(19) Europäisches Patentamt
European Patent Office
Office européen des brevets

(11) Publication number: **0 446 610 A1**

(12) EUROPEAN PATENT APPLICATION

(21) Application number: **91101693.9**

(51) Int. Cl.5: **H01Q 3/26**

(22) Date of filing: **07.02.91**

(30) Priority: **07.03.90 US 490028**

(43) Date of publication of application:
18.09.91 Bulletin 91/38

(84) Designated Contracting States:
DE FR GB IT

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(54) Magnified phased array with a digital beamforming network.

(57) A magnified phased array antenna system (10) incorporating a digital beamforming network (22) therein. The magnified phased array antenna system (10) comprises a reflector system (12) employing a transfer lens (14) disposed at the focal plane of the reflector system (12) and an antenna array (20) which illuminates or receives energy from the transfer lens (14). In satellite to/from ground links where the field of view is limited, the present invention achieves adequate gain using a minimum number of antenna elements. The digital beamforming network (22) provides multibeam capability in an effective manner. The digital beamforming network (22) provides for fast scanning spot beams and reconfigurable area coverage beams. The present invention has a reduced number of elements, and its reliability is improved because of redundancy in the array. The use of digital beamforming provides for multiple, simultaneous, reconfigurable beams.

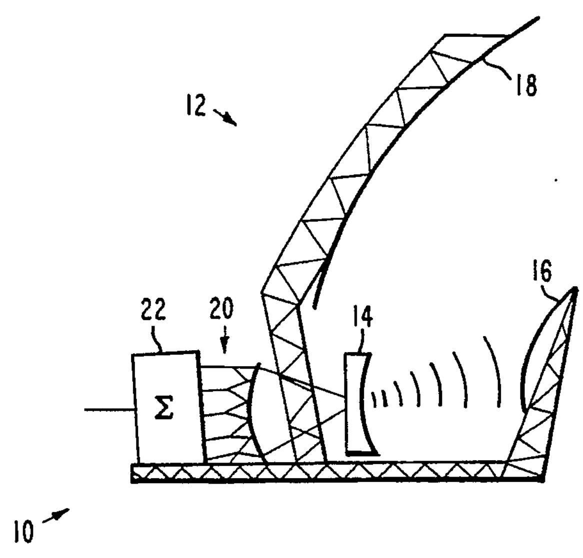

Fig. 1

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BACKGROUND

The present invention relates generally to phased array antenna systems and more particularly to a magnified phased array antenna system which incorporates a digital beamforming network therein.

Conventional phased array antenna systems typically incorporate a large number of antenna elements. The large number of antenna elements is generally required to provide sufficient gain. In addition, such large conventional phased array antenna systems are generally reconfigurable. As such the beams profiles employed in such conventional antennas are easily maneuverable, and are not susceptible to jamming due to their generally agile nature. Furthermore, in large aperture array antennas in which large scan volumes are require, the beamforming process generally involves the use of phase shifters are required to provide time delays among the different antenna elements. Consequently, the beamforming process does not involve simple coefficient multiplication of the signal vectors to achieve signal detection and steering.

SUMMARY OF THE INVENTION

In order to overcome the limitations of conventional phased array antenna systems, including their large number of elements and multiple sets of phase shifters and complex feeds, the present invention provides for a magnified phased array antenna system that incorporates a digital beamforming network therein. The number of antenna elements is therefore reduced compared to conventional antennas. The incorporation of the digital beamforming network permits the formation of multiple simultaneous beams that are reconfigurable and which may be steered in a variety of selectable directions. The field of view of the present invention is therefore limited, but the gain of the system is enhanced by the use of the magnifying portion thereof. This magnifying portion may be a telescope, such as a Cassegrain telescope, or the like, and may include a transfer lens that is employed to provide an intermediate focal plane on which the outputs of the antenna elements are imaged. The magnified phased array has a focal plane located at the plane radiating surface of the transfer lens, which is used to radiate the transmitted signals to remote locations or focus incoming signals for processing by the feed array system.

In geo-synchronous satellite to/from ground links where the field of view is limited, the present invention provides apparatus which achieves adequate gain using a minimum number of antenna elements. The digital beamforming network provides multibeam capability in an effective manner. The network provides for fast scanning spot beams and reconfigurable area coverage beams.

Therefore comparing the present invention to a conventional phased array antenna system, it has a reduced number of elements, thus reducing manufacturing costs. Compared to a conventional multibeam antenna, its reliability is improved because of redundancy in the array. Compared to a conventional antenna array, the use of digital beamforming provides for multiple, simultaneous, reconfigurable beams. In addition, the optimal efficiency of the present invention is achieved by dynamically allocating the spatial (beam forming) and temporal (waveform detection) processing sequence.

In particular, the present invention provides for a magnified phased array antenna system comprising an array of antenna elements and a magnification section having a predetermined field of view coupled to the array of antenna elements which increases the gain of the antenna system. A converter section coupled to the array of antenna elements which converts analog output signals derived from each of the elements in the array into digital signals when the antenna system operates in receive mode, and converts digital signals into analog signals transmittable by each of the elements in the array when the antenna system operates in transmit mode.

A digital beamforming network is coupled to the converter section which processes each of the digital signals derived from the elements of the array when the antenna system operates in receive mode by multiplying each of the digital signals by separate directional vectors and combining each of the multiplied digital signals into a single digital signal whose signal components are in phase, which digital signal represents a beam formed in the direction of the signals received by the array. The digital beamforming network also processes a digital signal to generate a beam transmittable in a predetermined direction when the antenna system operates in transmit mode by multiplying it by separate directional vectors having predetermined phase relationships such that the phase vectors associated with each of the digital signals generated thereby are such that upon transmission by the array, a beam is formed in the predetermined direction.

Multiple simultaneous beams are selectively formed in a plurality of directions by multiplying the transmitted signal by a plurality of separate sets of beam coefficients. A beam magnification section is optically coupled to the array of antenna elements which magnifies the respective beams provided by the digital beamforming network.

The digital beamforming network comprises circuitry that provides a plurality of directional vectors corresponding to directions from which or toward which the multiple simultaneous beam are received or transmitted, respectively. A plurality of multipliers are employed to combine a plurality of directional vectors with corresponding signals provided by the array of antenna elements. The multipliers provide a respective plurality of output signals which are substantially in phase. A summing circuit is coupled to the plurality of multipliers which combines the plurality of output signals into a single digital output string for each beam direction.

To compare the present invention to a conventional array, although the conventional array can be very agile, each beam requires a set of phase shifters in order to achieve such agility. More particularly, the conventional array has a large field of view, a large number of elements, for multiple beams, multiple sets of phase shifters are required, and the system has reasonable gain. The magnified phased array of the present invention has a limited field of view, moderate number of elements employs a digital beam former with no phase shifters, is capable of forming multiple beams, and has higher gain than the conventional phased array.

BRIEF DESCRIPTION OF THE DRAWINGS

The various features and advantages of the present invention may be more readily understood with reference to the following detailed description taken in conjunction with the accompanying drawings, wherein like reference numerals designate like structural elements, and in which:

FIG. 1 illustrates a magnified phased array antenna system in accordance with the principles of the present invention;

FIG. 2 illustrates the digital beamforming network of the system of FIG. 1 when operating in receive mode;

FIG. 3 illustrates the digital beamforming network of the system of FIG. 1 when operating in transmit mode; and

FIG. 4 illustrates a detailed diagram illustrating the operation of the digital beamforming network of the present invention.

DETAILED DESCRIPTION

Referring to FIG. 1, a magnified phased array antenna system 10 in accordance with the principles of the present invention is shown. The system 10 comprises a magnification system 12 which in FIG. 1 is shown as a Cassegrain antenna comprising a transfer lens 14, a first reflector 16 and a second reflector 18. Other magnification systems may also be employed including confocal lens systems or a confocal reflector system, or a single reflector with a transfer lens, such as is known by those skilled in the art. An antenna array 20 comprising a plurality of antenna elements is arranged in a conventional manner on the focal plane of the transfer lens 14. In the magnified phased array antenna system 10 of the present invention, an array of as few as sixteen (16) antenna elements may he employed. Each of the antenna element in the array 20 is coupled to a digital beamforming network (DBN) 22.

FIG. 2 illustrates the digital beamforming network 22 of the system 10 of FIG. 1 when operating in receive mode. Shown in FIG. 2 is the array 20 of antenna elements, represented by elements 20a-20n. Each of the antenna elements 20a-20n is coupled to down conversion circuitry 26 employed to convert signals received by the antenna array 20 into intermediate frequency (IF) signals which may be processed by the digital beamforming network 22.

The down conversion circuitry 26 may be comprised of a local oscillator generator 30a which includes a local oscillator 32a, coupled by way of a buffer amplifier 34a to a frequency multiplexer 36a (identified as X8). The output of the oscillator generator 30a is coupled to one input of a mixer 40a whose other input is coupled to the the first antenna element 20a. The output of the mixer 40a is connected to a band pass filter (BPF) 42a and a buffer amplifier 44 to an analog to digital conversion section 50.

Each of the antenna elements 20a-20n of the array 20 is individually coupled by way of separate down conversion circuitry 26 to the analog to digital conversion section 50. The analog to digital conversion section 50 is comprised of a plurality of analog to digital converters 50a-50n which separately convert the output signals from the down converter sections 26a-26n into digital signals which may be processed by the digital beamforming network 22.

As shown in FIG. 2, the analog to digital converters 50a-50n are coupled by way of decimate/presum circuits 52a-52n which may comprise digital circuitry such as accumulator, sign detector. This presuming operation usually will increase the dynamic range and reduce the processing bandwidth.

Outputs of the decimate/presum circuits 52a-52n are coupled to respective inputs of the digital beamforming network 22. The digital beamforming network 22 comprises a plurality of digital multipliers 60a-60n which each have one input provided by the outputs of respective decimate/presum circuits 52a-52n and have the other input coupled to beam coefficient generation circuitry 62a-62n which computes beam directional vectors. Outputs of each of the digital multipliers 60a-60n are coupled to a summing circuit 64 which combines the digital output signals into a single digital signal. The output of the summing circuit 64 is the output of the digital beamforming network 22, which may be processed, as an example of communications receiver, by means of a temporal processing circuitry 66 that performs demodulation, channelization decoding, data storage and forwarding.

With reference to FIG. 3, it illustrates the digital beamforming network 22 of the system 10 of FIG. 1 when operating in transmit mode. The circuitry of FIG. 3 is substantially the same as the circuitry shown in FIG. 2, except that the converter section 50 uses a plurality of digital to analog converters 50a'-50n', no decimate/presum circuits 52a-52n are employed the summing circuit 64 is replaced by a 1:N multiplexer 70, and input signals to be transmitted by the system 10 in transmit mode are provided by a base band data circuit 72 coupled to the multiplexer 70, which may be a data bus.

With reference to FIG. 4, a diagram illustrating the operation of the digital beamforming network 22 utilized in the circuits of FIGS. 2 and 3 are shown. The digital beamforming network 22 is comprised of the plurality of digital multipliers 60a-60n whose inputs are coupled to receive the output signals of the plurality of antenna elements 20a-20n and beam coefficients from the beam coefficient generation circuitry 62. The outputs of the plurality of digital multipliers 60a-60n are coupled to the summing circuit 70. Beam coefficients may be provided by means of the central processor, for example.

As is shown in FIG. 4 and represented by the plurality of arrows 78 having varying degrees of angular rotation which are representative of the relative amount of phase difference in the signals received by the plurality of antenna elements 20a-20n derived from a single signal source viewed by the antenna array 20. Each of the signals received by the antenna elements 20a-20n is separately combined with beam coefficients which are adapted to multiply the respective signals in order to generate signals which are in phase with one another. These signals are combined into a single signal by means of the summing circuit 70 which provides a signal representative of a formed beam whose beam direction vector points toward the radiating source.

With reference to FIG. 1, the operation of the magnified phased array antenna system 10 operating in receive mode will be described. For example, a four by four array 20 of antenna elements may be employed having an operational frequency centered at 60 GHz. A transmitted signal received by the antenna array 20 is amplified, down converted and dehopped to the processing intermediate frequency (IF) by means of the down conversion circuitry 26. The dehopped IF analog signals are then converted to digital signals after down conversion by the converter circuit 50, which in this case is comprised of the plurality of analog to digital converters 50a-50n. Typically, the down conversion will convert the 60 GHz signal with a 2 GHz hopping bandwidth and a 50 MHz instantaneous bandwidth, for example, to about a 1 GHz signal with 50 MHz bandwidth. The decimate/presum circuits 52a-52n may be employed to reduce the bandwidth requirements and enhance dynamic range of the digital signals processed by the digital beamforming network 22.

The incoming signals arrives at the antenna array 20 such that the phase vectors of the signal received by adjacent antenna elements 20a-20n are rotated progressively, as is shown more clearly in FIG. 4. The spatial rotational rate in degrees per element spacing depends on the angle of arrival. When a signal provided by a mechanical boresight, or other reference signal source, is processed, the rotational rate thereof is zero. The further the angle of arrival of a particular signal is from boresight, the faster the rotational rate thereof. Every antenna element 20a-20n is sampled separately and each signal may be represented as a signal vector. The digitized signal vectors are then multiplied by beam coefficients (directional vectors) in the digital beamforming network 22 such that the products are all in phase. These in phase signals are then added together by means of the summing circuit 64 to provide the single digital output signal.

Consequently, the digital beamforming process digitally aligns the signals received by each of the antenna elements 20a-20n. Therefore, a beam is formed toward the incoming signal direction. In a similar manner, multiple beams may be formed simultaneously by independently multiplying the signal vector by different directional vectors. In this manner, multiple received beams can be simultaneously processed, multiple transmit beams can be simultaneously processed, or the transmitted beam can be quickly steered to any desired direction by appropriately selecting the beam direction coefficients.

With reference to FIGS. 1 and 2, the magnified phased array antenna system 10 may be implemented in numerous ways, including employing Cassegrain reflectors 12 and a transfer lens 14 arrangement. The transfer lens is disposed at the focal plane of the Cassegrain reflector system 12.

In operation in the transmit mode, the antenna array 20 focuses radiated power at a small spot on the rear surface of the transfer lens 14. This spot serves as a virtual source to illuminate the Cassegrain reflector 12, which generates a spot beam in the far field. As the antenna array 20 focuses its radiated power at a different spot on the transfer lens 14, the beam in the far field will by "moved" accordingly. If two spots are created on the transfer lens 14, there will be two simultaneous spot beams in the far field. As more and more spot beams are generated, they are summed together to form an area coverage beam with instantaneous reconfigurability.

In satellite to/from ground links where the field of view is limited, the present invention provides apparatus which achieves adequate gain using a minimum number of antenna elements. The digital beamforming network provides multibeam capability in an effective manner. The network provides for fast scanning spot beams and reconfigurable area coverage beams.

Therefore comparing the present invention to a conventional phased array antenna system, it has a reduced number of elements, thus reducing manufacturing costs. Compared to a conventional multibeam antenna, its reliability is improved because of redundancy in the array. Compared to a conventional antenna array, the use of digital beamforming provides for multiple, simultaneous, reconfigurable beams. In addition, the optimal efficiency of the present invention is achieved by dynamically allocating the spatial (beam forming) and temporal (waveform detection) processing sequence.

Thus there has been described a new and improved phased array antenna system. It is to be understood that the above-described embodiments are merely illustrative of some of the many specific embodiments which represent applications of the principles of the present invention. Clearly, numerous and other arrangements can be readily devised by those skilled in the art without departing from the scope of the invention.

Claims

1. A magnified phased array antenna system comprising:

an array of antenna elements;

magnification means having a predetermined field of view coupled to the array of antenna elements for increasing the gain of the antenna system;

conversion means coupled to the array of antenna elements for (a) converting analog output signals derived from each of the elements in the array into digital signals when the antenna system operates in receive mode, and for (b) converting digital signals into analog signals transmittable by each of the elements in the array when the antenna system operates in transmit mode; and

digital beamforming means coupled to the conversion means for (a) processing each of the digital signals derived from the elements of the array when the antenna system operates in receive mode by multiplying each of the digital signals by separate directional vectors and combining each of the multiplied digital signals into a single digital signal whose signal components are in phase, which digital signal represents a beam formed in the direction of the signals received by the array, and for (b) processing a digital signal to generate a beam transmittable in a predetermined direction when the antenna system operates in transmit mode by multiplying it by separate directional vectors having predetermined phase relationships such that the phase vectors associated with each of the digital signals generated thereby are such that upon transmission by the array, a beam is formed in the predetermined direction.

2. The magnified phased array antenna system of Claim 1 wherein said digital beamforming means comprises:

coefficient generation means for providing a plurality of directional vectors corresponding to directions from which a signal is received by the array, or toward which a beam is to be transmitted, respectively;

a plurality of multiplying means for combining the plurality of directional vectors with corresponding ones of the signals provided by the array of antenna elements or corresponding signals which are to be transmitted by the system; and

summing means coupled to the plurality of multiplying means for combining the plurality of output signals into a single output signal when the antenna system operates in receive mode and for multiplexing the digital signal which is to be transmitted into a plurality of individual signals which are summed with the plurality of directional vectors in the multiplying means.

3. The magnified phased array antenna system of Claim 1 wherein said magnification means comprises:

reflector means for transmitting and receiving the beams and for focusing the beams in the far field; and

a transfer lens disposed between the array of antenna elements and the reflector means for coupling the beams therebetween.

4. The magnified phased array antenna system of Claim 3 wherein said reflector means comprises:

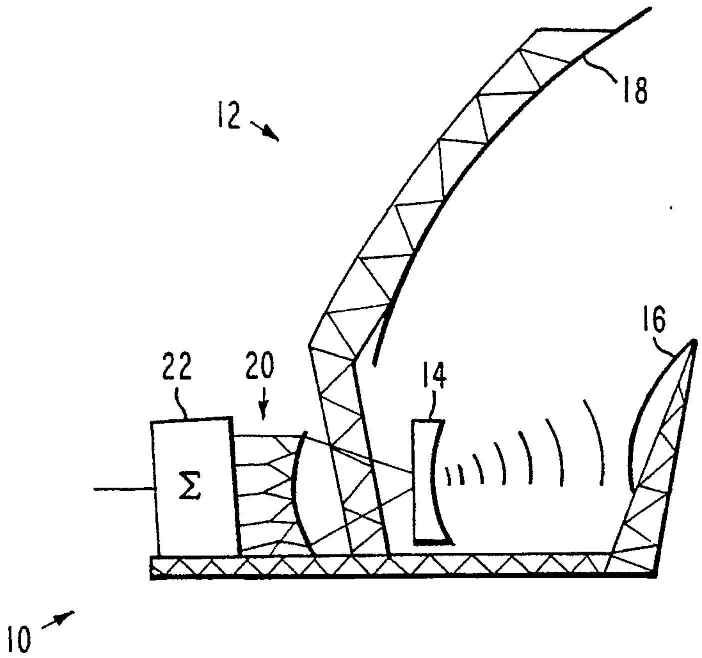
Cassegrain reflector and transfer lens means for magnifying the respective beams provided by the digital beamforming means.

5. The magnified phased array antenna system of

Claim 1 which further comprises:
computer means coupled to the digital beamforming means for providing beam direction coefficients which determine the directions from which or toward which the beams are received or transmitted, respectively.

6. The magnified phased array antenna system of Claim 1 which further comprises:
down conversion means coupled between the array of antenna elements and the conversion means for reducing the data rate at which signals are processed by the system.

7. The magnified phased array antenna system of Claim 6 wherein said down conversion means further comprises:
separate down conversion and presuming means coupled to each antenna element of the array of antenna elements for individually reducing the data rate and enhancing the dynamic range at which signals are processed by the digital beamforming means.


12
18
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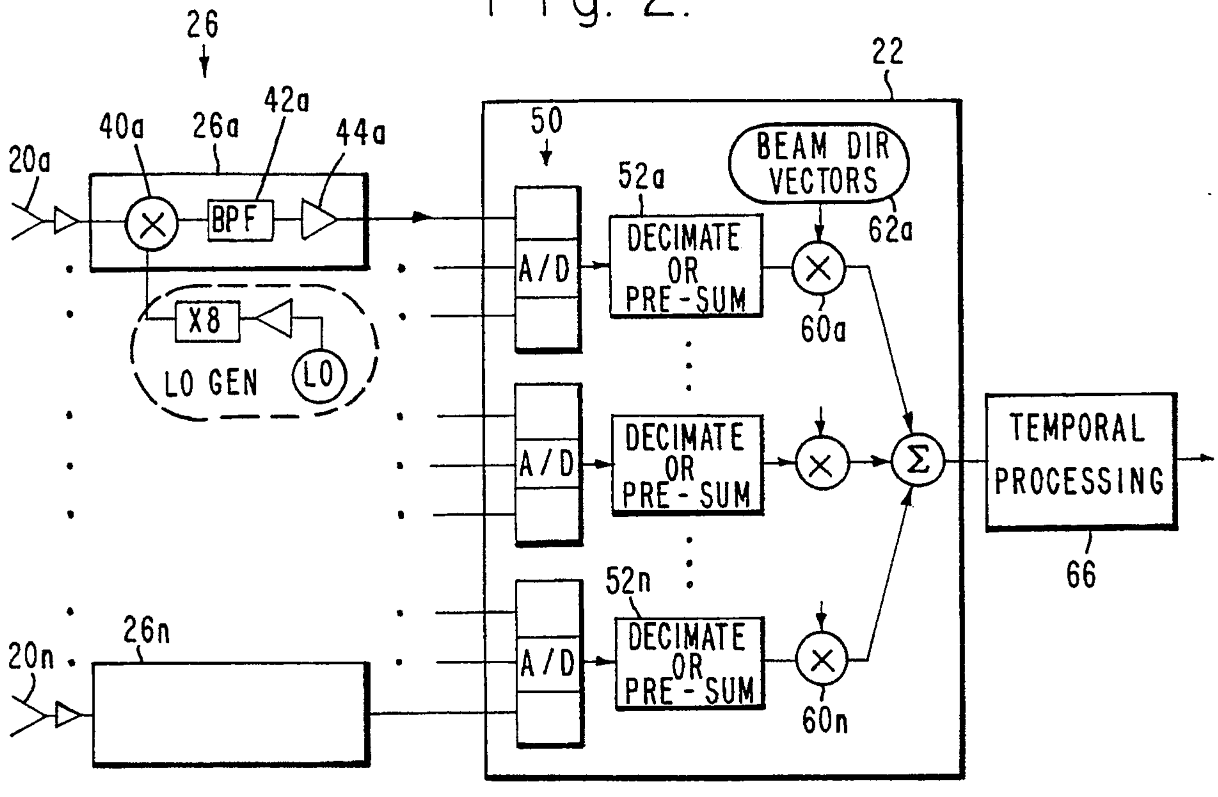
Σ
10

Fig. 1.

Fig. 2.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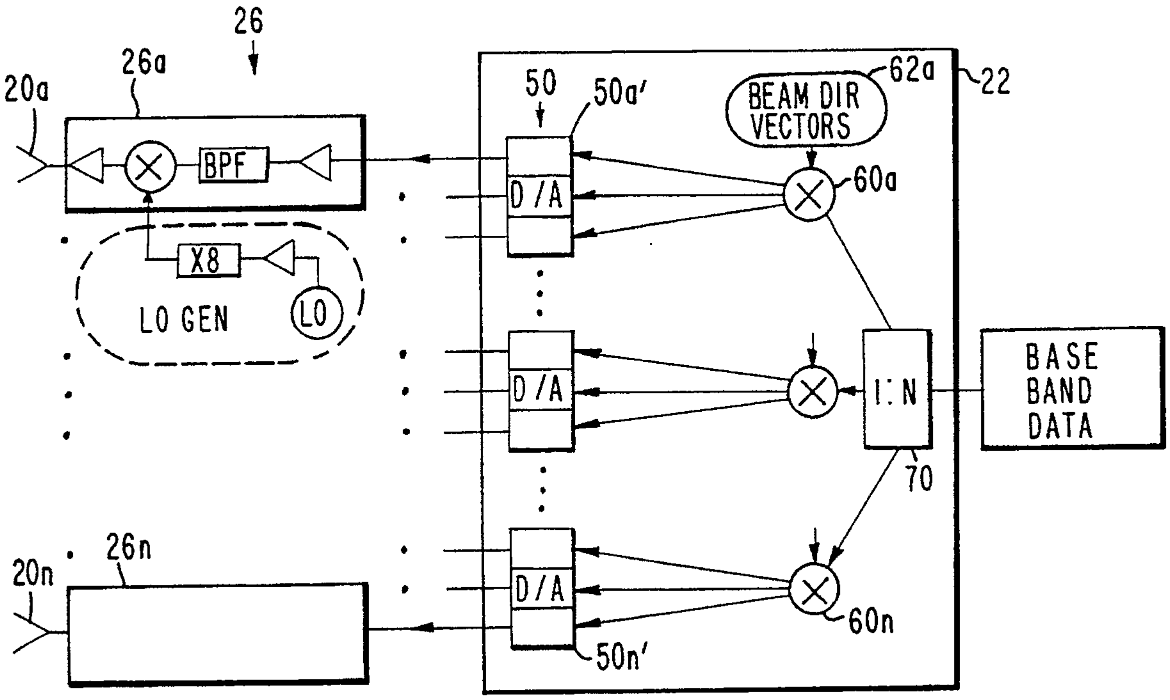
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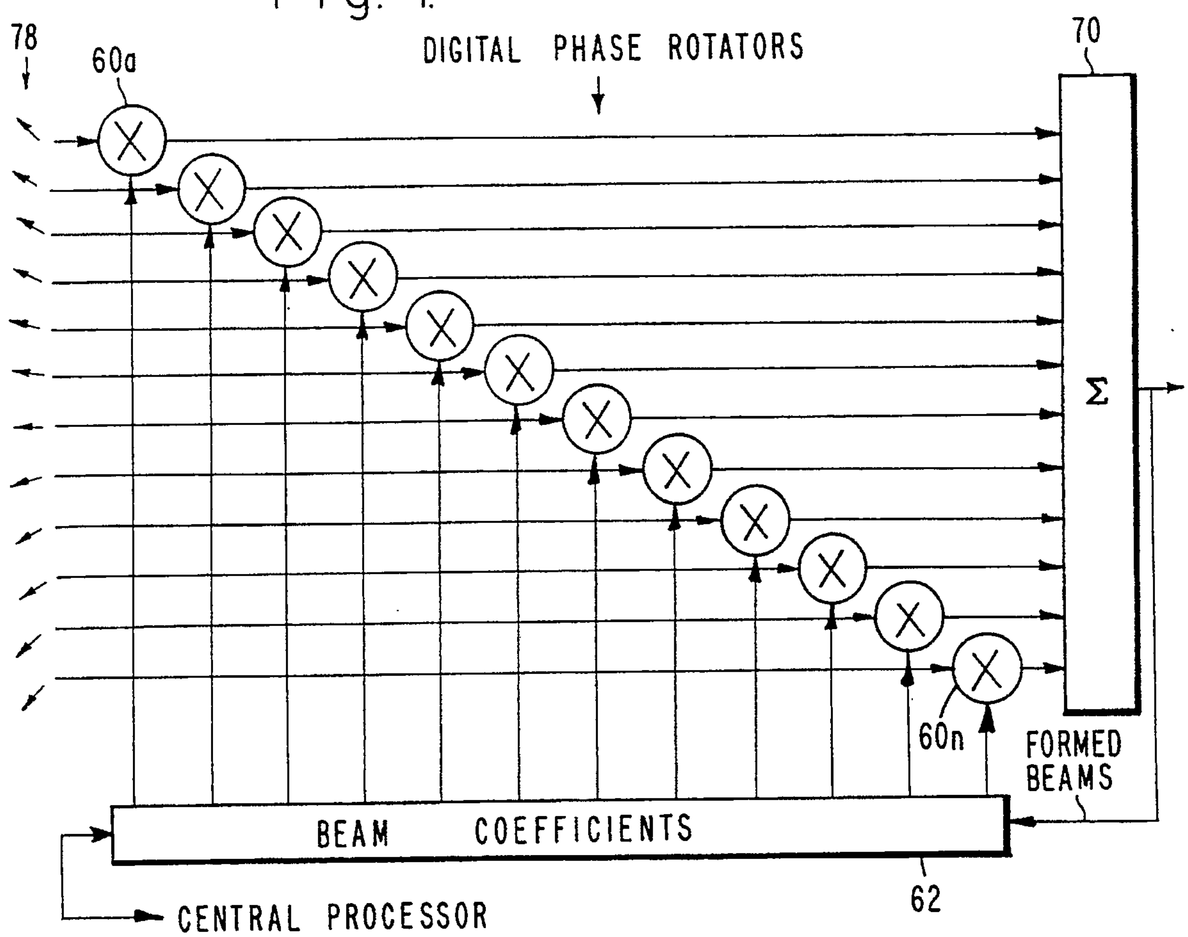
Fig. 3.

Fig. 4.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BEAM COEFFICIENTS
62
CENTRAL PROCESSOR

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EUROPEAN SEARCH REPORT

Application Number

EP 91 10 1693

DOCUMENTS CONSIDERED TO BE RELEVANT

Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	CLASSIFICATION OF THE APPLICATION (Int. Cl.5)
Y	GB-A-2 130 798 (STC LTD) * Page 1, lines 13-28; page 1, line 53 - page 2, line 2; claims 1,10,11,13; figures 1,2,4 *	1,3-7	H 01 Q 3/26
A		2	
Y	FR-A-2 588 422 (THOMSON) * Page 1, lines 4-6; page 1, line 25 - page 2, line 2; page 5, line 14 - page 6, line 16; figure 4 *	1,3-7	
A		2	
A	EP-A-0 109 322 (THOMSON) * Claims 1,2; figure 2 *	1,3,4	
A	EP-A-0 276 817 (MITSUBISHI) * Page 2, column 1, line 42 - column 2, line 19; page 4, column 6, lines 8-26; page 4, column 6, lines 43-52; figures 2-8 *	1,2,7	

TECHNICAL FIELDS SEARCHED (Int. Cl.5)

H 01 Q

The present search report has been drawn up for all claims

Place of search	Date of completion of search	Examiner
The Hague	10 June 91	BUTLER N.A.

CATEGORY OF CITED DOCUMENTS

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