the said other currents.

25. An antenna modulation system including means for generating a carrier frequency current, a source of modulation currents of the characteristics required for the simultaneous transmission of signals covering simultaneously a band of frequencies, means for applying one of said currents to create an omnidirectional field, and means for applying the other of said currents to create a field in which components rotate at the frequencies corresponding to the frequencies of said modulation.

26. The method of transmitting simultaneously a wide range of modulation frequencies which includes radiating an unmodulated carrier wave, establishing a rotating field, and varying the rate of rotation of said field as a function of said modulation frequencies.

JOHN F. BYRNE.