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(54) Improvements in and relating to antennas

(57) A directional antenna (1) comprising a first plurality of antenna sub-arrays (2 - 11) forming an antenna array, a second plurality of RF receiver units (13 - 19) fewer in number than the first plurality and each arranged for receiving RF signals from one or more of the antenna sub-arrays and for outputting a receiver signal accord-

ingly. A signal processor (20) processes the receiver signals according to a directional antenna beam pattern. At least two non-neighbouring said sub-arrays (2, 5) are connected to a common one RF receiver unit (13) to provide a combined RF signal thereto.

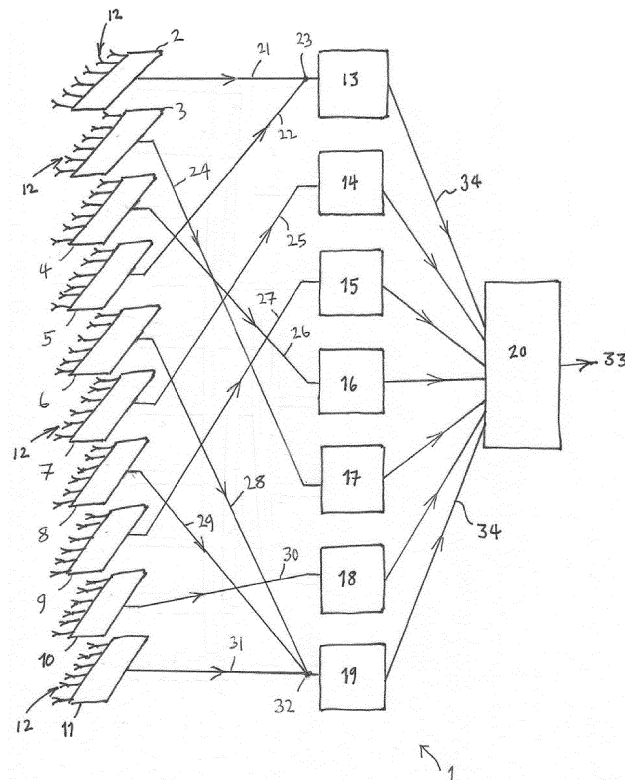


Figure 1

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Description

FIELD OF THE INVENTION

5 **[0001]** The invention relates to antenna systems, such as antenna systems comprising multiple separate sub-antennas, or sub-arrays of antennas, used in combination to form an antenna beam such as, but not limited to, phased antenna arrays.

BACKGROUND ART

10 **[0002]** A phased array antenna system comprises a directive antenna made up of a number of individual antenna radiating elements driven with signals controlled so that the radiation beam pattern produced by the antenna radiating elements collectively may be steered in direction. The converse is true of the receiving beam pattern. The beam of an array of antenna elements can be electronically steered rapidly as a result.

15 **[0003]** A linear antenna array may consist of antenna elements, or separate sub-arrays of antenna elements, arranged in a straight line in one dimension, typically with an equal spacing between antenna elements, or sub-arrays. An idealised linear array composed of N isotropic array elements with an equal spacing d apart may produce a combined output voltage E in response to an incoming radio signal of wavelength λ received from a broadside direction θ to the line of the array, which is the sum of the voltages of the voltages of the array elements and takes the form:

20

$$|E(\theta)|^2 = \left[\frac{\sin[N\pi(d/\lambda)\sin(\theta)]}{\sin[\pi(d/\lambda)\sin(\theta)]} \right]^2$$

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[0004] This is known as the field-intensity pattern and also corresponds to the radiation beam pattern of the idealised antenna array. It has a maximum values when:

30

$$\sin(\theta) = \pm N\pi(d/\lambda)$$

35 **[0005]** The maximum occurring at N=0 corresponds to the main beam of the antenna array. The beam of the idealised linear array may be steered in direction to an angle θ_0 by applying a relative signal phase shift δ equal to:

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$$\delta = 2\pi(d/\lambda)\sin(\theta_0)$$

between successive elements in the array. The normalised intensity pattern of the linear array then becomes:

45

$$G(\theta) = \left[\frac{\sin[N\pi(d/\lambda)(\sin\theta - \sin\theta_0)]}{N \sin[\pi(d/\lambda)(\sin\theta - \sin\theta_0)]} \right]^2$$

50 which has a maximum when $\sin(\theta) = \sin(\theta_0)$, thus θ_0 is the beam direction which may be changed as desired by varying the relative signal phase shift δ . This is an idealised situation, but illustrates the formation of an antenna beam using an array of antenna elements in combination.

[0006] So-called "grating lobes", will appear in the intensity pattern of the idealised array at angles θ_g whenever:

55

$$|\sin\theta_g - \sin\theta_0| = n \frac{\lambda}{d}$$

Thus, the spacing of the elements (d) should preferably be no greater than half the signal wavelength in order to avoid grating lobes appearing to close to the main beam position. Grating lobes are generally undesirable side lobes within a beam pattern which can cause ambiguities, and can lead to misidentification of objects in radar systems. It is also to be noted that grating lobes may occur not only when the element spacing of an array is too large but also when the regularity of the spacing of the elements (d) is broken. For example, when in an array most of the elements are spaced by a regular distance (d), but some neighbouring elements are spaced by a greater distance (e.g. $2d$), grating lobes appear in the beam pattern. The greater the deviation from regularity in the element array structure, generally speaking, the greater is the size of the resulting grating lobe(s).

[0007] The invention addresses this in an antenna structure.

SUMMARY OF THE INVENTION

[0008] In a first aspect, the invention may provide a directional antenna comprising: a first plurality of sub-antennas forming an antenna array; a second plurality of RF receiver units fewer in number than the first plurality and each arranged for receiving RF signals from one or more of said sub-antennas and for outputting a receiver signal accordingly; a signal processor for receiving and processing said receiver signals according to a directional antenna beam pattern; wherein at least two non-neighbouring said sub-antennas are connected to a common one said RF receiver unit to provide a combined RF signal thereto.

[0009] More than two non-neighbouring said sub-antennas may be connected to a common one said RF receiver unit to provide a combined RF signal thereto and none of the sub-antennas so connected are neighbouring sub-antennas.

[0010] Preferably, at least two said RF receiver units are separately connected to a respective at least two non-neighbouring said sub-antennas which provide a combined RF signal thereto.

[0011] In a second aspect, the invention may provide a directional antenna comprising: a plurality of sub-antennas forming an antenna array; a plurality of RF receiver units each arranged for receiving RF signals from a respective one of said sub-antennas and for outputting a receiver signal accordingly; a signal processor for receiving and processing said receiver signals according to a directional antenna beam pattern; wherein neighbouring said RF receiver units are connected to non-neighbouring respective said sub-antennas.

[0012] The directional antenna may include a signal processor and in which the plurality of sub-antennas form a phased-array of sub-antennas, wherein the signal processor is arranged to control the phases applied to sub-arrays of the antenna array to control the beam pattern direction thereof.

[0013] One, some or each of said sub-antennas may comprise a sub-array comprising a plurality antenna radiating elements. A said sub-array preferably comprises a linear array of antenna radiating elements. Each sub-antenna of the antenna array is preferably spaced from each neighbouring sub-antenna by a common distance.

BRIEF DESCRIPTION OF THE DRAWINGS

[0014]

Figure 1 schematically illustrates an antenna system according to an embodiment of the invention;

Figure 2 schematically illustrates an antenna system according to an embodiment of the invention.

DETAILED DESCRIPTION

[0015] Figure 1 schematically illustrates an antenna system 1 comprising a vertical stack of ten equally-spaced sub-arrays of antenna elements (2 to 11), each of which is a substantially identical regular horizontally linear array of six radiating elements 12 connected via a common RF signal input/output port of the sub-array to an RF signal input port of a respective one of seven RF receiver units (13 to 19), and thence to a signal processing unit 20 arranged to process received RF signals and output the result 33 for use as desired.

[0016] RF receivers are typically expensive and quite large items of equipment. Their use in antenna systems, especially in compact and relatively light-weight radar systems, may be minimised as shown schematically in Figure 1.

[0017] A first and uppermost sub-array 2 of the ten sub-arrays and a fourth intermediate sub-array 5 of the ten sub-arrays are each connected to the RF signal input port of a common, shared first RF receiver unit 13 via an RF signal transmission line (21, 22) containing a directional coupler 23 for combining the RF signals output by the first and fourth sub-arrays into one combined RF signal for input to the shared RF receiver unit.

[0018] The second 3, third 4, sixth 7, eighth 9 and ninth 10 intermediate sub-arrays of the ten sub-arrays are connected, respectively, to a fifth 17, fourth 16, second 14, third 15 and sixth 18 separate, dedicated RF receiver unit via a respective RF signal transmission line (24 to 31).

[0019] Finally, the fifth 6 and seventh 8 intermediate sub-arrays and the lowermost tenth sub-array 11 is each connected to the RF signal input port of a common, shared seventh RF receiver unit 19 via an RF signal transmission line (28, 29 and 31) containing a directional coupler 32 for combining the RF signals output by the fifth, seventh and tenth sub-arrays into one combined RF signal for input to the shared RF receiver unit.

[0020] Consequently, the first and fourth sub-arrays effectively form one larger "super" sub-array having an effective "super" sub-array centre mid-way between the two sub-arrays which form it. Similarly, the fifth, seventh and tenth sub-arrays effectively form one more even larger "super" sub-array having an effective "super" sub-array centre located between the outer two sub-arrays which form its upper and lower limits.

[0021] It is to be noted that the sub-arrays which form a part of any one of the two "super" sub-arrays sharing a common receiver unit are non-neighbouring sub-arrays. The result is that the effective centres of the two "super" sub-arrays is each located substantially close to or between a given two of the other sub-arrays of the antenna array. This means the separation between the effective centre of any "super" sub-array and a given sub-array closest to that effective centre, is not greater than the regular separation between sub-arrays of the antenna array. This minimises the effects of grating lobes for the reasons outlined above in respect of the idealised array example. Had the sub-arrays forming a given "super" all been a succession of neighbouring sub-arrays, the effective mid-point centre of the "super" array would have been spaced from the nearest regular (non-"super") sub-array by a distance exceeding the regular spacing between sub-arrays. This would tend to promote the presence and effects of grating lobes.

[0022] The allocation of which of the ten sub-arrays to connect to which of the seven RF receiver units is preferably generated randomly, e.g. via a random selection, with the condition that if more than one sub-array is assigned to a given RF receiver unit, then not all of the sub-arrays are neighbouring arrays, and more preferably that none of the sub-arrays are neighbouring sub-arrays (as shown in Figure 1). This randomised selection/allocation process has been found to provide better suppression of grating lobe effects across the array by spreading out those effects across the array. In other embodiments, only the allocation of the sub-arrays to be connected to a common receiver unit is performed in this way, and the allocation of remaining sub-arrays to single, dedicated receiver units may be non-random. In alternative

embodiments the allocation of which of the ten antenna sub-arrays to connect to which of the seven RF receiver units is made to provide optimal antenna performance as desired, subject to the conditions described above.

[0023] In any case, the signal processor unit contains a mapping table which tabulates which of the antenna sub-arrays is connected to which of the RF receiver units such that the signal processor 20 may determine the relative location (within the array) of the sub-array, or "super" sub-array, responsible for a given received signal 34. This is because the relative positions of the receiver units generally no longer correlates directly to the physical positions of the sub-arrays they receive RF signals from in use.

[0024] The invention in the aspect illustrated in Figure 1, and discussed above, permits a limited number of RF receivers to be used with a greater number of antenna sub-arrays. The benefit is lower cost and weight, while having the advantages of "super" sub-arrays which each have a greater aperture size, gain and resolution than any one sub-array alone, while managing and at least to some extent suppressing the otherwise deleterious effects of grating lobes.

[0025] In another aspect of the invention, is illustrated in Figure 2 which shows an antenna system 35 comprising a vertical stack of ten equally-spaced sub-arrays of antenna elements (2 to 11), each of which is a substantially identical regular horizontally linear array of six radiating elements (12) connected via a common RF signal input/output port of the sub-array to an RF signal input port of a respective one of ten RF receiver units (40 to 49), and thence to a signal processing unit 20 arranged to process received RF signals 34 and output the result 33 for use as desired. Each antenna sub-array has a dedicated RF receiver unit connected to it alone, via an RF signal transmission line (50 to 59).

[0026] The allocation of which of the ten antenna sub-arrays to connect to which of the ten RF receiver units is preferably made to provide optimal antenna performance as desired, with the condition neighbouring antenna sub-arrays are assigned to a non-neighbouring RF receiver units (as shown in Figure 2). This selection/allocation process has been found to provide better suppression of grating lobe effects across the array in the event of failure of two or more neighbouring RF receiver units. This is due to the spreading out those effects across the array. The signal processor unit contains a mapping table which tabulates which of the antenna sub-arrays is connected to which of the RF receiver units such that the signal processor may determine the relative location (within the array) of the sub-array responsible for a given received signal. This is because the relative positions of the receiver units generally no longer correlates directly to the physical positions of the sub-arrays they receive RF signals from in use.

[0027] Failure of RF signal receivers may often happen due to overheating for example. In such a case, a given overheated receiver unit may cause overheating in a neighbouring receiver unit, typically nearby. Thus, receiver units arranged in an antenna system are susceptible to failure in neighbouring groups. In the even of such a failure, and were it not for the non-neighbour allocation of antenna sub-arrays to neighbouring receiver units, the effect would be the loss of two neighbouring antenna sub-arrays within the antenna array (e.g. the middle two sub-arrays) producing a "hole" in the working antenna array structure. The resultant effect upon the antenna beam pattern would be the generation of grating side lobes for the reasons given above. By avoiding the allocation of neighbouring antenna sub-arrays to neighbouring receiver units, to likelihood of this occurring is minimised because the failure of two neighbouring receiver units

does not lead to the loss of a corresponding two neighbouring antenna sub-arrays.

[0028] The example shown in Figure 1 and Figure 2 is a vertical array of horizontal antenna sub-arrays with grating lobes suppressed in the elevation direction, however by turning the array through 90 degrees one may provide a horizontal array of vertical antenna sub-arrays with grating lobes suppressed in the azimuth direction.

[0029] The embodiments described above are presented for illustrative purposes and it is to be understood that variations, modifications and equivalents thereto such as would be readily apparent to the skilled person are encompassed within the scope of the invention.

Claims

1. A directional antenna comprising:

a first plurality of sub-antennas forming an antenna array;
 a second plurality of RF receiver units fewer in number than the first plurality and each arranged for receiving RF signals from one or more of said sub-antennas and for outputting a receiver signal accordingly;
 a signal processor for receiving and processing said receiver signals according to a directional antenna beam pattern;
 wherein at least two non-neighbouring said sub-antennas are connected to a common one said RF receiver unit to provide a combined RF signal thereto.

2. A directional antenna according to any preceding claim in which more than two non-neighbouring said sub-antennas are connected to a common one said RF receiver unit to provide a combined RF signal thereto and none of the sub-antennas so connected are neighbouring sub-antennas.

3. A directional antenna according to any preceding claim in which at least two said RF receiver units are separately connected to a respective at least two non-neighbouring said sub-antennas which provide a combined RF signal thereto.

4. A directional antenna comprising:

a plurality of sub-antennas forming an antenna array;
 a plurality of RF receiver units each arranged for receiving RF signals from a respective one of said sub-antennas and for outputting a receiver signal accordingly;
 a signal processor for receiving and processing said receiver signals according to a directional antenna beam pattern;
 wherein neighbouring said RF receiver units are connected to non-neighbouring respective said sub-antennas.

5. A directional antenna according to any proceeding claim including a signal processor and in which the plurality of sub-antennas form a phased-array of sub-antennas, wherein the signal processor is arranged to control the phases applied to sub-arrays of the antenna array to control the beam pattern direction thereof.

6. A directional antenna according to any preceding claim in which one, some or each of said sub-antennas comprises a sub-array comprising a plurality antenna radiating elements.

7. A directional antenna according to claim 6 in which said sub-array comprises a linear array of antenna radiating elements.

8. A directional antenna according to any preceding claim in which each sub-antenna of the antenna array is spaced from each neighbouring sub-antenna by a common distance.

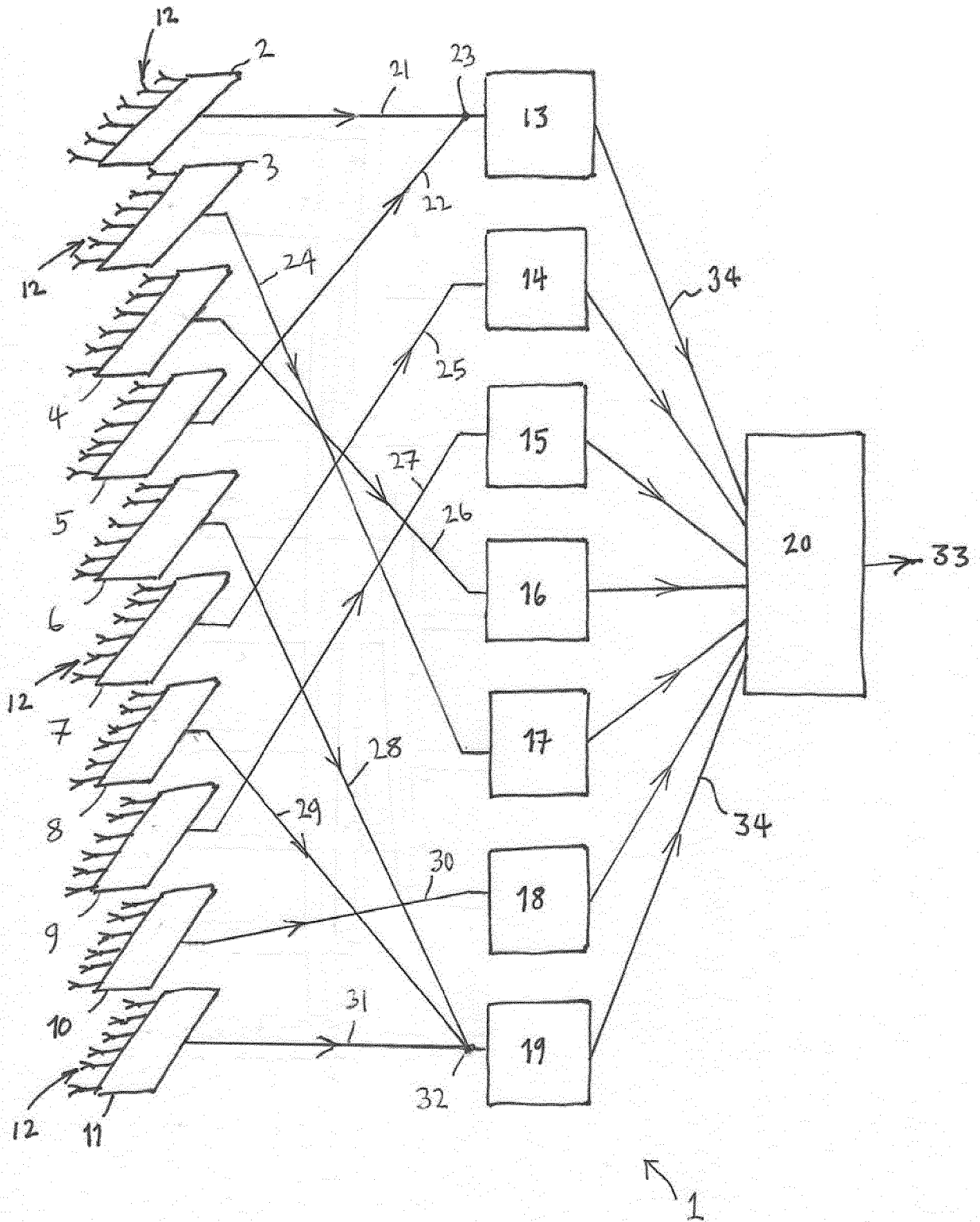


Figure 1

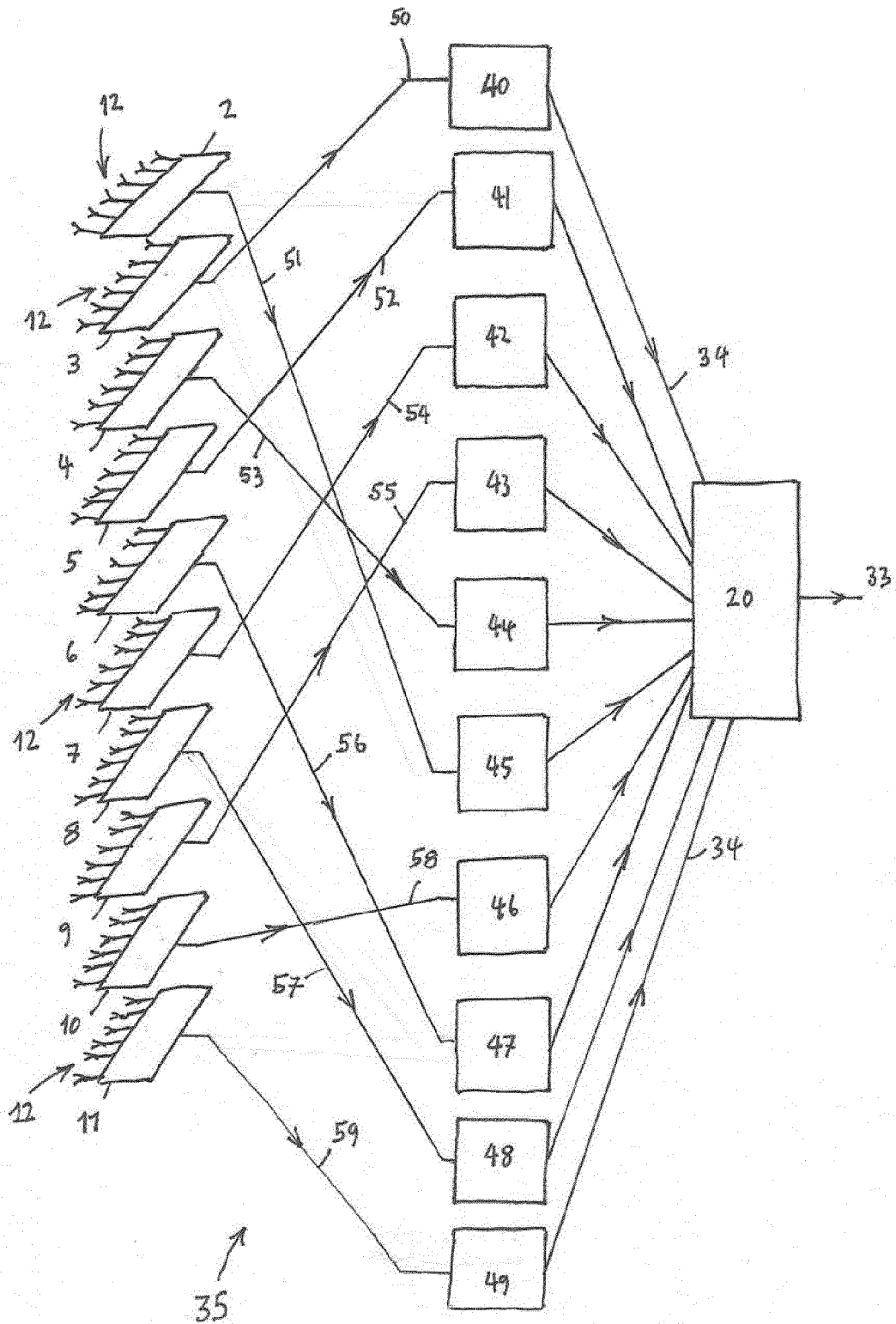


Figure 2



EUROPEAN SEARCH REPORT

Application Number
EP 12 27 5203

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Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	CLASSIFICATION OF THE APPLICATION (IPC)
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The present search report has been drawn up for all claims			
Place of search Munich		Date of completion of the search 10 July 2013	Examiner Kaleve, Abraham
CATEGORY OF CITED DOCUMENTS X : particularly relevant if taken alone Y : particularly relevant if combined with another document of the same category A : technological background O : non-written disclosure P : intermediate document		T : theory or principle underlying the invention E : earlier patent document, but published on, or after the filing date D : document cited in the application L : document cited for other reasons & : member of the same patent family, corresponding document	

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EPO FORM 1503 03.82 (P04C01)



EUROPEAN SEARCH REPORT

Application Number
EP 12 27 5203

DOCUMENTS CONSIDERED TO BE RELEVANT			
Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	CLASSIFICATION OF THE APPLICATION (IPC)
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			TECHNICAL FIELDS SEARCHED (IPC)
The present search report has been drawn up for all claims			
Place of search Munich		Date of completion of the search 10 July 2013	Examiner Kaleve, Abraham
CATEGORY OF CITED DOCUMENTS X : particularly relevant if taken alone Y : particularly relevant if combined with another document of the same category A : technological background O : non-written disclosure P : intermediate document T : theory or principle underlying the invention E : earlier patent document, but published on, or after the filing date D : document cited in the application L : document cited for other reasons & : member of the same patent family, corresponding document			

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EPO FORM 1503 03.82 (P04C01)



Application Number

EP 12 27 5203

CLAIMS INCURRING FEES

The present European patent application comprised at the time of filing claims for which payment was due.

☐ Only part of the claims have been paid within the prescribed time limit. The present European search report has been drawn up for those claims for which no payment was due and for those claims for which claims fees have been paid, namely claim(s):

☐ No claims fees have been paid within the prescribed time limit. The present European search report has been drawn up for those claims for which no payment was due.

LACK OF UNITY OF INVENTION

The Search Division considers that the present European patent application does not comply with the requirements of unity of invention and relates to several inventions or groups of inventions, namely:

see sheet B

☒ All further search fees have been paid within the fixed time limit. The present European search report has been drawn up for all claims.

☐ As all searchable claims could be searched without effort justifying an additional fee, the Search Division did not invite payment of any additional fee.

☐ Only part of the further search fees have been paid within the fixed time limit. The present European search report has been drawn up for those parts of the European patent application which relate to the inventions in respect of which search fees have been paid, namely claims:

☐ None of the further search fees have been paid within the fixed time limit. The present European search report has been drawn up for those parts of the European patent application which relate to the invention first mentioned in the claims, namely claims:

☐ The present supplementary European search report has been drawn up for those parts of the European patent application which relate to the invention first mentioned in the claims (Rule 164 (1) EPC).



**LACK OF UNITY OF INVENTION
SHEET B**

Application Number
EP 12 27 5203

The Search Division considers that the present European patent application does not comply with the requirements of unity of invention and relates to several inventions or groups of inventions, namely:

1. claims: 1-3, 5-8

Antenna array comprising sub-antennas, and RF receiver units fewer in number than the sub-antennas and adapted to receive RF signals from one or more sub-antennas and to output receiver signals, a signal processor adapted to receive the receiver signals, wherein at least two non-neighbouring said sub-antennas are connected to a common one said RF receiver unit to provide a combined RF signal thereto.

2. claim: 4

Antenna array comprising sub-antennas, and RF receiver units each adapted to receive RF signals from a respective sub-antenna and to output receiver signals, a signal processor adapted to receive the receiver signals, wherein neighbouring said RF receiver units are connected to non-neighbouring respective said sub-antennas.

**ANNEX TO THE EUROPEAN SEARCH REPORT
ON EUROPEAN PATENT APPLICATION NO.**

EP 12 27 5203

This annex lists the patent family members relating to the patent documents cited in the above-mentioned European search report. The members are as contained in the European Patent Office EDP file on
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10-07-2013

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EPO FORM P0459

For more details about this annex : see Official Journal of the European Patent Office, No. 12/82