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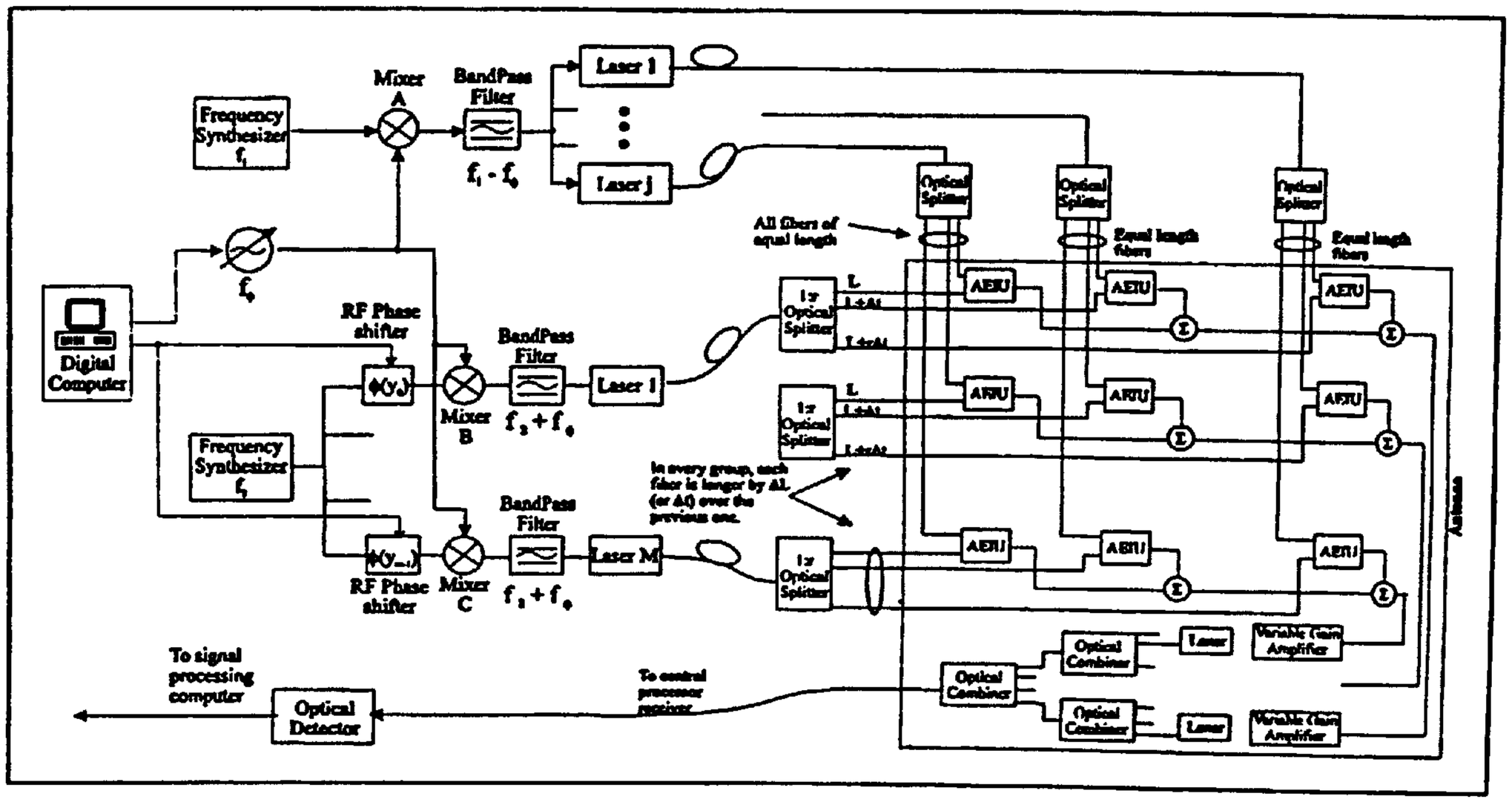

(57) Abrégé/Abstract:
Optical control of array antennas in a radar and communication application is described. The opto-electronic architecture simplifies the antenna element interface unit (AEIU) by executing the phase control function in a central processor unit, thus lowering the fabrication cost, and providing greater stability of the phase control. This architecture further eliminates the need for a distribution network for the phase control information. Dynamic amplitude control is performed in a specific number of locations. Signal distribution is done through a fiber-optic network allowing a more flexible and lighter distribution network with lower propagation loss and immunity to electromagnetic interference.

Abstract of the Disclosure

Optical control of array antennas in a radar and communication application is described. The opto-electronic architecture simplifies the antenna element interface unit (AEIU) by executing the phase control function in a central processor unit, thus lowering the fabrication cost, and providing greater stability of the phase control. This architecture further eliminates the need for a distribution network for the phase control information. Dynamic amplitude control is performed in a specific number of locations. Signal distribution is done through a fiber-optic network allowing a more flexible and lighter distribution network with lower propagation loss and immunity to electromagnetic interference.

DESIGN OF AN ELECTRONIC BEAM FORMING NETWORK FOR PHASED ARRAY APPLICATIONS

Field of the Invention:

This invention relates generally to controlling a beam transmitted from a phased array antenna and more particularly to reducing the complexity of the circuitry for controlling such a beam.

Background of the Invention:

Phased array antennas are in development for many radar and communication applications. Some current work in the field of phased array antenna design is outlined in R.obert J. Mailloux, "Antennas and Radar", Microwave Journal, March 1987, pp.28-33, Eli Brookner, "Array Radars: An Update Part II", Microwave Journal, March 1987, pp.167-174, and Farzin Lalezari, Theresa C. Boone, J. Mark Rogers, "Planar millimeter-wave arrays", Microwave Journal, April 1991, pp.85-92. Phased array antennas offer several advantages over conventional antennas. For example, beam steering is possible without any mechanical movement of an antenna, side-lobe cancellation is achievable electronically, two-dimensional scanning becomes more flexible, power consumption can be reduced, and phased array antennas have a much higher protection against catastrophic failure. However, the large number of transmit/receive modules - in the order of 10,000 in some cases - forming these phased array antennas presents some demanding requirements. The signal distribution to and from each antenna element creates formidable topology, EMI, and crosstalk problems. These problems are discussed by H. Wong, S.S. Chang, and T.Q. Ho in "Signal Distribution techniques for active phased-array antennas", Microwave Journal, June 1991 pp. 147-154. The phase and amplitude control of the signals for each element, is not a trivial matter as discussed by T.C. Cheston in "Beam steering of planar phased array", Proceedings of the 1970 phased array antenna symposium, pp. 219-221.

In current phased array antennas, phase and amplitude control of the transmit or receive signals for beam steering and beam nulling is done at the antenna element according to a control signal sent by a central processor. This approach presents a number of drawbacks. First, for an M•N element array, M•N phase and amplitude shifters are

required. Second, the two most critical functions of beam forming, viz. phase and amplitude control, are maintained at the antenna element. Knowing that the performances of phase shifters and variable amplifiers vary with temperature, sophisticated feedback circuitry must be included at each antenna element increasing fabrication costs. Third, RF signals and control signals are distributed to each antenna element rendering the distribution network complex.

In an attempt to overcome these limitations, a number of methods have evolved for beam steering. In "Introduction to radar system", McGraw-Hill, 1962, p.311, M. Skolnik proposes a method of RF frequency scanning where, by changing the transmit frequency, the output beam would be steered because of path delay in the distribution network. Skolnik indicated how the method could be extended to two dimensions. The method however, requires large bandwidth and output frequencies are dependent on the beam position.

In "Optical beam forming techniques for phased-array antennas", Microwave Journal, July 92, pp. 74-83, A. Seeds proposes a modification to the method of Skolnik, by providing an additional signal, which, when mixed with a first signal, removes the frequency shift created for beam steering. The method is proposed for a one-dimensional array and for the transmit mode of a radar application. The method makes use of optical fibres of known lengths for generating path delays.

It is an object of the invention to reduce the number of required phase shifters and required control lines and therefore in fabrication cost for a phased array antenna.

Summary of the Invention:

In accordance with the invention there is provided a method of controlling a transmit beam of a phased array antenna comprising the steps of: (a) digitally computing on a computer phase and amplitude information of RF signals required at a plurality of phased array elements of the antenna to obtain a desired beam shape in a desired direction; (b) applying to the RF signals information related to the digitally computed phase and amplitude information; (c) converting the RF signals to optical signals; (d) distribute the optical signals to interface units of the antenna elements; (e) converting the distributed optical signals to electrical signals; and (f) radiating the electrical signals at the elements.

In accordance with the invention there is further provided a method of controlling a phased array antenna to receive a beam comprising the steps of: (a) digitally computing on a computer phase and amplitude information of RF signals required at a plurality of phased array elements of the antenna to obtain a desired beam shape in a desired direction; (b) applying to the RF signals information related to the digitally computed phase and amplitude information; (c) converting the RF signals to optical signals; (d) distribute the optical signals to interface units of the antenna elements; (e) converting the distributed optical signals to electrical signals; and (f) utilizing the electrical signals as a local oscillator to downconvert the received signal to an intermediate frequency that corresponds in phase to the information computed in step (a).

In accordance with the invention there is further provided a phased array antenna having a plurality of antenna elements disposed in a predetermined pattern for radiating first RF signals having relative phase and amplitude characteristics and formed by a combination of second signals provided thereto, a method of controlling a beam comprising the steps of: (a) digitally computing the phase and amplitude characteristics of the first RF signals required at some phased array antenna elements, using a processor; (b) digitally computing, for each of some phased array antenna elements, characteristics of a plurality of second signals and associating said second signals with said phased array antenna element of said some phased array antenna elements wherein a combination of some of the plurality of second signals at an associated phased array antenna element results in substantially an approximation of the required first RF signal of step (a) and wherein some of the second signals associated with a phased array antenna element are substantially the same as second signals associated with other phased array antenna elements; (c) generating the plurality of associated second signals with characteristics computed in step (b) for some phased array antenna elements; (d) providing to some phased array antenna elements the generated second signals for said phased array antenna elements; and (e) from said phased array antenna elements, radiating an RF signal in dependence upon a combination of the generated second signals provided thereto.

In accordance with an embodiment of the invention there is provided a phased array antenna having a plurality of antenna elements disposed in a predetermined pattern for receiving first RF signals having relative phase and amplitude characteristics, a method of controlling a beam comprising the steps of: (a) digitally computing the phase and amplitude characteristics of the first RF signals for reception by some phased array

antenna elements, using a processor; (b) digitally computing, for each of some phased array antenna elements, characteristics of a plurality of second signals and associating said second signals with said phased array antenna element of said some phased array antenna elements wherein a combination of some of the plurality of second signals at an associated phased array antenna element results in substantially an approximation of the required first RF signal for reception as computed in step (a) and wherein some of the second signals associated with a phased array antenna element are substantially the same as second signals associated with other phased array antenna elements; (c) generating the plurality of associated second signals with characteristics computed in step (b) for some phased array antenna elements; (d) providing to some phased array antenna elements the generated second signals for said phased array antenna elements; and (e) filtering signals received by said phased array antenna elements in dependence upon a combination of the generated second signals provided thereto.

In accordance with another embodiment of the invention there is provided a phased array antenna comprising: a plurality of antenna elements disposed in a predetermined pattern for radiating first RF signals having relative phase and amplitude characteristics and formed by a combination of second signals provided thereto; means for digitally computing the phase and amplitude characteristics of the first RF signals required at some phased array antenna elements; means for digitally computing, for each of some phased array antenna elements, characteristics of a plurality of second signals and associating said second signals with said phased array antenna element of said some phased array antenna elements wherein a combination of some of the plurality of second signals at an associated phased array antenna element results in substantially an approximation of the required first RF signal as computed in step (a) and wherein some of the second signals associated with a phased array antenna element are substantially the same as second signals associated with other phased array antenna elements; means for generating the plurality of associated second signals; means for providing to some phased array antenna elements the generated second signals associated with said phased array antenna elements; means for combining the generated second signals; and means for radiating, from said phased array antenna elements, an RF signal in dependence upon a combination of the generated second signals provided thereto.

Brief Description of the Drawings:

Exemplary embodiments of the invention will now be described in accordance with the drawings in which:

Fig. 1 is a graphical presentation of the general geometry showing numeric symbols used within the application.

Fig. 2 shows an overall schematic diagram of an optically control array for radar applications;

Fig. 3 presents a schematic diagram of a central processor unit for radar applications;

Fig. 4 shows a schematic diagram of an optical signal distribution network;

Fig. 5 presents a schematic diagram of an antenna element interface unit for radar applications;

Fig. 6 shows a schematic diagram of an architecture for a central processor and distribution functions for communications applications with a distribution network similar to the one shown in Fig. 2; and

Fig. 7 presents a schematic of an antenna element interface unit for communications applications.

Detailed Description of the Invention

The present invention describes an improved method of controlling beams in a phased array antenna implementation wherein the array has N rows and M columns. An opto-electronic architecture is described that allows for beam stirring with fewer than N•M phase shifters as are used in the prior art. The opto-electronic architecture simplifies the antenna element interface unit (AEIU) by executing the phase control function in a central processor unit and hence lowering the fabrication cost and providing greater stability of the phase control. Dynamic amplitude control is performed in a specific number of locations.

1. SYSTEM DESCRIPTION

Fig. 1 shows a graphical presentation of the general geometry showing numeric symbols used within equation (1). An N•M array of elements 100 at a plane of an antenna is shown. A field at element (n, m) located at (x_n, y_m), has phase $\phi(x_n, y_m)$ and amplitude $A_{n,m}$. A far field pattern of this two-dimensional array antenna in a direction (α,β) is expressed as:

$$E(\alpha,\beta) = \sum_{n=1}^{N} \sum_{m=1}^{M} A_{n,m} e^{j(2\pi ft - \frac{2\pi}{\lambda} \sin\beta[x_n \cos\alpha + y_m \sin\alpha] + \phi(x_n, y_m))} \quad (1)$$

where;

	a	angle of far field point measured from the z-axis in the x-z plane (azimuth angle, taken from antenna plane),
	b	angle of far field point measured from the y-axis in the y-z plane (elevation angle from the normal to the antenna plane),
	λ	RF mid-band free space wavelength,
	X_n	along track coordinate of antenna element (n,m)
	N	number of columns in the antenna,
	y_m	across track coordinate of antenna element (n,m),
	M	number of rows in the antenna,
	ω	angular frequency of operation (=2πf),
	$\phi(x_n,y_m)$	phase weight applied to element (n,m),
	$A_{n,m}$	amplitude weight applied to element (n,m)
	n	element number in x-dimension (row number) ranging from 0 to N-1
	m	element number in y-dimension (column number) ranging from 0 to M-1
	f	frequency of operation (f = c/λ)
	c	velocity of electromagnetic wave

From equation (1) it is seen that the phase weight, $\phi(x_n,y_m)$, which must be applied to the element (n.m), to have a single beam in the direction of α and β is mathematically represented by the sum of two phase weights; one defined by the element position along track (x_n) and the other one by its position across track (y_m):

$$\phi(x_n, y_m) = \phi(x_n) + \phi(y_m) \qquad (2)$$

wherein

$$\phi(x_n) = \frac{2\pi}{\lambda}\sin\beta x_n \cos\alpha \quad \text{(along track)} \qquad (3)$$

$$\phi(y_m) = \frac{2\pi}{\lambda}\sin\beta y_m \sin\alpha \quad \text{(across track)} \qquad (4)$$

Thus, phases for a two-dimensional array are separable into x_n and y_m. Equation (2) expresses that if beam shaping is not needed, no more than one phase shifter per row and one per column is needed to steer a beam into a direction defined by (α,β). This means that only (*M*+*N*) phase shifters are needed instead of (*M*•*N*) according to the prior art, where N is the number of rows and M the number of columns in the antenna. Further simplification can be achieved by taking advantage of the linear progression of the phase shifts. The separate phases are linearly proportional to the co-ordinates x_n and y_m. The separated signals are described below with reference to a signal in a first direction or dimension, and a signal in a second direction or dimension. It will be apparent to one of skill in the art, that further directions of dimensions are employed when RF signals are separated into more than 2 component signals. As will be shown hereafter, only M RF phase shifters could be used.

Beam steering to the direction (α, β) is accomplished on either transmit or receive by applying appropriate phase shifts $\phi(x_n, y_m)$ to a received or transmitted signal. Using a brute force method and according to the prior art, all N•M elements are provided with a phase shifter to set phase shifts, $\phi(x_n, y_m)$. Similarly, beam shaping is accomplished by appropriately applying amplitude weights, $A_{n,m}$. In most radar applications and in a number of communication systems, in order to maximize the transmit output power, amplitude control is done only on the received signal. Moreover, the amplitude control is

often fixed in one direction (say along track)and dynamically varied in the other direction. If this is the case, it may be wise to "hardwire" one set of amplifiers (along track) and address only M variable amplifiers, i.e. one per row, instead of one per element. If amplitude control can not be separated into along track (x_n) and across track (y_m) settings, variable amplifiers, or attenuators, will be required for every element, with the corresponding distribution network.

Skolnik (in "Introduction to Radar Systems", M. Skolnik McGraw-Hill 1962 - pp. 310-320) proposed an RF frequency scanning technique whereby changing the transmit frequency, the output beam would be steered because of path delay in the distribution network. His method however, required large bandwidth and the output frequency would be dependent on the beam position. Seeds in "Optical Beamforming Techniques for Phased Array Antennas", Alwyn Seeds Microwave Journal, July 1992 - pp. 74-83, proposed a modification to the approach of Skolnik by adding a second signal, which, when mixed to the first one, at the antenna element, would remove the frequency shift created for beam steering. Seed's proposal dealt only with a one-dimensional array and was described only for the transmit mode of a radar application.

In accordance with the present invention, the transmit and receive modes for both radar and communication applications are described for a two-dimension array antenna. Figs. 2 to 5 give the schematic diagrams of a system in accordance with the present invention for a radar application while Figs. 6 and 7 present schematic diagrams dealing with a communication system. Fig. 2 shows an overall schematic of an optically controlled array antenna for a radar application. It shows the controller section and the distribution network to the antenna elements. Figs. 3 to 7 expands for both applications. Figs. 3 and 6 show the diagram of a central processor unit, for radar and communication respectively, where the amplitude and phase weights are computed, and where most of the signal conditioning is done (i.e. application of the phase and amplitude weights to the RF signals and the RF-to-optics and optics-to-RF interfaces) for the radar and communication application respectively. Fig. 4 shows the schematic of a signal distribution network along with an amplitude conditioning group for both applications. Figs 5 and 7 show the proposed antenna element interface unit (AEIU).

2. RADAR APPLICATIONS

Fig. 2 shows an overall schematic diagram of a proposed architecture. Figs. 3, 4 and 5 expand on the different functions: central processor controller, signal distribution, and antenna element.

2.1 Central Processor Controller

The central processor (Fig. 3) for a radar application is responsible for the computation of the required amplitude and phase of the RF signals, the application of phase settings on the RF signals and to provide the RF-to-optics conversion on transmit and the optics to RF conversion on receive.

Three RF frequencies need to be synthesized (Fig. 2). A first frequency $f1$, serves as a frequency reference. A second frequency, $f2$, ($f1 + f2$ equals the frequency of operation) carries the across-track phase information. The third frequency f_ϕ, as will be seen, defines the along track phase settings. The frequency f_ϕ, is mixed with f_1 and f_2 in conventional frequency mixers. The lower sideband, $f_1 - f_\phi$, produced at mixers A, and the upper sideband $f_2 + f_\phi$, produced at mixers B, are kept. Alternatively, the other sidebands could also be used. Those two frequencies are converted to the optical domain by modulating the intensity of a laser source. For example, direct modulation of laser diodes (Fig. 3) or external modulators can be used. The number of lasers, j, required to carry frequency $(f_1 - f_\phi)$, to every antenna element depends on a power budget. The number of lasers required to carry frequency $(f_2 - f_\phi)$, equals the number of rows N in the antenna if direct modulation is used or depends on the power budget if external modulation is used. Those two frequencies are then carried to the antenna elements via a fibre optic link. At the antenna elements, they are mixed at mixer C, and the sum frequency, at $f_1 + f_2$, is filtered by the bandpass filter (Fig. 5).

The across track phase shifts, $\phi(y_m)$, are applied to frequency, f_2, through M conventional RF phase shifters, $\phi(y_i)$, one per row of the antenna. Alternatively, the phase shifters, $\phi(y_o)$ to $\phi(y_{m-1})$ are replaced by optical time delays to make the across-track beam steering

frequency independent. The along track phase settings $\phi(x_n)$, are based on the value of f_ϕ, and are done using a differential delay network.

Alternatively optical heterodyne techniques are used to generate frequencies f_1 and f_2 allowing optical phase shifters to be used instead of conventional RF ones.

2.2 Distribution Network

As shown in Fig. 4, the along track frequency, (f_1-f_ϕ), is distributed to every antenna element in a parallel fashion, that is every signal arrives in phase at every element. In accordance with an embodiment of the invention, a most practical mean of achieving this is by using a fibre optic distribution network. A waveguide approach would be much too complex to implement. The across track frequency, (f_2+f_ϕ), is distributed sequentially in each row, with a delay of Δt between each antenna element. Equation 5, giving the phase weight of an element (m,n), may then be rewritten as:

$$\phi(x_n, y_m) = \phi(y_m) + 2\pi(n-1)\Delta t(f_2 + f_\phi) \text{ radians} \qquad (5)$$

Δt is related to a path length difference, Δl, through a relation $\Delta t = \Delta l * \eta/c$ where η is the refractive index of the fiber optic and c is the light velocity. The Δl is implemented by incremental increases in fiber length as seen in Fig. 4. It is shown that if $\Delta t = k / f_2$ where k is an integer, the frequency f_ϕ required to position the beam in the α,β direction is given by:

$$f_\phi = f_2\left(\frac{d}{\lambda_0 k}\right)\sin\beta\cos\alpha \qquad (6)$$

where *d* is the physical antenna element spacing in the along track dimension and λ the free space wavelength of f_1+f_2. The path length difference, between adjacent elements in a row is then taken as $\Delta l = k\,(c/\eta f_2)$.

It is worth noting that in a frequency agile system, the presented beam forming network (BFN) is easily made frequency independent by changing the frequency f_ϕ as the frequency f_1 is varied while the frequency f_2 remains fixed. In this case, the M RF phase shifters also need to be re-addressed but since M is usually small, this is easily done.

2.3 Antenna Element

Fig. 5 gives the schematic diagram of the AEIU. Under this configuration, the same BFN is used for both the transmit and receive signals. Each antenna element receives, from the processor unit, two optical signals corresponding to the along track and across track information. Those optical signals are converted to the electrical domain by optical detectors. The desired RF signal, with proper phase, is obtained by mixing the two detected optical signals and filtering the desired sideband (f_1+f_2). During transmission, the RF switch directs the frequency towards the power amplifier and the radiating element. During reception, the switch directs that frequency towards the local oscillator (LO) port of a front end mixer. The received signal, through a circulator, is fed to the RF port of this mixer. Consequently, out of the intermediate frequency (IF) port (Fig. 5), is a signal at the difference frequency with a phase equal to the difference between the phase of the LO and RF signals. Along track amplitude control may then be done. Since the signals of every element are in phase, they may be added together as shown in Fig. 5. Moreover, the resulting signal is at an IF level, rendering its distribution back to the central processor even easier.

3. COMMUNICATION APPLICATIONS

3.1 Central Processor Controller

In some communications applications, the phased array would be expected to transmit and receive simultaneously. Therefore the radar architecture described above would not be acceptable. Moreover, since in satellite communications, the transmit and receive links are done at two different frequencies, the phase and amplitude weights required for beam steering must also be different, as shown from equation 1. Two steering processors must then be implemented. However, for applications where only one beam is required at any time, and when beam shaping is not needed, the functions described in the radar

application can still be used. Phase shifts can be broken down in two separate sections: along track and across track and differential time delays can still be used.

Fig. 6 shows the architecture for simultaneous transmit and receive for a communications application. If only one of the two function is needed, then the configuration would be correspondingly simplified. The information to be transmitted is embedded on an RF carrier at frequency f_1. This carrier is mixed with a signal $f_{\phi t}$ which, as in the radar application, provides the along track phase steering for transmission. For the receive mode, another RF signal, at frequency f_3, is used. This signal is mixed with f_r to provide the along track phase shift for the receive mode. The across track phase is applied using conventional RF phase shifters on a carrier of frequency f_2. Two sets of phase shifters are required, one for the transmit beam ϕ_{tm} and one for the receive beam ϕ_{rm}. The frequency f_1 phase weighted with $\phi_{tm,}$ is mixed the frequency $f_{\phi t}$, filtered to keep the one of the sideband and converted to optics using laser at wavelength λ_1. The frequency f_2, phase weighted with ϕ_{rm}, is mixed the frequency $f_{\phi r}$, filtered to keep the one of the sideband and converted to optics using laser at wavelength λ_2. Those two modulated optical signals are combined using a wavelength division multiplexing (WDM) combiner and are distributed to the antenna elements using the same distribution network as with the radar application.

If multiple beams are required, one controller per beam is needed. However, since such a controller is relatively compact, this should not be a problem.

3.2 Distribution Network

This distribution network could be similar to the one proposed for the radar application if wavelength division multiplexing (WDM) is used. Otherwise four optical fibres would be needed per antenna element. Consequently, two sets of lasers, at different wavelengths, are required as shown in Fig. 6.

The optical approach is best suited for multiple beam application since the same distribution network can carry the information of every controller described above. Wavelength division multiplexing could easily be used and the size and weight of the distribution network would not increase.

3.3 Antenna Element

In the AEIU, the four signals now have to be split and mixed accordingly. As shown in Fig. 7, wavelength demultiplexers are used and the signals associated with the transmit mode are mixed together, filtered, amplified and radiated. The two signals associated with the receive mode are also mixed and filtered but are used as the local oscillator of a mixer to downconvert the received signal. The intermediate frequency generated is filtered and carried back to the central processor in a similar approach than with the radar application.

4. CONCLUSION

In accordance with the present invention, a novel architecture for the optical control of array antennas in a radar and a communication application is described. The architecture could readily be implemented with today's technology. The present invention has several advantages over conventional RF techniques described in the prior art references. First, the present invention simplifies the AEIU by executing the phase control function in the central processor unit. This lowers the fabrication cost of the element, allows better stability of the phase control and eliminates the need for a distribution network for the phase control information. Second, phase control is greatly simplified from the use of a frequency synthesis and a differential delay line approach. Third, the received signal is downconverted at the antenna element, which allows an improvement in the signal-to-noise ratio and dynamic range while reducing the complexity of the distribution network for the returned path. Fourth, the received signals, being downconverted and phased properly at the antenna elements, are added together, offering "free" gain. Fifth, the distribution network is based on fiber optics, allowing a more flexible network than with conventional RF waveguides. Sixth, the number of phase shifters is reduced from one per element to one per row with the addition of a frequency synthesizer.

5. ADVANTAGES

1. Phase control function is done in the central processor unit. This lowers the fabrication cost of the element, allows better stability of the phase control and eliminates the need for a distribution network for the phase

control information.

2. Phase control is done using a combination of conventional RF phase shifters, and with the use of a frequency synthesis and a differential delay line approach. The RF phase shifters offer a high degree of freedom in the phase weighting while the differential delay line reduces the component count.

3. The received signal is downconverted at the antenna element. The signal-to-noise ratio and the dynamic range are improved. The complexity of the distribution network for the returned path is reduced.

4. The received signals from the different elements are added in phase in the distribution network.

5. The distribution network is based on fiber optics, allowing a more flexible network than with conventional RF waveguides.

6. Wavelength division multiplexing is used to carry the information for beam steering the transmit and receive beams in the same distribution network.

The above-described embodiments of the invention are intended to be examples of the present invention and numerous modifications, variations, and adaptations may be made to the particular embodiments of the invention without departing from the scope and spirit of the invention, which is defined in the claims.

Claims

What we claim is:

1. A method of controlling a transmit beam of a phased array antenna comprising the steps of:

(a) digitally computing on a computer phase and amplitude information of RF signals required at a plurality of phased array elements of the antenna to obtain a desired beam shape in a desired direction;

(b) applying to the RF signals information related to the digitally computed phase and amplitude information;

(c) converting the RF signals to optical signals;

(d) distribute the optical signals to interface units of the antenna elements;

(e) converting the distributed optical signals to electrical signals;

(f) radiating the electrical signals at the elements.

2. A method of controlling a phased array antenna to receive a beam comprising the steps of:

(a) digitally computing on a computer phase and amplitude information of RF signals required at a plurality of phased array elements of the antenna to obtain a desired beam shape in a desired direction;

(b) applying to the RF signals information related to the digitally computed phase and amplitude information;

(c) converting the RF signals to optical signals;

(d) distribute the optical signals to interface units of the antenna elements;

(e) converting the distributed optical signals to electrical signals;

(f) utilizing the electrical signals as a local oscillator to downconvert the received signal to an intermediate frequency that corresponds in phase to the information computed in step (a).

3. In a phased array antenna having a plurality of antenna elements disposed in a predetermined pattern for radiating first RF signals having relative phase and amplitude characteristics and formed by a combination of second signals provided thereto, a method of controlling a beam comprising the steps of:

(a) digitally computing the phase and amplitude characteristics of the first RF signals required at some phased array antenna elements, using a processor;

(b) digitally computing, for each of some phased array antenna elements, characteristics of a plurality of second signals and associating said second signals with said phased array antenna element of said some phased array antenna elements wherein a combination of some of the plurality of second signals at an associated phased array antenna element results in substantially an approximation of the required first RF signal of step (a) and wherein some of the second signals associated with a phased array antenna element are substantially the same as second signals associated with other phased array antenna elements;

(c) generating the plurality of associated second signals with characteristics computed in step (b) for some phased array antenna elements;

(d) providing to some phased array antenna elements the generated second signals for said phased array antenna elements; and

(e) from said phased array antenna elements, radiating an RF signal in dependence upon a combination of the generated second signals provided thereto.

4. A method of controlling a beam as defined in claim 3 wherein each of a plurality of second signals is an RF signal provided to phased array antenna elements having a predetermined spatial relation.

5. A method of controlling a beam as defined in claim 3 wherein the step of generating the plurality of second signals includes the steps of generating second RF signals and converting the second RF signals into optical signals, the method further comprising the step of:

converting the optical signals received at an antenna element into RF signals for combination.

6. A method of controlling a beam as defined in claim 3 wherein the digitally computed characteristics of the second signals

$$\phi(x_n) = \frac{2\pi}{\lambda}\sin\beta x_n \cos\alpha$$

are of the form

$$\phi(y_m) = \frac{2\pi}{\lambda}\sin\beta y_m \sin\alpha$$

7. A method of controlling a beam as defined in claim 3 wherein two second signals are provided to an antenna element and wherein second signals including one of the two

second signals and another different second signal are provided to another antenna element.

8. A method of controlling a beam as defined in claim 3 wherein the second signals comprise a fixed frequency signal combined with signals comprising at least one of control information and information for transmission.

9. A method of controlling a beam as defined in claim 3 wherein the second signals comprise a fixed frequency signal combined with signals comprising at least one of phase information and information for transmission.

10. A method of controlling a beam as defined in claim 3 wherein providing to some phased array antenna elements the generated second signals for said phased array antenna elements is performed maintaining relative phase information within the generated second signals.

11. In a phased array antenna having a plurality of antenna elements disposed in a predetermined pattern for receiving first RF signals having relative phase and amplitude characteristics, a method of controlling a beam comprising the steps of:

(a) digitally computing the phase and amplitude characteristics of the first RF signals for reception by some phased array antenna elements, using a processor;

(b) digitally computing, for each of some phased array antenna elements, characteristics of a plurality of second signals and associating said second signals with said phased array antenna element of said some phased array antenna elements wherein a combination of some of the plurality of second signals at an associated phased array antenna element results in substantially an approximation of the required first RF signal for reception as computed in step (a) and wherein some of the second signals associated with a phased array antenna element are substantially the same as second signals associated with other phased array antenna elements;

(c) generating the plurality of associated second signals with characteristics computed in step (b) for some phased array antenna elements;

(d) providing to some phased array antenna elements the generated second signals for said phased array antenna elements; and

(e) filtering signals received by said phased array antenna elements in dependence upon a combination of the generated second signals provided thereto.

12. A method of controlling a beam as defined in claim 11 wherein the filtering is performed by combining the second signals with the signal received by an antenna element to generate a receive signal.

13. A phased array antenna comprising:

a plurality of antenna elements disposed in a predetermined pattern for radiating first RF signals having relative phase and amplitude characteristics and formed by a combination of second signals provided thereto;

means for digitally computing the phase and amplitude characteristics of the first RF signals required at some phased array antenna elements;

means for digitally computing, for each of some phased array antenna elements, characteristics of a plurality of second signals and associating said second signals with said phased array antenna element of said some phased array antenna elements wherein a combination of some of the plurality of second signals at an associated phased array antenna element results in substantially an approximation of the required first RF signal as computed in step (a) and wherein some of the second signals associated with a phased array antenna element are substantially the same as second signals associated with other phased array antenna elements;

means for generating the plurality of associated second signals;

means for providing to some phased array antenna elements the generated second signals associated with said phased array antenna elements;

means for combining the generated second signals; and

means for radiating, from said phased array antenna elements, an RF signal in dependence upon a combination of the generated second signals provided thereto.

14. A phased array antenna as defined in claim 13, wherein the means for providing to some phased array antenna elements the generated second signals comprises optical transmission means.

15. A phased array antenna as defined in claim 13, wherein the means for providing to some phased array antenna elements the generated second signals comprises RF to optical conversion means; optical transmission means; and optical to RF conversion means.

16. A phased array antenna as defined in claim 13, wherein the means for providing to some phased array antenna elements the generated second signals is for maintaining phase information of the generated second signals.

17. A phased array antenna as defined in claim 13, wherein the plurality of antenna elements disposed in a predetermined pattern for radiating first RF signals are disposed in an array of rows and columns and wherein some means for generating second signals are coupled with a plurality of phased antenna elements in a row and some means for generating second signals are coupled with a plurality of phased array antenna elements in a column.

18. A phased array antenna as defined in claim 13, wherein the means for radiating an RF signal comprises a plurality of means associated with each of a plurality of phased array antenna elements and absent phase shifters, each means for combining the second signals provided thereto.

19. A phased array antenna as defined in claim 13, wherein the means for generating the plurality of second signals comprises a plurality of frequency synthesisers, mixers, filters, and RF to Optical signal conversion circuits.

20. A phased array antenna as defined in claim 19, wherein the means for generating the plurality of second signals further comprises a processor controlled frequency generator.

21. A phased array antenna as defined in claim 13, wherein the plurality of antenna elements disposed in a predetermined pattern are disposed in rows and columns and wherein the means for providing to some phased array antenna elements the generated second signals associated with said phased array antenna elements comprises means coupled to a plurality of antenna elements in one of a row and a column for providing a same second signal to the plurality of antenna elements.

22. A phased array antenna as defined in claim 13, wherein the means for combining the generated second signals comprises: a switch for switchably providing the combined signal to the means for radiating in a first mode of operation and to a filtering circuit for filtering a signal received by the radiating element in a second mode of operation.

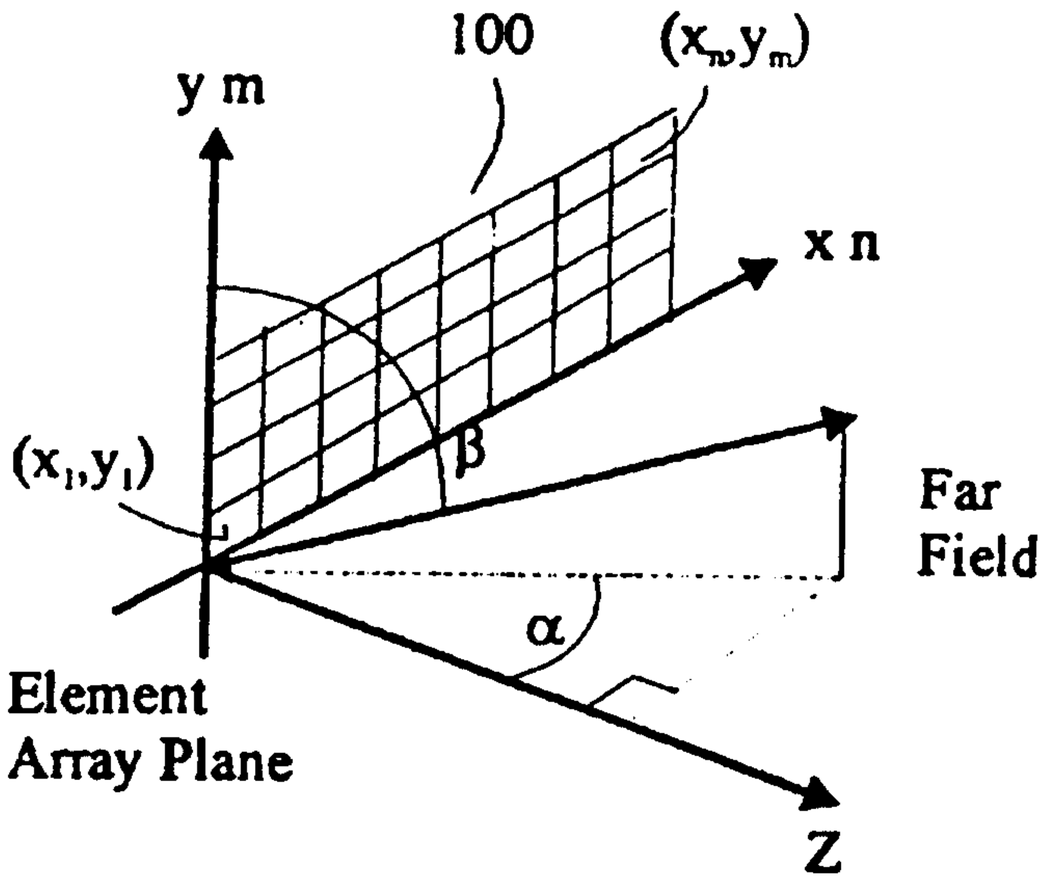

Fig. 1

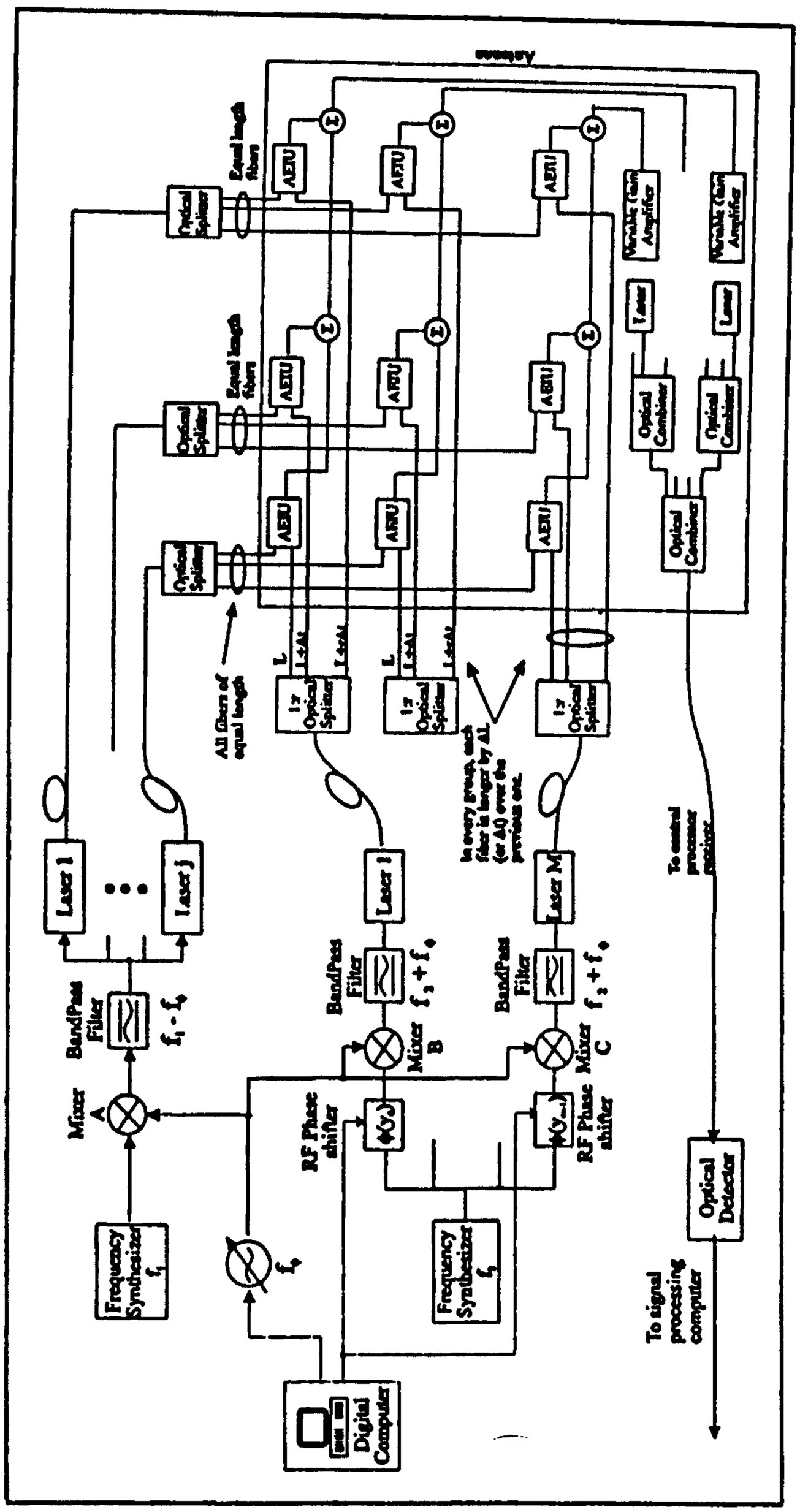
Antenna
Equal length fibers
Optical Splitter
ABTU
Variable fiber Amplifier
Laser
Optical Combiner
All fibers of equal length
L
L+ΔL
L+2ΔL
1:r Optical Splitter
In every group, each fiber is longer by ΔL (or 4L) over the previous one
To central processor station
Laser 1
Laser j
Laser M
BandPass Filter
f1 - fo
f2 + fo
Mixer A
Mixer B
Mixer C
RF Phase shifter
Frequency Synthesizer f1
fo
Frequency Synthesizer f2
To signal processing computer
Optical Detector
Digital Computer

Fig. 2

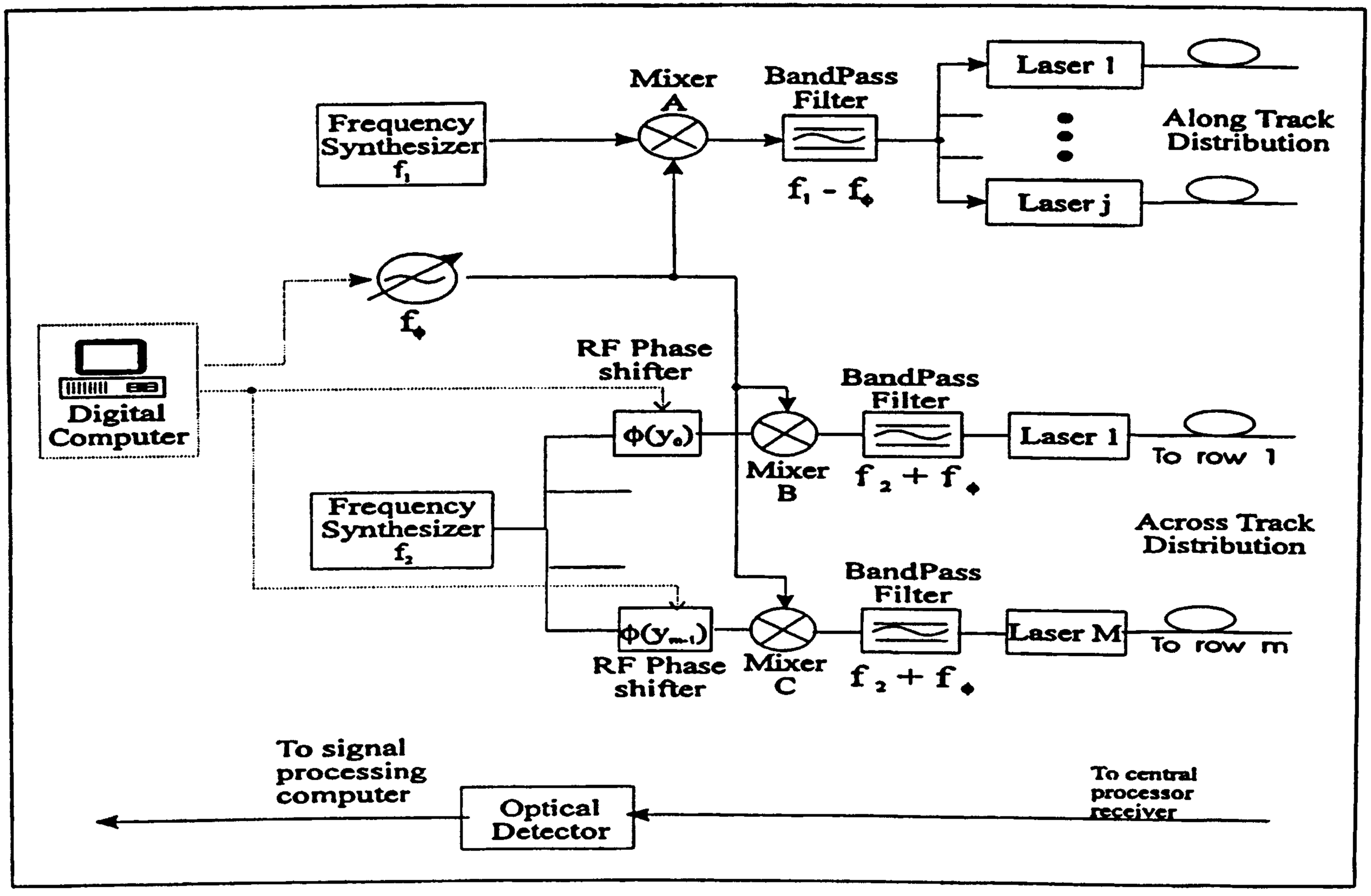

Fig. 3

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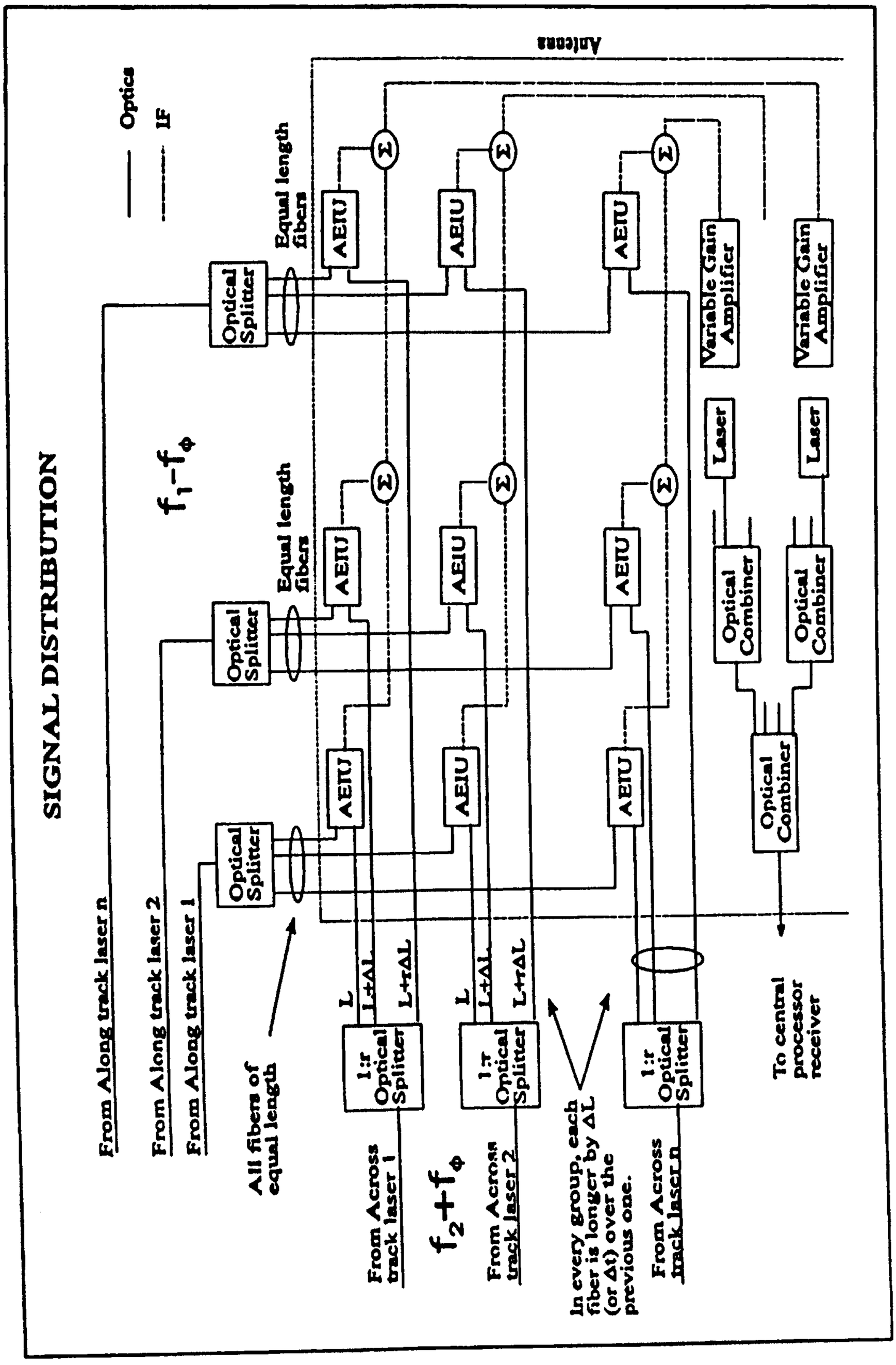

SIGNAL DISTRIBUTION
Optics
IF
Antennas
Equal length fibers
AEIU
Optical Splitter
Variable Gain Amplifier
Laser
Optical Combiner
f_1-f_ϕ
f_2+f_ϕ
From Along track laser n
From Along track laser 2
From Along track laser 1
All fibers of equal length
From Across track laser 1
From Across track laser 2
From Across track laser n
L
L+ΔL
L+2ΔL
1:r Optical Splitter
In every group, each fiber is longer by ΔL (or Δt) over the previous one.
To central processor receiver

Fig. 4

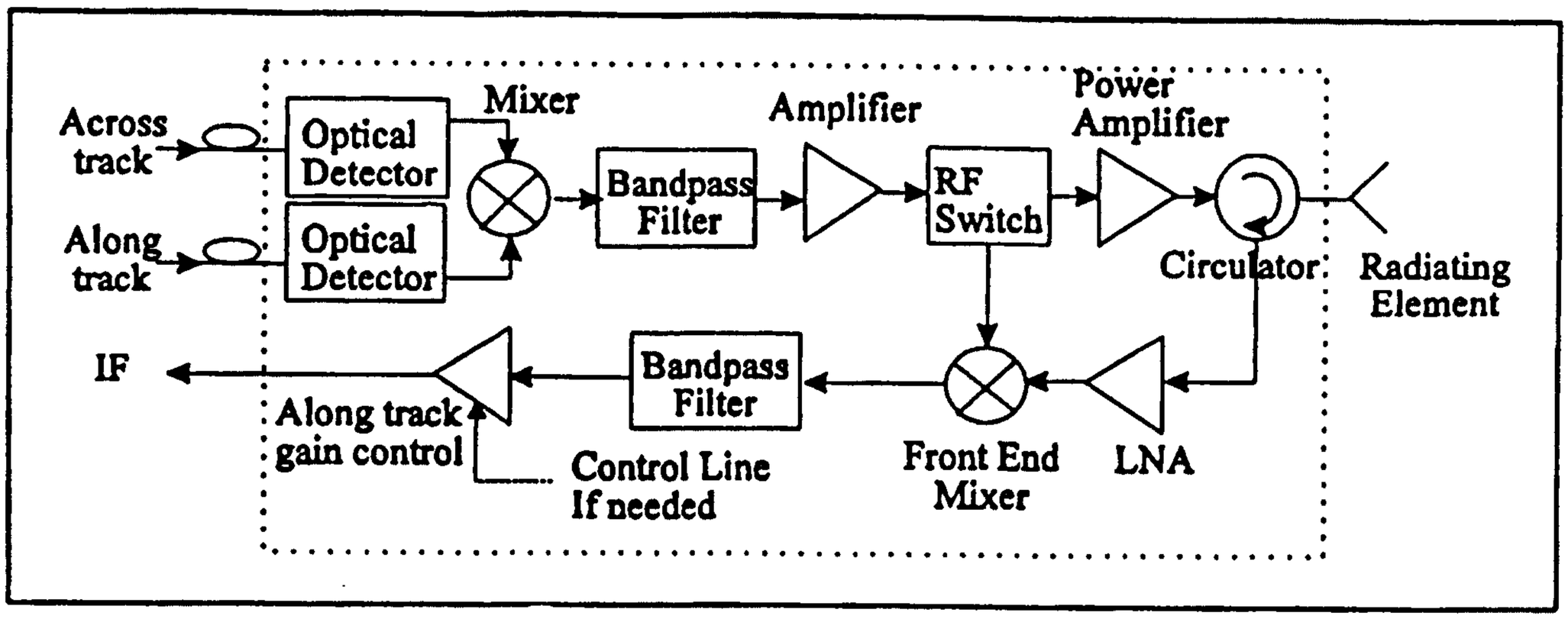

Across track
Along track
Optical Detector
Optical Detector
Mixer
Bandpass Filter
Amplifier
RF Switch
Power Amplifier
Circulator
Radiating Element
IF
Along track gain control
Bandpass Filter
Control Line If needed
Front End Mixer
LNA

Fig. 5

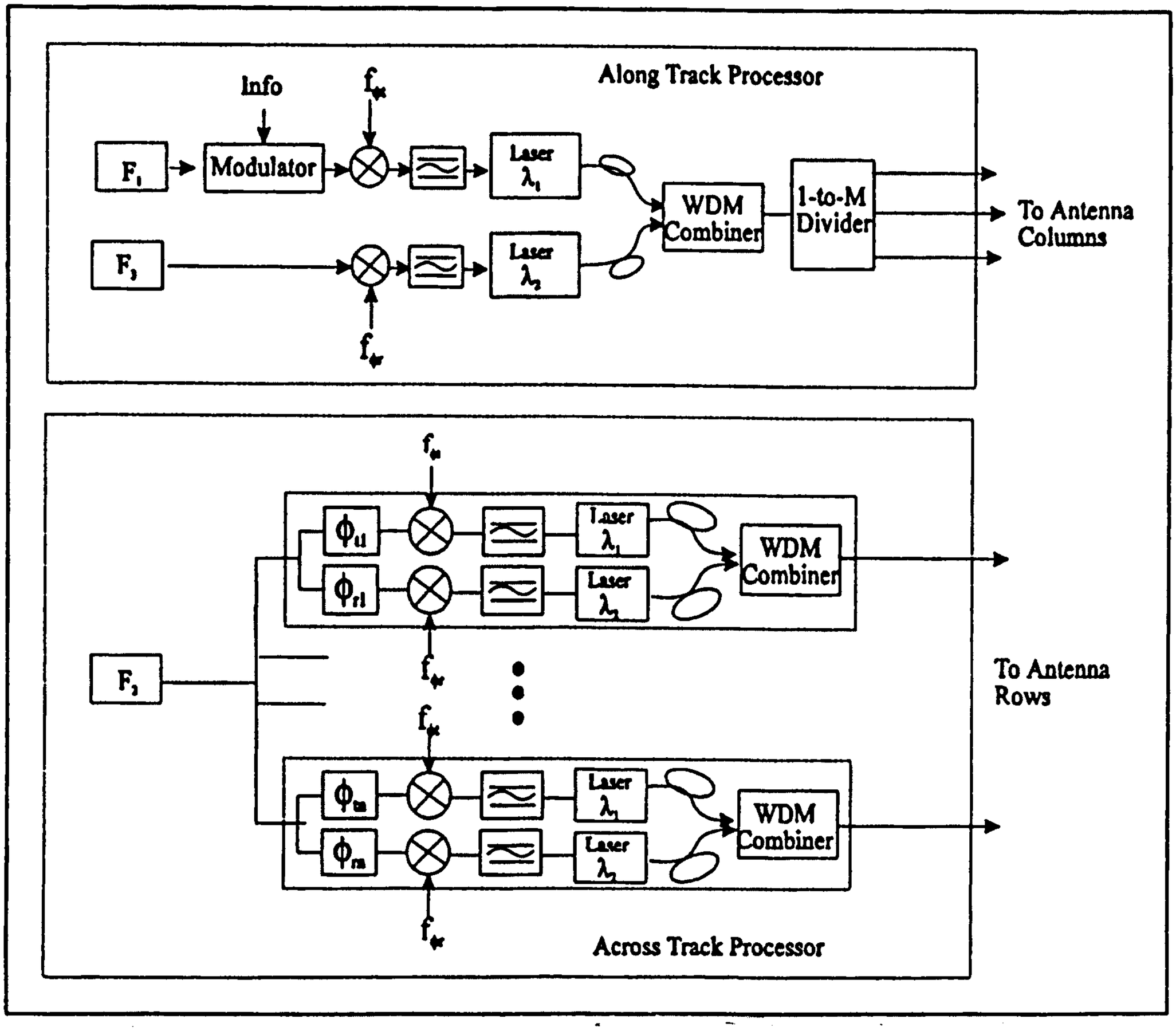

Along Track Processor
Info
f_{ut}
F_1
Modulator
Laser λ_1
F_2
Laser λ_2
f_{ut}
WDM Combiner
1-to-M Divider
To Antenna Columns
f_{ut}
ϕ_{t1}
ϕ_{r1}
Laser λ_1
Laser λ_2
WDM Combiner
F_2
f_{ut}
f_{ut}
ϕ_{tn}
ϕ_{rn}
Laser λ_1
Laser λ_2
WDM Combiner
f_{ut}
To Antenna Rows
Across Track Processor

Fig. 6

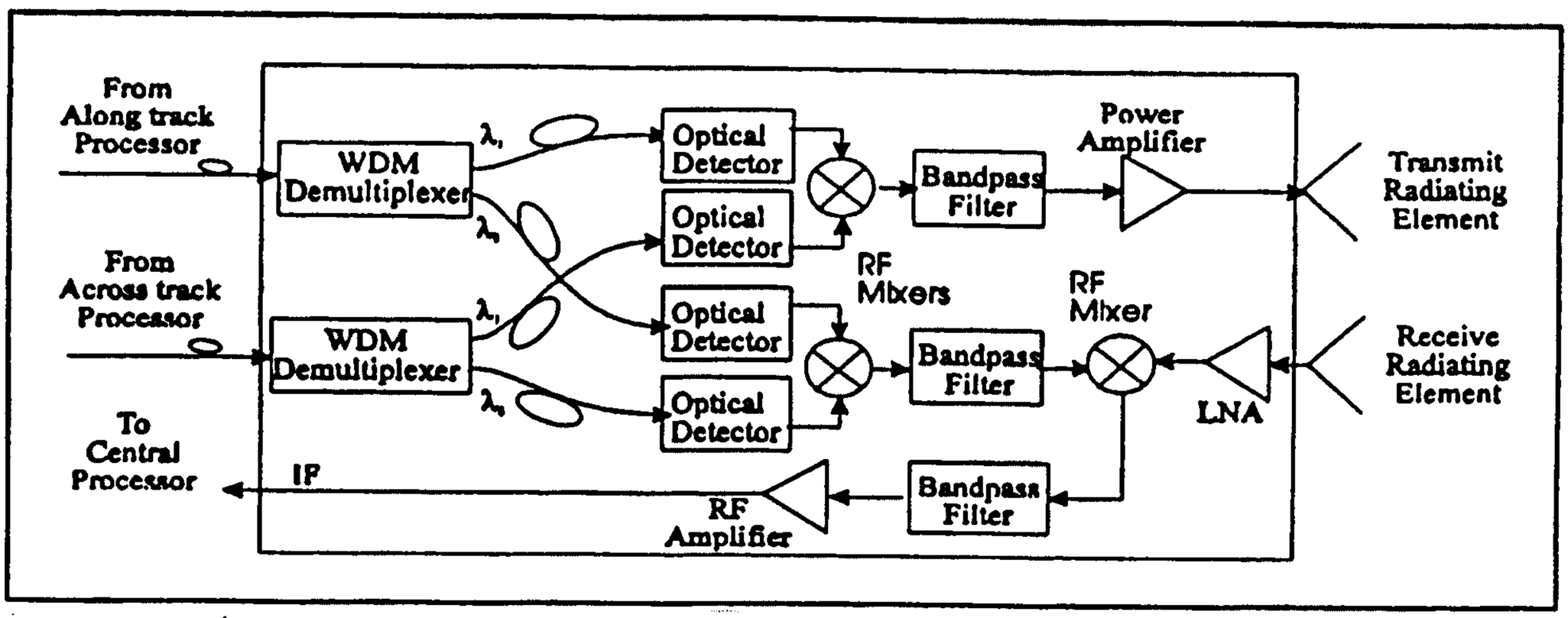
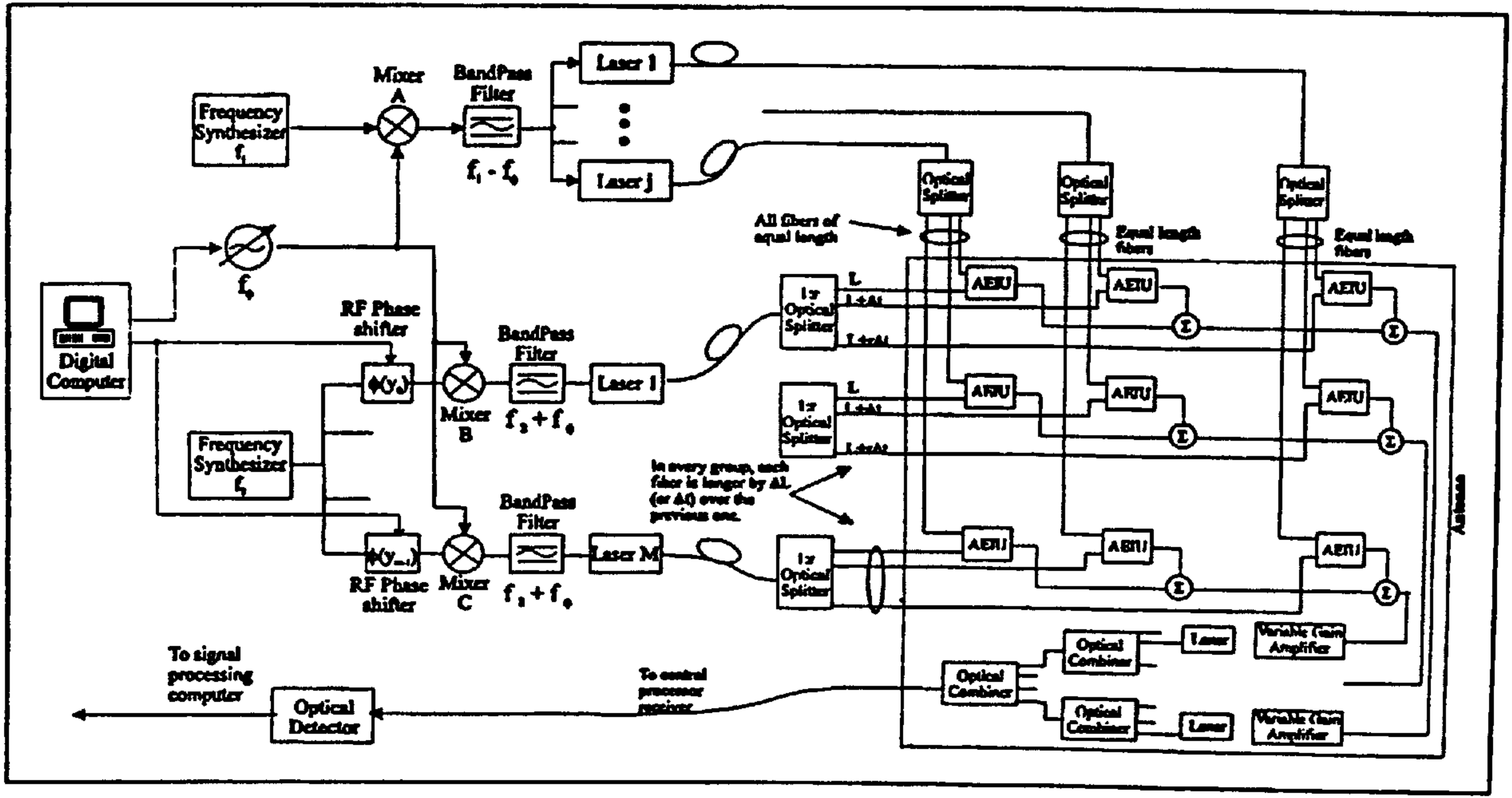

From
Along track
Processor
From
Across track
Processor
To
Central
Processor
WDM
Demultiplexer
WDM
Demultiplexer
λ1
λn
λ1
λn
Optical
Detector
Optical
Detector
Optical
Detector
Optical
Detector
RF
Mixers
Bandpass
Filter
Bandpass
Filter
Power
Amplifier
RF
Mixer
Transmit
Radiating
Element
Receive
Radiating
Element
LNA
IF
RF
Amplifier
Bandpass
Filter

Fig. 7


Laser 1
Mixer A
BandPass Filter
Frequency Synthesizer f_1
$f_1 - f_\phi$
Laser j
f_ϕ
All fibers of equal length
Optical Splitter
Optical Splitter
Optical Splitter
Equal length fibers
Equal length fibers
RF Phase shifter
Digital Computer
BandPass Filter
Laser 1
1:r Optical Splitter
L
L+ΔL
L+rΔL
AEIU
AEIU
AEIU
Mixer B
$f_2 + f_\phi$
Frequency Synthesizer f_2
In every group, each fiber is longer by ΔL (or Δl) over the previous one.
BandPass Filter
Laser M
1:r Optical Splitter
AEIU
AEIU
AEIU
RF Phase shifter
Mixer C
$f_2 + f_\phi$
Optical Combiner
Laser
Variable Gain Amplifier
Optical Combiner
Optical Combiner
Laser
Variable Gain Amplifier
To signal processing computer
Optical Detector
To central processor receiver
Antenna