COMMUNICATION STATION EMPLOYING AN ANTENNA ARRAY

Filed Oct. 31, 1962 3 Sheets-Sheet 1

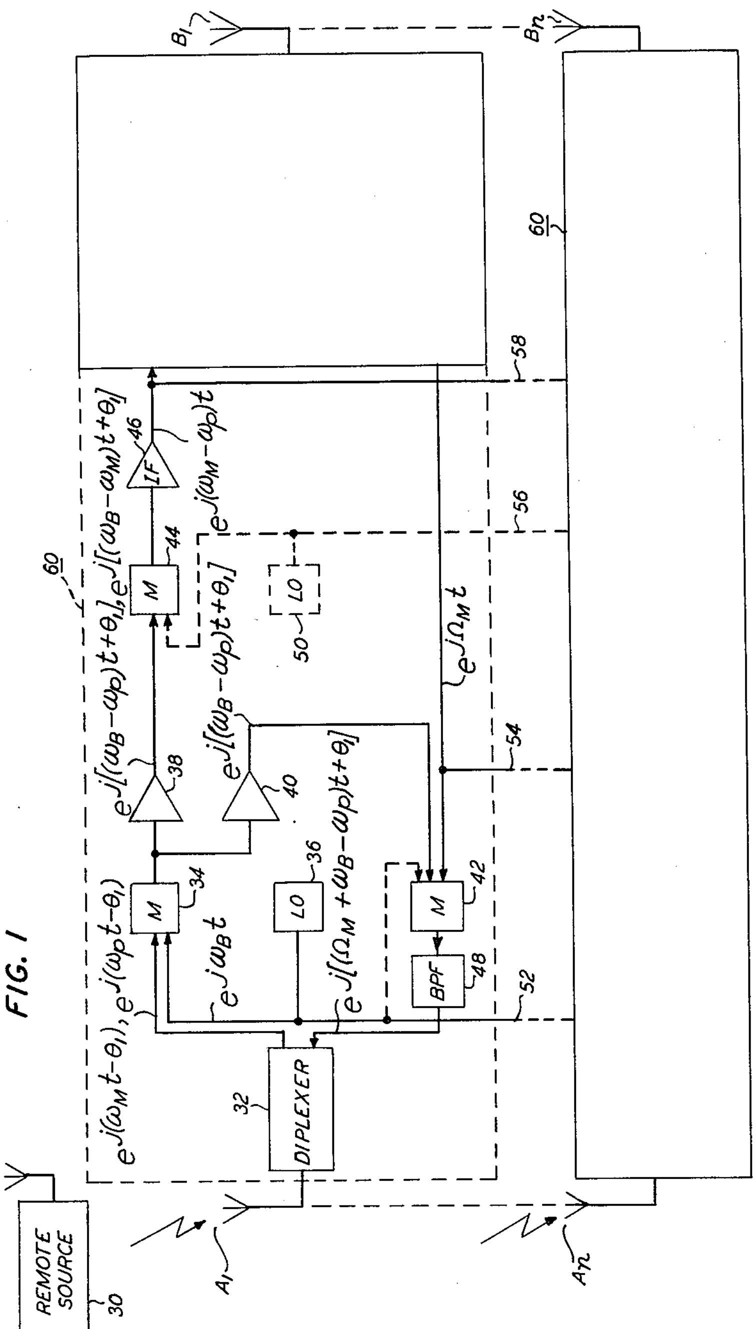

FIG. 1

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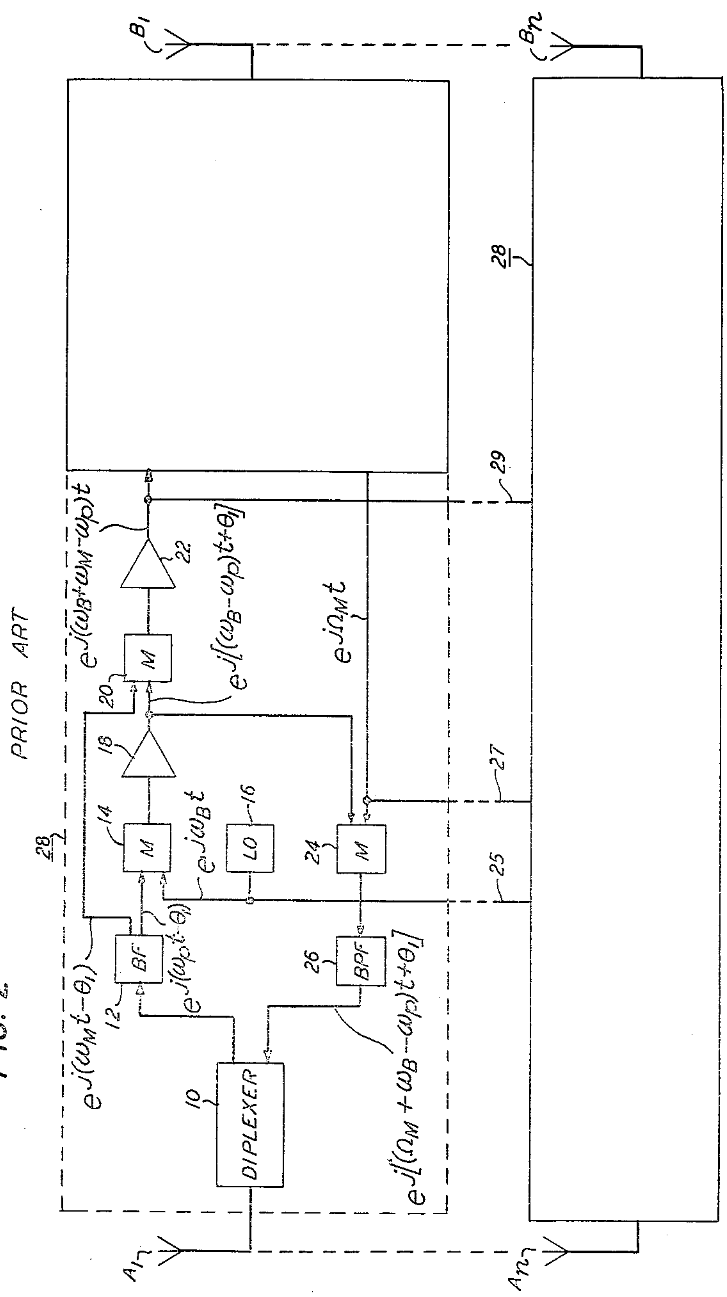
FIG. 2



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COMMUNICATION STATION EMPLOYING AN ANTENNA ARRAY

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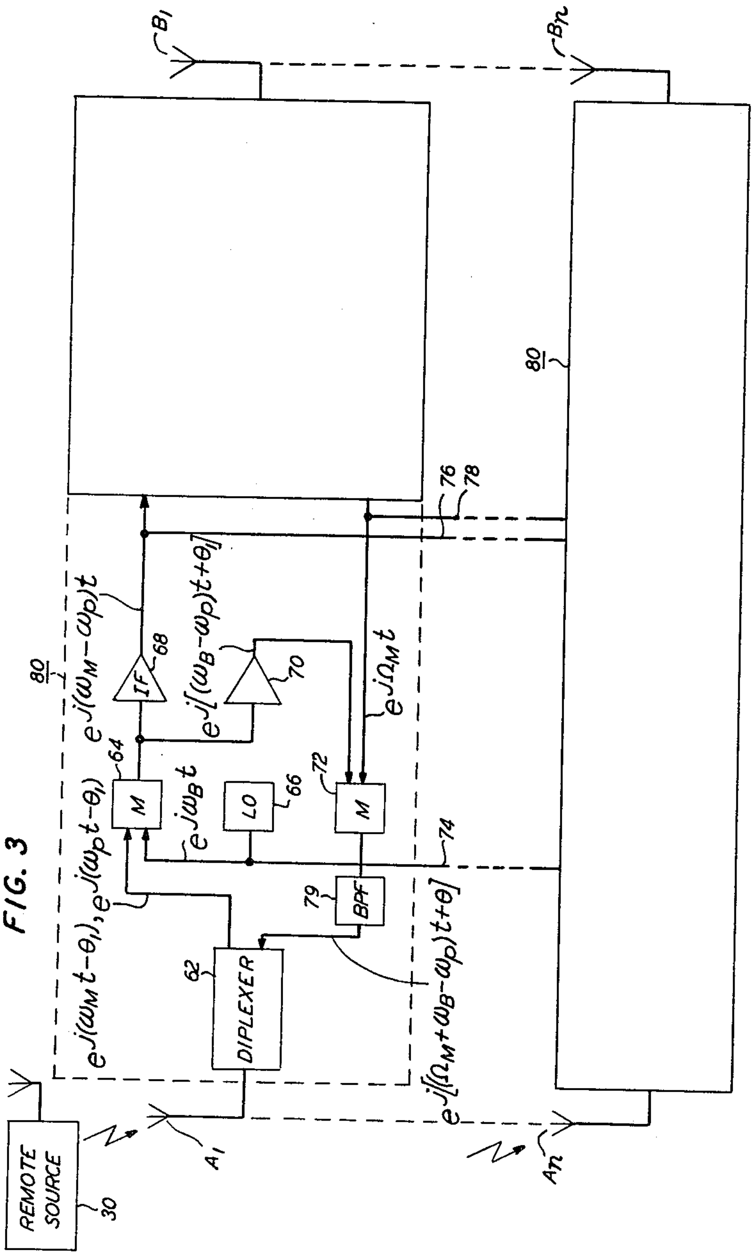

FIG. 3

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3,166,749

COMMUNICATION STATION EMPLOYING AN ANTENNA ARRAY

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7 Claims. (Cl. 343—100)

This invention relates to communication stations, and specifically, to a communication station employing a self-steering antenna array.

An application of C. C. Cutler, R. Kompfner, and L. C. Tillotson, Serial No. 162,165, filed December 26, 1961 and assigned to the assignee of the present application, discloses a communication station having an antenna array that directionally transmits radio waves toward a remotely located source of radio waves impinging upon the array. According to reciprocity, for constructive interference, and thus directional transmission, of the energy radiated from the array toward the remote source to take place, the phase differences between the signals applied to the array elements for radiation are required to be equal in magnitude and opposite in sense to the phase differences between the portions of the impinging wave intercepted by the array elements from the remote source, assuming that transmission and reception are at the same frequency. In the above-mentioned application these conditions, and thus self-steering array performance, are achieved by a series of mixing and filtering operations repeated for each antenna element of the array. The remote source emits a pilot component (usually an unmodulated or "pure" sine wave signal) and an information component. The portion of the pilot component of the wave impinging upon each antenna element is mixed with the output from a local oscillator, the frequency of which is greater than that of the impinging wave. The phase of the resulting difference frequency sideband is equal in magnitude and inverted or opposite in sense to the phase of the intercepted portion. When mixed with the output of a source of signals to be conveyed to the remote source this sideband imparts to it the proper phase for radiation from the element toward the remote source. This sideband is also mixed with the information component intercepted by the array element and the resulting sum frequency sideband is in phase with, and is combined with similar portions of the information component received by the other antenna elements.

Wherever directional, line-of-sight communications are to be carried on between two points which are relatively movable in an unpredictable way, the Cutler-Kompfner-Tillotson communication station is potentially useful. Among such applications number communication satellites, cross-country radio relay repeaters in which the antenna towers are subject to large deflections, mobile radio stations, and scanning or tracking antennas. In many such applications frequency conversion of the information component from the radio frequency range to intermediate frequency would most likely be practiced. The Cutler-Kompfner-Tillotson application does not disclose any arrangements employing frequency conversion. To modify any of these arrangements to provide for frequency conversion is, of course, straightforward. But, since each antenna element has associated with it identical and complete transmitting and receiving circuitry, the addition of several components to the circuitry of each antenna element to implement frequency conversion in straightforward fashion greatly increases the over-all circuit complexity of the station.

It is, therefore, the object of the present invention to install intermediate frequency conversion in the Cutler-Kompfner-Tillotson communication station without appreciably increasing the circuit complexity thereof.

In accordance with the above object, a communication station is provided with an array of antenna elements that are irradiated by an incoming radio wave, comprising a pilot component and an information component, from a remotely located source. Both the information component and the pilot component of the portion of the impinging wave intercepted by each antenna element are mixed with the output from a local oscillator, the frequency of which is greater than that of the impinging wave. The resulting difference frequency sideband of the pilot component is inverted in phase as called for by the Cutler-Kompfner-Tillotson application and the difference frequency sideband of the information component is at an intermediate frequency, making for facility of handling. A portion of the pilot component sideband is mixed with information to be radiated from the array toward the remote source and the sum frequency sideband is applied to the antenna element. A second portion of the pilot component sideband is mixed with the modulation component and the resulting difference frequency sideband is in phase with, and thus can be combined additively with, similar portions derived from the other array elements.

These and other features of the invention will be understood more fully from the following detailed description taken in conjunction with the drawings in which:

FIG. 1 is a schematic diagram in block form of a communication station in accordance with the invention;

FIG. 2 is a schematic diagram in block form of a communication station disclosed in the above-mentioned Cutler-Kompfner-Tillotson application; and

FIG. 3 is a schematic diagram in block form of a second communication station embodying the invention.

Generally, a radio wave from a remote source that impinges upon an array of antenna elements is intercepted by the elements with phase differences dependent upon the angle of incidence of the wave and the placement of the antenna elements. According to reciprocity, in order to radiate a wave of the same frequency from the array toward the same remote source, the signals applied to the antenna elements must have phase differences which are equal in magnitude and opposite or inverse in sense to those between the intercepted portions of the impinging wave.

In the following discussion the signals of interest will be represented in the form $e^{j(\omega t-\theta)}$, where ω equals 2π times the frequency of the signal represented and θ equals the phase of the signal represented with respect to an arbitrary reference. The amplitude term will be dispensed with because it is not essential to an explanation of the mode of operation of the invention. It is understood that what is actually meant throughout is either the real or imaginary part of $e^{j(\omega t-\theta)}$.

FIG. 2 discloses a repeater shown in the Cutler-Kompfner-Tillotson application which will be used as a basis for comparison with arrangements disclosed herein and embodying the invention. An array of antenna elements A_1 through A_n and an array of antenna elements B_1 through B_n communicate with remotely located stations (not shown). Blocks **28** contain identical circuitry, part of which associated with element A_1 is shown, interconnecting all the corresponding elements of the two arrays and exchanging information between the two remote stations. In operation, a portion of the radio wave intercepted from one of the remote stations by antenna element A_1 is applied through a diplexer **10** to a branching filter **12** which separates a pilot component, represented by $e^{j(\omega_P t-\theta_1)}$, where ω_P equals 2π times the pilot frequency, t equals time, and θ_1 equals the phase of the portion intercepted by element A_1 with respect to some arbitrary reference and an information component, represented by $e^{j(\omega_M t-\theta_1)}$, where ω_M equals 2π times the center frequency of the information component. The pilot component can be generated at the remote source as an unmodulated sine wave signal removed in frequency from the information component and transmitted to the array or it can be developed at the array from a portion of the carrier of the information component by filtering. The pilot component is applied to a mixer **14** where it is beat with the output of a local oscillator **16**, represented by $e^{j\omega_B t}$, where ω_B equals 2π times the local oscillator frequency and is larger than ω_P. The output from local oscillator **16** is also applied to mixers similar to mixer **14** in the other blocks **28** by a bus **25**. The difference frequency sideband produced by mixer **14**, represented by $e^{j[(\omega_B-\omega_P)t+\theta_1]}$, is amplified and isolated by an amplifier **18** and coupled both to a mixer **20** and a mixer **24**.

This sideband, it will be noted, has a phase angle which is equal in magnitude and opposite in sense, with respect to some reference, to that of the portion of the wave intercepted by antenna element A_1. In mixer **24** this sideband is beat with an information signal to be conveyed to one of the remote sources, represented by $e^{j\Omega_M t}$, where Ω_M equals 2π times the center frequency of the information. The same information signal is applied to all of blocks **28** by a bus **27**. The sum frequency sideband developed by mixer **24**, represented by

$$e^{j[(\Omega_M+\omega_B-\omega_P)t+\theta_1]}$$

is separated by a bandpass filter **26** after which it is applied through diplexer **10** to antenna element A_1 for radiation. The signals radiated from antenna elements A_1 through A_n are designed to be equal in frequency and their phasse angles are all equal in magnitude and opposite in sense to the corresponding properties of those portions of the impinging wave intercepted by antenna elements A_1 through A_n. Thus, directional transmission toward the remote source occurs from the array. Schemes to permit transmission from the array of a wave differing in frequency from the impinging wave, which may be utilized in the embodiments shown in this application, are disclosed in the Cutler-Kompfner-Tillotson application.

The portion of the output from amplifier **18** applied to mixer **20** is beat therein with the information component separated by branching filter **12**. The resulting sum frequency sideband, represented by $e^{j(\omega_B+\omega_M-\omega_P)t}$, is in the radio frequency range, and must be beat in another mixer, not shown, if handling is to be facilitated by practicing intermediate frequency conversion. This sideband is separated, amplified by an amplifier **22** after which, being in phase with similar sidebands of other of blocks **28**, it is combined therewith by means of a bus **29**. By duplication of elements **10, 12, 14, 16, 18, 20, 22, 24**, and **26** in the right side of block **28** the processed information represented by $e^{j(\omega_B+\omega_M-\omega_P)t}$, can be prepared for transmission by the array of antenna elements B_1 through B_n to the other remote station and the information represented by $e^{j\Omega_M t}$ and appearing on bus **27** can be processed from a wave from the other remote station impinging upon the array composed of elements B_1 through B_n.

FIG. 1 shows a modification of the Cutler-Kompfner-Tillotson repeater disclosed in FIG. 2 and illustrates the principles of the invention. A remotely located source **30** of radio waves illuminates antenna elements A_1 through A_n of an array. Each element of the array is linked to a corresponding element of an array composed of elements B_1 through B_n, communicating with another remote station (not shown), by circuitry in blocks **60**, part of which is shown in the block **60** associated with element A_1. Antenna element A_1, for example, intercepts a portion of the impinging wave composed of pilot and information components. This portion, represented by $e^{j(\omega_P t-\theta_1)}$ and $e^{j(\omega_M t-\theta_1)}$, is applied through a diplexer **32** to a mixer **34** in which it is beat with the output from a local oscillator **36**, represented by $e^{j\omega_B t}$, where ω_B is larger than ω_P. The difference frequency sideband of the pilot component, represented by $e^{j[(\omega_B-\omega_P)t+\theta_1]}$, is isolated and amplified by an amplifier **40** after which it is applied to a mixer **42**. The difference frequency sidebands of both the pilot and information components, represented by $e^{j[(\omega_B-\omega_P)t+\theta_1]}$ and $e^{j[(\omega_B-\omega_M)t+\theta_1]}$, respectively, are separated and amplified **38** the output of which is connected to a mixer **44**. In mixer **44** these two sidebands are beat with each other and the difference frequency sideband thus produced, represented by $e^{j(\omega_M-\omega_P)t}$, is an intermediate frequency signal. The absence of a phase angle in the expression signifies that this signal is in phase with similar signals developed by the other antenna elements of the "A" array. This intermediate frequency information signal is amplified and separated by an intermediate frequency amplifier **46** and combined with similar signals of the other blocks **60** by a bus **58**. An optional addition to permit relaxation of the bandwidth tolerance of the intermediate frequency equipment to lessen the constraints on the frequency plan of a large radio relay system employing the arrangement (refer to the article commencing on page 1505 of the November, 1960 issue of the Bell System Technical Journal for a detailed consideration of the frequency plan of a system) is shown in a dashed outline. The output from an intermediate frequency local oscillator **50** is beat with the pilot and information components in mixer **44** and is also applied to the other blocks **60** by a bus **56**. Here, a third order sideband having the desired phase characteristic is the one separated by amplifier **46** and combined by bus **58**.

The output of amplifier **40** is beat in mixer **42** with information to be radiated toward source **30**, represented by $e^{j\Omega_M t}$, which information also is applied by a bus **54** to the other blocks **60** for radiation from their respective antenna elements of the "A" array. The resulting sum frequency sideband, represented by $e^{j[(\Omega_M+\omega_B-\omega_P)t+\theta_1]}$ and in substantially the frequency range of the impinging wave, is separated by a bandpass filter **48** and radiated from antenna element A_1 after passing through diplexer **32**. More flexibility in the frequency of transmission from antenna elements A_1 through A_n can be obtained by beating a local oscillator signal, shown applied by a dashed line, in mixer **42** and radiating a third order sideband having the desired phase characteristic. Duplication of compents **32, 34, 36, 38, 40, 42, 44, 46**, and **48** on the right side of block **60** permits development of the information appearing on bus **54** from a wave impinging upon antenna elements B_1 through B_n from an unshown remote source and transmission of the information signal carried by the wave intercepted by antenna elements A_1 through A_n toward the unshown source from antenna elements B_1 through B_n. If the invention is to be practiced in a terminal station instead of a repeater, bus **58** would lead to a local utilization circuit and bus **54** would lead to a local source of information.

It should be noted that the arrangement of FIG. 1, although it provides intermediate frequency conversion of the information signals, employs the same number of mixers as the prior art configuration of FIG. 2.

FIG. 3 discloses another embodiment of the invention, shown in one of identical blocks **80**, that realizes an actual reduction in circuit components over the prior art arrangement of FIG. 2. Antenna element A_1 here intercepts a portion of the wave from remote source **30** which is coupled through a diplexer **62** to a mixer **64**. The intercepted portion, represented by $e^{j(\omega_M t-\theta_1)}$ and $e^{j(\omega_P t-\theta_1)}$, is beat with the output from a local oscillator **66**, represented by $e^{j\omega_B t}$. The difference frequency sideband, represented by $e^{j[(\omega_B-\omega_P)t+\theta_1]}$, is separated and amplified by an amplifier **70** and applied to a mixer **72** where it is beat with information, represented by $e^{j\Omega_M t}$, appearing on a bus **78**. The resulting sum frequency sideband, represented by $e^{j[(\Omega_M+\omega_P-\omega_B)t+\theta_1]}$ and in substantially the same frequency range as the impinging wave, is separated by a bandpass filter **79** and applied to diplexer **62** for radiation from antenna element A_1.

Another, sideband produced in mixer 64, represented by $e^{j(\omega_M-\omega_P)t}$, contains the information transmitted from source 30 converted to intermediate frequency and is in phase with similar signals developed by the other blocks 80. This sideband is amplified and isolated by an intermediate frequency amplifier 68, connected to a bus 76 for distribution among all of blocks 80. In this embodiment the functions of both mixers 34 and 44 (FIG. 1) are consolidated in mixer 64.

The invention can be practiced in connection with any of the arrangements disclosed in the above-cited Cutler-Kompfner-Tillotson application. In addition, it can be practiced with a system wihch does not radiate a pilot component from the remote source but which instead derives the pilot component at the repeater from the information component of the impinging wave, such as the arrangement disclosed in an application of L. H. Enloe, Serial No. 220,010, filed August 28, 1962, and assigned to the assignee of the present invention.

What is claimed is:

1. In a communication system, an array of antenna elements, a source of information-bearing electromagnetic waves for irradiating said array, combining means, and apparatus individual to each antenna element comprising means for recovering an information component and an unmodulated sine wave signal to serve as a pilot component from the portion of said wave impinging upon said element, means for mixing said information component with said pilot component, and means for applying the difference frequency side band resulting from said mixing means to said combining means.

2. A communication system comprising an array of antenna elements, a source of electromagnetic waves for irradiating said array remotely located from said array, the waves from said source including an information component and a pilot component, combining means for said information component, and apparatus individual to each antenna element comprising means for recovering a portion of said wave impinging upon said element, means for mixing together the information component and the pilot component of said portion, and means for applying the difference frequency side band resulting from said mixing means to said combining means.

3. In a communication system, an array of antenna elements, a source of electromagnetic waves carrying information, a source of information to be transmitted toward said source of electromagnetic waves, a local oscillator the frequency of which is greater than the frequency of said wave, and apparatus associated with each antenna element comprising means for recovering an information component and an unmodulated sine wave signal to serve as a pilot component from the portion of said wave intercepted by said antenna element, a first mixer for beating said information component and said pilot component with the output of said oscillator, the difference frequency sideband of said information component resulting from said first mixer being at an intermediate frequency, a second mixer for beating the output from said source of information to be transmitted with the difference frequency sideband of said pilot component resulting from said first mixer, and means for applying the sum frequency sideband resulting from said second mixer to said antenna element.

4. In a communication system, an array of antenna elements, a source of electromagnetic waves having a pilot component and an information component, a source of information to be transmitted toward said source of electromagnetic waves, a local oscillator the frequency of which is greater than the frequency of said wave, and apparatus associated with each antenna element comprising means for recovering the portion of said wave impinging upon said antenna element, a first mixer for beating said information component and said pilot component with the output of said oscillator, the difference frequency sideband of said information component resulting from said first mixer being at an intermediate frequency, a second mixer for beating the output from said source of information to be transmitted with the difference frequency sideband of said pilot component resulting from said first mixer, and means for applying the sum frequency sideband resulting from said second mixer to said antenna element.

5. A communication system comprising a plurality of antenna elements arranged in an array, a source of electromagnetic waves carrying information and irradiating said array, a source of information to be transmitted toward said source of electromagnetic waves, utilization means, a local oscillator the frequency of which is greater than the frequency of said wave, and apparatus associated with each antenna element comprising means for recovering an information component and an unmodulated sine wave signal to serve as a pilot component from the portion of said wave intercepted by said antenna element, means for beating said information component with said pilot component, and said pilot component with the output from said local oscillator, means for applying the difference frequency sideband resulting from beating said information component with said pilot component to said utilization means, means for beating with the output from said source of information to be transmitted the difference frequency sideband resulting from beating said pilot component with the output of said local oscillator, and means for applying the sum frequency sideband resulting from said last-mentioned beating means to said antenna element.

6. In a communication system, an array of antenna elements, a remotely located source of electromagnetic waves for illuminating said array, said waves comprising an information component and a pilot component, a source of information to be radiated toward said remote source, a local oscillator the frequency of which is greater than the frequency of said wave, and circuitry individual to each antenna element comprising means for recovering a portion of said wave impinging upon said antenna element, first means for mixing said wave with the output from said local oscillator, second means for mixing the difference frequency sideband of the pilot component of said wave resulting from said first mixing means with the output from said source of information to be radiated, means for applying the sum frequency sideband resulting from said second mixing means to said antenna element, third means for mixing the pilot component and the information component of the difference frequency sideband resulting from said first mixing means, and means for combining the sum frequency sideband resulting from said third mixing means with similar quantities derived by the remaining antenna elements.

7. An antenna system comprising a plurality of antenna elements arranged in an array, a source of information-bearing electromagnetic waves for irradiating said array, utilization means, a source of information to be radiated toward said source of said wave, a local oscillator the frequency of which is greater than the frequency of said wave, and circuitry associated with each of said antenna elements comprising means for recovering an information component and an unmodulated sine wave signal serving as a pilot component from the portion of said wave impinging upon said antenna element, means for mixing said information component and said pilot component of said portion with the output of said local oscillator, means for applying the difference frequency sideband of said information component and said pilot component to said utilization means, means for mixing the difference frequency sideband of said local oscillator output and said pilot component with the output from said source of information to be radiated, and means for applying to said antenna element the sum frequency sideband resulting from said last-mentioned mixing means.

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UNITED STATES PATENT OFFICE

CERTIFICATE OF CORRECTION

Patent No. 3,166,749 January 19, 1965

John C. Schelleng et al.

It is hereby certified that error appears in the above numbered patent requiring correction and that the said Letters Patent should read as corrected below.

In the grant, lines 2 to 4, for ", assignors to Bell Telephone Laboratories, Incorporated, of New York, N. Y., a corporation of New York," read -- ; said Tillotson assignor to Bell Telephone Laboratories, Incorporated, of New York, N. Y., a corporation of New York, --; line 13, for "Bell Telephone Laboratories, Incorporated, its successors" read -- John C. Schelleng, his heirs or assigns and Bell Telephone Laboratories, Incorporated, its successors --; in the heading to the printed specification, lines 5 to 7, for ", assignors to Bell Telephone Laboratories, Incorporated, New York, N. Y., a corporation of New York" read -- ; said Tillotson assignor to Bell Telephone Laboratories, Incorporated, New York, N. Y., a corporation of New York --.

Signed and sealed this 6th day of July 1965.

(SEAL)
Attest:

ERNEST W. SWIDER
Attesting Officer

EDWARD J. BRENNER
Commissioner of Patents

UNITED STATES PATENT OFFICE
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