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(71) Applicant: MITSUBISHI DENKI KABUSHIKIKAISHA
2-3, Marunouchi 2-chome Chiyoda-Ku
Tokyo(JP)

(72) Inventor: Aoki, Toshihiko c/o Mitsubishi Denki K.K.
325, Kamimachiya
Kamakura-shi Kanagawa-ken(JP)
Inventor: Katagi, Takashi c/o Mitsubishi Denki K.K.
325, Kamimachiya
Kamakura-shi Kanagawa-ken(JP)
Inventor: Orime, Nobutake c/o Mitsubishi Denki K.K.
325, Kamimachiya
Kamakura-shi Kanagawa-ken(JP)
Inventor: Hishinuma, Susumu c/o Mitsubishi Denki K.K.
325, Kamimachiya
Kamakura-shi Kanagawa-ken(JP)
Inventor: Ogiso, Koushi c/o Mitsubishi Denki K.K.
325, Kamimachiya
Kamakura-shi Kanagawa-ken(JP)
Inventor: Nishioka, Yasuhiko c/o Mitsubishi Denki K.K.
325, Kamimachiya
Kamakura-shi Kanagawa-ken(JP)

(74) Representative: Pfenning, Meinig & Partner
Mozartstrasse 17
D-8000 München 2(DE)

(54) Antenna system.

(57) An antenna system for transmitting radio waves in the same direction as the direction of arrival of incoming radio waves. The arrival direction is detected by a fast Fourier transform processor. The transmitting direction is adjusted by phase-shifting radio waves from a feeder on the basis of the detected arrival direction. Further, signals in the system are transmitted through optical fibers in order to decrease the processing time.

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ANTENNA SYSTEM

The present invention relates to an antenna system having retrodirective characteristics in which beams of radio waves to be transmitted are automatically radiated in the direction of arrival of incoming radio waves.

In Fig. 1, which represents a block diagram of a conventional antenna sytem, the reference symbols 1a to 1d represent transmitting/receiving element antennas; 2a to 2d duplexers for separating transmitted radio waves and received radio waves; 13 the direction of arrival of incoming radio waves; 14 an equiphase front (equiphase wave surface) of the incoming radio waves arriving from the direction of arrival 13 of the incoming radio waves received when the element antenna 1a is the reference; (15a) to (15d) distances from the equiphase front 14 to each of the element antennas 1a to 1d; and 16a through 16d represent amplifiers for amplifying the incoming radio waves and for providing the radio waves to be transmitted.

A description will now be given of the operation. The incoming radio waves received from the direction of arrival 13 thereof are received by the element antenna 1a and are delivered via the duplexer 2a to the amplifier 16b. The incoming radio waves are amplified by the amplifier 16b, and then provided as radio waves to be transmitted. The thus formed radio waves to be transmitted travel through the duplexer 2d and are then transmitted from the element antenna 1d. Similarly, the incoming radio waves received by element antenna 1b travel via the duplexer 2b, the amplifier 16d and the duplexer 2c, and are then transmitted from the element antenna 1c. The incoming radio waves received by the element antenna 1c pass through the duplexer 2c, the amplifier 16c and the duplexer 2b, and are transmitted from the element antenna 1b. The incoming radio waves received by the element antenna 1d travel via the duplexer 2d and the amplifier 16a, and are radiated from the element antenna 1a through duplexer 2a. The electrical characteristics of each system are substantially the same, and the element antennas 1a through 1d are arranged in symmetry with respect to the central line 21. Hence, distances of arrival (15a) to (15d) from the equiphase front 14 based on the element antenna 1a to the individual element antennas 1a to 1d are expressed by the following formulae:

(15a)[=0] + (15d) = (15d)   (1)

(15b) + (15c) = (15d)   (2)

When the incoming radio waves travel the arrival distance (15d) from the equiphase front 14 and are received by the element antenna 1d and then transmitted from the element antenna 1a, the delay in each system is ignored here because all the electrical characteristics of the respective systems are substantially equal to each other, and the radio waves received by the element antenna 1a and transmitted from the element antenna 1d travel a distance corresponding to the arrival distance (15d) from the element antenna 1d [(15a) = 0]. Similarly, the radio waves which are received by the element antenna 1b and transmitted from the element antenna 1c travel the arrival distance (15d) from the equiphase front 14 during the same time period. It is therefore apparent from the formula 2 that the radio waves have travelled the distance corresponding to the arriving distance (15c) from the element antenna 1c. At the same time, the radio waves which are received by the element antenna 1c and transmitted from the element antenna 1b travel the arrival distance (15d) from the equiphase front 14. Hence, it follows from the formula 2 that the radio waves reach a position spaced apart from the element antenna 1b by the arrival distance (15b).

The situation with respect to the equiphase front of the radio waves to be transmitted is the same as the equiphase front 14 of the incoming radio waves arriving from the direction of arrival thereof. Namely, the radio waves transmitted travel the arrival distance (15a) [=0] from the element antenna 1a; the arrival distance (15b) from the element antenna 1b; the arrival distance (15c) from the element antenna 1c; and the arrival distance (15d) from the element antenna 1d. Hence, the transmitted beams can be automatically radiated in the same direction as the direction of arrival 13 of the radio waves.

In the thus arranged conventional antenna system, all the electrical characteristics of each part of the system are required to be equal to each other. Therefore, the frequency of the transmitted radio waves has to be equalized with that of the incoming radio waves. A problem arises, however, in that the incoming radio waves interfere with the transmitted ones if the frequencies thereof are equalized. In order to obviate this problem, it is required that the frequency of the transmitted radio waves is different from that of the incoming radio waves. If this, however, the electrical characteristics in the receiving mode differ from those in the transmitting mode. As a result, another problem occurs because the beams of transmitted radio waves cannot be automatically radiated in the direction of arrival 13 of the incoming radio waves, since the equiphase front of the incoming radio waves arriving in the direction of arrival 13 thereof does not coincide with the equiphase front of the transmitted radio waves.

It is a primary object of the present invention to obviate the above-described problems and to provide an antenna system in which beams of transmitted radio waves can be automatically radiated in the direction of arrival of incoming radio waves even if the frequency of the incoming radio waves differs from that of the transmitted radio waves.

To this end, according to one aspect of the invention, there is provided an antenna system comprising a plurality of transmitting/receiving element antennas; a phase-shifter installed in a transmitting system (or path) of the plurality of transmitting/receiving element antennas; a digital-to-analog converter installed in a receiving system for converting an incoming signal into a digital signal; and a signal processor installed likewise in the receiving system for digitally processing an incoming digital signal delivered from each element.

The digital-to-analog converter according to the present invention serves to convert an incoming signal into a digital signal so as to permit the signal processor to effect digital processing. The signal processor detects the direction of arrival of the incoming radio waves on the basis of the incoming digital signal derived from the signals received by each element antenna and calculates control signals for each transmitting system so that the beams of transmitted radio waves are radiated in the direction of arrival of the incoming radio waves. The phase-shifter provided in each transmitting system is intended to control an equiphase front of transmitted radio waves radiated from each element antenna on the basis of a control signal.

With such an arrangement, even when the frequency of the transmitted radio waves differs from that of the incoming radio waves, the beams of transmitted radio waves can be radiated in the direction of arrival of the incoming radio waves.

The foregoing and other objects and advantages of the invention will become more apparent upon reading the following discussion with reference to the accompanying drawings

Fig. 1 is a block diagram illustrating a prior art antenna system;

Fig. 2 is a block diagram illustrating one embodiment of the present invention;

Fig. 3 is a block diagram of the signal processor depicted in Fig. 1; and

Fig. 4 is a diagram of a coordinate system showing the direction of arrival of incoming radio waves.

Referring to Fig. 2, the reference symbols 1a and 1b represent transmitting/receiving element antennas; 2a and 2b designate duplexers for separating transmitted radio waves and incoming radio waves; 3a and 3b denote receivers; 4a and 4b designate analog-to-digital converters for converting the incoming signals from the receivers 3a and 33b into digital signals; 5a and 5b indicate electro-optical converters for converting electric signals into optical signals in order to transfer the signals from the analog-to-digital converters 4a and 4b at high velocity through optical fibers 6a and 6b to photoelectric converters 7a and 7b which convert the optical signals transmitted through the optical fibers 6a and 6b at high velocity into electric signals; 8 denotes a signal processor. The signal processor, as shown in Fig. 3, comprises digital detecting circuits 17a and 17b, which detect phases and amplitudes on the basis of the digital signals received from the element antennas 1a and 1b via the optical fibers 6a and 6b; an FFT (Fast Fourier Transform) circuit 18 for computing intensities of incoming radio waves in all directions on the basis of the phases and the amplitudes which are detected by the digital detecting circuits 17a and 17b; an incoming radio wave arrival direction detecting circuit for detecting arriving the direction of arrival 13 of incoming radio waves, i.e., the direction of the incoming radio waves having the maximum intensity among the intensities of incoming radio waves arriving in all directions which are detected by the FFT circuit 18; and a control signl computing circuit for computing control signals that are utilized to control the phases of the radio waves radiated from the element antennas 1a and 1b so as to make the beams of transmitted radio waves correspond to the direction of arrival 13 of the incoming radio waves detected by the direction detecting circuit 19. An electro-optical converter 5c converts the electric signal computed by the signal processor for each transmitting system into an optical signal which serves to transmit the control signals at high velocity through an optical fiber 6c to a photoelectric converter 7c which converts the optical signal transmitted at high speed into an electric signal. Registers 9a and 9b hold the control signals to be provided to each transmitting system. Phase-shifters 11a and 11b are adapted to the frequencies of the transmitted radio waves for controlling the equiphase front of the transmitted radio waves radiated from the element antennas 1a and 1b by controlling the phases of the transmitted radio waves supplied from a feed system 10 on the basis of the control signals stored in the registers 9a and 9b. Transmitters 12a and 12b amplify the transmitted radio waves the phases of which are controlled by the phase-shifters 11a and 11b and eliminate unnecessary radio waves. The reference number 13 indicates the direction of arrival of incoming radio waves. 14 denotes an equiphase front of the incoming radio waves arriving from the direction of arrival 13 thereof with the element antenna 1a serving as a reference, and (15a) and (15b) represent arrived distances from the equiphase front

14 to the respective element antennas 1a and 1b.

Next, the operation will be explained. The incoming radio waves approaching from the arrival direction 13 are received by the element antennas 1a and 1b. Subsequently, the received radio waves are transferred via the duplexers 2a and 2b to the receivers 3a and 3b. The receivers 3a and 3b serve to detect incoming signals from the received radio waves. The incoming signals are converted into digital signals by means of the analog-to-digital converters 4a and 4b preparatory to a step of undergoing digital processing by use of the signal processor 8, thus becoming incoming digital signals. The digital signals received are further converted into optical signals by the electro-optical converters 5a and 5b for the purpose of tranmitting these signals to the signal processor 8 at a high velocity exceeding the limit of electrical transmission. In this case, the transmission of optical signals involves the use of the optical fibers 6a and 6b. The optical signals are converted into electric signals by the photoelectric converters 7a and 7b just before being fed to the signal processor 8. The digital detecting circuits 17a and 17b in the signal processor 8 detect phases and amplitudes of the receiving radio waves from the element antennas 1a and 1b, which phases and amplitudes correspond to the arrival distances 15a and 15b from the equiphase front 14 of the element antennas 1a and 1b, on the basis of the received digital signals delivered from the element antennas 1a and 1b through the optical fibers 6a and 6b. Based on the phases and the amplitudes detected by the digital detecting circuits 17a and 17b, the FFT circuit 18 computes the intensities of the incoming radio waves in every direction in conformity with the following formula (1):

$$E_{\ell} = \sum_{i=1}^{n} A_i \cdot e^{jk_1 \psi_i} \quad \ldots\ldots (1)$$

where n is the number of element antennas 1a and 1b; A_i is the amplitude detected by the digital detecting circuits 17a and 17b; ψ_i is the phase detected by the digital detecting circuits 17a and 17b; e^j is the complex number; k_1 is the constant determined by the frequency of the incoming radio waves; and E_ℓ is the intensity of the incoming radio waves in each direction; here ℓ = 1 to n, E_ℓ (ℓ = 1 to n) indicates the intensity of the incoming radio waves in each direction which is given by equally dividing all directions of the space by n. The E_ℓ is calculated by the Fast Fourier Transform (FFT) circuit 18.

The incoming radio wave arrival direction detecting circuit 19 detects the direction of arrival 13 of the incoming radio waves, i.e., the direction having the maximum intensity among the intensities E_ℓ of incoming radio waves in each direction, which are computed by the FFT circuit 18. A control signal computing circuit 20 serves to compute an amount of control for the phases of transmitting radio waves to be transmitted from the element antennas 1a and 1b in accordance with the following formula 2 in order to have the beams of transmitted radio waves correspond to the direction of arrival 13 of incoming radio waves detected by the incoming radio wave arrival direction detecting circuit 19, viz., to make the equiphase front 14 of the incoming radio waves coincide with the equiphase front of the transmitted radio waves.

$\psi_i = k_2 (x_i \sin\theta \cos\phi + y_i \sin\theta \sin\phi)$ (2)

where i =1 to n; n is the number of element antennas 1a and 1b; x_i and y_i are the coordinates of the element antennas 1a and 1b; θ and ϕ are the coordinates of the direction of arrival 13 of the incoming radio waves detected by the incoming radio wave arrival direction detecting circuit 19 as shown in Fig. 4; and k_2 is the constant determined by the frequency of transmitted radio waves.

The signal processor 8 outputs the control quantity calculated by the control signal computing circuit 2 in serial fashion after adding identification codes to each transmitting system as a control signal. As in the case of the receiving mode, the transmission of control signals to the transmitting system is effected in such a manner that the electric signals are converted into optical signals by means of the electro-optical converter 5c with a view to attaining high-speed transmission thereof, and the optical signals are converted into electric signals by the photoelectric converter 7c just before being fed to the transmitting system. Here, since only one optical fiber 6c is used for the transmission of control signals to the transmitting system, the identification codes are added to the control signals for each transmission system, and then the control signals are reformed in series. After the optical signals have been converted into the electric signals by means of the photoelectric converter 7c, the corresponding control signals are allocated to the respective transmitting systems in accordance with the identification codes. The control signals transmitted to the respective transmitting systems are held by the registers 9a and 9b. The phases of transmitted radio waves sent from the feed system 10 are varied by the phase-shifters 11a and 11b in accordance with the control signals held in the registers 9a and 9b. The transmitting radio waves whose phases are changed by the phase-shifters 11a and 11b are amplified by the transmitters 12a and 12b, and unnecessary radio waves thereof are at the same time eliminated. The transmitted radio waves travel via the duplexers 2a and 2b and are then transmitted from the element antennas 1a and 1b. At this time, the phase-shifters 11a and 11b change the phases of transmitted radio waves on the basis of the control signals coming from the signal processor 8 so that the equiphase front of the transmitted radio waves coincides with the equiphase front 14 of the incoming radio waves. As a result, the beams of transmitted radio waves are radiated in the same direction as the direction of arrival 13 of incoming radio waves.

Even if the frequency of transmitted radio waves is different from that of incoming radio waves, the beams of transmitted radio waves can be radiated in the same direction as the direction of arrival 13 of the incoming radio waves because the phase-shifters 11a and 11b can be adapted to the frequency of the transmitted radio waves.

The above-described embodiment utilizes two element antennas 1a and 1b. Even when an arbitrary plural number of element antennas are employed, however, the same effects can also be obtained.

In the above-mentioned embodiment, the description has been focused on a case where the element antenna 1a is defined as a reference of the equiphase front. If another arbitrary element antenna serves as the basis, however, the same effects can be exhibited.

According to the explanation of the foregoing embodiment, the direction of arrival 13 of incoming radio waves is arranged to be unidirectional. However, similar effects can be acquired with respect to incoming radio waves coming from other arbitrary directions.

Additionally, a single optical fiber 6c is used in the aforementioned embodiment for transmitting the control signal from the signal processor 8 to the transmitting system. However, the same effects can be obtained with respect to a combination incorporating a plurality of similar transmitting systems.

In accordance with the above-described embodiment, a piece of optical fiber 6a or 6b is employed for transmission of the incoming signals of one receiving system. Where the incoming signals of a plurality of receiving systems are transmitted through one optical fiber, the same effects can also be exhibited.

In the foregoing embodiment, the optical fibers 6a, 6b and 6c are utilized both for transmission of the incoming signals of a receiving system and for transmission of the control signals of a transmitting system. However, similar effects can be achieved in a case where the control signals and the incoming signals are transmitted as electric signals in just the transmitting system or the receiving system, or in both the transmitting system and receiving system.

Furthermore, in the above-described embodiment, the signal processor 8 incorporates the digital detecting circuits 17a and 17b, the Fast Fourier Transform (FFT) circuit 18, the incoming radio wave arrival direction detecting circuit 19 and the control signal computing circuit 20; that is the signal processor 8 is constituted by all these circuits. However, it will be apparent to those skilled in the art that a part or all of such components may be replaced by software subroutines to obtain the same effects.

As discussed above, in accordance with the present invention, the phase-shifter is installed in the transmitting system of the plurality of transmitting/receiving element antennas, while the analog-to-digital converter for converting the received signals into digital signals is disposed in the receiving system. In addition, the receiving system is equipped with the signal processor for computing the control signals of the transmitting system on the basis of the digital signals from the receiving system. With this arrangement, direction of arrival of the incoming radio waves is detected, and even if the frequencies of the transmitted and incoming radio waves are different from each other, the beams of transmitted radio waves can be automatically radiated in the same direction as the direction of arrival of the incoming radio waves.

Although the illustrative embodiment of the present invention has been described in great detail with reference to the accompanying drawings; it is to be understood that the invention is not limited to the precise embodiment shown. Various changes or modifications may be effected thereto by one skilled in the art without departing from the scope or spirit of the invention.

Claims

1. An antenna system comprising:
a plurality of transmitting/receiving element antennas;
a phase-shifter installed in a receiving system of said plurality of transmitting/receiving element antennas;
an analog-to-digital converter, installed in a receiving system, for converting received signals into digital signals; and
a signal processor installed in said receiving system for digitally processing received digital signals transmitted from said element antennas, said signal processor detecting the direction of arrival of incoming

radio waves and controlling said phase-shifter in said transmitting system on the basis of control signals generated by said signal process or so that beams of transmitted radio waves may be radiated in the same direction as said detected direction of arrival of incoming radio waves.

2. An antenna system as set forth in Claim 1, wherein said signal processor includes a Fast Fourier Transform (FFT) circuit.

3. An antenna system as set forth in Claim 1, wherein said received digital signals are transmitted through an optical fiber.

4. An antenna system as set forth in Claim 1, wherein a signal optical fiber is used for transmitting said control signals of said plurality of transmitting systems.

5. A transmitter-receiver system comprising:
means for receiving a radio wave;
means for detecting the direction of the received radio wave;
means for feeding a radio wave signal to be transmitted;
means for shifting the phase of the radio wave signal from said feeding means in such a manner that the equiphase front of the transmitted radio wave is parallel to the equiphase front of said received radio wave; and
means for radiating the phase-shifted radio wave.

6. A transmitter-receiver system as set forth in Claim 5, wherein said radio wave receiving means and said radiating means comprises a common means for transmitting and receiving a radio wave.

7. A transmitter-receiver system as set forth in Claim 6, wherein said transmitting and receiving means comprises a plurality of element antennas.

8. A transmitter-receiver system as set forth in Claim 5, wherein said direction detecting means comprises an FFT circuit.

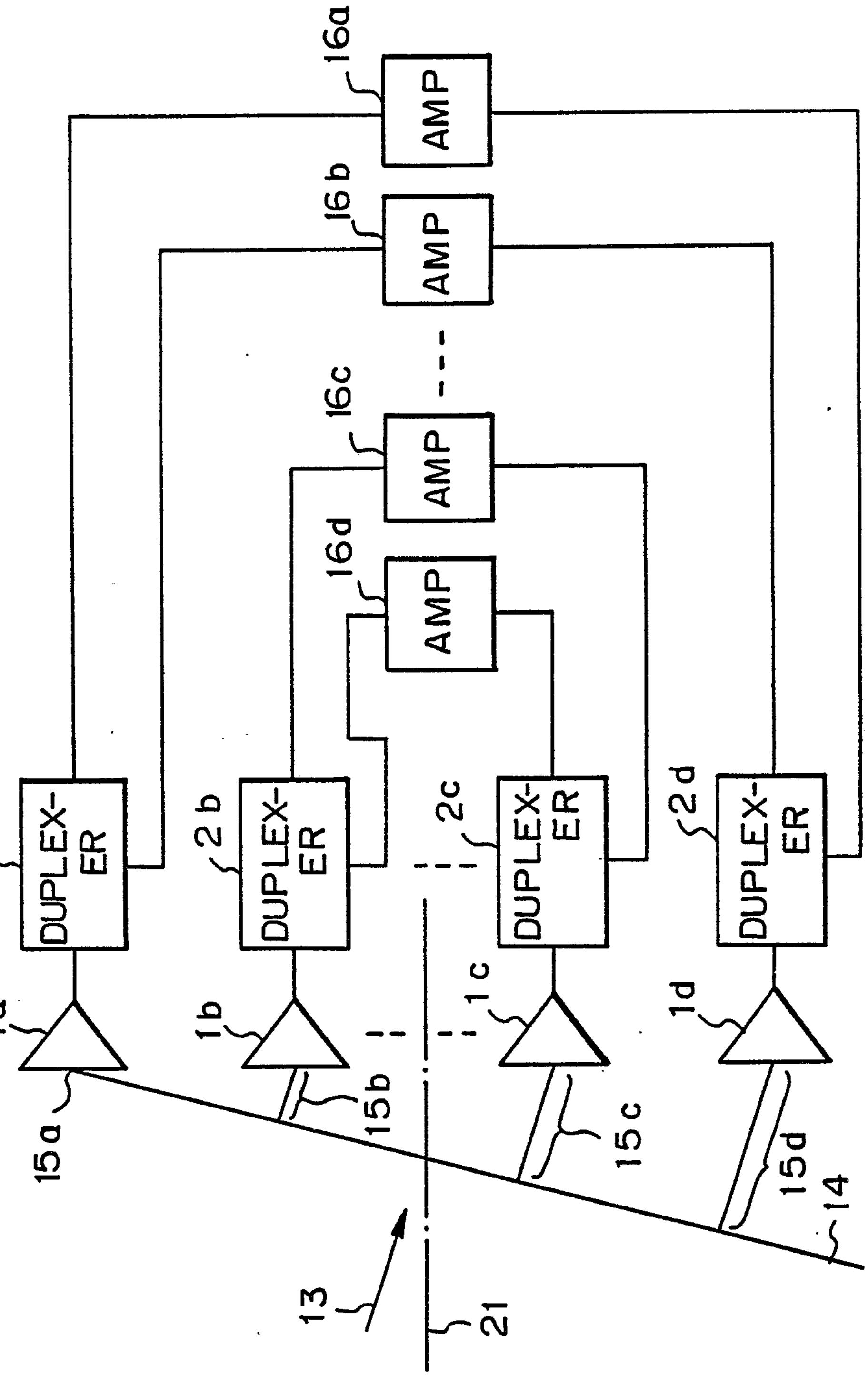
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Fig. 1

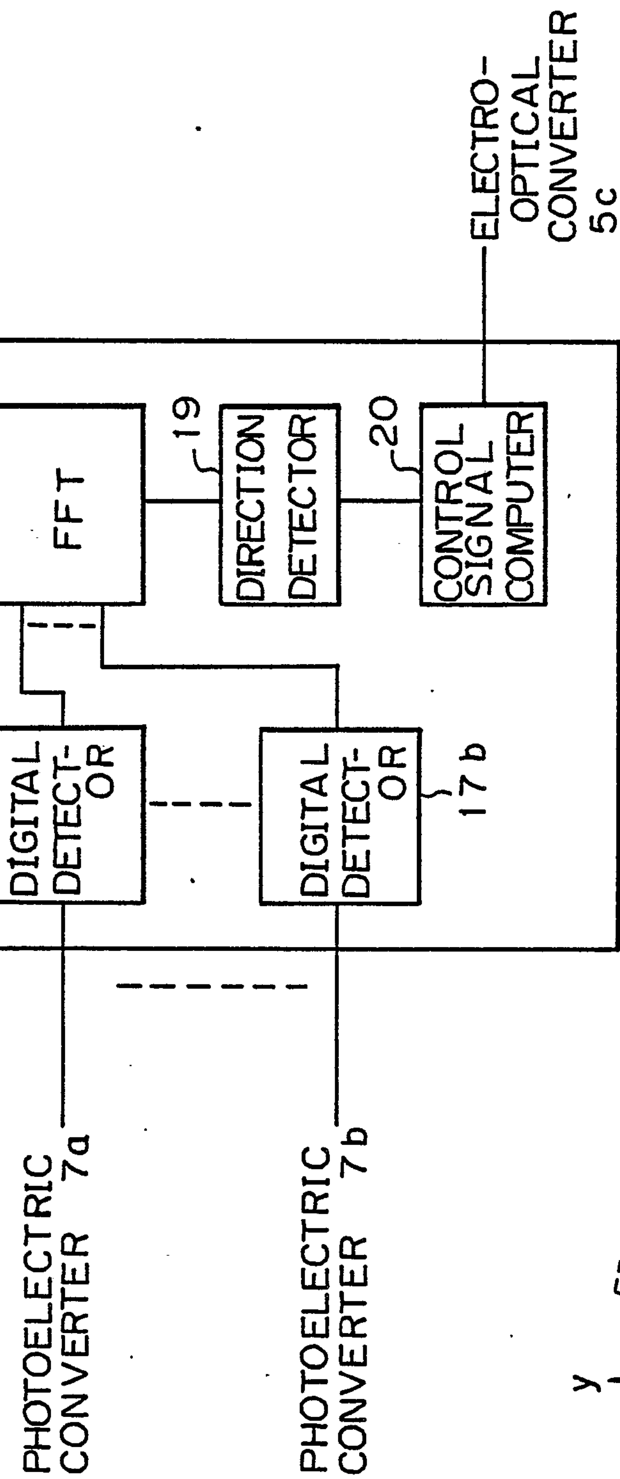
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Fig. 3

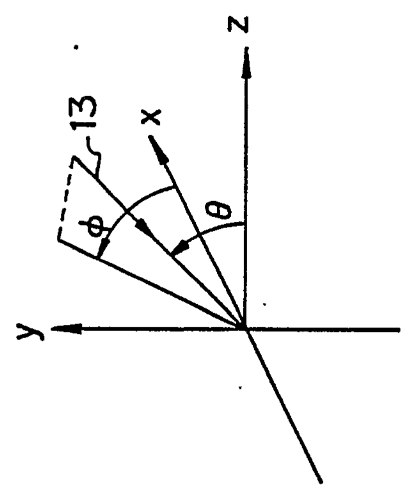
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Fig. 4