

Nov. 4, 1947.

H. M. LEWIS

2,430,296

RADIATED-SIGNAL RECEIVING SYSTEM

Filed Oct. 27, 1943

4 Sheets-Sheet 1

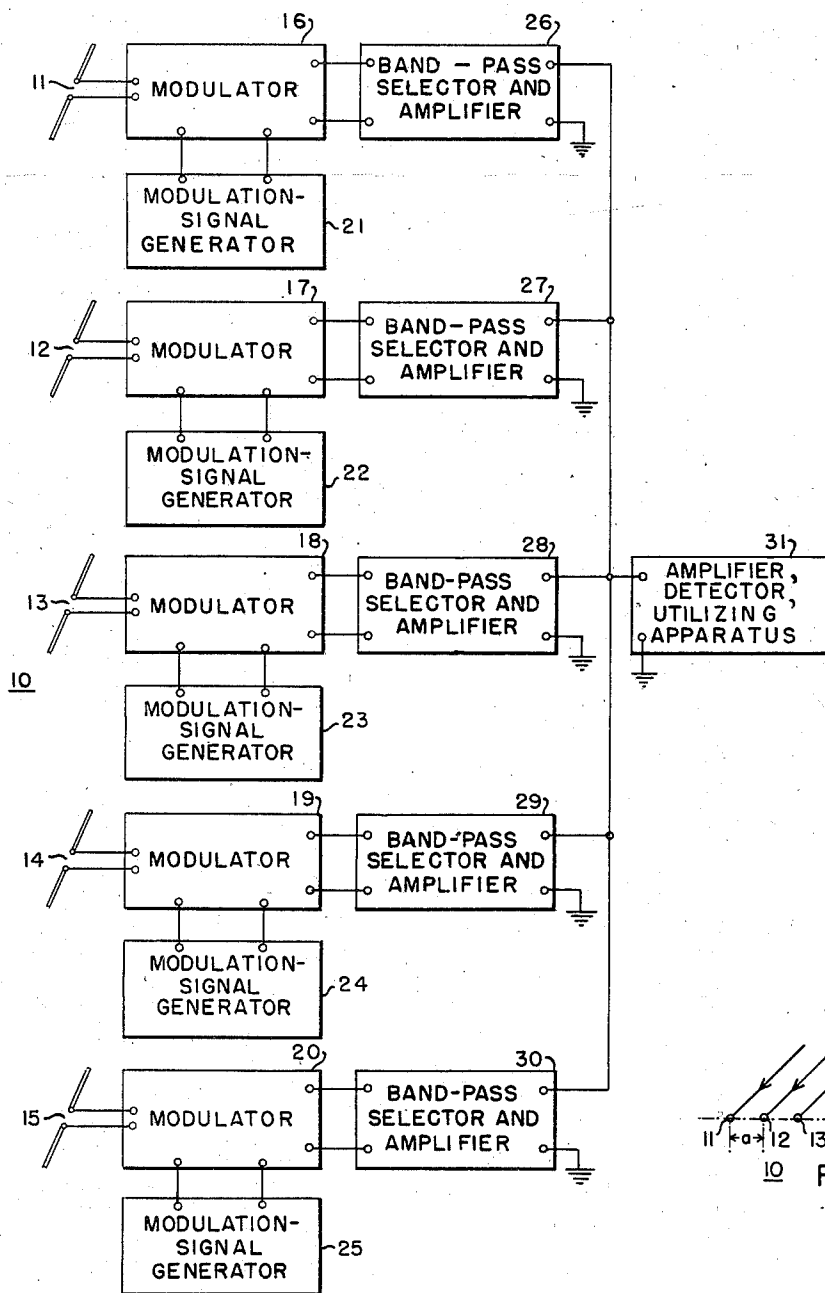


FIG. 1

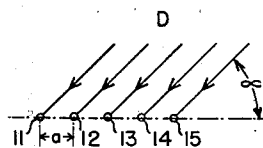


FIG. 1A

INVENTOR
HAROLD M. LEWIS
BY *Harry B. Page*
ATTORNEY

Nov. 4, 1947.

H. M. LEWIS

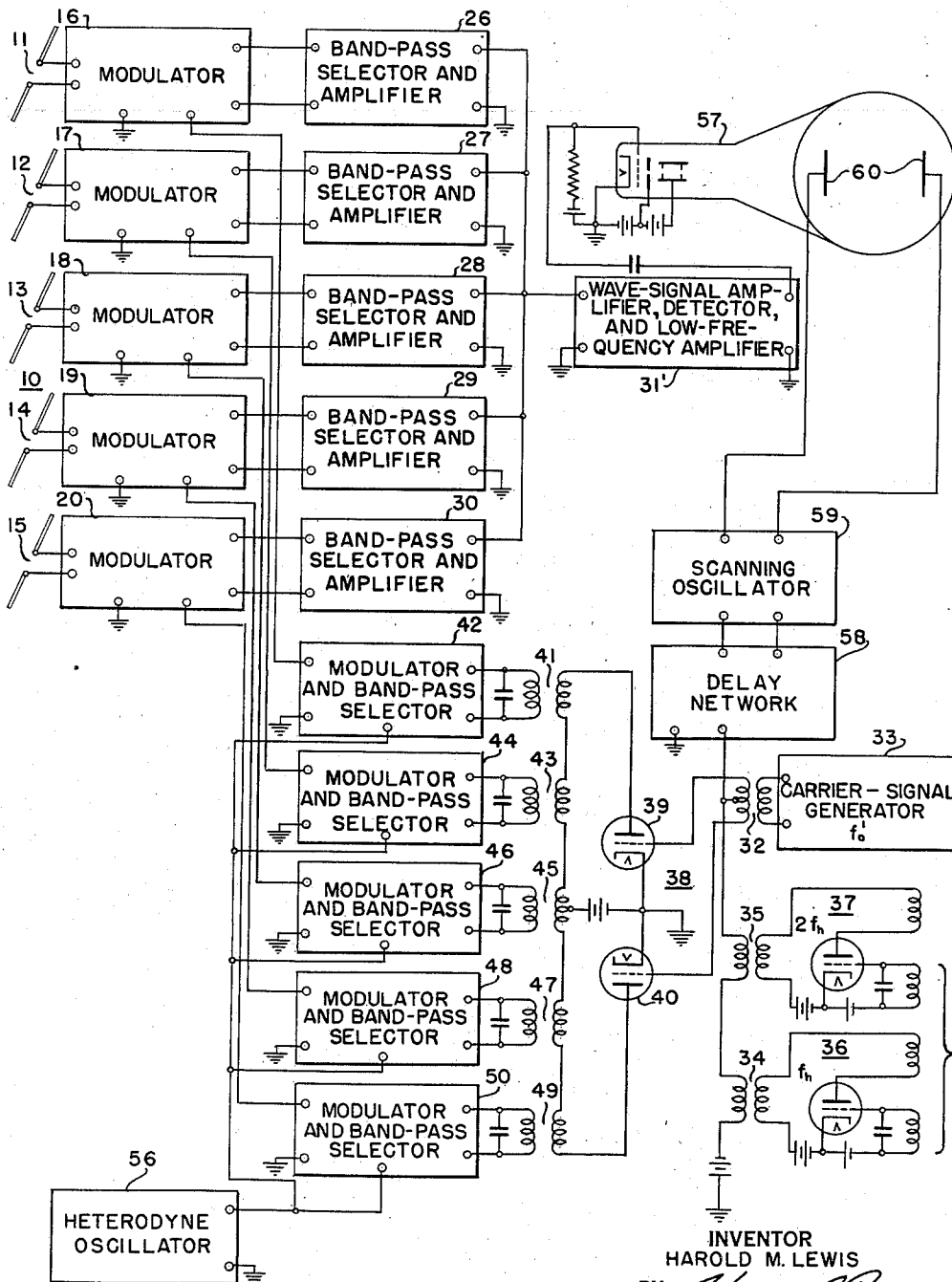
2,430,296

RADIATED-SIGNAL RECEIVING SYSTEM

Filed Oct. 27, 1943

4 Sheets-Sheet 2

FIG. 2



INVENTOR
HAROLD M. LEWIS
BY *Harold M. Lewis*
ATTORNEY

Nov. 4, 1947.

H. M. LEWIS

2,430,296

RADIATED-SIGNAL RECEIVING SYSTEM.

Filed Oct. 27, 1943

4 Sheets-Sheet 3

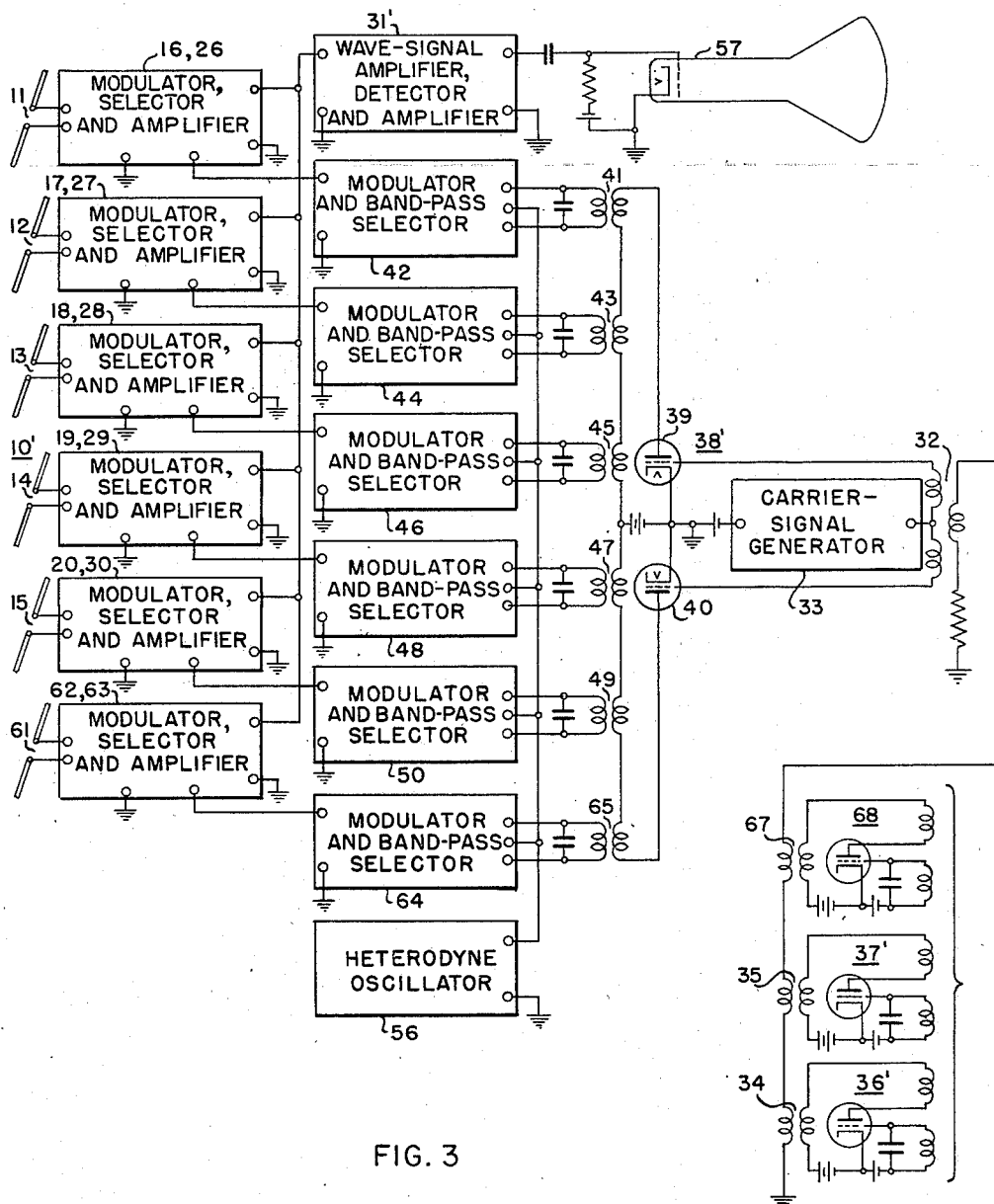


FIG. 3

INVENTOR
HAROLD M. LEWIS
BY *Harold M. Page*
ATTORNEY

Nov. 4, 1947.

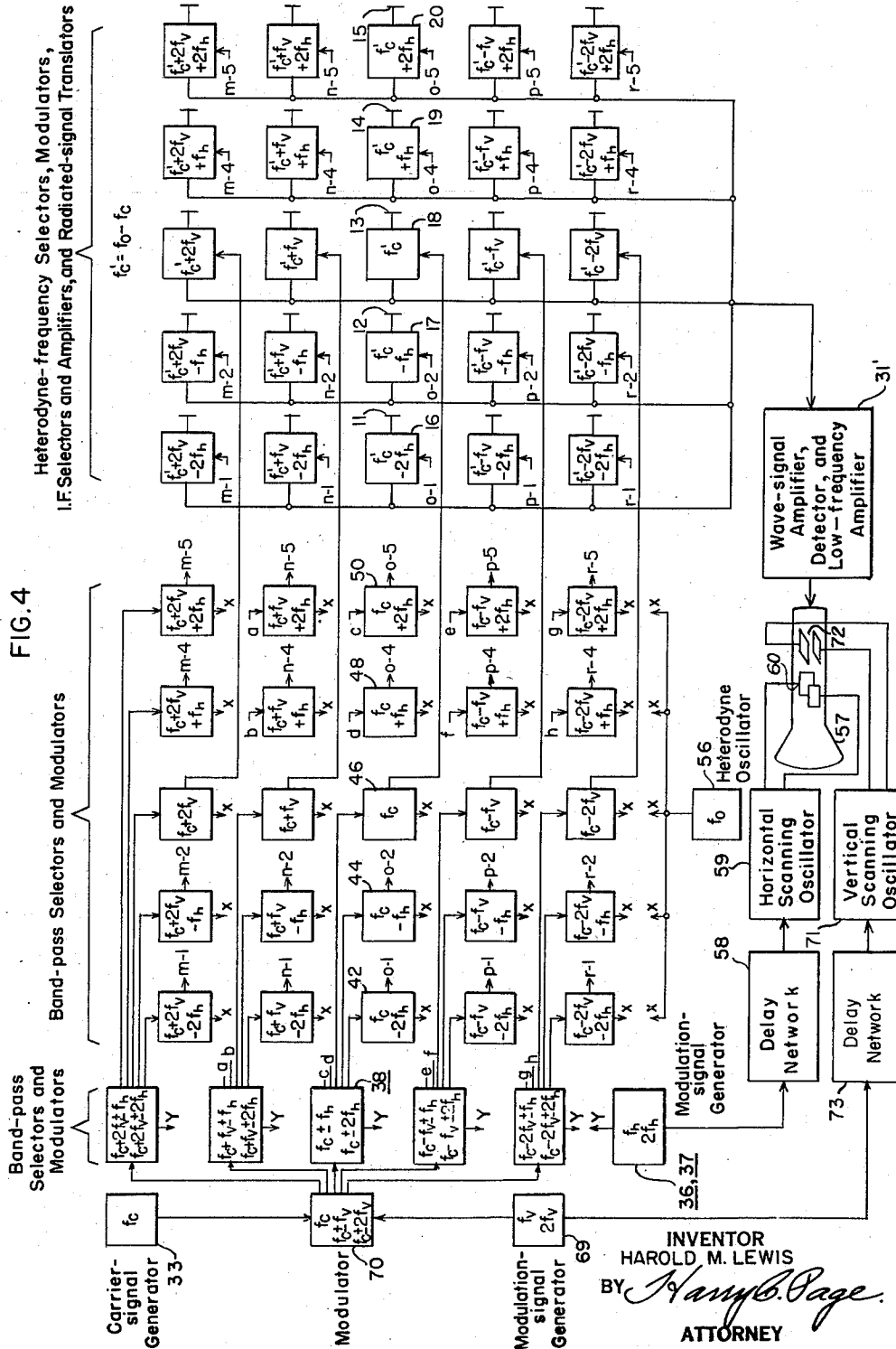
H. M. LEWIS

2,430,296

RADIATED-SIGNAL RECEIVING SYSTEM

Filed Oct. 27, 1943

4 Sheets-Sheet 4



UNITED STATES PATENT OFFICE

2,430,296

RADIATED-SIGNAL RECEIVING SYSTEM

Harold M. Lewis, Allenhurst, N. J., assignor, by
mesne assignments, to Hazeltine Research, Inc.,
Chicago, Ill., a corporation of Illinois

Application October 27, 1943, Serial No. 507,860

21 Claims. (Cl. 250—11)

1

The present invention relates to radiated-signal receiving systems and, particularly, to such systems of a type having a sharply directive response characteristic variable in direction. While the invention is of general application, it has particular utility in systems of the type disclosed and claimed in the copending application of Harold M. Lewis, Serial No. 507,861, filed concurrently herewith, entitled System for locating a radiated-signal reflector, and assigned to the same assignee as the present application. In this system, a predetermined space is scanned with a sharply concentrated radiated beam in order to locate a radiated-signal reflector, such as an aircraft.

In certain applications, it is desirable to provide a radiated-signal receiving system having a sharply directive response characteristic variable in direction. It has been proposed, in accordance with several prior art arrangements, that this be accomplished by the use of a radiated-signal translator system having a directional-response characteristic in the form of a sharply concentrated beam, this translator system being physically moved by suitable mechanical apparatus to effect the scanning action. The general disadvantages and limitations of mechanical scanning arrangements of this nature are well understood by those skilled in the art. Among these may be mentioned the disadvantages, perhaps outstanding, that appreciable power is required physically to move the radiated-signal translating system for purposes of scanning and the fact that the rate of scanning is necessarily low, which unduly restricts and limits the usefulness of the radiated-signal receiving system.

A wave-signal scanning system substantially entirely electrical in nature forms the subject matter of copending applications of Arthur V. Loughren, Serial Nos. 395,172 and 418,712, filed May 26, 1941, and November 12, 1941, now Patents 2,407,169 and 2,409,944, issued September 3, 1946, and October 22, 1946, respectively. That system provides that the sharply directive response characteristic of the system be caused to scan a predetermined space by the use of an array of physically spaced radiated-signal translators which are coupled through individual wave-signal delay means or phase shifters to a common wave-signal translating channel. The present invention constitutes an improvement on the electrical scanning system of the aforesaid Loughren applications.

It is an object of the present invention, there-

2

fore, to provide a new and improved radiated-signal receiving system having a sharply directive response characteristic variable in direction and one which avoids one or more of the disadvantages and limitations of the prior art systems of this nature.

It is an additional object of the invention to provide a new and improved radiated-signal receiving system having a sharply directive response characteristic variable in direction and one in which the variation of its directive response is effected entirely electrically.

It is a further object of the invention to provide a radiated-signal receiving system having a sharply directive response characteristic variable in direction and one in which either or both the rate of scanning and the shape of the directive-response characteristic may be readily and easily controlled by one or more simple adjustments of wave-signal apparatus included in the system.

In accordance with the invention, a radiated-signal receiving system having a sharply directive response characteristic variable in direction comprises a plurality of spaced radiated-signal translators each adapted to receive a radiated signal, and modulator means coupled to the translators for modulating the wave signals translated by one of the translators with a modulation signal and for modulating the wave signal translated by another of the translators with a modulation signal of frequency different from that of the first-named modulation signal. The system also includes means for utilizing primarily those predetermined ones of the modulation components of the wave signals thus modulated which have additive phase only for one direction of reception by the translators, this direction varying continuously and periodically over a predetermined angular range.

For a better understanding of the present invention, together with other and further objects thereof, reference is had to the following description taken in connection with the accompanying drawings, and its scope will be pointed out in the appended claims.

Referring now to the drawings, Fig. 1 represents a circuit diagram, partly schematic, of a complete radiated-signal receiving system embodying the present invention; Fig. 1A represents the translating system, per se, of the Fig. 1 arrangement which includes five equally spaced radiated-signal translators; Figs. 2 and 3 are circuit diagrams, partly schematic, of complete radiated-signal receiving systems embodying the

3

present invention in modified forms; and Fig. 4 represents schematically a complete radiated-signal receiving system essentially similar to the arrangement of Fig. 2 but embodying an additionally modified form of the invention wherein the direction of maximum reception of the system constantly and periodically varies over two angular ranges in directions normal to each other.

Referring now more particularly to Fig. 1 of the drawings, there is represented a complete radiated-signal receiving system having a sharply directive response characteristic variable in direction and one which embodies the present invention in a particular form. The system includes an array 10 of aligned spaced radiated-signal translators 11-15, inclusive, each adapted to receive a radiated signal. These radiated-signal translators may, for example, be vertical dipole antennas horizontally aligned.

The receiving system also includes modulator means coupled to the translators of the system 10 for modulating the wave signal translated by one of the translators with a modulation signal and for modulating the wave signal translated by another of the translators with a modulation signal of frequency different from that of the first-named modulation signal. This modulator means comprises a plurality of modulators 16-20, inclusive, having input circuits individually coupled to the respective translators 11-15, inclusive. The modulator means includes a plurality of modulation-signal generators 21-25, inclusive, which are individually coupled to an input circuit of the respective modulators 16-20, inclusive. Each modulation-signal generator has a frequency different from that of any other generator. Specifically, the individual frequencies of the modulation signals generated by the generators 21-25, inclusive, have values related to the spacing of an associated translator from a reference point fixed with relation to all of the translators as will presently be explained in greater detail.

The receiving system additionally includes means for utilizing primarily those predetermined ones of the modulation components of received wave signals thus modulated by the modulators 16-20, inclusive, which have additive phase only for one direction of reception by the translators of the system 10. This direction is one which varies continuously and periodically over a predetermined angular range thus to cause the receiving system to have a sharply directive response characteristic variable in direction. This last-mentioned means comprises a plurality of intermediate-frequency band-pass selectors and amplifiers 26-30, inclusive, which have input circuits coupled to the output circuits of the respective modulators 16-20, inclusive, and have output circuits which are coupled in common to the input circuit of a unit 31. The latter unit may include one or more stages of intermediate-frequency amplification, a detector, and suitable apparatus for utilizing the detected received wave signal.

Considering now the operation of the receiving system just described, and referring to Fig. 1A which shows only the translating system 10, assume that a wave signal is received by each of the translators of the translating system 10, that the direction D of arrival of the wave signal forms an angle α with the direction of alignment of the translators, and that the source of the wave signal is located at a distance from the

4

translating system 10 which is large compared with the spacing a of the translators. Assume further that the translators have equal spacing and that the wave signal received by the centrally positioned translator 13, for example, is given by the relation:

$$e_c = E_c \cos \omega c t \quad (1)$$

where

e_c = the instantaneous value of wave-signal voltage received by translator 13,

E_c = the maximum voltage amplitude of the received wave signal,

$\omega c = 2\pi f c$,

$f c$ = the frequency of the received wave signal, and t = time.

Similarly, the wave signal received by an adjacent translator, for example the translator 12, is given by the relation:

$$e_c' = E_c \cos (\omega c t - \phi) \quad (2)$$

where

e_c' = the instantaneous value of wave-signal voltage received by translator 12, and

ϕ = the phase angle of the wave signal received by translator 12 relative to that received by the translator 13.

The value of the phase angle ϕ in Equation 2, however, is given by the relation:

$$\phi = 2\pi a \cos \alpha \quad (3)$$

where

a = the fraction of a wave length of the received wave signal at which the translators 12 and 13 are spaced.

When the value of ϕ as given by Equation 3 is substituted in Equation 2, the wave signal received by the translator 12 is given by the relation:

$$e_c' = E_c \cos (\omega c t - 2\pi a \cos \alpha) \quad (4)$$

It can be shown in the same manner that the wave signal received by any of the other translators of the translating system 10 is given by the relation:

$$e_c = E_c \cos (\omega c t + 2\pi m a \cos \alpha) \quad (5)$$

where

m = an integer indicating the relative position of the translator from the center translator 13, m being negative for the translators 11 and 12 and positive for the translators 14 and 15.

The wave signals received by the translators 11-15, inclusive, are applied to the input circuit of their respective associated modulators 16-20, inclusive. There is applied from the generator 23 to the modulator 18, which is associated with the centrally positioned translator 13, a modulation signal given by the relation:

$$e_o = K E_o \cos \omega o t \quad (6)$$

where

K = an arbitrary constant,

E_o = the voltage amplitude of the modulation signal,

$\omega o = 2\pi f o$, and

$f o$ = the frequency of the modulation signal.

There consequently is developed in the output circuit of the modulator 18 a modulated wave signal given by the relation:

$$e_m = K E_o E_c \cos \omega c t \cos \omega o t \quad (7)$$

5

It is well known that this modulated wave signal contains, as can readily be shown by expansion of Equation 7, one component having a frequency equal to the sum of the frequencies of the received wave signal and the modulation signal and a second component equal to the difference of the frequencies of these signals. The difference-frequency component is given by the relation:

$$e_{i,f}' = \frac{K E_0 E_c}{2} \cos (\omega_c t - \omega_0 t) \quad (8)$$

This component, an intermediate-frequency wave signal, is selected by the band-pass selector of unit 23, amplified by the intermediate-frequency amplifier thereof, and applied to the input circuit of the unit 31.

Now, in accordance with the invention, the remaining generators 21, 22, 24 and 25 generate modulation signals having individual frequencies different from that of any other generator. Specifically, the modulation signal generated by any of the generators 21, 22, 24 or 25 is given by the relation:

$$e_0' = K_m E_0 \cos (\omega_0 t - m \omega_h t) \quad (9)$$

where

K_m = an arbitrary constant,

$\omega_h = 2\pi f_h$, and

f_h = an incremental frequency related to the spacing of the translators 11-15, inclusive, and to the desired rate of scanning by the directive characteristic of the receiving system. This relationship is more fully considered hereinafter in connection with Equations 11 and 12.

It can readily be shown that the difference-frequency component of the modulated wave signal developed in the output circuits of any of the modulators 16, 17, 19 or 20 and selected and amplified by any of the respective units 26, 27, 29 or 30 is given by the relation:

$$e_{i,f}'' = \frac{K_m E_0 E_c \cos}{2} [(\omega_c - \omega_0) t + m(2\pi a \cos \alpha + \omega_h t)] \quad (10)$$

The most general form of equation expressing the combined difference-frequency components developed in the common output circuits of the several modulators, and applicable to any receiving system which includes an odd number of radiated-signal translators, is given by the relation:

$$e_{i,f} = \frac{E_0 E_c}{2} \left[K_0 + 2 \sum_{m=1}^{m=m'} K_m \cos m(\omega_h t + 2\pi a \cos \alpha) \right] \cos (\omega_c - \omega_0) t \quad (10a)$$

where

K_0 and K_m = arbitrary constants, and

m = the number of the term in the series, the last term m' of which is determined by the following relations; n = the number of radiated-signal translators, and

$$m' = \frac{n-1}{2}$$

For the case of five radiated-signal translators, as in the Fig. 1 arrangement, the combined difference-frequency component developed in the input circuit of unit 31 is given by the relation:

$$e_{i,f}' = \frac{E_0 E_c}{2} [K_0 + K_1 2 \cos (\omega_h t + 2\pi a \cos \alpha) + K_2 2 \cos 2(\omega_h t + 2\pi a \cos \alpha)] \cos (\omega_c - \omega_0) t \quad (10b)$$

It will be evident from Equations 10, 10a and 10b that the difference-frequency components have a frequency equal to that of the difference-frequency, or intermediate-frequency, component applied from unit 23 to the input circuit of unit

6

31, and given by Equation 8, but have a phase coefficient relative thereto given by the relation:

$$\phi' = m(2\pi a \cos \alpha + \omega_h t) \quad (11)$$

- 5 The phase coefficient ϕ' of all of the difference-frequency components equates to zero for any given value of t when α has the value:

$$\alpha = \cos^{-1} \left(\frac{-\omega_h t}{2\pi a} \right) \quad (12)$$

It should be noted that Equations 11 and 12 apply to the difference-frequency modulation component appearing in the output circuit of all of the units 26, 27, 29 and 30. Hence, for any selected value of t , the value of α given by Equation 12 is one which causes all of such difference-frequency components to be in the same phase in the output circuits of all of the units 26-30, inclusive, and thus to add in phase in the input circuit of unit 31. For values of α which do not satisfy Equation 12, the difference-frequency components developed in the output circuits of units 26-30, inclusive, are out of phase with each other with the result that the magnitude of the input signal to unit 31 is reduced. The receiving system consequently has a sharply directive response characteristic with maximum response in the direction where the value of α satisfies Equation 12 for any selected value of t . Further, it will be apparent that the direction of maximum response varies continuously and periodically over a predetermined angular range since the value of α required to satisfy Equation 12 varies with the value of t . This scanning action of the directional-response characteristic of the receiving system of Fig. 1 has many important applications, one such application being disclosed in the aforementioned Lewis application.

Equations 11 and 12 are important from another aspect. These equations show that for any given spacing a between any adjacent pair of translators of the translating system 10, the velocity of scanning of the directive-response characteristic of the system varies directly with the frequency difference ω_h between the modulation signals of the generators associated with such pair of translators; and secondly, that for any given value of frequency difference ω_h , the rate of scanning by the major lobe varies inversely with the spacing a of the translators; and thirdly, that the ratio of ω_h to a must be the same for any given

55 pair of adjacent translators of the translating system 10 as for any other adjacent pair if the difference-frequency components are all to add in the input circuit of unit 31. For equal spacing of the translators, the modulation signals of the generators associated with any adjacent pair of translators have a frequency difference equal to that of any other pair of generators associated with any other adjacent pair of translators. Where the translators have unequal spacing, on the other hand, the rule just mentioned regarding the equality of the ratio of ω_h to a requires that the frequency of the modulation signal of any

generator associated with a given translator must have a frequency difference with respect to a reference generator, associated with a reference translator, in proportion to the spacing of the given translator from the reference translator.

Thus, for any given geometrical spacing of the translators, the modulator means of the receiving system modulates the wave signals translated by the translators with individual modulation signals having individual frequencies increasing in the order of geometric spacing of the translators and having frequency differences as between any adjacent pair of translators proportional to the spacing of the translators of such pair from a reference point fixed with relation to all of the translators. For the case where the translators are equally spaced, the modulator means of the receiving system thus modulates the wave signal translated by one of the translators with a modulation signal and modulates the wave signals translated by others of the translators with individual modulation signals of individual frequencies different from that of the first-mentioned modulation signal and equally spaced in the frequency spectrum with relation thereto.

One additional feature regarding the operation of the Fig. 1 arrangement may well be considered at this point. Assume that the source of the received wave-signal energy is located at a fixed point from the receiving system. Since the directive characteristic of the receiving system continuously scans, it will be apparent that the wave signal applied to the unit 31 is in the nature of a pulse amplitude-modulated wave signal even though it may be an unmodulated or a conventional amplitude-modulated signal at the source. If the rate of scanning of the directive characteristic is sufficiently high, the signal-modulation components of the received wave signal may, nevertheless, be derived by the detector of unit 31 and utilized as in any conventional pulse-modulation system. This is likewise true even though the source, contrary to the last assumption, is moving as on an airplane, particularly in that the rate of movement of the source when located at any reasonable distance from the receiving system is slow in comparison to the rate of scanning by the directive characteristic. Thus, the utilizing apparatus of unit 31 may, for example, be a sound-reproducing device to reproduce voice or music signals with which the received wave signal is modulated. In this application of the present invention, the receiving system has utility in effecting time sharing between several signal sources positioned at different geographical points but operating on the same frequency or on frequencies sufficiently closely spaced that they fall within the pass band of each of the receiving channels, for example the channel comprised by the units 13, 26 and 31.

A receiving system embodying the present invention also has utility in indicating the direction from the system of a source of received wave signals. An application of this nature will shortly be considered in connection with a modified form of the invention.

The directive characteristic of the present receiving system may have one or more major lobes of directivity and one or more minor or spurious lobes depending upon the number and relative spacing of the translators of the translating system 10 and the relative amplitudes of the modulation signals generated by the generators 21-25, inclusive. Additionally, the configuration of the major lobe in general varies with the scanning angle. The rate of scanning varies with the frequency differences between the signals of the generators 21-25, inclusive. Reference is made to the copending application of Harold M. Lewis, Serial No. 507,859, filed concurrently herewith,

entitled System for space-scanning with a radiated wave-signal beam, and assigned to the same assignee as the present application, where the effect of the system parameters on these factors is considered in greater detail in connection with a radiated-signal transmitting system. The broad principles underlying the operation of the last-mentioned system also govern the operating characteristics of the present receiving system.

While the receiving system hereinbefore described utilizes a plurality of modulation-signal generators 21-25, inclusive, by which to provide the several required modulation signals of individual frequencies, it will be apparent that these several modulation signals may well be considered as corresponding to individual modulation components of a modulated carrier signal. Fig. 2 is a circuit diagram, partly schematic, of a complete radiated-signal receiving system embodying a preferred form of the invention of this nature. This receiving system is essentially similar to that of Fig. 1, similar circuit elements being designated by similar reference numerals, except that the present system includes means for deriving a signal having harmonically related frequency components and for applying to the modulator means of the receiving system modulation signals having frequencies related to individual frequency components of such derived signal. The wave signals received by the translators of the translating system 10 are modulated with individual ones of these modulation signals. This arrangement is particularly suitable for a translating system wherein the translators thereof have proportional spacings. The harmonically related frequency components of the aforementioned derived signal themselves have proportional spacings in the frequency spectrum and effect the desired scanning of the directive-response characteristic of the receiving system.

More specifically, the aforementioned signal deriving means comprises an input circuit including an input-circuit transformer 32 adapted to have applied thereto a carrier signal which is generated by a carrier-signal generator 33. It also includes a second input circuit, comprising input-circuit transformers 34 and 35 having secondary windings connected in series, which is adapted to have applied thereto a signal having frequency components relatively spaced in the frequency spectrum in proportion to the physical spacing of the translators of the translating system 10 from a reference point common to all of the translators. Further, the lowest-frequency component has a value of frequency related to the desired rate of scanning by the directivity characteristic of the receiving system. The fundamental-frequency or lowest-frequency component of this signal is generated by an oscillator 36, which has a frequency f_h , and a second harmonic-frequency component of the signal is generated by an oscillator 37 having a frequency $2f_h$. The oscillatory circuits of these last-named oscillators are mutually coupled to maintain them in relative synchronism and their output circuits include individual ones of the transformers 34 and 35. More specifically, the secondary windings of the transformers 34 and 35 are serially included between a center-tapped point on the secondary winding of the input transformer 32 and the cathodes of a pair of vacuum tubes 39, 40 provided in a modulator 38, whereby the outputs of the oscillators 36 and 37 are applied in the same polarity to the input electrodes of the vacuum tubes 39 and 40. The secondary winding of the trans-

former 32 is connected in push-pull to the input electrodes of these vacuum tubes to apply to the latter in opposite polarities the signal output of the carrier-signal generator 33.

The output circuit of the vacuum tube 39 of the modulator 38 is coupled through a transformer 41 to a modulator and band-pass selector 42, is coupled through a transformer 43 to a modulator and band-pass selector 44, and is coupled in push-pull relation with the output circuit of vacuum tube 40 and through a transformer 45 to a modulator and band-pass selector 46. The output circuit of the vacuum tube 49 is similarly coupled through a transformer 47 to a modulator and band-pass selector 48 and through a transformer 49 to a modulator and band-pass selector 50. The transformers 41, 43, 45, 47 and 49 are tuned to individual modulation components of a modulated carrier signal developed in the output circuit of the modulator 38. The frequency of the generator 33 is preferably chosen sufficiently low that the last-named transformers may readily accomplish this desired selection of components.

There is also coupled to an input circuit of the modulators of units 42, 44, 46, 48 and 50 a heterodyne oscillator 56 which simply provides in the output circuit of each modulator sum-frequency and difference-frequency heterodyne components related to the individual modulation components applied to the units 42, 44, 46, 48 and 50. The band-pass selectors of the latter units are tuned to select in each case the difference-frequency or the sum-frequency heterodyne components, whichever is convenient. The output circuits of the units 42, 44, 46, 48 and 50 are individually coupled to the input circuits of the respective modulators 16-20, inclusive. As in the arrangement of Fig. 1 the output circuits of the selector-amplifier units 26-30, inclusive, of the Fig. 2 arrangement are coupled to a common input circuit of a unit 31' which may include one or more stages of wave-signal amplification, a detector for deriving a control effect or control potential, and one or more stages of low-frequency amplification for suitably amplifying the control effect or control potential.

The utilizing apparatus, indicated as included in the unit 31 of the Fig. 1 receiving system, is shown in the present arrangement as comprising means responsive to the control effect or control potential derived from unit 31' for indicating the direction from the translators of the translating system 10 of the source of the radiated signal received by the translators. The last-named means comprises a cathode-ray tube 57 having input electrodes coupled to the output circuit of the unit 31'. The present receiving system also includes means for deflecting the cathode-ray beam of the tube 57 in synchronism with the directive-response characteristic of the receiving system. This means comprises a delay network 58 having an input circuit coupled to the output circuit of the signal generators 36 and 37 and having an output circuit coupled to a synchronizing circuit of a scanning oscillator 59. The output circuit of the latter oscillator is coupled to a pair of beam-deflecting electrodes 60 provided in the cathode-ray tube 57.

The operation of the Fig. 2 receiving system is essentially similar to that of Fig. 1 and differs therefrom only insofar as the operation of the modulation-signal deriving means is concerned. In this connection, the oscillator 36 generates the fundamental-frequency component $E_h \cos \omega_h t$ and the oscillator 37 generates the harmonic-

frequency component $E_h \cos 2\omega_h t$ of the signal which is applied to the modulator 38. There is also applied to this modulator a carrier signal $E_0' \cos \omega_0' t$ generated by the relatively low-frequency subcarrier generator 33, whereby there is developed in the output circuit of the modulator 38 a modulated carrier signal, the desired components of which are given by the relation:

$$e_0' = E_0' \cos \omega_0' t + E_0' \cos (\omega_0' t \pm \omega_h t) + E_0' \cos (\omega_0' t \pm 2\omega_h t) \quad (13)$$

The transformers 41, 43, 45, 47 and 49 select individual modulation components of this modulated carrier signal and apply to the respective modulators 42, 44, 46, 48 and 50 modulation components given by the following relations:

$$e_{42} = E_0' \cos (\omega_0' t - 2\omega_h t) \quad (14)$$

$$e_{44} = E_0' \cos (\omega_0' t - \omega_h t) \quad (15)$$

$$e_{46} = E_0' \cos \omega_0' t \quad (16)$$

$$e_{48} = E_0' \cos (\omega_0' t + \omega_h t) \quad (17)$$

$$e_{50} = E_0' \cos (\omega_0' t + 2\omega_h t) \quad (18)$$

The oscillations ω_0'' of the heterodyne oscillator 56 are also applied to the modulators 42, 44, 46, 48 and 50 and the sum-frequency heterodyne components which are selected by the band-pass selectors of these units and applied to the respective modulators 16-20, inclusive, are given by the respective relations:

$$e_{16} = E \cos (\omega_0' + \omega_0'' - 2\omega_h) t \quad (19)$$

$$= E \cos (\omega_0 - 2\omega_h) t \quad (20)$$

$$e_{17} = E \cos (\omega_0' + \omega_0'' - \omega_h) t \quad (21)$$

$$= E \cos (\omega_0 - \omega_h) t \quad (22)$$

$$e_{18} = E \cos (\omega_0' + \omega_0'') t \quad (23)$$

$$= E \cos \omega_0 t \quad (24)$$

$$e_{19} = E \cos (\omega_0' + \omega_0'' + \omega_h) t \quad (25)$$

$$= E \cos (\omega_0 + \omega_h) t \quad (26)$$

$$e_{20} = E \cos (\omega_0' + \omega_0'' + 2\omega_h) t \quad (27)$$

$$= E \cos (\omega_0 + 2\omega_h) t \quad (28)$$

where

$$\omega_0 = \omega_0' + \omega_0''$$

It will be seen that Equations 20, 22, 24, 26 and 28 satisfy Equation 9 and, hence, that the modulation signals applied from units 42, 44, 46, 48 and 50 to the respective modulators 16-20, inclusive, have the frequency relation required to cause the receiving system to have a sharply directive response characteristic variable in direction as hereinbefore described in connection with Fig. 1. The rate of scanning of the directivity characteristic is dependent, as will be apparent from the last-mentioned equations, only upon the value of ω_h . Thus, the rate of scanning may be easily and readily varied at will simply by adjustment of the frequencies of oscillators 36 and 37 and slight retuning, as by unicontrol tuning means of the transformers 41, 43, 45, 47 and 49. In general, this will not require readjustment of the selectors of units 42, 44, 46, 48 and 50 which have a relatively broad pass band at the higher frequencies characteristic of the heterodyne-frequency components. The configuration of the major lobe or lobes is readily controlled, on the

11

other hand, by the relative amplitudes of the heterodyne-frequency components developed by the units 42, 44, 46, 48 and 50 and thus may readily be changed by suitable adjustments of the relative amplitudes of the components generated by the oscillators 36 and 37 or relative degrees of modulation of the last-mentioned units, or both.

The in-phase modulation components of the wave signals applied from the selector-amplifier units 26-30, inclusive, to the input circuit of unit 31' are suitably amplified by the wave-signal amplifier of the latter, detected by the detector thereof, and after suitable amplification by the low-frequency amplifier of this unit are applied to the input electrodes of the cathode-ray tube 57 to modulate the cathode-ray beam of the latter. At the same time, there are applied to the deflecting electrodes 60 of this tube scanning potentials which may be of saw-tooth wave form, generated by the oscillator 59. The scanning oscillator 59 is synchronized in operation by the signal generated by oscillator 36 and applied to the former through the delay network 58. The delay network 58 preferably so controls the synchronization of oscillator 59 that a scanning cycle of the cathode-ray tube 57 is initiated at the time when the directivity angle α of the receiving system is zero.

Since the directive characteristic of the receiving system continuously scans a predetermined space, the wave signal applied to the input circuit of the unit 31' is in the nature of a pulse-modulated wave signal, even though the wave signal at its source is unmodulated or is modulated with a modulation signal. The pulse-modulation components of the received wave signal are derived by the detector of the unit 31', are amplified by the low-frequency amplifier thereof, and are applied to the input electrodes of the cathode-ray tube 57 to modulate the cathode-ray beam thereof. Since the receiving system effectively pulse-modulates the received wave signal once during each scanning cycle, and since the deflection of the cathode-ray beam of tube 57 is synchronized with the scanning of the receiver, the pulse-modulation components applied to the input electrodes of tube 57 produce a stationary spot, assuming the source of the received wave signals is itself stationary, on the screen of the latter tube. The distance of the spot along the trace of the cathode-ray tube is a measure of the direction of the source of the received wave signal from the receiving system.

Fig. 3 is a circuit diagram, partly schematic, of a portion of a radiated-signal receiving system which is essentially similar to that of Fig. 2, similar circuit elements being designated by similar reference numerals and analogous circuit elements by similar reference numerals primed, except that the present receiving system is one which utilizes a translating system 10' having an even number of radiated-signal translators 11-15, inclusive, and 61 as contrasted with the odd number of translators included in the translating system 10 of Fig. 2. The use of the additional translator 61 requires, of course, the addition of a unit 62, 63 which includes a modulator, band-pass selector and amplifier similar to those of the unit 16, 26 for example, and requires a modulator and band-pass selector unit 64 which is similar to the unit 42, for example. The modulator-selector unit 64 is coupled to the output circuit of the vacuum tube 40 of the modulator 38' through a transformer 65 which is tuned to an

12

individual modulation component, presently to be considered in greater detail, of the modulated carrier signal developed in the output circuit of the modulator 38'.

The modulator 38' in the present receiving system is of the balanced carrier-suppressed type in which the output circuit of the carrier-signal generator 33 is coupled between the cathodes of tubes 39 and 40 and the center tap of the secondary winding of the input-circuit transformer 32. The primary winding of the latter transformer is coupled through the transformers 34, 35 and a transformer 67 to the respective oscillators 36, 37 and an oscillator 68. The oscillator 36' generates a modulation-signal component

$$\frac{f_h}{2}$$

the generator 37' now generates a third harmonic component

$$\frac{3f_h}{2}$$

and the oscillator 68 generates a fifth harmonic component

$$\frac{5f_h}{2}$$

of the signal. The scanning system for the cathode-ray tube 57 is not shown for purposes of simplicity, but may be the same as that of the Fig. 2 arrangement. It will be understood, of course, that the balanced form of modulator shown requires that the primary windings of all of the transformers 41, 43, 45, 47, 49 and 65 be inductively coupled to ensure balanced output.

The operation of the Fig. 3 receiving system is essentially similar to that of Fig. 2 except for the operation of the modulator 38'. In the present system, the modulated carrier signal developed in the output circuit of the modulator 38' has no carrier component but includes three upper-sideband and three lower-sideband frequency components corresponding to the fundamental and harmonic-frequency components of the signal generated by the oscillators 36', 37' and 68. Of these components, the transformers 41, 43, 45, 47, 49 and 65 select and apply to the respective modulator-selector units 42, 44, 46, 48, 50 and 64 the component given by the respective relations:

$$e_{42} = E_0' \cos \left(\omega_0' t - \frac{5\omega_h t}{2} \right) \quad (29)$$

$$e_{44} = E_0' \cos \left(\omega_0' t - \frac{3\omega_h t}{2} \right) \quad (30)$$

$$e_{46} = E_0' \cos \left(\omega_0' t - \frac{\omega_h t}{2} \right) \quad (31)$$

$$e_{48} = E_0' \cos \left(\omega_0' t + \frac{\omega_h t}{2} \right) \quad (32)$$

$$e_{50} = E_0' \cos \left(\omega_0' t + \frac{3\omega_h t}{2} \right) \quad (33)$$

$$e_{64} = E_0' \cos \left(\omega_0' t + \frac{5\omega_h t}{2} \right) \quad (34)$$

The band-pass selectors of the units 42, 44, 46, 48, 50 and 64 all select either the difference or the sum-frequency heterodyne components as in the Fig. 2 arrangement. It will thus be seen from Equations 29 to 34, inclusive, and the foregoing description of the Fig. 2 receiving system that the wave signals received by the translators of the

translating system 10' are modulated with individual modulation signals which have the required frequency relationships, expressed by Equation 9, to cause the receiving system to have a sharply directive response characteristic variable in direction. The operation of the Fig. 3 receiving system is otherwise essentially similar to that of Fig. 2 and will not be repeated.

In connection with receiving systems of the general type represented by that of Fig. 3 which utilize an even number of radiated-signal translators, it may be instructive to add that the most general form of equation expressing the combined difference-frequency component developed in the common output circuit of the several modulators thereof is given by the relation:

$$e_{i.f.} = \frac{E_0 E_c}{2} \left[\sum_{m=1}^{m=m'} K_m \cos \left[\frac{2m-1}{2} (\omega_h t + 2\pi a \cos \alpha) \right] \right] \cos (\omega_c - \omega_0) t \quad (35)$$

where

K_m = an arbitrary constant dependent upon the gain of the individual modulators; and
 m = the number of the term in the series as determined by the following relation: $n = 2m' =$ the number of radiated-signal translators.

Thus, the equation for the difference-frequency component developed in the input circuit of unit 31' in the Fig. 3 system is expressed by the relation:

$$e_{i.f.} = \frac{E_0 E_c}{2} \left[K_1 \cos \frac{1}{2} (\omega_h t + 2\pi a \cos \alpha) + K_2 \cos \frac{3}{2} (\omega_h t + 2\pi a \cos \alpha) + K_3 \cos \frac{5}{2} (\omega_h t + 2\pi a \cos \alpha) \right] \cos (\omega_c - \omega_0) t \quad (36)$$

Fig. 4 represents schematically a complete radiated-signal receiving system which is essentially similar to that of Fig. 2, similar circuit elements being designated by similar reference numerals and analogous circuit elements by similar reference numerals primed, except that the present receiving system is one having a sharply directive response characteristic providing maximum reception in a direction which varies continuously and periodically over two angular ranges normal to each other. The scanning pattern of this system is preferably in the nature of a raster of parallel lines similar to that employed in an image pick-up or an image-reproducing tube of a conventional television system.

The present radiated-signal receiving system may be said to embody a plurality of systems of the Fig. 2 type, each operating with a slightly different nominal or mean heterodyne frequency. All of the elements of the Fig. 2 arrangement are included in the Fig. 4 system and, as previously mentioned, are designated by the same reference numerals. It will be understood that the unnumbered elements in Fig. 4 which occupy positions corresponding to numbered elements are identical in all respects thereto except for the frequency translated by each, these frequencies being appropriately designated in Fig. 4. The radiated-signal translators of the present system are grouped into linear arrays, one such array including the translators 11-15, inclusive, and a linear bank of such arrays. The present system includes, in addition to the modulation-signal

generator 36, 37 of the Fig. 2 arrangement, a modulation-signal generator 69 which generates a modulation signal having frequency components f_v and $2f_v$ related to the spacing of the arrays of radiated-signal translators in the bank of arrays. An output circuit of the generator 69 is coupled to an input circuit of the modulator 70 and there is also coupled to an input circuit of the latter unit the carrier-signal generator 33. It will be evident from the foregoing description of the invention that the frequency components of the modulated carrier signal developed in the output circuit of the modulator 70 are thus suitably spaced in the frequency spectrum to effect scanning in one direction of the directive-response characteristic of the receiving system when these modulation components are suitably applied to the radiated-signal translator system in the manner taught above. These modulation components are individually selected and applied to a second bank of modulators, which includes the modulator 38, where the selected modulation components are treated as individual carrier signals and are each modulated by the modulation signals of the generator 36, 37. The modulation components of these several signals are indicated by appropriate frequency designations, see for example the frequency designations as related to modulator 38, and, in each case, a particular one of these modulation components is selected and translated by a particular one of the group of units designated "Band-pass selectors and modulators" which includes the units 42, 44, 46, 48 and 50. These last-named components are preferably of relatively low frequency to facilitate their separation by suitable band-pass selectors and are heterodyned to a higher frequency by the heterodyne oscillator 56. The difference-frequency heterodyne components are individually selected and applied to particular ones of the modulators of the units designated "Heterodyne-frequency selectors, modulators, I. F. selectors and amplifiers, and radiated-signal translators" which include the units 16-20, inclusive, and radiated-signal translators or antennas 11-15, inclusive. An input circuit of the last-mentioned modulators is coupled to an individual one of the radiated-signal translators.

It will be noted from the frequency designations applied to Fig. 4 that the last-mentioned modulators have applied thereto modulation signals having individual frequencies such that the wave signals received by the radiated-signal translators are modulated with individual modulation signals having individual frequencies which increase in the order of spacing of associated translators in each array and increase in the order of spacing of associated arrays in the bank of such arrays. The present receiving system thus has a directive characteristic providing maximum reception in a direction which varies continuously and periodically over two predetermined angular ranges in directions which are normal to each other. That is, the modulation signals applied to the modulators associated with any adjacent pair of translators in an array have a frequency difference f_h , whereby the directive characteristic of the receiving system scans in a first or horizontal direction at a first and preferably high scanning rate, whereas the modulation signals applied to the modulators associated with any adjacent pair of translators in the bank of arrays have a frequency difference f_v , thus to cause the directive characteristic of the receiving system to scan in a second or vertical direction

15

at a second and preferably low rate of scanning. The resulting scanning pattern is thus one of parallel scanning lines which may be interlaced if desired, as in conventional television practice.

As in the Fig. 2 arrangement, the output signals of all of the modulators last considered are combined in a common intermediate-frequency channel and applied to the unit 31'. The signal output of the latter is applied to the cathode-ray tube 57 to modulate the cathode-ray beam thereof, as in Fig. 2. Since scanning of the directive characteristic of the receiving system is in two directions in the present system, there is provided a vertical scanning oscillator 71 having a synchronizing circuit coupled through a delay network 73, having the same function as the delay network 58, to the modulation-signal generator 69 and having an output circuit which supplies scanning potentials of saw-tooth wave form and which is coupled to a pair of deflecting electrodes 72 provided in tube 57 and normal to the deflecting electrodes 60. The cathode-ray beam of tube 57 is thus caused to scan in two directions normal to each other to provide a raster of parallel scanning lines. The signal applied from the output circuit of unit 31' to the cathode-ray tube 57 so modulates the cathode-ray beam of the latter that there are produced on the screen of this tube two dimensional indications of the direction of the source of all received wave signals from the receiving system.

The directivity characteristic of the several forms of receiving system hereinbefore described in general includes a major directivity lobe and one or more undesired minor or spurious directivity lobes. The magnitudes of such minor lobes appearing in the directivity characteristic of any of these several systems may be reduced by so controlling the gains of the several signal-translating channels thereof, for example by controlling the gains of the modulators 16-20 of the Fig. 1 arrangement, that the difference-frequency components developed in the output circuits of these units have unequal amplitudes. Referring to general Equations 10a and 35, this means that the several K_0 and K_m coefficients are made unequal. These general equations still apply in such case if the coefficient K_m is equal in those terms which express the difference-frequency component developed in the output circuits of pairs of modulator units, there being one pair of such units for each pair of radiated-signal translators situated equidistant from the center point of the translator system.

While there have been described what are at present considered to be the preferred embodiments of this invention, it will be obvious to those skilled in the art that various changes and modifications may be made therein without departing from the invention, and it is, therefore, aimed in the appended claims to cover all such changes and modifications as fall within the true spirit and scope of the invention.

What is claimed is:

1. A radiated-signal receiving system having a sharply directive response characteristic variable in direction comprising, a plurality of spaced radiated-signal translators each adapted to receive a radiated signal, modulator means coupled to said translators for modulating the wave signal translated by one of said translators with a modulation signal and for modulating the wave signal translated by another of said translators with a modulation signal of frequency different from that of said first-named modulation signal, and

16

means for utilizing primarily those predetermined ones of the modulation components of the wave signals thus modulated which have additive phase only for one direction of reception by said translators, said direction varying continuously and periodically over a predetermined angular range.

2. A radiated-signal receiving system having a sharply directive response characteristic variable in direction comprising, a plurality of spaced radiated-signal translators each adapted to receive a radiated signal, modulator means coupled to said translators for modulating the wave signal translated by one of said translators with a modulation signal and for modulating the wave signal translated by another of said translators with a modulation signal of frequency different from that of said first-named modulation signal, and means for selecting and utilizing primarily those predetermined ones of the modulation components of the wave signals thus modulated which have additive phase only for one direction of reception by said translators, said direction varying continuously and periodically over a predetermined angular range.

3. A radiated-signal receiving system having a sharply directive response characteristic variable in direction comprising, a plurality of spaced radiated-signal translators each adapted to receive a radiated signal, modulator means coupled to said translators for modulating the wave signal translated by one of said translators with a modulation signal and for modulating the wave signal translated by another of said translators with a modulation signal of frequency different from that of said first-named modulation signal, and means for selecting, combining, and utilizing primarily those predetermined ones of the modulation components of the wave signals thus modulated which have additive phase only for one direction of reception by said translators, said direction varying continuously and periodically over a predetermined angular range.

4. A radiated-signal receiving system having a sharply directive response characteristic variable in direction comprising, an array of aligned spaced radiated-signal translators each adapted to receive a radiated signal, modulator means coupled to said translators for modulating the wave signal translated by one of said translators with a modulation signal and for modulating the wave signal translated by another of said translators with a modulation signal of frequency different from that of said first-named modulation signal, and means for utilizing primarily those predetermined ones of the modulation components of the wave signals thus modulated which have additive phase only for one direction of reception by said translators, said direction varying continuously and periodically over a predetermined angular range.

5. A radiated-signal receiving system having a sharply directive response characteristic variable in direction comprising, a plurality of equally spaced radiated-signal translators each adapted to receive a radiated signal, modulator means coupled to said translators for modulating the wave signal translated by one of said translators with a modulation signal and for modulating the wave signals translated by others of said translators with individual modulation signals of individual frequencies different from that of said first-named modulation signal and equally spaced in the frequency spectrum with relation thereto, and means for utilizing primarily those predetermined ones of the modulation compo-

nents of the wave signals thus modulated which have additive phase only for one direction of reception by said translators, said direction varying continuously and periodically over a predetermined angular range.

6. A radiated-signal receiving system having a sharply directive response characteristic variable in direction comprising, a plurality of geometrically spaced radiated-signal translators each adapted to receive a radiated signal, modulator means coupled to said translators for modulating the wave signals translated by said translators with individual modulation signals having individual frequencies increasing in the order of geometric spacing of said translators, and means for utilizing primarily those predetermined ones of the modulation components of the wave signals thus modulated which have additive phase only for one direction of reception by said translators, said direction varying continuously and periodically over a predetermined angular range.

7. A radiated-signal receiving system having a sharply directive response characteristic variable in direction comprising, a plurality of spaced radiated-signal translators each adapted to receive a radiated signal, a plurality of modulators individually coupled to said translators, means for applying to one of said modulators a modulation signal and for applying to another of said modulators a modulation signal of different frequency, and means for utilizing primarily those predetermined ones of the modulation components of the wave signals thus modulated which have additive phase only for one direction of reception by said translators, said direction varying constantly and periodically over a predetermined angular range.

8. A radiated-signal receiving system having a sharply directive response characteristic variable in direction comprising, a plurality of equally spaced radiated-signal translators each adapted to receive a radiated signal, modulator means coupled to said translators, means for deriving a signal having harmonically related frequency components and for applying to said modulator means modulation signals having frequencies related to individual frequency components of said derived signal to modulate the wave signals translated by said translators with individual ones of said modulation signals, and means for utilizing primarily those predetermined ones of the modulation components of the wave signals thus modulated which have additive phase only for one direction of reception by said translators, said direction varying continuously and periodically over a predetermined angular range.

9. A radiated-signal receiving system having a sharply directive response characteristic variable in direction comprising, a plurality of spaced radiated-signal translators each adapted to receive a radiated signal, modulator means coupled to said translators for modulating the wave signals translated by said translators with individual modulation signals corresponding to individual modulation components of a modulated carrier signal, and means for utilizing primarily those predetermined ones of the modulation components of the wave signals thus modulated which have additive phase only for one direction of reception by said translators, said direction varying continuously and periodically over a predetermined angular range.

10. A radiated-signal receiving system having a sharply directive response characteristic variable in direction comprising, a translating system in-

cluding a plurality of spaced radiated-signal translators each adapted to receive a radiated signal, a plurality of modulators individually coupled to said translators, means for generating a modulated carrier signal having modulation sideband frequency components, means for applying at least the side-band frequency components of said modulated carrier signal individually to said modulators with the components of increasing frequency applied in order to the modulators in the order of spacing of their associated translators from an end translator of said translating system, and means for utilizing primarily those predetermined ones of the modulation components of the wave signals thus modulated which have additive phase only for one direction of reception by said translators, said direction varying continuously and periodically over a predetermined angular range.

11. A radiated-signal receiving system having a sharply directive response characteristic variable in direction comprising, a plurality of spaced radiated-signal translators each adapted to receive a radiated signal, modulator means coupled to said translators, an input circuit adapted to have applied thereto a carrier signal, means responsive to said applied carrier signal for deriving a plurality of modulation signals of individual different frequencies and for applying at least said derived modulation signals to said modulator means to modulate the wave signals translated by said translators individually with said derived modulation signals, and means for utilizing primarily those predetermined ones of the modulation components of the wave signals thus modulated which have additive phase only for one direction of reception by said translators, said direction varying continuously and periodically over a predetermined angular range.

12. A radiated-signal receiving system having a sharply directive response characteristic variable in direction comprising, a plurality of spaced radiated-signal translators each adapted to receive a radiated signal, a first modulator means coupled to said translators, a second modulator means having a first input circuit adapted to have applied thereto a carrier signal, a second input circuit for said second modulator means adapted to have applied thereto a signal having frequency components proportional to the spacing of said translators from a reference point common to all said translators, means responsive to said applied carrier signal and to said last-named signal for deriving a modulated carrier signal from said second modulator means and for applying individual modulation-frequency components thereof to said first modulator means to modulate the wave signals translated by said translators individually with said applied modulation-frequency components, and means for utilizing primarily those predetermined ones of the modulation components of the wave signals thus modulated which have additive phase only for one direction of reception by said translators, said direction varying continuously and periodically over a predetermined angular range.

13. A radiated-signal receiving system having a sharply directive response characteristic variable in direction comprising, a plurality of spaced radiated-signal translators each adapted to receive a radiated signal, a plurality of modulators individually coupled to said translators, an additional modulator having a first input circuit adapted to have applied thereto a carrier signal, a second input circuit for said additional modu-

lator adapted to have applied thereto a signal having frequency components proportional to the spacing of said translators from a reference point common to all said translators, means responsive to said applied carrier signal and to said last-named signal for deriving a modulated carrier signal from said additional modulator and for applying modulation-frequency components thereof individually to said first-named modulators to modulate the wave signals translated thereby individually with said applied modulation-frequency components, and means for utilizing primarily those predetermined ones of the modulation components of the wave signals thus modulated which have additive phase only for one direction of reception by said translators, said direction varying continuously and periodically over a predetermined angular range.

14. A radiated-signal receiving system having a sharply directive response characteristic variable in direction comprising, a translating system including an uneven number of equally spaced radiated-signal translators each adapted to receive a radiated signal, a plurality of modulators individually coupled to said translators, means for generating a modulated carrier signal having a carrier component and modulation sideband frequency components all equally spaced in the frequency spectrum, means for applying said carrier component to the one of said modulators which is coupled to the center one of said translators, means for applying the upper sideband modulation components of said modulated carrier signal individually to the ones of said modulators which are coupled to those translators positioned on one side of said one translator with the components of increasing frequency applied in order to the modulators in the order of spacing of their associated translators from said one translator, means for applying the lower sideband modulation components of said modulated carrier signal individually to the remainder of said modulators with the modulation components of decreasing frequency applied in order to the modulators in the order of spacing of their associated translators from said one translator, and means for utilizing primarily those predetermined ones of the modulation components of the wave signals thus modulated which have additive phase only to one direction of reception by said translators, said direction varying continuously and periodically over a predetermined angular range.

15. A radiated-signal receiving system having a sharply directive response characteristic variable in direction comprising, a translating system including an even number of equally spaced radiated-signal translators, a plurality of modulators individually coupled to said translators, means for generating a modulated carrier signal having a suppressed carrier component and upper and lower sideband modulation-frequency components all equally spaced in the frequency spectrum, means for applying the upper sideband modulation components of said modulated carrier signal individually to those modulators which are coupled to translators positioned on one side of the center point of said translating system with the components of increasing frequency applied in order to the modulators in the order of spacing of their associated translators from said center point, means for applying the lower sideband modulation components of said modulated carrier signal individually to the others of said modulators with the components of decreasing

frequency applied in order to the modulators in the order of spacing of their associated translators from said center point, and means for utilizing primarily those predetermined ones of the modulation components of the wave signals thus modulated which have additive phase only for one direction of reception by said translators, said direction varying continuously and periodically over a predetermined angular range.

16. A radiated-signal receiving system having a sharply directive response characteristic variable in direction comprising, a plurality of spaced radiated-signal translators each adapted to receive a radiated signal, modulator means coupled to said translators for modulating the wave signal translated by one of said translators with a modulation signal and for modulating the wave signal translated by another of said translators with a modulation signal of frequency different from that of said first-named modulation signal, means for combining primarily those predetermined modulation components of the wave signals thus modulated which have additive phase only for one direction of reception by said translators, said direction varying continuously and periodically over a predetermined angular range, and means responsive to said predetermined modulation components for indicating the direction from said translators of the source of said radiated signal.

17. A radiated-signal receiving system having a sharply directive response characteristic variable in direction comprising, a plurality of spaced radiated-signal translators each adapted to receive a radiated signal, modulator means coupled to said translators for modulating the wave signal translated by one of said translators with a modulation signal and for modulating the wave signal translated by another of said translators with a modulation signal of frequency different from that of said first-named modulation signal, means for utilizing primarily those predetermined modulation components of the wave signals thus modulated which have additive phase only for one direction of reception by said translators to derive a control effect, said direction varying continuously and periodically over a predetermined angular range, a cathode-ray tube, and means for applying said control effect to said cathode-ray tube to provide an indication of the direction from said translators of the source of said radiated signal.

18. A radiated-signal receiving system having a sharply directive response characteristic variable in direction comprising, a plurality of spaced radiated-signal translators each adapted to receive a radiated signal, modulator means coupled to said translators for modulating the wave signal translated by one of said translators with a modulation signal and for modulating the wave signal translated by another of said translators with a modulation signal of frequency different from that of said first-named modulation signal, means for utilizing primarily those predetermined ones of the modulation components of the wave signals thus modulated which have additive phase only for one direction of reception by said translators to derive a control signal, said direction varying continuously and periodically over a predetermined angular range, a cathode-ray tube, means for deflecting the cathode-ray beam of said tube in synchronism with the variation of said direction, and means for applying said control signal to said cathode-ray tube to modulate the beam thereof, whereby said cathode-ray tube provides

21

an indication of the direction from said translators of the source of said radiated signal.

19. A radiated-signal receiving system having a sharply directive response characteristic variable in direction comprising, a plurality of spaced radiated-signal translators grouped into arrays and at least one bank of arrays and adapted to receive a radiated signal, modulator means coupled to said translators for modulating the wave signals translated by said translators with individual modulation signals having individual frequencies which increase in the order of spacing of associated translators in each array and increase in the order of spacing of associated arrays in said bank of arrays, and means for utilizing primarily those predetermined ones of the modulation components of the wave signals thus modulated which have additive phase only for one direction of reception by said translators, said direction varying continuously and periodically over two predetermined angular ranges in directions normal to each other.

20. A radiated-signal receiving system having a sharply directive response characteristic variable in direction comprising, a plurality of equally spaced radiated-signal translators grouped into linear arrays and at least one linear bank of arrays and adapted to receive a radiated signal, a plurality of modulators individually coupled to said translators for modulating the wave signals translated by said translators with individual applied modulation signals having individual frequencies which increase in the order of spacing of associated translators in each array and increase in the order of spacing of associated arrays in said bank of arrays, and means for utilizing primarily those predetermined ones of the modu-

22

lation components of the wave signals thus modulated which have additive phase only for one direction of reception by said translators, said direction varying continuously and periodically over two predetermined angular ranges in directions normal to each other and the modulation signals applied to modulators associated with adjacent radiators in each array having a frequency difference of a first predetermined value and the modulation signals applied to modulators associated with adjacent radiators in said bank of arrays having a frequency difference of a second predetermined value which first and second predetermined values are related to the desired rates of scanning of the directive characteristic of said receiving system over said two angular ranges.

21. A radiated-signal receiving system having a sharply directive response characteristic variable in direction comprising, a plurality of spaced radiated-signal translators each adapted to receive a radiated signal, modulator means coupled to said translators, means for deriving a signal having frequency components proportional to the spacings of said translators from a reference point common to all said translators and for applying to said modulator means said derived frequency components to modulate the wave signals translated by said translators with individual ones of said derived frequency components, and means for utilizing primarily those predetermined ones of the modulation components of the wave signals thus modulated which have additive phase only for one direction of reception by said translators, said direction varying continuously and periodically over a predetermined angular range.

HAROLD M. LEWIS.