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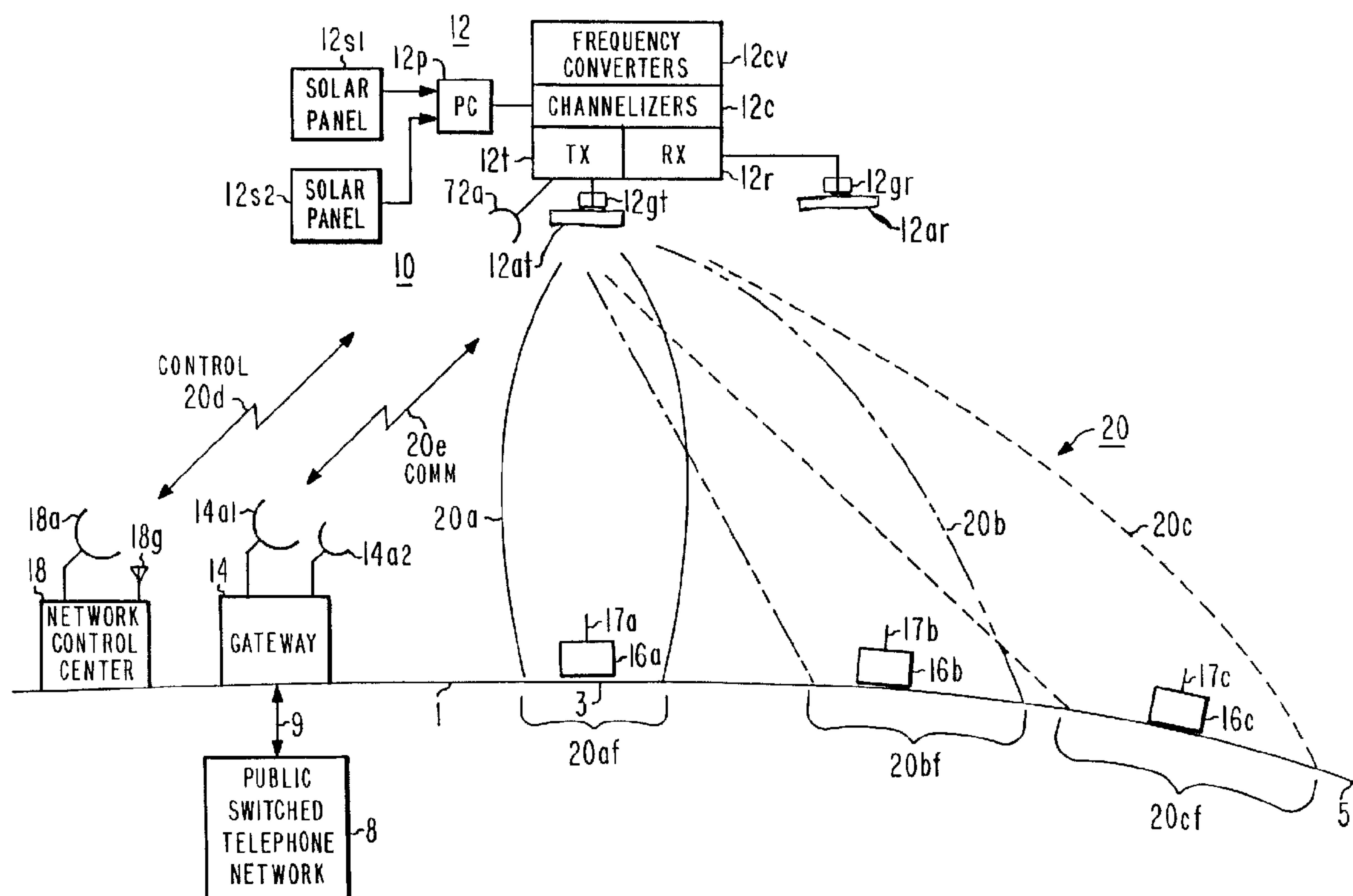
(71) Demandeur/Applicant:
LOCKHEED MARTIN CORPORATION, US

(72) **Inventeurs/Inventors:**
KAUTZ, GREGORY MICHAEL, US;
LIER, ERIK, US;
PURDY, DANIEL SANFORD, US

(74) **Agent:** SWABEY OGILVY RENAULT

(54) Titre : PROCEDE ET APPAREIL POUR OPERER PAR MONO-IMPULSION D'UN ANTENNE RESEAU

(54) Title: METHOD AND APPARATUS FOR MONOPULSE OPERATION OF AN ARRAY ANTENNA



(57) **Abrégé/Abstract:**

A method for generating at least two mutually skewed antenna beams involves generating the information signal(s) to be transmitted, encoding the signals with mutually orthogonal (separable) codes, and applying the resulting coded signals to an array antenna for transmission. The combined signals are separable at a receiver by decoding with corresponding codes. In one specific embodiment, plural versions of the same signal are generated, each of which is encoded with one of the mutually orthogonal codes. The encoded signals are combined for application to the antenna. In another embodiment, separate beam weights are generated, one set for each beam, and the beam weights are separately encoded. The encoded beam weights are applied to control the beamformer.

Abstract of the Disclosure

A method for generating at least two mutually skewed antenna beams involves generating the information signal(s) to be transmitted,
5 encoding the signals with mutually orthogonal (separable) codes, and applying the resulting coded signals to an array antenna for transmission. The combined signals are separable at a receiver by decoding with
10 corresponding codes. In one specific embodiment, plural versions of the same signal are generated, each of which is encoded with one of the mutually orthogonal codes. The encoded signals are combined for application to
15 the antenna. In another embodiment, separate beam weights are generated, one set for each beam, and the beam weights are separately encoded. The encoded beam weights are applied to control the beamformer.

METHOD AND APPARATUS FOR MONOPULSE OPERATION
OF AN ARRAY ANTENNA

This invention relates to array
antennas including phase and/or amplitude
5 control, and more particularly to such antennas
in which monopulse operation is desired,
particularly for array attitude determination.

Background of the Invention

Monopulse systems are widely used for
10 antennas, especially for the determination of
the location of a target without the
requirement for sweeping the antenna beam over
the region in which the target is located.
This is particularly advantageous in the
15 context of a radar system, in which monopulse
techniques are used to determine the location
of a target with reference to or "within" the
antenna beam. If the location of the target is
known, monopulse techniques may be used to
20 determine the pointing direction of the antenna
as a whole. In a communications context,
monopulse applied to a receive antenna can be
used to track the location of a transmitting
source. Other applications of monopulse

include tracking for missile guidance.

Basically, monopulse involves the use of overlapping squinted antenna beams (beams which have noncoincident or skew axes). The
5 amplitude or phase of the signals received from a target will differ as between the two beams, and the beams are summed and differenced to derive information about the angle of the target relative to the antenna boresight (or
10 equivalently the angle of the boresight relative to the known location of a target). The monopulse technique is not applicable to transmit antennas, because the signal produced at the overlap of the squinted beams is a sum
15 signal from which useful information is difficult or impossible to derive by a receiving probe antenna. Thus, monopulse may be easily applied to an antenna which is capable of both transmission and reception,
20 because the monopulse techniques are applied in the reception mode.

Modern active array antennas may contain unidirectional elements such as amplifiers. Active array antennas using such
25 unidirectional elements may be operable in separate transmit and receive modes, as described, for example, in U.S. Patent 5,017,927, issued May 21, 1991 in the name of Agrawal et al. Some systems, however, such as
30 communication systems in which transmission and reception must occur simultaneously, may have transmit-only active array antennas. In such

systems, it may be necessary to determine the pointing direction of the transmit array antenna. This might be the case, for example, in the context of a communication spacecraft including both transmit- and receive-only active arrays.

Allowed U.S. Patent application 08/986,611, filed December 8, 1997 in the name of Kent et al., describes a spacecraft communication system in which the spacecraft transmit antenna attitude is controlled by a closed-loop system in which sequential lobing monopulse is performed by the ground station receiving antenna, and the resulting information is uplinked to the spacecraft to effect the desired control of the transmit antenna.

Improved antenna arrangements are desired.

Summary of the Invention

In general, a method according to the invention, for generating at least mutually skewed antenna beams (which may be sum and difference beams), includes the steps of generating a signal to be transmitted, which may be a continuous-wave (CW) radio-frequency (RF) signal, and encoding the signal to be transmitted with at least first and second mutually orthogonal codes, to thereby generate at least components of first and second encoded signals. The orthogonal codes may be Hadamard codes. In the general method, the next step is

to apply the first and second encoded signals to an array antenna, for transmitting components of at least one sum and one difference beam. These components are
5 separable at a receiver by decoding the received signal with codes corresponding to the first and second mutually orthogonal codes.

In a first specific embodiment of the method, the step of encoding the signal to be
10 transmitted includes the steps of generating plural versions of the signal to be transmitted, as for example by dividing the signal in a signal splitter, and encoding each of the plural versions of the signal to be
15 transmitted with one of the first and second mutually orthogonal codes, which results in generation of the components of the first and second encoded signals. In this embodiment, the step of applying the first and second
20 encoded signals to an array antenna includes the step of combining at least some of the components of the first and second encoded signals encoded with the first code with a component of the first and second encoded
25 signals encoded with the second code, to thereby form combined coded signal components.

Each of the combined coded signal components is applied to an element of the array antenna.

In another specific embodiment of the
30 method, the step of encoding the signal to be transmitted with at least first and second mutually orthogonal codes includes the steps of

replicating the signal to be transmitted to form first and second versions of the signal to be transmitted, as in the first specific embodiment. The first version of the signal to be transmitted is encoded with first code, to thereby generate first coded signal to be transmitted. The second version of the signal to be transmitted is encoded with second code, to thereby generate second coded signal to be transmitted. Plural versions of each of the first and second coded signals to be transmitted are generated. The combination of at least one of the versions of the first coded signal and one of the versions of the second coded signal are applied to at least some elements of the array antenna.

These first two methods modulate the signals for each beam with one of the mutually orthogonal waveforms, and apply the signals so modulated through individual beamformers to the antenna array.

In a third specific embodiment of the method, the step of encoding the signal to be transmitted with at least first and second mutually orthogonal codes includes the steps of (a) generating first and second sets of beam weights, and (b) using the first and second sets of beam weights, sequentially encoding the first and second beam weights with first and second mutually orthogonal codes, to thereby generate at least first and second encoded weight sets, which are the components of first

and second encoded signals. In this third embodiment, the step of applying the first and second encoded signals to an array antenna includes the steps of (a) combining the
5 components of the first and second encoded signals, to thereby form a time-sequential set of composite sets of beam weights representing time-sequential composite beams, (b)

generating plural versions of the signal
10 to be transmitted, (c) multiplying each of the plural versions of the signal to be transmitted by one of the weights of the composite set of beam weights, to form weighted signals to be transmitted; and (d) applying the weighted
15 signals to be transmitted to the antenna elements, for transmitting components of at least one sum and one difference beam. These components are separable by decoding at the receiver with corresponding codes.

20 This third embodiment allows the Hadamard coding or other orthogonal coding to be implemented with a single beamformer, and is accomplished by calculating the beamformer phase and amplitude weights which are needed to
25 generate the two beams with mutually orthogonal modulation, and adding together those phase and amplitude weights to form a single combined set of weights. The single combined set of weights is applied to the single beamformer.

30 Brief Description of the Drawing

FIGURE 1 is a simplified illustration of a spacecraft-based communication system

similar to that in the prior art;

FIGURE 2 is a simplified block diagram of an array antenna according to an aspect of the invention, which may be used in the system of FIGURE 1, to provide a plurality of transmit beams for communication purposes, together with simultaneous monopulse operation in one plane;

FIGURE 3 is a simplified block diagram of a monopulse receiver according to an aspect of the invention, which extracts the sum and difference signals for the one plane;

FIGURE 4 is a simplified block and schematic diagram of another embodiment of the invention, in which two like versions or samples of the signal are applied to modulators; and

FIGURE 5 is a simplified block and schematic diagram of another embodiment of the invention, in which combined amplitude and phase weights representing the two modulated skewed antenna beams are calculated, and applied to the beamformer.

Description of the Invention

FIGURE 1 is a simplified illustration of a communication system 10, similar to that described in the abovementioned Kent et al. patent document. In system 10 of FIGURE 1, the spacecraft 12 includes a transmitter (TX) arrangement 12t, a receiver (RX) arrangement 12r, and a frequency-dependent channelizer 12c, which routes bands of frequencies from the

receiver 12r to the transmitter 12t.
Spacecraft 12 also includes an array of
frequency converters 12cv, which convert each
uplink frequency to an appropriate downlink
5 frequency. Spacecraft 12 includes a power
source which includes a solar panel (SP)
illustrated as 12s, and a power converter (PC)
or conditioner 12p for converting the solar
array power into power suitable for powering
10 the transmitter, receiver, and converters, and
other devices on the spacecraft, such as, for
example, attitude control systems. A
transmitting antenna 12at mounted to the
spacecraft body by a two-axis gimbal 12gt
15 generates a plurality 20 of spot beams, one or
more spot beams for each frequency band. Some
of the spot beams 20a, 20b, and 20c of set 20
are illustrated by their outlines. Each
antenna beam 20x (where x represents any
20 subscript) defines a footprint on the surface 1
of the Earth below. The footprint associated
with spot beam 20a is at the nadir 3 directly
under the spacecraft, and is designated 20af.
The footprint associated with spot beam 20c is
25 designated 20cf, and is directed toward the
horizon 5, while the footprint 20bf associated
with spot beam 20b is on a location on surface
1 which lies between nadir 3 and horizon 5. It
will be understood that those antenna beams
30 which are illustrated in "lightning bolt" form
also produce footprints. As is known to those
skilled in the art, the footprints of antenna

beams from a spacecraft may overlap (overlap not illustrated in FIGURE 1), to provide continuous coverage of the terrestrial region served by the antennas. Spacecraft body 12b
5 also carries, by way of a two-axis gimbal 12gr, a receiving antenna 12ar, which produces spot beams which are intended to be identical to those of transmitting antenna 12at.

10 Spacecraft 12 also includes a further transmit-receive antenna 72a, which produces a single, or possibly two or three, broad transmit beam(s) and corresponding receive beam(s), such as those designated as 20d and
15 20e, which are illustrated by "lightning bolt" symbols in order to simplify the drawing.

As mentioned in the Kent et al patent document, each separate antenna beam forms an
20 infinite number of more-or-less concentric "footprints" centered about the maximum-beam-intensity point on the ground, with each being a fraction of a decibel (dB) greater than the next inner footprint. When "a" footprint is
25 mentioned, a selected energy distribution across the "footprint" is assumed. Thus, a common assumption is that the beam intensity will not vary more than 3 dB across the footprint, which defines the extent of the
30 footprint by the 3dB contour of the antenna beam. Similarly, overlap of the beams is taken to mean overlap at the designated beam

intensity. It should further be noted that a receiving antenna also preferentially receives signals within a receiving "beam," and for a given antenna, the receiving "beam" is
5 "dimensionally" identical to the transmitting beam, in that it has the same beamwidth and gain.

As illustrated in FIGURE 1, a group
10 16 of mobile terrestrial user terminals or stations includes three user terminals, denominated 16a, 16b, and 16c, each of which is illustrated as having an upstanding whip
antenna 17a, 17b, and 17c, respectively. User
15 terminal 16a lies on or within the footprint 20af, user terminal 16b lies within footprint 20bf, and user terminal 16c lies within footprint 20cf. User terminals 16a, 16b, and 16c provide communications service to users, as
20 described below. Those skilled in the art will recognize that the illustration of a single user terminal in each footprint is only for ease of understanding, and that many such user terminals may be found in each footprint. More
25 particularly, each illustrated user terminal 16a represents one of a plurality of user terminals which may be found within footprint 20af, and likewise illustrated user terminals 16b and 16c each represent one of a plurality
30 of user terminals which may be found in footprints 20bf and 20cf, respectively.

FIGURE 1 also illustrates a terrestrial gateway terminal (a fixed site, tower, or station) 14, which lies in a footprint (not designated) of the (or an) antenna beam 20e. While not illustrated, it should be understood that the footprint associated with beam 20e may also contain user terminals such as 16_x. Gateway terminal 14 communicates with antenna 72a of spacecraft 12 by way of C-band electromagnetic signals transmitted from an antenna 14a1, and receives C-band signals from the spacecraft by way of the same antenna. Gateway terminal 14 is coupled by a data path 9 with a land-line network or public switched telephone system (PSTN) illustrated as a block 8, and provides communication between spacecraft cellular communications system 10 and the PSTN 8. While a single gateway 14 is illustrated, the system 10 may contain many gateways at spaced-apart locations, to allow the spacecraft communication system to access different PSTNs. The signals traversing antenna beam 20e represent information signals from the user terminals 16 to the gateway terminal 14, and information signals from the gateway to various ones of the user terminals. The information signals are designated generally as COMM.

A network control center (NCC) 18 is illustrated in FIGURE 1 as a terrestrial terminal lying in a footprint (not designated)

of antenna beam 20d, originating from antenna 72a. The footprint may also contain user terminals (not illustrated). Network control center 18 includes an antenna 18a for
5 communication with the spacecraft, and for communication by way of the spacecraft to the user terminals 16 and the gateway(s) 14. Network control center 18 also includes a GPS receiving antenna 18g for receiving global
10 positioning time signals, to provide position information and an accurate time clock. Network control center 18 performs the synchronization and TDMA slot control which the spacecraft cellular communications network
15 requires. The functions of network control center 18 may be distributed throughout the communication system 10, but unlike the arrangement of the land-based GPS cellular communication system, in which control of the slot timing is independently set at each cell
20 center or tower, there is only one network control center associated with the spacecraft communication system 10, for the required control of the time-division multiple access slots cannot be applied simply to one cell or
25 antenna beam, but rather must be applied across the entire system. While network control center 18 is illustrated in FIGURE 1 as being separate from gateway 14, those skilled in the art will recognize that the network control
30 center 18 includes functions, such as the antenna 18a, which are duplicated in the

gateway 14, and that it may make economic sense to place the network control center 18, or the portions which together make up the network control center, at the site(s) of the gateway(s) such as gateway 14, so as to reduce the overall system cost by taking advantage of the redundancies to eliminate expensive subsystems.

10 The signals traversing antenna beam 20d between NCC 18 and spacecraft 12 of FIGURE 1 represent control signals. "Forward" control signals proceed from the NCC 18 to the remainder of the communication system 10 by way of spacecraft 12, and "reverse" or "return" control signals are those which originate at terrestrial terminals other than the NCC, and which are sent to the NCC by way of the spacecraft. Forward control signals include, for example, commands from the NCC 18 to the various user terminals 16_x, indicating which slot set is to be used by each user terminal for communication, while an example of a return control signal may be, for example, requests by various user terminals 16_x for access to the communication system 10. Other control signals are required, which are known in the art. As mentioned, those control signals flowing from NCC 18 to other portions of the communication system 18 are termed "forward" control signals, while those flowing in a retrograde direction, from the communication system 10 toward the

NCC, are denominated "return" control signals.

The spacecraft 12 of FIGURE 1 may need to produce many transmitted spot beams 20 from its antennas 12at and 12ar, and the transmissions over the spot beams may require substantial electrical power, at least in part because of the relatively low gain of the simple antennas 17 of the user terminals 16. In order to reduce the power required by the transmitters in the spacecraft, the largest number of downlink frequencies, namely those used for transmissions from the spacecraft to terrestrial user terminals, are desirably within a relatively low frequency band, to take advantage of increased component efficiencies (lower component losses) at the lower frequencies. The user terminals transmit to the spacecraft at the lower frequencies, for like reasons. The transmissions to and from the spacecraft from the NCC 18 and the gateway(s) 14 may be within a higher frequency band, in part because of FCC frequency allocation considerations, and in part to take advantage of high antenna gain available at the higher frequencies from large antennas at fixed installations, such as antennas 14a1 and 18a. In a specific embodiment of the invention, the uplinks and downlinks of the NCC and the gateways by way of antenna 72a may be at C-band (frequencies at about 3400 to 6700 MHz.), while the uplinks and downlinks of the user terminals

by way of antennas 12at and 12ar are at L-band
(frequencies at about 1500-1700 MHz). Thus,
the downlink signals from transmit antenna
12at, by way of antenna beams 20a, 20b, and 20c
5 of FIGURE 1, are at frequencies within the
relatively low L-band, while the uplink and
downlink signals in antenna beams 20d and 20e
of antenna 72a are at the higher C-band. The
uplink signals from the terrestrial user
10 terminals at L-band travel on receive spot
beams (not illustrated in FIGURE 1) of
spacecraft receive antenna 12ar, which, at
least in principle, correspond exactly with
transmit beams 20a, 20b, and 20c. At the
15 distances from the Earth's surface 1 at which
geosynchronous spacecraft orbit, the distance
between the transmit and receive antennas 12at
and 12ar does not materially affect the beam
correspondence, and even at low Earth orbit, is
20 of almost no consequence.

According to an aspect of the
invention, the pointing direction of the
transmit antenna 12at of FIGURE 1 is determined
25 by a monopulse method. In general, the
invention relies on separately coding the sum
and difference beams transmitted by an antenna,
so that the received components are separable
by decoding using corresponding codes. In
30 order for the separation at the receiver to be
effective, it is desirable to use mutually
orthogonal codes, such as the Hadamard codes

described in U.S. Patent 5,572,219, issued November 5, 1996 in the name of Silverstein et al.

5 FIGURE 2 is a simplified block and schematic representation of a first embodiment of an arrangement 200 according to an aspect of the invention. In FIGURE 2, the beacon signal to be transmitted (TX) for the purpose of
10 determination or control of the attitude of the transmit antenna 12at is generated in a block 214. This beacon signal may be as simple as a continuous-wave (CW) radio-frequency (RF) signal. Those skilled in the art know that,
15 while initially the term RF referred to a specific range of frequencies, it has developed over time to refer to mean any alternating frequency above about 20 KHz and below light frequencies. The signal produced by generator
20 214 is applied to a first power divider (1X2) 216, in which the signal from generator 214 is replicated (albeit at lower power in each branch) or divided into two essentially identical portions. The two similar versions
25 of the beacon signal are applied from power divider 216 by way of signal paths 236 and 238, respectively, to the input ports of further power dividers 218a and 218b, respectively, of a set 218 of 1XN power dividers. Each of power
30 dividers 218a and 218b has N output ports, corresponding in number to the number of driven antenna elements 1, 2, 3, . . . , N of antenna

12at. Those skilled in the art know that the number of actual radiating elements of the antenna 12at may exceed the number of driven elements, in those cases in which each driven element includes plural radiating elements. For purposes of this explanation, it is assumed that a driven element of the antenna array is a single radiator. As mentioned, each power divider 218a and 218b has N output ports, and thus there are a total of 2N drive signals at the outputs of the set 218 of dividers. The output ports of power divider 218a are denominated 218a1, 218a2, 218a3, . . . 218aN, and the output ports of power divider 218b are denominated 218b1, 218b2, 218b3, . . . , 218bN. Each output port 218a1, 218a2, 218a3, . . . 218aN, 218b1, 218b2, 218b3, . . . , 218bN is coupled to a corresponding one control element of a set 220 of control elements.

More particularly, output port 218a1 of power divider 218a of FIGURE 2 is coupled to a control element 220a1, output port 218a2 of power divider 218a is coupled to a control element 220a2, output port 218a3 of power divider 218a is coupled to a control element 220a3, . . . , and output port 218aN of power divider 218a is coupled to a control element 220aN. Similarly, output port 218b1 of power divider 218b is coupled to a control element 220b1, output port 218b2 of power divider 218b is coupled to a control element 220b2, output port 218b3 of power divider 218a is coupled to

a control element 220b3, . . . , and output port 218bN of power divider 218b is coupled to a control element 220bN. As illustrated in FIGURE 2, the control elements of sets 220a and 5 220b are controllable phase shifters ($\Delta\phi$), but they could be, or include, variable attenuators or variable gain devices.

As illustrated in FIGURE 2, the control elements 218a1, 218a2, 218a3, . . . , 10 218aN, 218b1, 218b2, 218b3, . . . , 218bN of set 220 are separately grouped into subsets 220a and 220b. The control elements 218a1, 218a2, 218a3, . . . , 218aN of subset 220a are controlled simultaneously by a code signal from 15 a code 1 generator 226a, while the control elements 218b1, 218b2, 218b3, . . . , 218bN of subset 220b are controlled simultaneously by a second code signal from a code 2 generator 226b. Codes 1 and 2 produced by code 20 generators 226a and 226b, respectively, are mutually orthogonal codes. Orthogonality, for this purpose, means that the encoded signals can be transmitted simultaneously through a signal path, and the original signals can be 25 reconstituted at the output of the signal path by decoding the composite received signal separately with corresponding codes. In a preferred embodiment of the invention, the codes are Hadamard codes, corresponding to 30 those disclosed in the Hadamard codes described in the abovementioned U.S. Silverstein et al. patent, and in U.S. Patent applications

09/352,508 and 09/352,509, filed July 12, 1999.

Since the codes must be maintained in synchronism for best separability, a controller illustrated as a block 228 is provided.

5 In the arrangement of FIGURE 2, the amplitude- or phase-shifted coded versions of the beacon signal appearing at the outputs of the various control elements 218a1, 218a2, 218a3, . . . , 218aN, 218b1, 218b2, 218b3, . . . , 218bN of set 220 are applied to certain
10 input ports of the beamformers 224₁, 224₂, 224₃, . . . , 224_N of set 224 of beamformers. More particularly, the amplitude- or phase-shifted output of control element 220a1, encoded with
15 code 1, is applied by way of a signal path 222a1 to an input port 224_{1a} of beamformer 224₁, and the amplitude- or phase-shifted output of control element 220b1, encoded by code 2, is applied by way of a signal path 222b1 to an
20 input port 224_{1b}. The amplitude- or phase-shifted output of control element 220a2, encoded with code 1, is applied by way of a signal path 222a2 to an input port 224_{2a} of beamformer 224₂, and the amplitude- or phase-shifted output of control element 220b1,
25 encoded by code 2, is applied by way of a signal path 222b2 to an input port 224_{2b} of beamformer 224₂. Similarly, the amplitude- or phase-shifted output of control element 220a3,
30 encoded with code 1, is applied by way of a signal path 222a3 to an input port 224_{3a} of beamformer 224₃, and the amplitude- or phase-

shifted output of control element 220b3,
encoded by code 2, is applied by way of a
signal path 222b3 to an input port 224_{3b} of
beamformer 224₃. Other amplitude- or phase-
5 shifters (not illustrated) are similarly
connected to the various beamformers. For
completeness, the amplitude- or phase-shifted
output of control element 220aN, encoded with
code 1, is applied by way of a signal path
10 222aN to an input port 224_{Na} of beamformer 224_N,
and the amplitude- or phase-shifted output of
control element 220bN, encoded by code 2, is
applied by way of a signal path 222bN to an
input port 224_{Nb} of beamformer 224_N.

15 In addition to the two beacon signals
originating from source 214 of FIGURE 2, and
encoded with mutually orthogonal codes 1 and 2,
which are applied to the 224xa and 224xb (where
X represents the set of all numbers ranging
20 from 1 to N) ports of the beamformers of set
224 of beamformers, information signals may be
applied to sets of additional input ports of
the beamformers, designated in FIGURE 2
generally as 224_{addt1}. A separate antenna beam,
25 directed in conformance with the settings of
the phase shifters (not illustrated) associated
therewith, is formed for each set of N signals
applied to a ports of ports 224_{addt1} of set 224
of beamformers.

30 Those skilled in the art will
understand that the signals having various
phase shifts applied to the N input ports of

the beamformers of set 224 of FIGURE 2 produce a beam in a given direction, and the signals having other phase shifts applied to the N input ports of the beamformers of set 224
5 produce a beam in some other direction. Thus, different phase settings of the various pair combinations applied to the 224xa and 224xb inputs of the beamformers of set 224 will produce a pair of skew beams, each encoded with
10 one of code 1 and code 2. The two beams, as transmitted from array 212, will overlap to some degree over a broad spatial angle, and, in the overlap region, a composite beam is transmitted, consisting of beacon signal
15 originating from source 214, partially encoded by code 1, and partially by code 2. It should be further noted that the information signals also produce various beams which overlap with each other and with the two beacon beams
20 described above (in the usual system, there will be three beacon signals, to provide a sum beam and difference beams in both the vertical and horizontal directions). However, the information signals will be mutually separable
25 and separable from the beacon signals by virtue of frequency or time division multiplex; that is to say that the signals on those beams which substantially overlap will be at different frequencies, or occupy different time slots.
30 Those information signals on individual antenna beams which do not substantially overlap do not interfere anyway, so there is no need for

frequency or time separation. However, the beacon signals are on (or at) the same frequency, and occur simultaneously, so they form a composite beam which, but for the
5 orthogonal coding, would not be separable from each other.

In FIGURE 3, arrangement 200 of FIGURE 2 is illustrated in further simplified form, and is illustrated as generating a
10 composite beam 310 illustrated by an arrow symbol. A receiving arrangement 320 includes a probe antenna 322, which receives at least the composite beacon signal, and applies it to a separation arrangement 324, if needed, to
15 separate the information signals from the composite beacon signal. The separation may be accomplished in separation arrangement 324 by frequency or time separation, or both, as appropriate. The information signals are
20 routed by a path 326 to a utilization arrangement, if appropriate. The combined beacon signals are applied over a signal path 326 to a pair of multipliers 328, 330, to which are applied code 1 and code 2, respectively.
25 The product from multiplier 328 represents the first beam, and the product from multiplier 330 represents the second beam, skewed from the first beam. The two beam-representative signals are applied to the input ports of a
30 summing (+) circuit 332 and a differencing (-) circuit 334. Summing circuit 332 produces the desired sum (Σ) signal, and the differencing

circuit 334 produces the difference (Δ) signal.

Thus, monopulse operation can be achieved
"from" the transmit antenna array 212.

It is worth noting that, while
5 control of the phase shifters of set 220 of
controllers or amplitude or phase shifters of
FIGURE 1 is described as being only by the
codes, additional control may be provided for
the purpose of adjusting the controllers to
10 redirect the beams which they control. Thus,
the controllers of set 220a may be adjusted to
direct beam 1 in the desired direction or to
control its beam characteristics, independently
of the control of beam 2, which is controlled
15 by the controllers of set 220b. The codes, in
any case, are bilevel (logic 1,0; high,low, or
the like), which toggle the controllers from
one state to another. In the case of phase-
shift controllers, the phase responsive to a
20 logic 1 may be unaltered, and may be toggled by
180° in response to a logic 0 in the code. In
the case of an amplitude controller, the
amplitude may be, for example, unity or 0 dB
for a logic 1, and -10 dB for a logic 0.

25 FIGURE 4 is a simplified block and
schematic diagram of another embodiment of the
invention. In FIGURE 4, elements corresponding
to those of FIGURE 2 are designated by like
reference numerals. In FIGURE 4, the
30 orthogonal codes are not applied to the subsets
220a, 220b of control elements of set 220 of
control elements. Instead, the two like

versions or samples of the beacon signal appearing at the output ports of power divider 216 are applied to modulators. For this purpose, the signal paths 236 and 238 of FIGURE 2 are broken into two portions, so that path 236 is broken into two portions 236a and 236b, and path 238 is broken into portions 238a and 238b. In FIGURE 4, a first modulator 410 is placed between signal path portions 236a and 236b, and a second modulator 412 is placed between signal path portions 238a and 238b. Those skilled in the art of electricity and systems know that the term "between" has a meaning which is different than the physical meaning, and refers instead to its relation to the flow of current or signal, respectively. In the present context, modulator 410 processes signal leaving power splitter or divider 216 and progressing to 1XN divider 218a, and modulator 412 processes signal leaving power divider 216 and progressing to 1XN divider 218b. Code 1 is applied to modulator 410, and code 2 is applied to modulator 412. Thus the beacon signal samples are encoded with the mutually orthogonal codes 1 and 2 before application to the dividers of set 218 and the controllers of set 220, and no codes are applied in the control elements of set 220. The operation of the system is otherwise the same as that described in conjunction with FIGURE 2, and the transmitted composite signal is the same as that produced by the arrangement

of FIGURE 2. Consequently, the composite beams associated with the beacon signal produced in the arrangement of FIGURE 4 are separable by the same receiver structure described in conjunction with FIGURE 3.

Yet another embodiment of the invention applies the orthogonal codes to the computed amplitude and phase weights for the two mutually skewed beacon antenna beams, and computes the combined beam pattern resulting from the combination of the coded weights, and finally determines the amplitude and phase weights which are required to produce the combined beam pattern so determined. The amplitude and phase weights, so determined, are applied to the controllers for generating the desired beams. FIGURE 5 illustrates such a system. In FIGURE 5, a source 214 of beacon signal to be transmitted generates signal which is applied to a $1 \times N$ divider or splitter 518. The various output signals from $1 \times N$ 518 are applied to a controller designated generally as 520, which contains N separate controllers, illustrated as phase and/or amplitude controllers ($\Delta\phi$) 520₁, 520₂, . . . , 520_N. The controlled output signals from controllers 520₁, 520₂, . . . , 520_N of set 520 are applied to a particular input port of a set 524 of beamformers. For example, the output of controller 520₁ is applied to the first (upper) port of a beamformer 524₁, the output of controller 520₂ is applied to the first (upper)

port of a beamformer $524_2, \dots$, and the output of controller 520_N is applied to the first (upper) port of a beamformer 524_N . The other input ports of the beamformers of set 524 receive information signals. Each beamformer of set 524 of beamformers drives a corresponding antenna element of set 212. In particular, controller 524_1 drives antenna element 1, controller 524_2 drives antenna element 2, $\dots$, and controller 524_N drives antenna element N. Note that, in this arrangement, only one input port (the first or upper port) of the beamformers is used to generate the composite beacon signal.

Also in FIGURE 5, the controller weights for the first skew antenna beam are calculated or stored in a block 510_1 , and the controller weights for the second skew antenna beam are calculated or stored in a block 510_2 . A first modulator 512_1 modulates the first-beam weights with the first code, and a second modulator 512_2 modulates the second-beam weights with the second code, orthogonal to the first.

The coded weights for the two separate beams are applied to a processor 514, which determines the radiation pattern of the combined, coded beams, and also determines the weights required to effect the composite, coded pattern. The weights as determined in block 514 are applied by way of a driver 516 to controller set 520, for controlling the individual control elements or controllers. In

operation, the composite beam drive is applied to the single ports of the set 524 of beamformers, and the two skew beacon beams are simultaneously generated as in the arrangements of FIGURES 2 and 4. The receiver of FIGURE 3 is again useful for determining the sum and difference monopulse values in respect of FIGURE 5.

Other embodiments of the invention will be apparent to those skilled in the art. For example, while difference beams or signals have been described for only a single plane or direction of control, those skilled in the art will understand that control in two mutually orthogonal directions ("vertical" and "horizontal," for example) requires only the addition of equipments, such as beamformers, for the orthogonal direction; the two directions or planes of control are independent, and may be treated separately. Those skilled in the art also know that the terms "squinted beams" or "skewed beams" could include shaped beams as well as pencil or spot beams. While the invention is best performed with all the beams transmitted on the same frequency, the frequencies may differ, so long as the phase changes are small over the duration of interest.

In general, a method according to the invention, for generating at least sum and difference antenna beams, includes the steps of generating (214) a signal to be transmitted,

which may be a continuous-wave (CW) radio-frequency (RF) signal, and encoding the signal to be transmitted with at least first and second mutually orthogonal codes (226a, 226b),
5 to thereby generate at least components of first and second encoded signals. The orthogonal codes may be Hadamard codes. In the general method, the next step is to apply the first (226a) and second (226b) encoded signals
10 to an array antenna (12at), for transmitting components of at least two mutually skewed beams, which in an example may be one sum and one difference beam. These components are separable at a receiver (320) by decoding the
15 received signal with codes corresponding to the first and second mutually orthogonal codes.

In a first specific embodiment (200) of the method, the step of encoding the signal to be transmitted includes the steps of
20 generating plural versions of the signal to be transmitted, as for example by dividing the signal in a signal splitter (216), and

encoding each of the plural versions of the signal to be transmitted with one of the
25 first and second mutually orthogonal codes, which results in generation of the components of the first and second encoded signals. In this embodiment (200), the step of applying the first and second encoded signals to an array
30 antenna includes the step of combining (in beamformers 224) at least some of the components of the first and second encoded

signals encoded with the first code with a component of the first and second encoded signals encoded with the second code, to thereby form combined coded signal components.

5 Each of the combined coded signal components is applied to an element (1, 2, 3, . . .N) of the array antenna (212).

In another specific embodiment (400) of the method, the step of encoding the signal to be transmitted with at least first and second mutually orthogonal codes includes the steps of replicating (in divider 216) the signal to be transmitted to form first and second versions of the signal to be transmitted, as in the first specific embodiment. The first version of the signal to be transmitted (on path 236a) is encoded with the first code, to thereby generate (on path 236b) first coded signal to be transmitted.

10 The second version of the signal to be transmitted (on path 238a) is encoded with second code, to thereby generate (on path 238b) second coded signal to be transmitted. Plural versions of each of the first and second coded signals to be transmitted are generated (218a, 218b). The combination of at least one of the versions of the first coded signal (on path 222a1, for example) and one of the versions of the second coded signal (on path 222b1, for example) are applied (by way of a beamformer of set 224) to at least some elements (element 1, for example) of the array antenna (212).

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In a third specific embodiment (500) of the method, the step of encoding the signal to be transmitted with at least first and second mutually orthogonal codes includes the steps of (a) generating first (510₁) and second (510₂) sets of beam weights, and (b) using the first and second sets of beam weights, sequentially encoding (512_{1,2}) the first and second beam weights with first (code 1) and second (code 2) mutually orthogonal codes, to thereby generate at least first and second encoded weight sets, which are the components of first and second encoded signals. In this third embodiment (500), the step of applying the first and second encoded signals to an array antenna includes the steps of (a) combining (514) the components of the first and second encoded signals, to thereby form a time-sequential set of composite sets of beam weights representing time-sequential composite beams, (b) generating (518) plural versions of the signal to be transmitted, (c) multiplying (520₁, 520₂, . . . , 520_N) each of the plural versions of the signal to be transmitted by one of the weights of the composite set of beam weights, to form weighted signals to be transmitted; and (d) applying (by way of the beamformers) the weighted signals to be transmitted to the antenna elements, for transmitting (combined) components of at least one sum and one difference beam. These components are separable by decoding at the

receiver with corresponding codes.

WHAT IS CLAIMED IS:

1. A method for generating at least sum and difference antenna beams, said method comprising the steps of:

5 generating a signal to be transmitted:

encoding said signal to be transmitted with at least first and second mutually orthogonal codes, to thereby generate at least components of first and second encoded signals; and

10

applying said first and second encoded signals to an array antenna, for transmitting components of at least two mutually skewed beams, which components are separable by decoding with codes corresponding to said first and second mutually orthogonal codes.

15

2. A method according to claim 1, wherein said step of applying said first and second encoded signals to an array antenna, for transmitting components of at least two mutually skewed beams, includes the step of applying said first and second encoded signals to an array antenna, for transmitting components of at least one sum and one difference beam.

5

3. A method according to claim 1, wherein said step of encoding said signal to be transmitted includes the steps of:

5 generating plural versions of said
signal to be transmitted; and
 encoding each of said plural versions
of said signal to be transmitted with one of
said first and second mutually orthogonal
codes, to thereby generate components of said
10 first and second encoded signals.

4. A method according to claim 3,
wherein said step of applying said first and
second encoded signals to an array antenna
includes the step of:

5 combining at least some of said
components of said first and second encoded
signals encoded with said first code with a
component of said first and second encoded
signals encoded with said second code, to
10 thereby form combined coded signal components;
and

 applying each of said combined coded
signal components to an element of said array
antenna.

5. A method according to claim 1,
wherein said step of encoding said signal to be
transmitted with at least first and second
mutually orthogonal codes comprises the steps
5 of:

 replicating said signal to be
transmitted to form first and second versions
of said signal to be transmitted;

 encoding said first version of said

10 signal to be transmitted with said first code
to generate first coded signal to be
transmitted;

encoding said second version of said
signal to be transmitted with said second code
15 to generate second coded signal to be
transmitted;

generating plural versions of each of
said first and second coded signals to be
transmitted; and

20 applying to at least some elements of
said array antenna the combination of at least
one of said versions of said first coded signal
and one of said versions of said second coded
signal.

6. A method according to claim 1,
wherein:

said step of encoding said signal to
be transmitted with at least first and second
5 mutually orthogonal codes, includes the steps
of

(a) generating first and second sets
of beam weights;

(b) using said first and second sets
10 of beam weights, sequentially encoding said
first and second beam weights with first and
second mutually orthogonal codes, to thereby
generate at least first and second encoded
weight sets, which are said components of first
15 and second encoded signals; and

said step of applying said first and

second encoded signals to an array antenna includes the steps of

20 (a) combining said components of said first and second encoded signals, to thereby form a time-sequential set of composite sets of beam weights representing time-sequential composite beams;

25 (b) generating plural versions of said signal to be transmitted;

(c) multiplying each of said plural versions of said signal to be transmitted by one of said weights of said composite set of beam weights, to form weighted signals to be transmitted; and

30 (d) applying said weighted signals to be transmitted to said antenna elements, for transmitting components of at least one sum and one difference beam, which components are separable by decoding with corresponding codes.

7. A method for generating at least sum and difference antenna beams, said method comprising the steps of:

5 generating two separate versions of a signal to be transmitted:

encoding each of said separate versions of said signal with first and second mutually orthogonal codes, to thereby generate first and second encoded signals, respectively:

10 applying said first encoded signal to a sum port of a beamformer of an array antenna, for thereby generating a sum beam; and

applying said second encoded signal
to a difference port of said beamformer of said
array antenna, for thereby generating a
15 difference beam occurring simultaneously with
said sum beam, whereby a combined beam is
transmitted, and whereby said signal in said
sum beam may be separated from said combined
20 beams by decoding with said first orthogonal
code, and said difference beam may be separated
from said combined beam by decoding with said
second orthogonal code.

8. A method according to claim 7,
further comprising the steps of:

generating a further version of said
signal to be transmitted:

5 encoding said further version of said
signal to be transmitted with a third code,
orthogonal to said first and second codes, to
thereby generate a third encoded signal;

10 applying said third encoded signal to
a further difference port of said beamformer of
said array antenna, for thereby generating a
second difference beam simultaneously with said
sum beam and in a different spatial plane,
whereby said combined beam as transmitted
15 includes said second difference beam, and
whereby said second difference beam may be
separated from other beams of said antenna by
decoding with said third code.

9. A method according to claim 7,

wherein said step of generating a sum and a difference beam includes the steps of generating first and second mutually skewed beams, and subtracting said second beam from said first beam.

10. A method according to claim 7, wherein said step of generating a difference beam includes the steps of generating a second beam phased so as to generate a null on the axis of said sum beam.

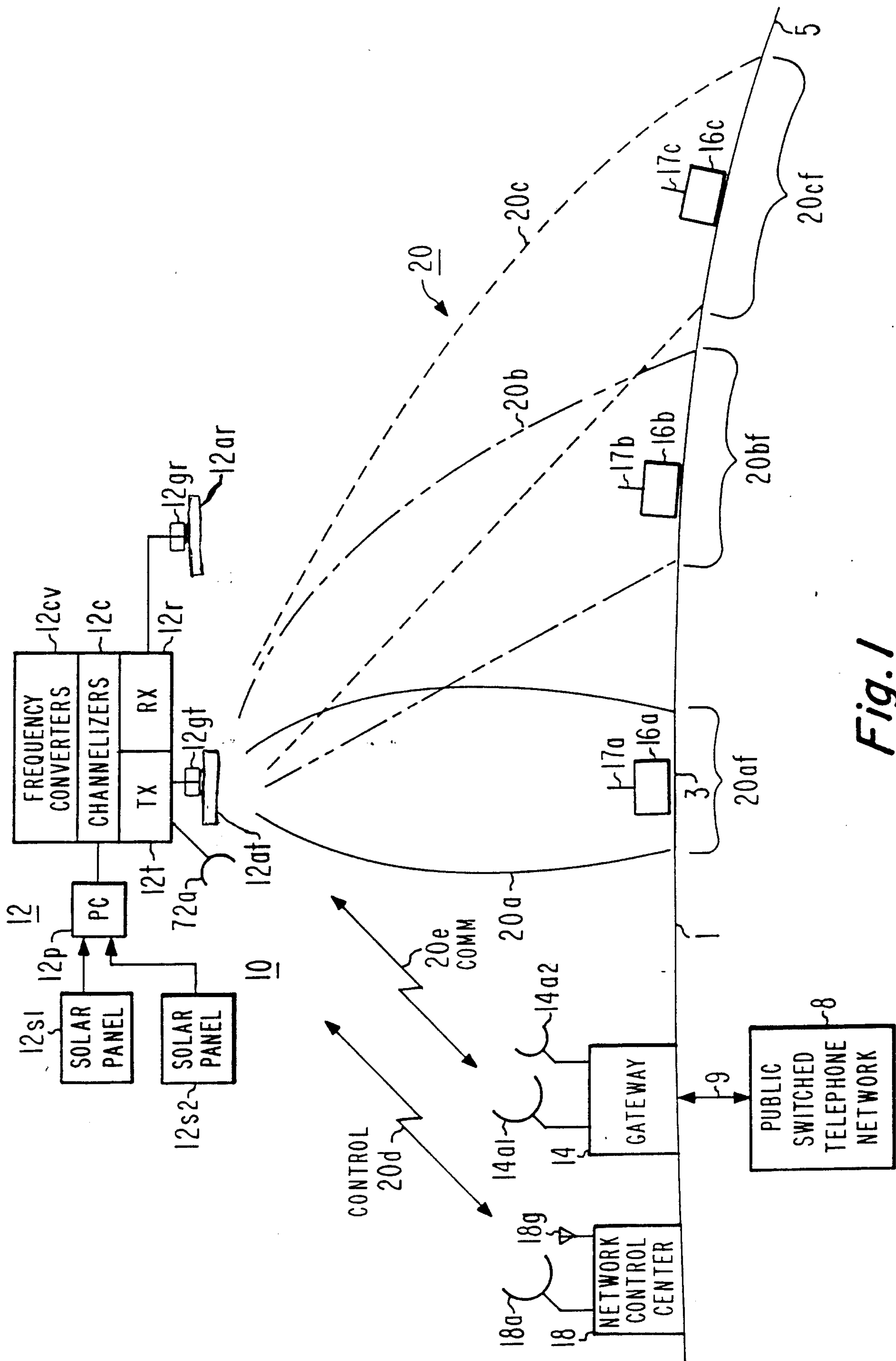


Fig. 1

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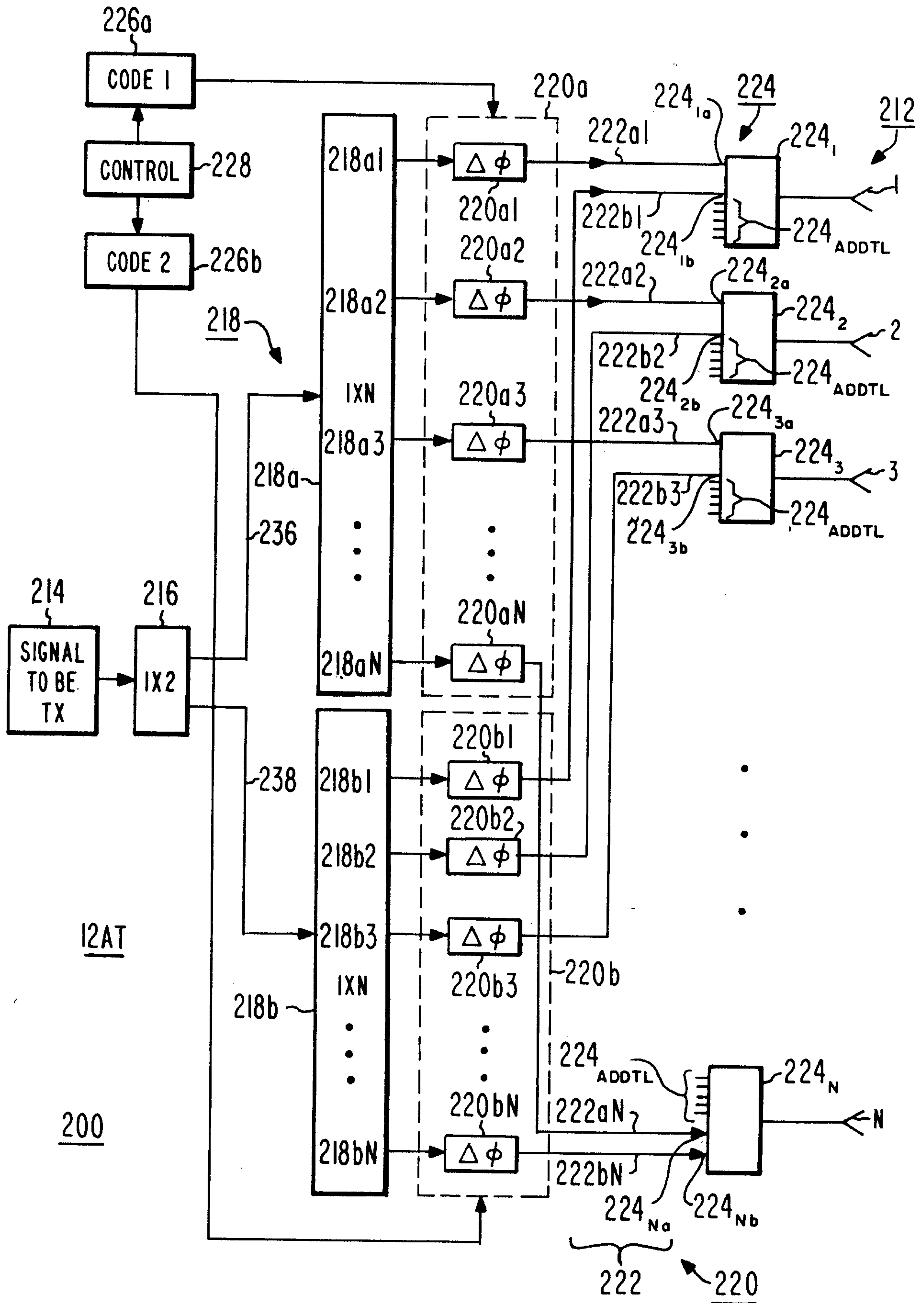


Fig. 2

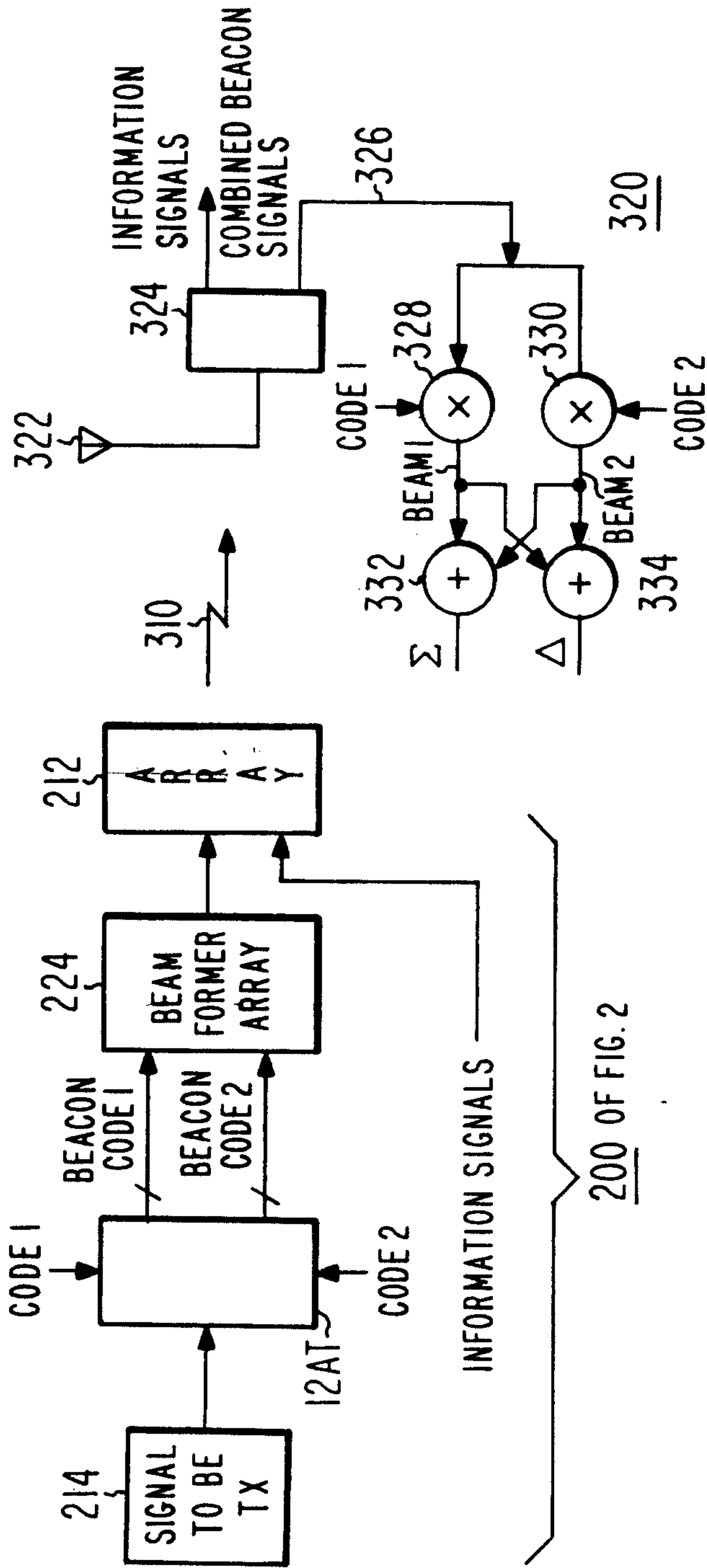
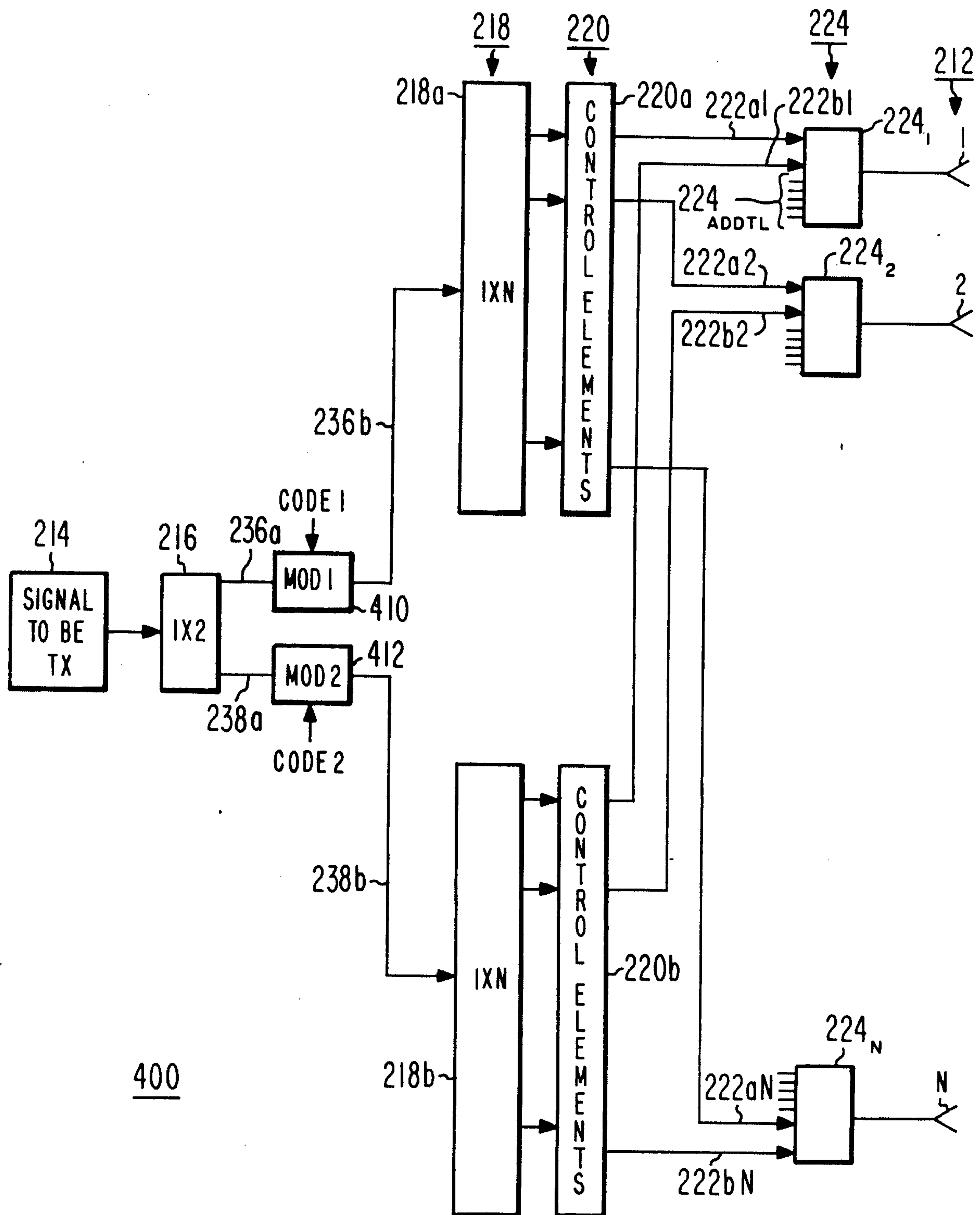


Fig. 3

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*Fig. 4*

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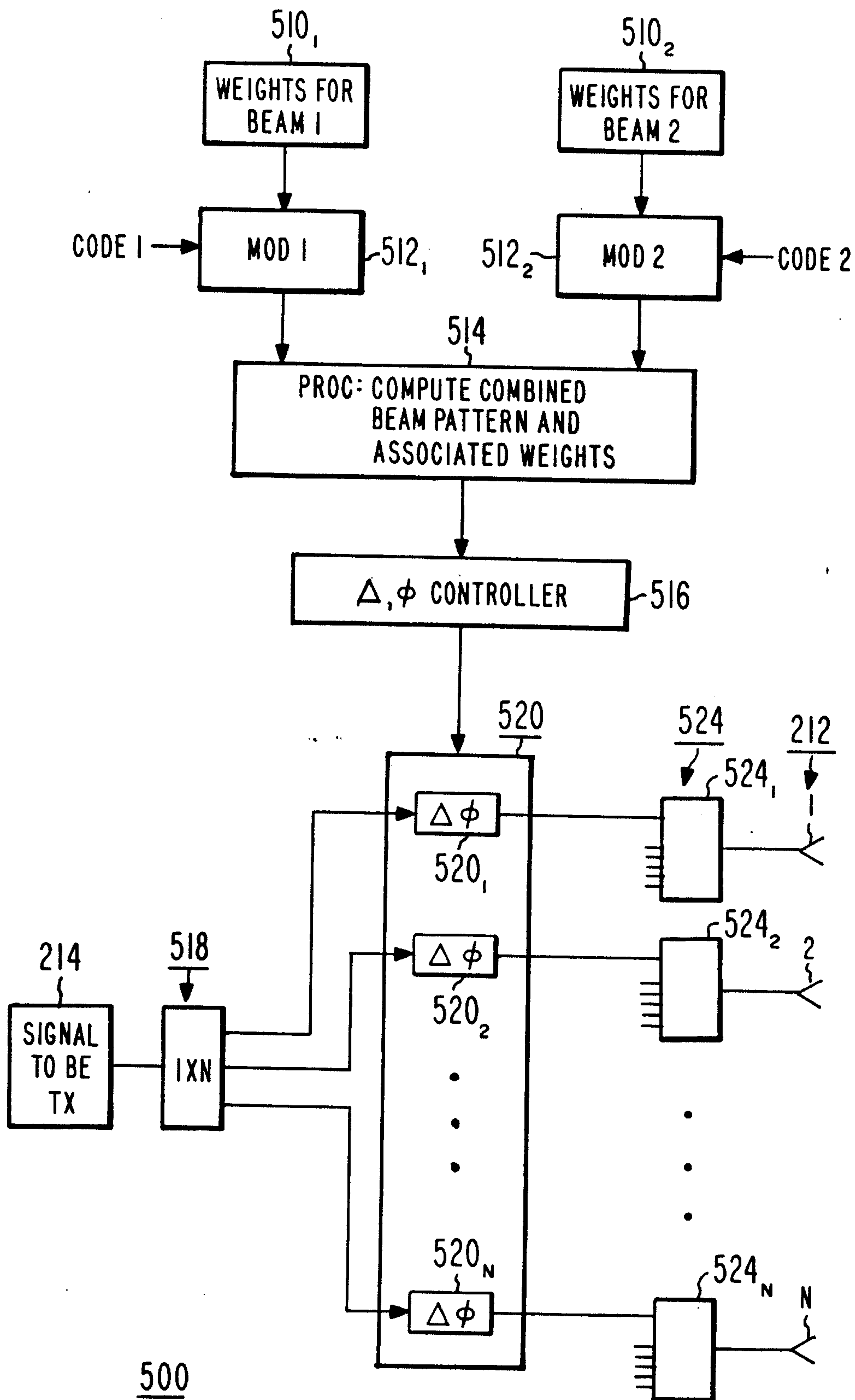


Fig. 5

