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(54) **ALL DIGITAL PHASED ARRAY USING SPACE/TIME CASCADED PROCESSING**

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(51) **Int. Cl.**^{7} **H01Q 3/26**
(52) **U.S. Cl.** **342/373**; 342/157; 342/368; 342/380
(58) **Field of Search** 342/157, 368, 342/373, 378–384

(56) **References Cited**

U.S. PATENT DOCUMENTS

5,396,256 A	*	3/1995	Chiba et al.	342/372
5,493,307 A	*	2/1996	Tsujimoto	342/380
5,600,326 A	*	2/1997	Yu et al.	342/17
6,061,023 A	*	5/2000	Daniel et al.	342/354
6,075,484 A	*	6/2000	Daniel et al.	342/372
6,345,188 B1	*	2/2002	Keskitalo et al.	455/561
6,480,154 B1	*	11/2002	Bella et al.	342/372
6,509,865 B2	*	1/2003	Takai	342/158
2002/0080066 A1	*	6/2002	Dent	342/373
2002/0180639 A1	*	12/2002	Rickett et al.	342/372
2002/0190901 A1	*	12/2002	Yoshida	342/383
2003/0020646 A1	*	1/2003	Yu	342/17

FOREIGN PATENT DOCUMENTS

JP	11251986 A	*	9/1999	H04B/7/10

OTHER PUBLICATIONS

Artical entitled "Transmitting Null Beam Forming With Beam Space Adaptive Array Antennas" by Isamu Chiba et al. in IEEE (1994).*

(List continued on next page.)

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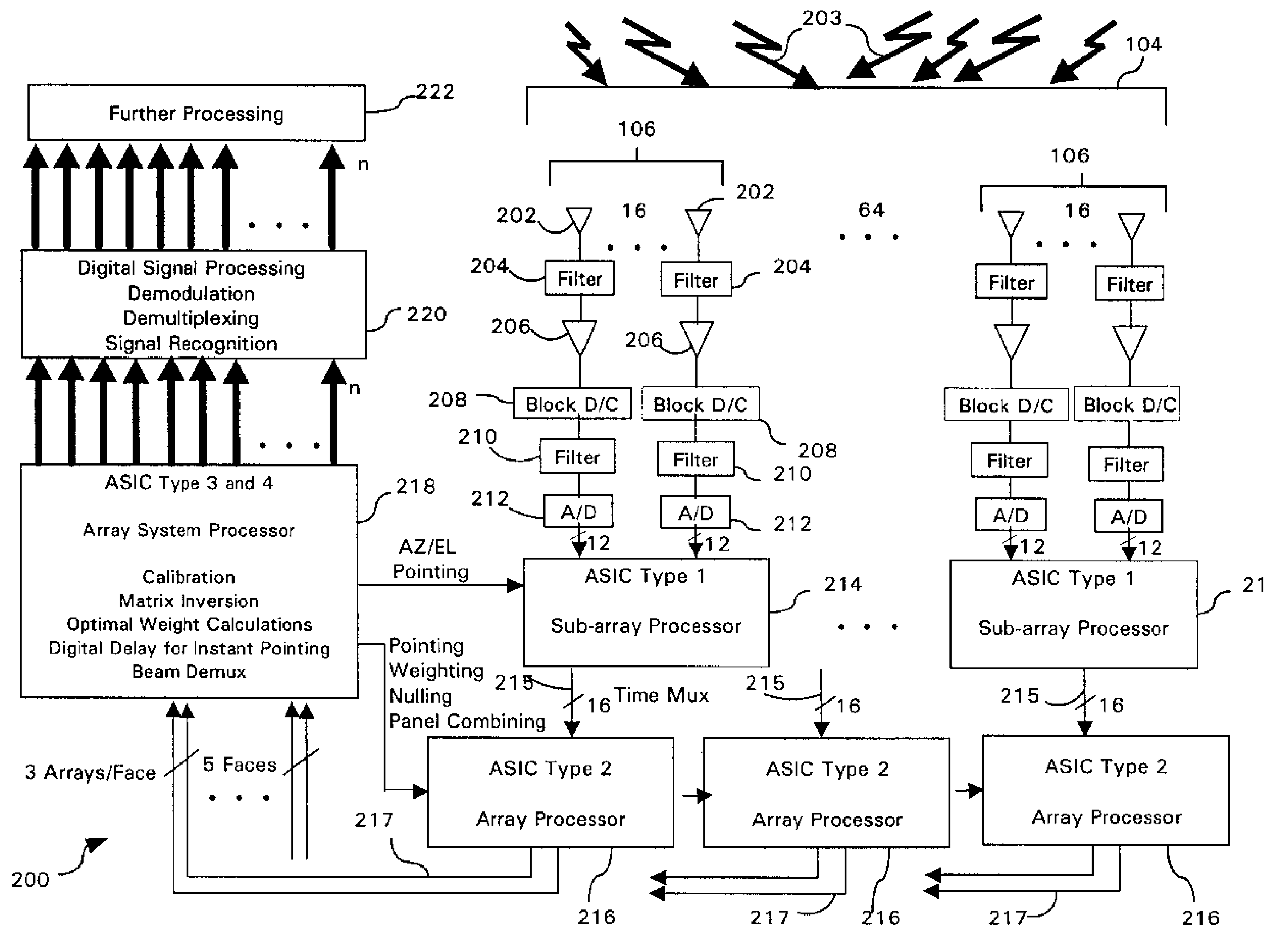
(57) **ABSTRACT**

The invention concerns a method and apparatus for cascaded processing of signals in a phased array antenna system in which a plurality of antenna elements are configured as a plurality of sub-arrays. A weighting factor is applied to each of the antenna elements to form a plurality of sub-array beams, each pointed in a selected direction. For each sub-array, an output from each the antenna elements in the sub-array can be combined to produce a sub-array output signal. The sub-array output signals are selectively weighted and combined in a fully adaptive process. Subsequently, the system can estimate an angle-of-arrival direction for a signal-of-interest ("SOI") and at least one signal-not-of-interest ("SNOI"). Based on this estimating step, the system calculates a new set of weighting factors for controlling one or more of the sub-array beams to improve the signal-to-noise plus interference ratio obtained for the SOI in the array output signal.

28 Claims, 4 Drawing Sheets



OTHER PUBLICATIONS

Artical entitled "Experimental Studies of Space–Divison–Multiple–Access Schemes for Spectral Efficient Wireless Communications" by G. Xu et al. IEEE (1994).*

Artical entitled "Beamforming Experiment with a DBF Multibeam Antenna in a Mobiel Satellite Enviorment" by Miura, Ryu . IEEE Transaction on Antennas and Propagation, vol. 45, No. 4, Apr. 1997, pp. 707–714.*

Artical entitled "Direction of Arrival Estimation Using Parametric Signal Models", by Ariela Zeira and Benjamin Freidlande, IEEE Transactions On Signal Processing, vol. 44, No. 2, Feb. 1996.*

Pascale, M., *Adaptive Beam Forming*, www.ewh.ieee.org/r2/baltimore/Chapter/Comm/adapt/index.htm, (Jan. 18, 2002).

* cited by examiner

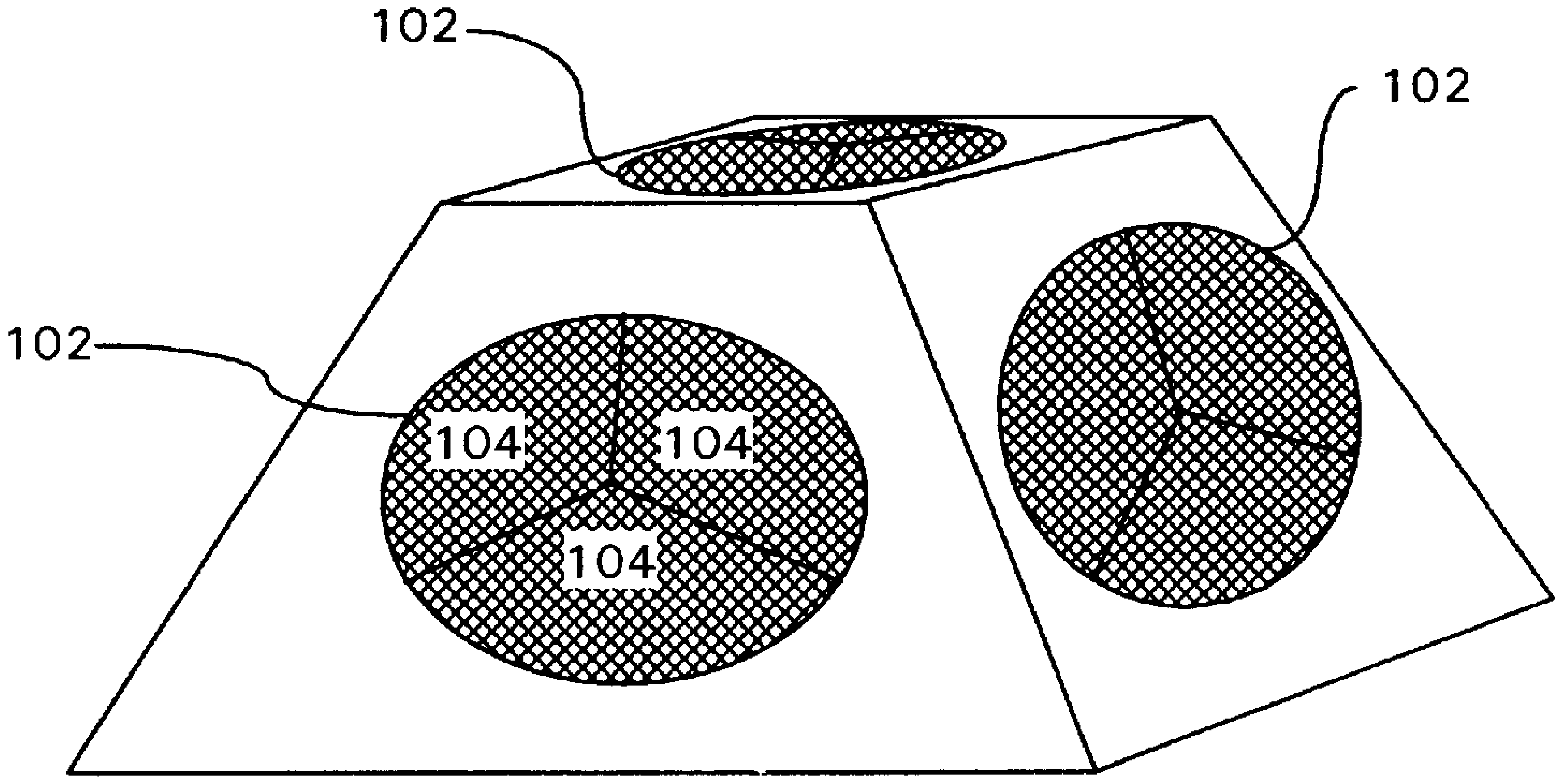
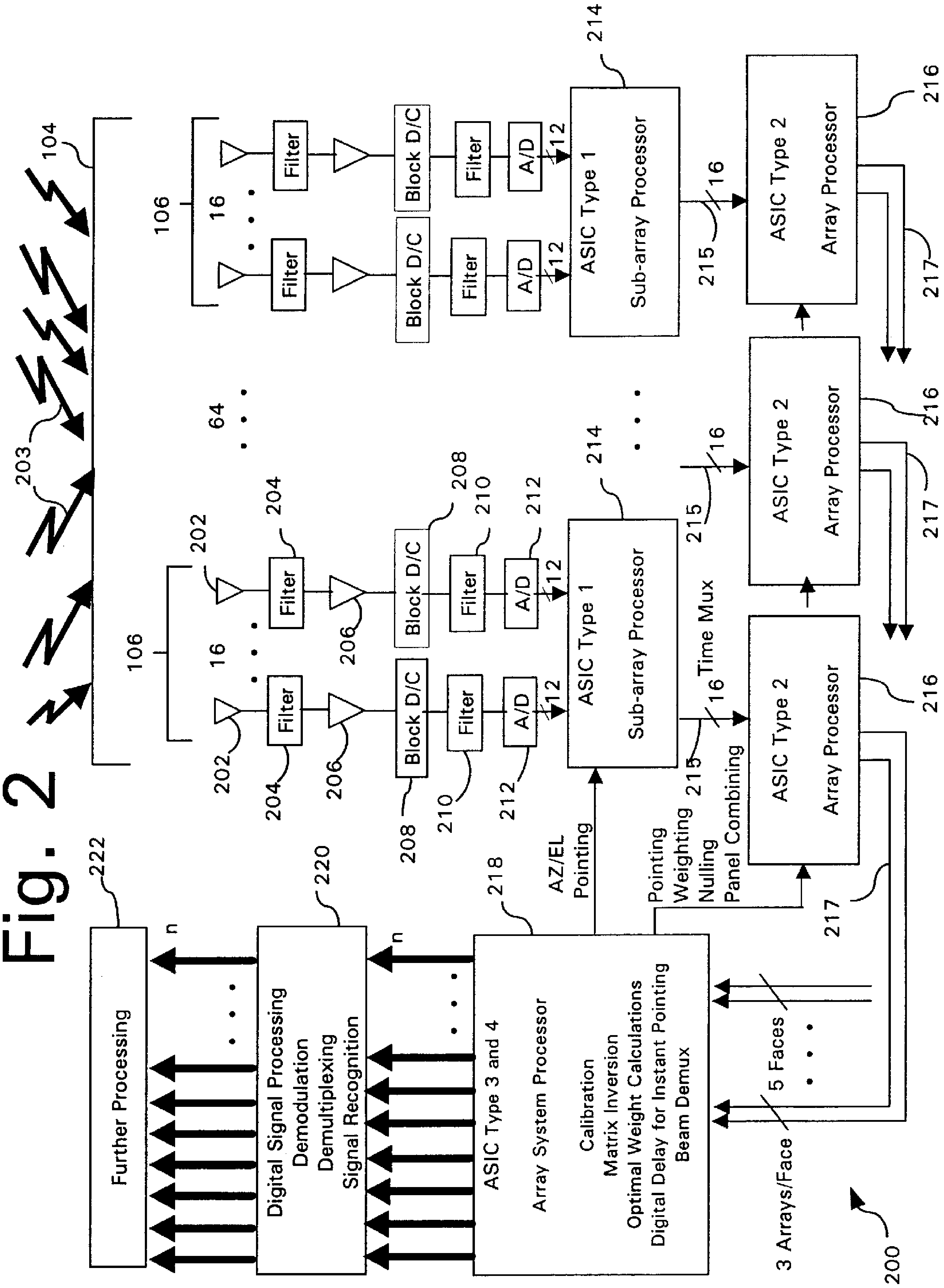


Fig. 1

Fig. 2


104
203
106
16
64
202
204
206
208
210
212
Filter
Block D/C
A/D
12
ASIC Type 1
Sub-array Processor
214
215
16
Time Mux
ASIC Type 2
Array Processor
216
217
AZ/EL
Pointing
Pointing
Weighting
Nulling
Panel Combining
218
ASIC Type 3 and 4
Array System Processor
Calibration
Matrix Inversion
Optimal Weight Calculations
Digital Delay for Instant Pointing
Beam Demux
3 Arrays/Face
5 Faces
220
Digital Signal Processing
Demodulation
Demultiplexing
Signal Recognition
n
222
Further Processing
200

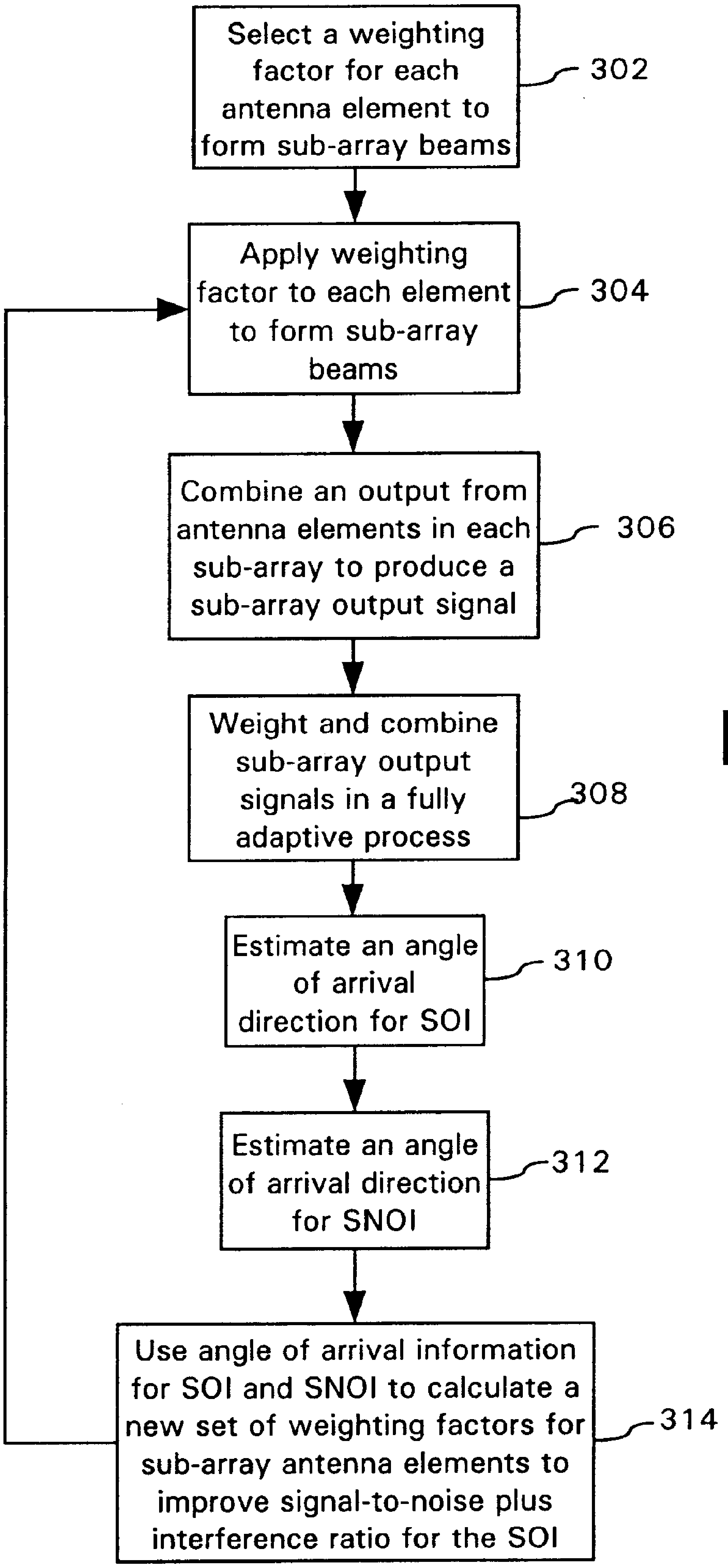

Select a weighting factor for each antenna element to form sub-array beams
302
Apply weighting factor to each element to form sub-array beams
304
Combine an output from antenna elements in each sub-array to produce a sub-array output signal
306
Weight and combine sub-array output signals in a fully adaptive process
308
Estimate an angle of arrival direction for SOI
310
Estimate an angle of arrival direction for SNOI
312
Use angle of arrival information for SOI and SNOI to calculate a new set of weighting factors for sub-array antenna elements to improve signal-to-noise plus interference ratio for the SOI
314

Fig. 3

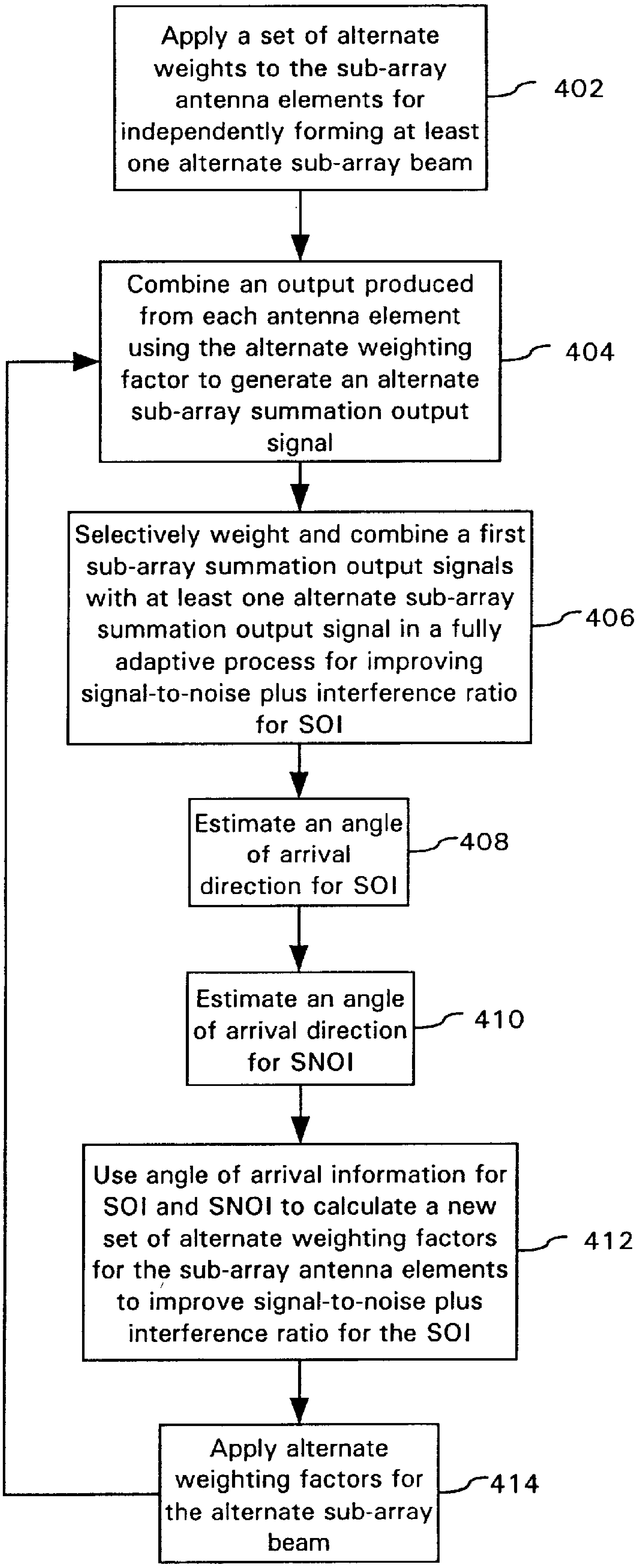

Apply a set of alternate weights to the sub-array antenna elements for independently forming at least one alternate sub-array beam
402
Combine an output produced from each antenna element using the alternate weighting factor to generate an alternate sub-array summation output signal
404
Selectively weight and combine a first sub-array summation output signals with at least one alternate sub-array summation output signal in a fully adaptive process for improving signal-to-noise plus interference ratio for SOI
406
Estimate an angle of arrival direction for SOI
408
Estimate an angle of arrival direction for SNOI
410
Use angle of arrival information for SOI and SNOI to calculate a new set of alternate weighting factors for the sub-array antenna elements to improve signal-to-noise plus interference ratio for the SOI
412
Apply alternate weighting factors for the alternate sub-array beam
414

Fig. 4

ALL DIGITAL PHASED ARRAY USING SPACE/TIME CASCADED PROCESSING

BACKGROUND OF THE INVENTION

1. Technical Field

The invention concerns phased array systems and more particularly a wide-band all-digital architecture for a phased array system that is capable of operating at high data rates.

2. Description of the Related Art

Phased array antenna systems create directional antenna beams by controlling phase and amplitude relationships (RF weighting) among a plurality of antenna elements that are typically arranged in a line or matrix pattern. Analog implementations of phased arrays have been used for many years in a wide variety of applications. These analog systems commonly make use of digital circuitry for baseband signal processing and control, but rely upon analog circuitry in the front-end RF stages to handle functions such as band pass filtering, and RF weighting of antenna elements.

Although analog phased array systems have many advantages over conventional fixed beam antenna systems, they also suffer from a number of disadvantages. For example, analog phased array systems are typically limited in the number of beams and nulls that can be formed. This is an important consideration for spatially differentiating multiple targets, tracking moving signal sources, or eliminating multiple jammers. With conventional analog phased array systems, the addition of more beams or nulls typically requires changes at the hardware and software level. These systems also tend to be RF unique in that each unit must be individually adjusted to compensate for differences in phase and amplitude in the RF circuitry from unit to unit. These problems are compounded by the inherent expense associated with analog RF systems.

All-digital phased array designs have long been considered desirable because they have the potential to overcome many of the problems of analog systems. Such systems can produce a nearly unlimited number of beams, are easily provided with additional beam-forming capability through software upgrades, have the ability to provide multiple nulls in the antenna pattern to thwart multiple jammers and can provide precise angle of arrival information. Such all-digital phased array systems also have the potential to provide a significant cost reduction as compared to analog systems.

Despite the clear advantages offered by the all-digital phased array, these systems have generally been considered impractical for wide band systems that operate at high data rates. This has primarily been due to limitations of existing technology. Systems using conventional covariance matrix techniques, a large number of array elements and high data rate signals, require many gigaflops of data to be processed. This limits the practicality of digital arrays to low data rates. In general, Analog to Digital converters (A/D's), Application Specific Integrated Circuits (ASICS), and Digital Signal Processors (DSP's) simply have not been available to meet the demands of an all-digital phased array operating in such an environment.

As with any complex system, there are a variety of architectural and processing options that can be adopted for implementing a digital phased array. However, one difficulty that has been confronted in this area is the selection of an appropriate architecture that can be combined with existing component technology that will permit the realization of a true all-digital phased array. Accordingly, a challenge remains to develop an all-digital phased array capable of operating at high frequency, wide bandwidth and high data rates using available component technology.

Notably, adaptive phased arrays are often used to form simultaneous multiple beams pointed toward desired signals and simultaneous multiple nulls pointed toward undesired signals. A typical system application might include reception and transmission of signals from/to multiple satellites or multiple airborne vehicles. In adaptive arrays where the number of elements is large, for example 100's or 1000's, the potential number of adaptive loops is very large—typically equal to N−1 where N is the number of elements in the array. The effective number of loops may be reduced by dynamic range effects, polarization rotation, element pattern, multipath and array shadowing (etc.) effects, however, there are typically many more adaptive loops than required in practice.

For example, in a typical communications scenario there may be one to four desired signals and a few interfering signals. If all of the elements are utilized in deriving a covariance matrix for weight control, the processing for digital versions of the arrays and the hardware for analog versions of the array is prohibitive or, at least, not affordable for the reasons outlined above. The fundamental issue is to selectively control the type and number of weights utilized so as to optimize the array performance in a given real world environment. The objective of this invention is to fulfill this need via intelligent control of cascaded processing that greatly simplifies both the adaptive weighting and control.

SUMMARY OF THE INVENTION

The invention concerns a method and apparatus for cascaded processing of signals in a phased array antenna system in which a plurality of antenna elements are configured as a plurality of sub-arrays. The method is designed to more effectively make use of available received signals to reduce interference from at least one undesired signal.

The process can begin by selectively applying a weighting factor to each of the antenna elements to form a plurality of sub-array beams, each pointed in a selected direction. The weighting factor can be selected exclusively amplitude, exclusively phase, time-delay or complex (phase and amplitude) weights associated with each the antenna element.

For each sub-array, an output from each antenna element in the sub-array can be combined to produce a sub-array output signal. Subsequently, the sub-array output signals can be selectively weighted and combined. In particular, the sub-array output signal received from one of the sub-arrays can be combined with a sub-array output signal from a second one of the sub-arrays in a fully adaptive process.

Subsequently, the system can estimate an angle-of-arrival direction for a signal-of-interest ("SOI") and at least one signal-not-of-interest ("SNOI"). The estimating step as described herein can also include estimating an incident power for at least one of the SOI and the at least one SNOI. The estimating can be based on blind source separation (BSS) techniques, a priori knowledge, or direction information of signals learned during system operation.

Based on this estimating step, the system can calculate a new set of weighting factors for controlling one or more of the sub-array beams to improve the signal-to-noise plus interference ratio obtained for the SOI in the array output signal. The calculating step can include calculating a surrogate covariance matrix based solution for at least one of the sub-arrays. This new set of weighting factors is used to selectively control the weighting factors for the one or more sub-array beams. Adjusting the weighting factors for the sub-arrays can result in re-pointing the sub-array beams, and the production of sub-array beam patterns comprising regions of relatively higher and lower gain. In either case, the intent is to improve the signal-to-noise plus interference ratio.

According to a further embodiment, the system can selectively apply one or more alternate weighting factors to each of the antenna elements in one or more of the sub-arrays. The alternate weighting factors are used to independently form alternate sub-array beams using the antenna elements. An output from each of the antenna elements using the alternate weighting factor can be combined to produce one or more alternate sub-array output signals. Selectively weighting and combining one or more of the sub-array output signals with the alternate sub-array output signals in a fully adaptive process can then further improve the signal-to-noise plus interference ratio.

The invention can further include estimating an angle-of-arrival direction for a second SOI and one or more SNOI. A new set of weighting factors can be calculated for controlling the alternate sub-array beams to improve a second signal-to-noise plus interference ratio obtained for the SOI in the alternate array output signal.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. **1** is a drawing useful for illustrating phased array face configurations.

FIG. **2** is a block diagram that is useful for illustrating the cascaded processing according to the inventive arrangements.

FIG. **3** is a flow chart useful for illustrating cascaded processing according to the inventive arrangements.

FIG. **4** is a flow chart useful for illustrating cascaded processing using alternate weighting factors.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

Conventional Digital Beam Forming (DBF) array architectures can range from those using RF weighting and in-parallel digital processing to a full-up all-digital array. The present invention concerns a hybrid variant of these and a processing methodology that could be implemented to achieve wide bandwidth all-digital operations for high data rate systems.

According to one aspect of the invention, digital processing complexity can be addressed via modular sub-arrays and cascaded processing. In particular, cascaded processing can be utilized in which first stage beam space processing and second stage fine beam and null steering can achieve wide dynamic range with a fraction of complexity as compared to direct inversion of N x N matrices. The invention also minimizes analog to digital converter (A/D) performance requirements, thereby overcoming a limiting factor in the present state of the art high bandwidth DBF systems.

FIG. **1** shows a set of array faces **102**. Each of the array faces **102** can be comprised of a large number of individual antenna elements. For example, a typical array face **102** can have 1024 antenna elements. Each of the array faces **102** will have a limited field of view in a direction roughly orthogonal to the surface of the face. For example, each array face can have a field of view of approximately 120 degrees. Accordingly, the array faces **102** can be arranged in several different directions to facilitate hemispherical or near hemispherical field of view when the faces are operated in combination with one another. In FIG. **1**, the array faces **102** are arranged in the form of a truncated pyramid for a total of five array faces. However, those skilled in the art will appreciate that the invention is not limited in this regard. For example, the faces can be arranged in a cubical formation, conformal to an exterior surface of vehicle, such as an aircraft, or distributed among several different locations aboard a vessel as may be dictated by the circumstances of a particular installation.

In the phased array antenna system of FIG. **1**, the antenna element contained on each array face **102** can be divided into a plurality of arrays **104**. The arrays **104** can be further divided to form a plurality of sub-arrays **106** (not shown in FIG. **1**). However, the invention is not limited in this regard and, for smaller arrays, each array face **102** could form a single array or sub-array including all of the elements on the array face.

FIG. **2** is an exemplary block diagram that is useful for illustrating a preferred architecture by which the present invention can be implemented. For this block diagram, it shall be assumed that each array panel **102** is divided into three arrays **104**, and that each array **104** is divided into 64 sub-arrays **106**. Each sub-array **106** is comprised of 16 antenna elements **202**. For greater clarity, only one of the 16 sub-arrays **106** for a particular array is shown in FIG. **2**. It should be understood that other architectures are also possible and the invention is not so limited.

Referring now to FIG. **2**, it can be seen that RF signals **203** (plus noise and interference signals) arrive from free space, incident on a radome of an array **104**. In each sub-array **106**, RF signals **203** are received by antenna elements **202**. These signals can be processed in bandpass filter **204** to remove any unwanted out of band signals. The signals can then be passed to low noise amplifier **206**. Depending on the frequency band of interest and the frequency limitations of the A/D converter **212**, a block frequency down converter **208** can optionally be provided to convert the received RF signals to an intermediate frequency (IF). In that case, further IF filtering can be provided in filter **210**, before the signal is passed to A/D converter **212**.

Performance requirements for A/D converter **212** represent a limiting factor. Assuming a 10 Mbps data rate, and a 100 Mhz bandwidth for received signals, it is preferred that A/D converter be of very high speed and wide dynamic range. Current state of the art is 12-bit output, approximately 200 Mhz data sampling rate, and about 80 db of dynamic range.

The digital output of A/D converters **212** is passed to a digital sub-array processor **214**. Each sub-array processor **212** is preferably comprised of an application specific integrated circuit (ASIC), but the invention is not so limited. As shown in FIG. **2**, digital sub-array level processing can be performed in parallel by sub-array processors **214**. More specifically, each sub-array processor **214** can concurrently process RF signals for a selected sub-arrray **106**. According to a preferred embodiment, each sub-array processor **214** can receive and respond to control inputs from array system processor **218** for beam control. According to an alternative embodiment, not shown, the A/D converter can be located at the output of the sub-array processor. In that case, it will be understood that the sub-array processor will manipulate the incoming signals in the analog domain rather than the digital domain.

The sub-array processors **214** have four basic functions. For each sub-array **106**, the associated sub-array processor can (1) perform digital filtering of unwanted signals received by each antenna element **202**, (2) selectively apply a weighting factor to each of the RF signals received by each element **202** of the associated sub-array **106**, (3) digitally add the received RF signals from each antenna element **202** to produce a sub-array beam summation, and (4) perform time division beam multiplexing for each beam associated with a sub-array **106**.

Beam multiplexing as that term is used herein can refer to time multiplexing the digital data stream for the several beams generated by the sub-array processor so that the data stream may be transported through a single output port.

The multiplexed sub-array beam summation output from each sub-array processor **214** is preferably communicated via a time multiplex bus **215** to an array processor **216**. Those skilled in the art will appreciate that the precise sequence and protocol adopted for the time multiplexing is not critical. Instead, any suitable time multiplexing arrangement can be used for transporting the digital data from the sub-array processor **214** to the array processors **216**.

Each array processor **216** preferably receives sub-array beam summation output data from a plurality of sub-array processors **214** associated with a particular array **104**. In the present case, since there are 64 sub-arrays **106** comprising the array **104**. The array processors **216** can preferably receive input control signals from the array system processor **218** for beam pointing, element weighting, nulling signals from interference sources, and for combining sub-arrays **106** associated with an array **104**. The array processors **216** apply sub-array weighting factors to sub-array beam summations to effectively control beam pointing and nulling for each array **104**. The array processors **216** also preferably add the sub-array beam summations from the plurality of sub-arrays to produce a beam summation for each array **104**.

The beam summation data for each of the arrays **104** can be communicated from the array processor **216** to array system processor **218**. The array system processors **216** for each array **104** are configured for weighting and combining the sub-array beam summation signals forming each sub-array in a fully adaptive process. A time division multiplex bus **217** can be used for facilitating communications between the array processor **216** and array system processor **218**. The array system processor performs system level processing on the digital beam data provided by each of the array processors. For example, the array system processor can perform calibration, matrix inversion processing, optimal weight calculations, digital delay for instant beam pointing, and time demultiplexing of digital beam data. The array system processor also coordinates the operation of each array face **102** so at to combine the limited fields of view offered by each face into a hemispherical or near hemispherical field of view. The output digital data from array system processor **218** is communicated to digital signal processor (DSP) **220** for demodulation of received signals, demultiplexing, and signal recognition. Any further processing required for specific system user applications can be performed in block **222**.

FIG. **3** is a flow chart that is useful for illustrating a preferred method for cascaded processing of signals received by the sub-arrays as described in FIGS. **1** and **2**. The method is intended to maximize a signal to noise ratio for a received signal of interest (SOI) while simultaneously reducing interference from at least one undesired signal, referred to herein as a signal not-of-interest (SNOI). In general, this will have the desired effect of producing a maximum signal to noise plus interference ratio.

In FIG. **3**, the process can begin in step **302** by applying a weighting factor to each of the antenna elements **202** in each sub-array **106**. The weighting factors are used to form for each sub-array a plurality of sub-array beams, each pointed in a selected direction. As a starting point, the sub-array beams can be pointed in a set of default directions. Alternatively the process can begin with the sub-array beams pointed in selected directions based on some a priori knowledge as to the location of one or more known SOI and/or SNOI.

In step **304**, appropriate weighting factors are applied to each sub-array antenna element **202** to form a set of sub-array beams. The weighting factors can be based on any of a variety of known techniques used for beam formation. For example, the weighting factor can be exclusively analog, exclusively phase, exclusively time delay or complex. The weighting factors can be applied to incoming signals using any suitable analog or digital means. For example, in FIG. **2**, digital weighting can be performed digitally within sub-array processor **214**. In step **306**, the sub-array processor **214** can combine an output from each of the antenna elements **202** in the sub-array **106** to produce a sub-array output signal **215**. The sub-array output signal **215** is a summation of the signals produced by the 16 sub-arrays.

In step **308**, each array processor **216** can selectively weight and combine the sub-array output signals received from the 64 sub-arrays in a fully adaptive process controlled by array system processor **218**. The resulting array output signal **217** of the array processor **216** will include an array output signal having a signal-to-noise plus interference ratio for the SOI. This signal-to-noise-plus interference ratio is based, at least in part, on the default weighting of the sub-array beams.

In step **310** and **312**, the array system processor can begin the process of improving the signal-to-noise plus interference ration by first estimating an angle-of-arrival direction for an SOI and at least one SNOI, if present. For example, this process can be performed using blind source separation (BSS) techniques or direction information for signals as learned during system operation. The estimating step can also preferably include estimating an incident power for the SOI, the SNOI or both.

In step **314**, responsive to the estimating step, the array system processor can calculate a new set of weighting factors for controlling the 64 sub-arrays. The new set of weighting factors are calculated so as to improve the signal-to-noise plus interference ratio obtained for the SOI in the array output signal **217**. This process can be performed using conventional adaptive processing techniques. For example, the array system processor **218** can calculate a surrogate covariance matrix based solution for each of the sub-arrays.

Subsequently, in step **204**, the array system processor **218** can use the calculated information to selectively control the weighting factors for each antenna element **202** in each sub-array **106**. For example, the weighting factors can be adjusted for re-pointing the sub-array beam, or to produce a sub-array beam pattern comprising regions of relatively higher and lower gain. In either case, the intention is to improve the signal-to-noise plus interference ratio for the SOI at the array output **217**. By using the foregoing technique, the system can substantially reduce the processing demands normally placed upon an adaptive array.

Alternate sub-array beams are commonly produced by many phased array systems for receiving signals from one or more additional SOI. These alternate sub-array beams can be used to further enhance the processing advantages obtained with the present invention. Alternate sub-array beams for additional SOI's are typically formed using the same sub-arrays **106** as described above, but independently applying a separate set of weighting factors. In some instances, these alternate sub-array beams can provide an improved set of signals upon which adaptive processing can be performed.

Referring now to FIG. **4**, the process according to a preferred embodiment can continue in step **402** with the application of an alternate set of weights to at least one set of sub-array antenna elements. These alternate weights can initially be based on default settings or based on a priori information available to the system. Using these preliminary alternate weights it is possible to independently form at least one alternate sub-array beam using sub-arrays **106**. In practice, all of the sub-array processors **214** can apply alternate weights to all of the sub-arrays, however it should be understood that the invention is not so limited.

In step **404**, the outputs from each antenna element **202** obtained using the preliminary alternate sub-array weights can be combined in a summation to form at least one alternate sub-array output signal. This alternate sub-array output signal can be provided to an array processor **216** as shown in FIG. **2**. In step **406**, the first set of sub-array output signals can be weighted and combined in the array processor with one or more alternate sub-array output signals. The appropriate weighting for each of the alternate sub-array outputs can be computed in a fully adaptive process handled by the array system processor **218**. With this process, it is possible to potentially obtain some further improvements to the signal-to-noise plus interference ratio for the SOI as compared to that attainable without using the alternate beams.

In steps **408** and **410**, the system can estimate an angle of arrival for the SOI and SNOI. The estimating step can also include estimating an incident power level for these signals. In any case, this estimated information can be used in step **412** to calculate a new set of alternate sub-array beam weighting factors to further improve the signal-to-noise plus interference ratio for the SOI. In step **414**, these new alternate sub-array weighting factors can be applied to sub-arrays **106** in step **414**. Thereafter, the system can loop back to step **404**, generating alternate sub-array summation output signals using the new alternate sub-array summation output signal. Finally in step **406**, the system can further improve the signal to noise plus interference ratio for the SOI in step **406** using a fully adaptive process.

Using similar techniques to those described in FIG. **3**, the alternate sub-array output signals from a first set of the sub-arrays can be weighted and combined with a second set of alternate sub-array output signal from a second set of sub-arrays to improve the signal-to-noise plus interference ratio for a second SOI.

We claim:

1. In a phased array antenna system having a plurality of antenna elements configured as a plurality of sub-arrays, a method for cascaded processing of signals to reduce interference from at least one undesired signal, comprising the steps of:

selectively applying a weighting factor to each of said antenna elements to form a plurality of sub-array beams, each pointed in a selected direction;

for each said sub-array combining an output from each said antenna element in said sub-array to produce a single sub-array output signal;

selectively weighting and combining said sub-array output signal received from at least one of said sub-arrays with a sub-array output signal from at least a second one of said sub-arrays in a fully adaptive process performed at an array level for producing an array output signal having a signal-to-noise plus interference ratio;

estimating an angle-of-arrival direction for a signal of interest SOI and at least one signal not of interest SNOI;

responsive to said estimating step, calculating a new set of weighting factors for controlling at least one said sub-array beam to improve said signal to-noise plus interference ratio obtained for said SOI in said array output signal; and

selectively controlling said weighting factors for said at least one sub-array beam in accordance with said calculating step.

2. The method according to claim **1** wherein said controlling step comprises adjusting said weighting factors for at least one of said sub-arrays for re-pointing said sub-array beam.

3. The method according to claim **1** wherein said controlling step comprises adjusting said weighting factors for at least one of said sub-arrays to produce a sub-array beam pattern comprising regions of relatively higher and lower gain to improve said signal-to-noise plus interference ratio.

4. The method according to claim **3** wherein said calculating step is further comprised of calculating a covariance matrix based solution for at least one of said sub-arrays.

5. The method according to claim **1** wherein said weighting factor is selected from the group consisting of exclusively amplitude, exclusively phase, time-delay and complex weights associated with each said antenna element.

6. The method according to claim **1** wherein said estimating step further comprises the step of estimating an incident power for at least one of said SOI and said at least one SNOI.

7. The method according to claim **1** wherein said selected direction in which at least one sub-array is initially pointed is a region of angular space expected to contain said SOI.

8. The method according to claim **1** wherein said estimating step further comprises a direction finding method based on at least one of:

blind source separation (BSS) techniques;

a priori knowledge;

direction information of signals learned during system operation.

9. The method according to claim **1** further comprising the steps of:

selectively applying at least one alternate weighting factor to each of said antenna elements in at least one of said sub-arrays to independently form at least one alternate sub-array beam using said antenna elements; and

combining an output from each said antenna element produced using said alternate weighting factor to produce at least one alternate sub-array output signal; and

selectively weighting and combining at least one of said sub-array output signals with said at least one alternate sub-array output signal in a fully adaptive process for improving said signal-to-noise plus interference ratio.

10. The method according to claim **9** further comprising selectively weighting and combining said at least one alternate sub-array output signal from a first one of said sub-arrays with a second alternate sub-army output signal from at least a second one of said sub-arrays in a fully adaptive process for producing an alternate array output signal having a second signal-to-noise plus interference ratio.

11. The method according to claim **10** further comprising the step of estimating an angle-of-arrival direction for a second SOI and at least one said SNOI.

12. The method according to claim **11** further comprising the step of calculating a new set of weighting factors for controlling at least one said alternate sub-array beam to improve said second signal to-noise plus interference ratio obtained for said SOI in said alternate array output signal.

13. The method according to claim **12** further comprising the step of selectively controlling said alternate weighting factors for said at least one alternate sub-array beam in accordance with said calculating step.

14. In a phased array antenna system having a plurality of antenna elements configured as a plurality of sub-arrays, a system for cascaded processing of signals to reduce interference from at least one undesired signal, comprising:

a plurality of sub-army processors for selectively applying a weighting factor to each of said antenna elements to form a plurality of sub-array beams, each pointed in a selected direction, and for combining an output from each said antenna element in said sub-arrays to produce a single sub-array output signal for each said sub-array;

at least one array processor for selectively weighting and combining said sub-array output signals received from at least a first one of said sub-arrays with a sub-array output signal from at least a second one of said sub-arrays in a fully adaptive process performed at an array level for producing an array output signal having a signal-to-noise plus interference ratio;

an array system processor for estimating an angle-of-arrival direction for a signal of interest SOI and at least one signal not of interest SNOI and, calculating a new set of weighting factors based on said estimated angle-of-arrival direction information for controlling at least one said sub-array beam to improve said signal to-noise plus interference ratio obtained for said SOI in said array output signal; and

control circuitry for selectively controlling said weighting factors for said at least one sub-array beam for applying said new set of weighting factors.

15. The system according to claim **14** wherein said controlling circuitry is responsive to array system processor for adjusting said weighting factors for at least one of said sub-arrays for re-pointing said sub-array beam.

16. The system according to claim **14** wherein said control circuitry is responsive to said array system processor for adjusting said weighting factors for at least one of said sub-arrays to produce a sub-array beam pattern comprising regions of relatively higher and lower gain to improve said signal-to-noise plus interference ratio.

17. The system according to claim **16** wherein said array system processor is configured for calculating a covariance matrix based solution for at least one of said sub-arrays.

18. The system according to claim **14** wherein said weighting factor is selected from the group consisting of exclusively amplitude, exclusively phase, time-delay and complex weights associated with each said antenna element.

19. The system according to claim **14** wherein said array system processor estimates an incident power for at least one of said SOI and said at least one SNOI.

20. The system according to claim **14** wherein said sub-array processor is responsive to said array-system-processor for initially pointing at least one said sub-array toward a region of angular space expected to contain said SOI.

21. The system according to claim **14** wherein said array system processor estimates an angle-of-arrival direction for said SOI and said at least one SNOI based on at least one of:

blind source separation (BSS) techniques;

a priori knowledge;

direction information of signals learned during system operation.

22. The system according to claim **14** wherein at least one said sub-array processor selectively applies at least one alternate weighting factor to each of said antenna elements in at least one of said sub-arrays to independently form at least one alternate sub-array beam using said antenna elements.

23. The system according to claim **22** wherein said at least one sub-array processor combines an output from each said antenna element produced using said alternate weighting factor to produce at least one alternate sub-army output signal.

24. The system according to claim **23** wherein said array processor selectively weights and combines at least one of said sub-array output signals with said at least one alternate sub-array output signal in a fully adaptive process for improving said signal-to-noise plus interference ratio.

25. The system according to claim **24** wherein said array processor selectively weights and combines said at least one alternate sub-array output signal from a first one of said sub-arrays with a second alternate sub-army output signal from at least a second one of said sub-arrays in a fully adaptive process for producing an alternate array output signal having a second signal-to-noise plus interference ratio.

26. The system according to claim **25** wherein said array system processor further estimates an angle-of-arrival direction for a second SOI and at least one said SNOI.

27. The system according to claim **26** wherein said array system processor calculates a new set of weighting factors for controlling at least one said alternate sub-array beam to improve said second signal to-noise plus interference ratio obtained for said SOI in said alternate army output signal.

28. The system according to claim **27** wherein said array system processor selectively controls said alternate weighting factors for said at least one alternate sub-array beam based on said new set of weighting factors.

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UNITED STATES PATENT AND TRADEMARK OFFICE

CERTIFICATE OF CORRECTION

PATENT NO. : 6,738,018 B2
DATED : May 18, 2004
INVENTOR(S) : Phelan et al.

Page 1 of 1

It is certified that error appears in the above-identified patent and that said Letters Patent is hereby corrected as shown below:

Column 10,
Line 49, delete "army" and replace with -- array --.

Signed and Sealed this

Fourth Day of January, 2005

Jon W. Dudas

JON W. DUDAS
Director of the United States Patent and Trademark Office