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54 **Direction-finding antenna system.**

57 In a direction-finding antenna system comprising an array of elements (1-8) mutually spaced in at least one direction and feeder means for forming sum and difference radiation patterns, the contribution of outer elements (1,5;4,8) lying beyond the phase centres of the sub-arrays from which the sum pattern is formed, relative to the contribution of inner elements (2,6;3,7), is less to the difference pattern than to the sum pattern, in order that the magnitude of the difference pattern should exceed that of the sum pattern except in the region of the central null in the difference pattern. The invention is particularly applicable to a curved array of relatively small aperture, such as an IFF array mounted on a parabolic radar antenna reflector operating at a much higher frequency.

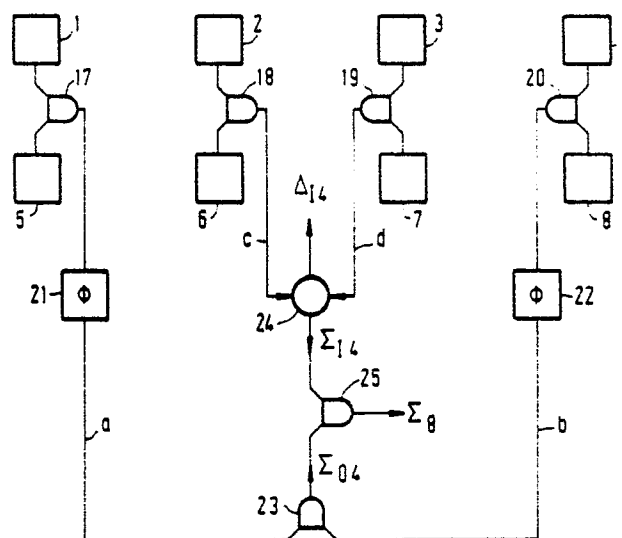


FIG. 3

"DIRECTION-FINDING ANTENNA SYSTEM"

The invention relates to a direction-finding antenna system comprising an array of antenna elements mutually spaced in at least one direction and further comprising feeder means for forming a sum radiation pattern and a difference radiation pattern from the elements. The invention relates particularly but not exclusively to such a system wherein the array is curved in the plane including said one direction and the axes of the radiation patterns.

Antenna systems as set forth in the opening sentence of this specification are well known. They may be used in so-called monopulse systems for determining the direction of incidence of RF signals, typically microwave signals, in arrangements which compare the amplitudes and/or phases of the signals respectively received with the sum and difference patterns. In such an arrangement, it may be desirable to ensure that the magnitude of the difference pattern should exceed that of the sum pattern, except in the region of the central null of the difference pattern, when the magnitude of the sum pattern lies within a specified range from its peak value. This may not be especially difficult to achieve with, for example, a large array which extends over many wavelengths, in particular one wherein an amplitude distribution which is not uniform across the array in said one direction can be applied to the contributions of the elements to the sum pattern. However, it may be difficult to achieve in certain conditions, for example with a relatively small array wherein little or no amplitude tapering can be applied to the sum pattern because it is necessary to maximise the gain from the relatively few elements that are available.

According to the invention, a direction-finding antenna system as set forth in the opening sentence of this specification is characterised in that the contribution of outer elements which with respect to said direction lie beyond the phase centres of the sub-arrays from which the sum pattern is formed, relative to the contribution of inner elements which lie at or between said phase centres, is less to the difference pattern than to the sum pattern.

It will be appreciated that whilst the term "contribution" may imply use of the array for reception, the array may additionally or alternatively be used for transmission.

Reducing the contributions of the outer elements to the difference pattern effectively reduces spacing between the phase centres of the sub-arrays and thus makes the difference pattern less directional than if the outer elements made the same contribution as to the sum pattern. One effect

of this is to increase the angular spacing between the peaks of the difference pattern and thus tend to raise the magnitude of the difference pattern at angles beyond these peaks. A suitable reduction in the contribution of the outer elements may be determined empirically. (It may be noted that another effect is to broaden the central angular range over which the magnitude of the sum pattern exceeds that of the difference pattern; the extent of broadening that is acceptable may vary in different applications. A suitable compromise between this broadening and the desired raising of the difference pattern at larger angles may be achievable empirically.)

In a particularly simple embodiment, at least one outer element which lies beyond the phase centre of each sub-array makes no contribution to the difference pattern.

The invention may be particularly suited for embodiment in an array which is curved in the plane including said one direction and the axes of the radiation patterns; in such an array, it may otherwise be especially difficult to obtain a difference pattern with the desired breadth. Such an array may be one wherein the elements are microstrip patch radiators supported on an antenna reflector which, in association with a feed radiator, operates at a substantially higher frequency than the array: the array may then have a relatively small extent in said direction which, as indicated above, may also make it particularly difficult to obtain a difference pattern with sufficient magnitude relative to the sum pattern. An example of such an arrangement is an IFF (Identification Friend or Foe) array which may operate in L-band at around 1 GHz and which is supported on the reflector of a radar antenna operating, for example, in X-band at around 9 GHz; the IFF array may thus be mechanically scanned together with the radar antenna. Whilst the aperture of the radar antenna may typically amount to many wavelengths at the operating frequency of the radar (e.g. 30 wavelengths), this dimension (within which the IFF array is constrained to fit) may amount to only a few wavelengths at the IFF frequency.

Embodiments of the invention will now be described, by way of example, with reference to the diagrammatic drawings, in which:-

Figure 1 is a schematic front view of a radar antenna parabolic reflector supporting a direction-finding array of microstrip patch antenna elements;

Figure 2 is schematic sectional view of a row of microstrip patches and the supporting reflector, also depicting the feed horn of the radar antenna;

Figure 3 is a schematic diagram of a feeder network for the direction-finding array;

Figure 4 shows measured sum and difference radiation patterns for a constructed embodiment, and

Figure 5 shows a modified portion of the feeder network.

Figure 1 depicts an array of antenna elements for a direction-finding system embodying the invention. The elements of the array are in this instance formed as eight microstrip patch elements 1-8 and supported on a parabolic reflector 9 of a radar antenna. The microstrip patch radiators are arranged in two rows, each of four patches, extending in a horizontal direction; two rows of elements are used (rather than one) to increase the gain. The reflector is curved in a plane including the axes of the sum and difference radiation patterns of the array (i.e. the normal to the plane of the drawing) and the direction of extent of the rows, that is to say, the reflector is curved in a horizontal plane (as drawn); it is also curved in a vertical plane. The curvature in the horizontal plane is depicted in Figure 2, which is a cross-section on the line II-II in Figure 1; for simplicity, only one row of elements is shown. Figure 2 also shows schematically a feed horn radiator 10 operatively associated with the reflector 9. With respect to the horizontal direction normal to the axes of the radiation patterns, there is an element at each of four locations mutually spaced by the same distance D.

As shown in Figure 2, each of the patches comprises a thin conductive layer 11 which forms the radiator. This is disposed on a dielectric layer 12 which in turn is supported on the reflector 9. To provide the ground plane of the microstrip, the reflector may be of conductive material, or may be of dielectric material with a conductive coating on at least the surface facing the feed radiator 10. In this embodiment, the front surface of the dielectric layer 12 supporting the conductive layer 11 of each patch element is planar whilst the rear surface conforms to the curved surface of the reflector 9. As a result, the thickness of the patch element, i.e. the spacing between the conductive layer 11 and the ground plane provided by the reflector 9, varies across the patch: this increases the bandwidth of the patch antenna element, which is advantageous for transmission and reception at different respective frequencies.

To form a sum radiation pattern, the whole array of eight elements is used. The eight elements may be considered as forming two sub-arrays, comprising elements 1, 2, 5, 6 and 3, 4, 7, 8 respectively, on opposite sides of the phase centre 13 of the whole array. As will be mentioned again with reference to Figure 3, the feeder network of this embodiment comprises phase delays for the

outermost elements of the array so that, with respect to transmission or reception at an angle close to the axes of the sum difference patterns - (boresight), the elements are effectively substantially collinear in the horizontal plane. The phase centres, 14 and 15 respectively, of each of the two sub-arrays are thus mid-way between the horizontal locations of the elements of the respective sub-array.

Figure 3 depicts schematically a feeder network for forming the sum and difference radiation patterns from the array of elements 1-8. The network comprises four 3 dB in-phase power dividers/combiners 17-20 which respectively combine the signals from each two adjacent elements, respectively in the two rows, at the same location in the horizontal direction.

As mentioned above, the feeders for the outermost elements (combiners 17 and 20) include phase delays, denoted schematically by $\emptyset$ at 21, 22 respectively, so that the four elements in a row are effectively substantially collinear with respect to transmission or reception on boresight. Following these phase delays, the feeders are denoted a and b respectively, and the feeders from combiners 18 and 19 are denoted c and d respectively. The signals on lines a and b are added in a further 3 dB in-phase power combiner 23 to form the sum of the signals from the outer four elements, Σ_{04} . The signals from the inner four elements on lines c and d are respectively supplied to two ports of a hybrid junction 24 which at two further ports produces the sum and the difference of these signals, Σ_{14} and Δ_{14} respectively. Σ_{14} is added to Σ_{04} in yet another 3 dB in-phase power combiner, 25, to produce the sum of the signals from all eight elements, Σ_8 .

Since the difference signal Σ_{14} is derived from only the inner elements which are spaced a distance D apart in the horizontal direction while the sum signal Σ_8 is derived from the two sub-arrays whose phase centres are a distance 2D apart, the difference pattern is less directional than if it had been derived from the two sub-arrays from which the sum pattern is derived. Consequently, whereas if the difference pattern were derived from said two sub-arrays, its magnitude would tend to fall below that of the sum pattern at angles fairly close to boresight (apart from the central null of the difference pattern), this need not be the case for the embodiment of the invention. Figure 4 shows, in dB against the angle θ in degrees with respect to mechanical boresight, a sum pattern (continuous line) and a difference pattern (dashed line) measured on a constructed embodiment similar to that described above with reference to Figures 1 to 3. This embodiment had to satisfy the criterion that, apart from the central null, the magnitude of the difference pattern should exceed the magnitude of

the sum pattern if the magnitude of the sum pattern was within 20 dB of its peak value. As can be seen, this criterion was satisfied by a substantial margin.

As an alternative to using two phase delays $\emptyset$ - (21,22) between combiner 23 and combiners 17 and 20 respectively, a single phase delay $\emptyset$ may be used between combiners 23 and 25.

As an alternative to outer elements of the array making no contribution at all to the difference pattern, their contributions (relative to those of the inner elements) may merely be somewhat reduced. This has the possible advantages of increasing the gain of the difference pattern and of reducing the central angular range over which the magnitude of the sum pattern exceeds that of the difference pattern, but the disadvantage of being somewhat more complex. Figure 5 shows schematically a modified portion of the feeder network of Figure 3 in which the one hybrid junction 24 and the two combiners 23 and 25 of Figure 3 are replaced by at least two hybrid junctions and two combiners. The arrangement of Figure 5 uses the same four feeder lines a-d as in Figure 3. Lines c and d are the inputs for a first hybrid junction 24 producing outputs Δ_{14} and Σ_{14} (as in Figure 3), while lines a and b are the inputs to a second junction 27 producing outputs (the difference between the signals from the two outer pairs of elements) and Σ_{04} . The sum signals Σ_{14} and Δ_{04} are applied to a 3 dB in-phase combiner 28 which produces the signal Σ_s . The difference signal Δ_{04} is supplied to an attenuator 29 whose output is added to the difference signal Δ_{14} in a 3 dB in-phase combiner 30 which produces the signal $(\Delta_{14} + k\Delta_{04})$ where $0 < k < 1$. As an alternative to the attenuator 29 and equal power combiner 30, a combiner/divider giving unequal combination/division may be used.

As an alternative to reducing the absolute magnitudes of the contributions of the outer elements to the difference pattern, the absolute magnitude of the contributions of the inner elements to the difference pattern (but not the sum pattern) may be increased by amplification, so that the contributions of the outer elements relative to the contributions of the inner elements is less to the difference pattern than the sum pattern.

Where the invention is embodied in an array comprising, for example, eight or more elements uniformly spaced in the relevant direction, the outer elements whose relative contributions are less to the difference pattern than to the sum pattern need not be the outermost elements with respect to said direction, but should nevertheless lie beyond the phase centres of the sub-arrays from which the sum pattern is formed (rather than between or at the phase centres) so as to achieve the desired broadening of the difference pattern.

The array may comprise elements at an odd number (rather than an even number) of locations spaced in the relevant direction. For example, there may be an element at the phase centre of the whole array. In that case, the central element would not be used in forming the difference pattern but could be used in forming the sum pattern, and the contribution of the central element to the sum pattern could then notionally be divided equally between the two sub-arrays on opposite sides of the phase centre of the whole array.

In the above-mentioned constructed embodiment, the patches were 9 cm wide horizontally and 11 cm wide vertically. Their spacing was 17 cm horizontally (distance D) and 20 cm vertically. The value of the phase delay $\emptyset$ was of the order of 50-60 degrees; the power dividers/combiners were of the Wilkinson type, and the hybrid junction was a 180 degrees hybrid ring with a circumference of one and a half wavelengths. These components were formed on alumina substrates of 0.635 mm thickness. The thickness of the dielectric of the patches varied from 1.5 cm at the edges to about 2.0 cm at the centre of the patches; the dielectric material was P10 polyurethane foam available from The Plessey Co. The radar antenna reflector was of conductive carbon fibre material; it had apertures of approximately 107 cm horizontally and 41 cm vertically, and had a focal length of 43 cm. The patch array operated at 1.03 and 1.09 GHz, and the radar antenna operated in the range 9.0-9.5 GHz.

Claims

1. A direction-finding antenna system comprising an array of antenna elements mutually spaced in at least one direction and further comprising feeder means for forming a sum radiation pattern and a difference radiation pattern from the elements, characterised in that the contribution of outer elements which with respect to said direction lie beyond the phase centres of the sub-arrays from which the sum pattern is formed, relative to the contribution of inner elements which lie at or between said phase centres, is less to the difference pattern than to the sum pattern.

2. A system as claimed in Claim 1 wherein at least one outer element which lies beyond the phase centre of each sub-array makes no contribution to the difference pattern.

3. A system as claimed in Claim 1 or 2 wherein the array is curved in the plane including said one direction and the axes of the radiation patterns.

4. A system as claimed in Claim 3 wherein the elements are microstrip patch radiators supported on an antenna reflector which, in association with a feed radiator, operates at a substantially higher frequency than the array.

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5. A system as claimed in any preceding claim comprising, with respect to said direction, one or more elements at each of four mutually-spaced locations.

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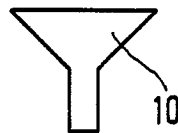
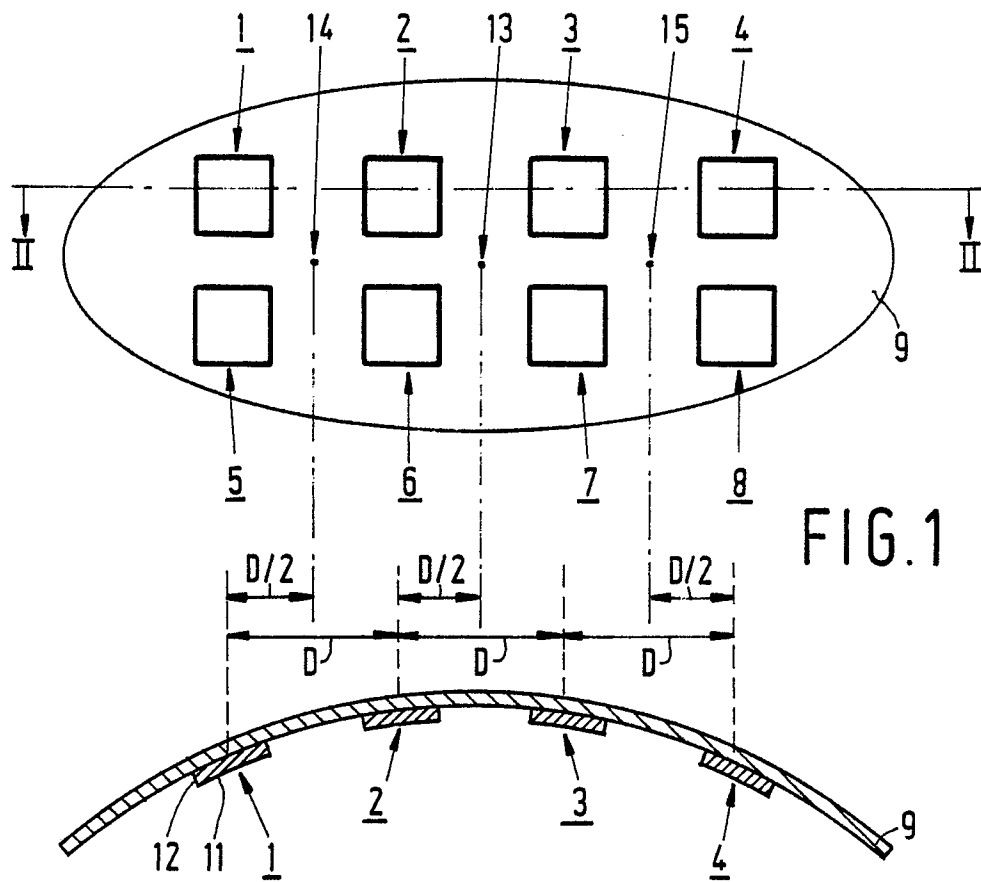
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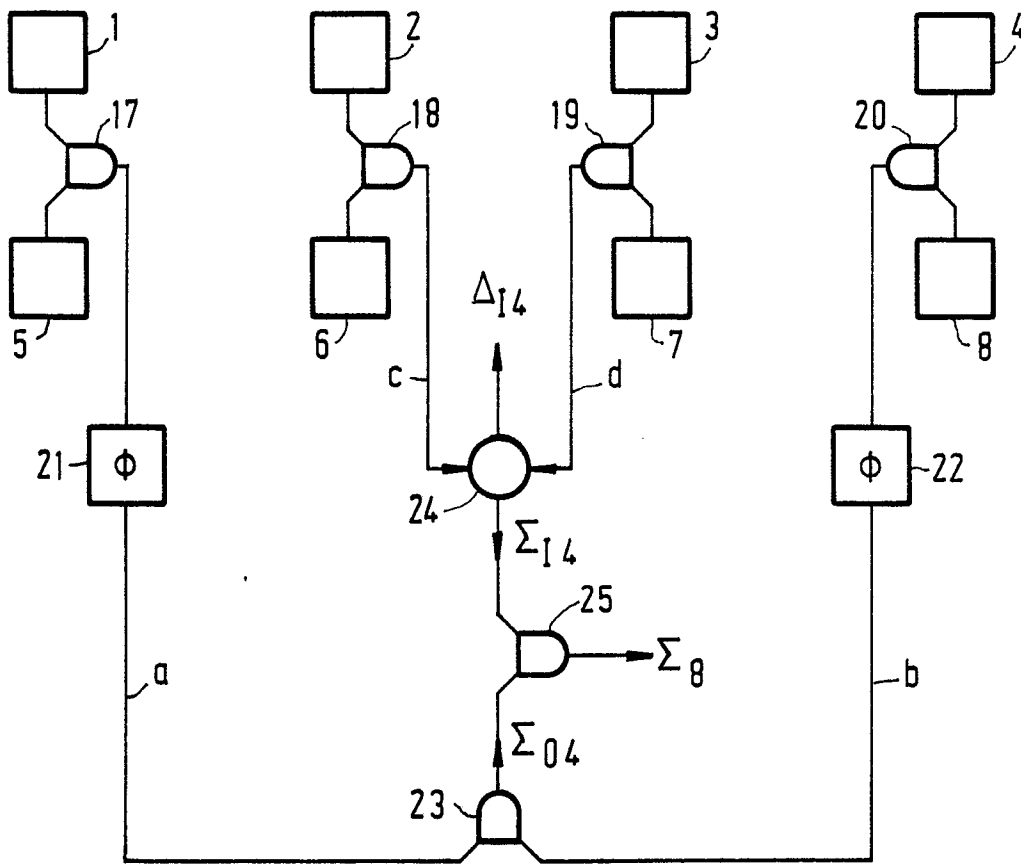


FIG. 3

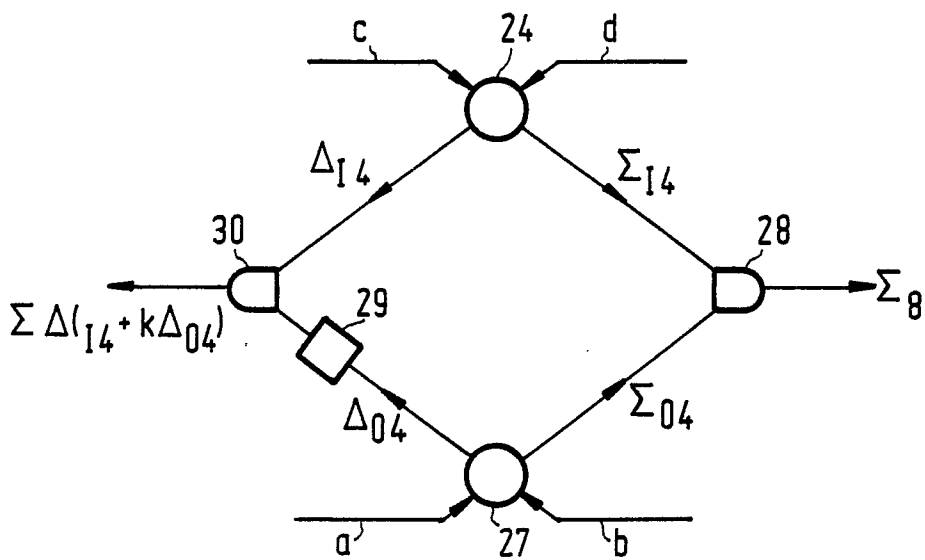


FIG. 5

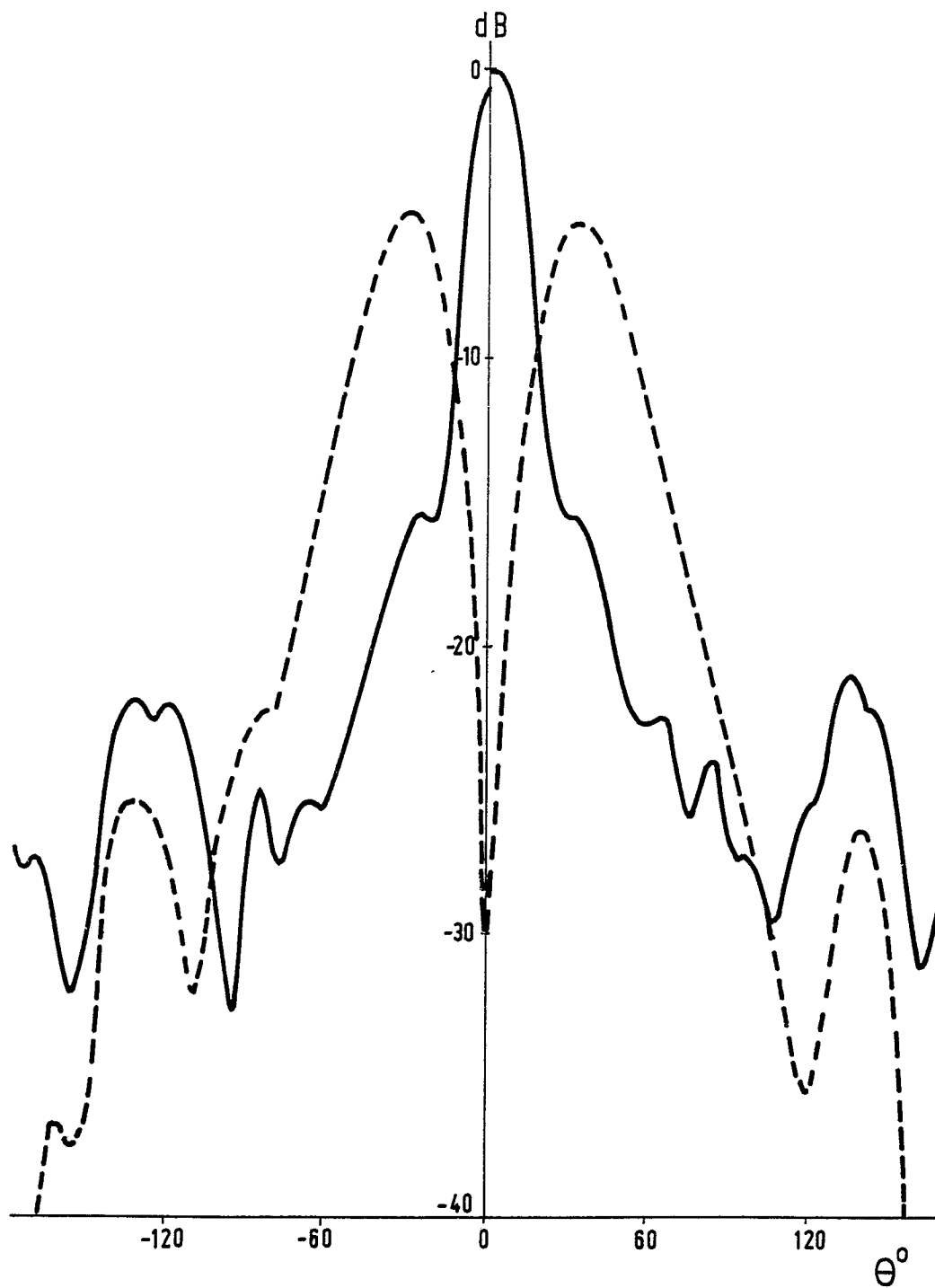


FIG.4



EP 87 20 0343

DOCUMENTS CONSIDERED TO BE RELEVANT			
Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	CLASSIFICATION OF THE APPLICATION (Int. Cl.4)
A	US-A-3 594 811 (R.L. PIERROT) * figure 3; column 2, lines 30-44 *	2	H 01 Q 25/02
Y	* figure 3; abstract *	1	
Y	--- EP-A-0 021 193 (CONTRAVES ITALIANA) * figure 1, abstract *	1	
A	* figure 1, abstract *	3, 4	
A	--- DE-C-2 737 750 (SIEMENS) * figure 1; claims 1, 2 *	1	TECHNICAL FIELDS SEARCHED (Int. Cl.4)
A	--- EP-A-0 012 055 (THOMSON-CSF) * figure 2, abstract *		H 01 Q 25/02 G 01 S 13/76
A	--- EP-A-0 013 240 (THOMSON-CSF) * figure 1, abstract *		
A	--- US-A-4 283 729 (P.N. RICHARDSON) * figure 2, abstract *		

The present search report has been drawn up for all claims			
Place of search BERLIN		Date of completion of the search 02-06-1987	Examiner BREUSING J
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			