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## (54) Monopulse antenna with improved sidelobe suppression.

(57) Radar system using sum and difference signals for tracking targets, wherein the system includes aperture means having a cross sectional area for transmitting energy toward a target and receiving return energy ; and circuit means for generating sum and difference signals, the circuit means being selectively coupled to said aperture means, with the sum signal being generated using energy from the entire aperture means and with the difference signals being generated using return energy from the aperture means exclusive of energy from a predetermined area (E). The invention permits simultaneous optimization of the sum and difference signals and also suppresses the near-in sidelobes in the difference signals.

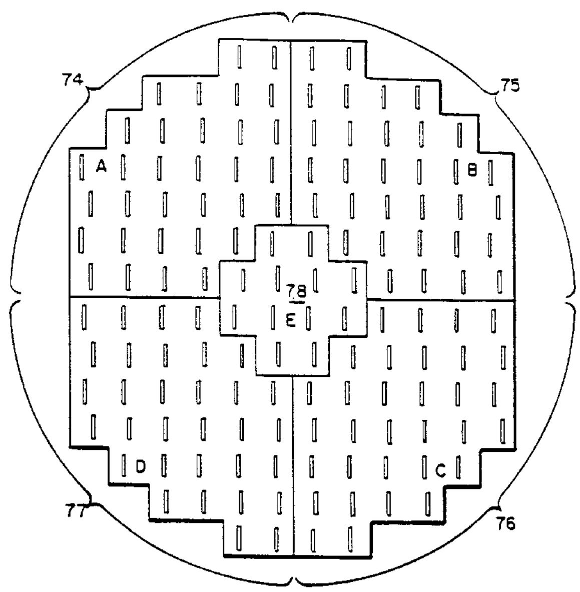



Fig. 3a.

EP 0 544 081 A1

The present invention relates to an antenna system adapted for radar application using sum and difference signals for tracking a target including

a) a monopulse antenna having

a1) a cross sectional area for transmitting energy toward a target and receiving return energy;

a2) an array of excitable elements symmetrically disposed about azimuth and elevation axes;

b) circuit means coupled to said excitable elements said circuit means generating a sum signal and azimuth and elevation difference signals using return energy from said excitable elements.

The invention further relates to a method of operating an antenna system adapted for radar application using sum and difference signals for tracking a target including the steps of:

a) transmitting energy toward said target and receiving return energy with a monopulse antenna, said monopulse antenna comprising a cross sectional area with an array of excitable elements symmetrically disposed about azimuth and elevation axes;

b) coupling return energy from said monopulse antenna to circuit means,

c) generating with said circuit means a sum signal and azimuth and elevation difference signals.

An antenna system and a method of this kind are known from the publication "A Multielement High Power Monopulse Feed with Low Sidelobe and High Aperture Efficiency" by Nam San Wong et al., IEEE Transactions on Antennas and Propagation, Vol. AP-22, No. 3, May 1974.

More specifically, the invention relates to optimization of antenna sum and difference patterns, and in particular, to a sidelobe suppression arrangement for a monopulse antenna using sum and difference patterns to track targets.

As is generally known, a monopulse antenna may be subdivided into sections, for example, by using horns or quadrants, and the radar then senses the target displacement by comparing the amplitude and phase of the echo signal for each horn or quadrant.

The RF circuitry for a conventional antenna divided into quadrants subtracts the output of the left pair from the output of the right pair to sense any imbalance in the azimuth direction (azimuth difference pattern) and the output of the top pair from the output of the bottom pair to sense any imbalance in the elevation direction (elevation difference pattern). See Radar Handbook, Merrill Skolnik, McGraw Hill, 1970. The subtractor outputs, i.e., the difference patterns, are zero when the target is on axis, increasing in amplitude with increasing displacement of the target from the antenna axis.

A sum signal, usually representative of the energy received over the entire aperture, is generated and used as a reference signal, for video input, and for gain control.

There are many trade-offs in feed design and radiation patterns because optimum sum and difference signals, low sidelobe levels, polarization diversity, compactness, and simplicity cannot all be fully satisfied simultaneously, especially when using a single feed. Historically, a common approach has been to optimize the sum pattern and to tolerate the resulting difference pattern signal. However, it is generally regarded that optimizing undesirable features of the difference patterns are important in eliminating significant tracking problems. See Corlin, US 4,525,716; June 15, 1985. For example, high sidelobes in the difference signals increase radar susceptibility to interference from background clutter or other off axis sources of radiation which results in tracking error and loss of efficiency.

It is thus one major goal of the present invention to provide an antenna system of the kind described above which simultaneously optimizes the sum and difference signals.

The publication by Nam San Wong, mentioned at the outset, describes an approach of optimizing the sum and difference signals in terms of sidelobe suppression. As a result of a mathematical model, the signals received from 32 elements are multiplied with excitation coefficients, i.e. weighted. The excitation coefficients are complicated fractional expressions and different for the calculation of the sum, the azimuth difference and the elevation difference.

The arrangement of antenna elements in a certain pattern, although for a different purpose (namely to switch a monopulse antenna between wide-beam acquisition mode and narrow-beam tracking mode), is already known from US 3,965,475.

DE-A-27 36 497 also deals with side lobe suppression. However, this publications aims primarily at the generation of a combined difference signal.

Document US-3,711,858 is also concerned with a monopulse radar antenna using sidelobe suppression. In this antenna wave guide sections are provided in the four quadrants with adjacent ends of the wave guides in the quadrants being staggerd such that certain wave guides in one quadrant extend into the adjacent quadrant and vice-versa. Thereby the lobe of the transition in phase from one quadrant to the other is reduced.

According to the present invention, an antenna system of the kind mentioned at the outset is characterized in that

c) said cross sectional area is divided into four quadrants and a center section,

d) said circuit means provide

d1) said sum signal as the sum of the return energy of all said excitable elements in said four quadrants and said center section,

d2) said azimuth difference signal as the difference between

d2.1) the sum of the return energy of the excitable elements in the left-hand two of said quadrants and

d2.2) the sum of the return energy of the excitable elements in the right-hand two of said quadrants,

d3) said elevation difference signal as the difference between

d3.1) the sum of the return energy of the excitable elements in the upper two of said quadrants and

d3.2) the sum of the return energy of the excitable elements in the lower two of said quadrants.

Further the method mentioned at the outset comprises the steps of

d) dividing said cross sectional area into four quadrants and a center section,

e) generating said sum signal as the sum of the return energy of all said excitable elements in said four quadrants and said center section,

f) generating said azimuth difference signal as the difference between

f1) the sum of the return energy of the excitable elements in the left-hand two of said quadrants and

f2) the sum of the return energy of the excitable elements in the right-hand two of said quadrants,

g) generating said elevation difference signal as the difference between

g1) the sum of the return energy of the excitable elements in the upper two of said quadrants and

g2) the sum of the return energy of the excitable elements in the lower two of said quadrants

In a mode of realization disclosed in European patent application 87 907 265, the sum signal is calculated as the sum of the return energy of all of the excitable elements; that the azimuth difference signal is calculated as the difference between the sum of the return energy of the excitable elements in the left-hand two quadrants and the left horizontal strip (i.e., a left-hand segment), and the sum of the return energy of the excitable elements in the right-hand two quadrants and the right horizontal strip (i.e., a right-hand segment); and that the elevation difference signal is calculated as the difference between the sum of the return energy of the excitable elements in the upper two quadrants and the top vertical strip (i.e., an upper segment), and the sum of the return energy of the excitable elements in the lower two quadrants and the bottom vertical strip (i.e., a lower segment).

It is a specific goal of the present invention to minimize the number of necessary circuit means, in particular hybrids. According to the invention, the cross sectional area of the monopulse antenna is therefore divided into four quadrants and a center section, wherein the center section is only taken into account upon calculation of the sum signal, not of the two difference signals. The invention further relates to an appropriate method to perform near in sidelobe suppression.

The effect of the above measures is that the sum and difference signals are simultaneously optimized.

In the drawings,

Fig. 1 is a conventional five horn antenna for providing sum and difference patterns;

Fig. 2a is an embodiment of European patent application 87 907 265 showing an aperture having an array of elements partitioned into quadrants and strips;

Fig. 2b is a sum and difference network for providing desired sum and difference signals for the embodiment of Fig. 2a;

Fig. 3a is an embodiment of the present invention showing an aperture having an array of elements partitioned into quadrants and a selectively excluded center section;

Fig. 3b is a sum and difference network for providing desired sum and difference signals for the embodiment of Fig. 3a;

Fig. 4a is a comparison of the elevation difference pattern signals for the embodiment of Fig. 2a, before and after selectively excluding elements along the elevation axis in generating the signals, and

Fig. 4b is a comparison of the azimuth difference pattern signals for the embodiment of Fig. 2a, before and after selectively excluding elements along the azimuth axis in generating the pattern signals.

Refer again to Fig. 1. There is shown a conventional five horn antenna for providing sum and difference signals. As shown in Fig. 1, five horn antennas A,B,C,D,E are arranged with antenna A, the left antenna; B, the top antenna; C, the right antenna; D, the bottom antenna; and E, the antenna filling the center space around which antennas A,B,C, and D are arranged. An elevation difference signal is obtained by subtracting the return energy from antenna D from the return energy of antenna B and an azimuth difference signal is provided by subtracting the return energy of antenna C from the return energy of antenna A. A sum signal is provided by the return energy of antenna E alone. This form of antenna feed and others have been used in tracking radar systems, but have suffered from the problem of achieving high sum gain while preserving low sidelobes in the difference patterns. Similar problems are encountered where the antenna consists of a single aperture containing an array of radiating elements and the difference patterns are similarly generated using one half the aperture minus the opposite half of the aperture.

Referring now to Fig. 2a, there is shown an embodiment of the above mentioned European patent application 87 907 265. In Fig. 2a, the antenna 10 is shown as having an aperture 12 circular in shape and as having an array of radiating and receiving elements 20. The antenna is a broadband antenna designed to operate, for example, in a missile. The aperture is partitioned into substantially equal and symmetrical quadrants 14, 15, 16 and 17. Quadrants 14 and 15 define the top elevation hemisphere for aperture 12, while quadrants 16 and 17 define the bottom elevation hemisphere for aperture 12. More particularly, quadrant 14 defines the top left quadrant, quadrant 15 the top right quadrant, quadrant 16 the bottom right quadrant, and quadrant 17 the bottom left quadrant.

Also shown in Fig. 2a is a horizontal strip of elements 24 along the elevation axis and a vertical strip of elements 26 along the azimuth axis. Strip 24 includes strip K, which contains elements which may be taken substantially equally from quadrants 14 and 17. Strip 24 also includes strip I which contains elements which may be taken substantially equally from quadrants 15 and 16. Strip 26 includes strip H, which contains elements which may be taken substantially equally from quadrants 14 and 15 and strip J, which contains elements which may be taken substantially equally from quadrants 16 and 17. As further shown in Fig. 2a, quadrants A, B, C, and D refer to the remainder of quadrants 14, 15, 16 and 17 in Fig. 2a respectively after taking the respective elements for strips 24 and 26.

In operation in this embodiment strips 24 and 26 are selectively excluded in generating the difference pattern signals, resulting in a reduction in the sidelobes for the azimuth and elevation difference patterns as further explained below.

Referring now to Fig. 2b, there is shown a diagram of the sum and difference network for connecting the return signals from the quadrants and strips of Fig. 2b for achieving low difference pattern sidelobes.

The sum pattern to be used for the antenna of Fig. 2a, to be provided by the network of Fig. 2b, is (A + B + C + D) + (H + I + J + K); the azimuth difference pattern is (A + D + K) - (B + C + I); and the elevation difference pattern is (A + B + H) - (C + D + J).

To achieve the necessary combination of returns to provide the desired sum and difference patterns mentioned above, initially the return of each quadrant and strip is selectively coupled with that of one other quadrant or strip at parallel hybrids 41, 42, 43, and 44. The hybrids are standard commercially available sum and difference hybrids, i.e., sum and difference magic T's, commonly used in comparator circuits. The coupling coefficient for each hybrid would vary depending on aperture design and would be chosen to provide, as close as possible, an ideal sum distribution pattern. As shown in Fig. 2b, the returns from strips K and I are fed into hybrid 41. The returns from strips H and J are likewise fed into hybrid 42. The returns from quadrants A and D are fed into hybrid 43. The returns from quadrants B and C are fed into hybrid 44. K and I are combined at hybrid 41 to provide (K + I) and the difference is taken at hybrid 41 to provide (K - I). The same process is repeated for H and J at hybrid 42 to provide (H + J) and (H - J); at hybrid 43 to provide (A + D) and (A - D); and at hybrid 44 to provide (B + C) and (B - C).

Referring further to Fig. 2b, the outputs from hybrids 41, 42, 43, and 44 are selectively added and subtracted to provide further desirable combinations of quadrants A, B, C, D and strips H, I, J, and K. The (K + I) output from hybrid 41 and the (H + J) output from hybrid 42 are combined in phase at hybrid 51 for providing at the output of hybrid 51 (H + J + K + I). The (B + C) output at hybrid 44 is subtracted from the (A + D) output of hybrid 43 at hybrid 52 for providing at the output of hybrid 52 (A + D) - (B + C), and is combined in phase with (B + C) to provide (A + D + B + C). The (A - D) output of hybrid 43 is likewise combined with the (B - C) output of hybrid 44 for providing at the output of hybrid 53 (A +B) - (C + D) and is subtracted at hybrid 53 to provide at the output of hybrid 53, (A + C) - (B + D) which is not used and is therefore terminated.

To provide the sum signal, (A + D + B + C) + (H + I + J + K); the azimuth difference signal, (A + D + K) - (B + C + I); and the elevation difference signal, (A + B + H) - (C + D + J), the outputs from hybrids 51, 52, and 53 are further selectively combined.

To provide the sum signal, the output of hybrid 51, (H + J) + (K +I) is combined with the (A + B) + (C + D) output of hybrid 52 at hybrid 61 to provide (A + B + C + D) + (H + I + J + K).

To provide the azimuth difference signal, the (K - I) output of hybrid 41 is combined with the (A + D) - (B + C) output of hybrid 52 at hybrid 62 to provide (A + D + K) - (B + C + I) at the output of hybrid 62.

To provide the elevation difference signal, the (H - J) output of hybrid 42 is combined with the (A + B) - (C + D) output of hybrid 53 at hybrid 63 to provide (A + B + H) - (C + D + J) at the output of hybrid 63.

Shown in Fig. 4a and Fig. 4b are comparisons of measured data for the original difference signals using the whole ("original") aperture return signal of Fig. 2a compared to the difference signals with the horizontal and vertical strips selectively excluded using the return in Fig. 2b. The difference signals are for all practical purposes symmetrical on either side of boresight and the discussion below applies to the sidelobe patterns on both the right and left of boresight.

Refer now to Fig. 4a. Shown is the original configuration elevation sum and difference signals (left side figure) and the elevation difference signal with horizontal strips I and K excluded (right side figure). It is observed from Fig. 4a that the original elevation difference pattern has a near in sidelobe of around -15dB at around 20°. Compare this to the right side figure of 4a, which depicts the elevation difference pattern with the horizontal strip excluded. Here the near in sidelobes rapidly drop to near -25dB at 30° and form deep nulls.

Even more dramatic results are displayed in Fig. 4b. Shown are the original azimuth sum and difference signals (left side figure) and the azimuth difference signal with strips H and J excluded (right side figure). The original azimuth difference pattern displays near-in sidelobes of -15dB at around 25°. The azimuth difference pattern with the vertical strip excluded is markedly different. The near in sidelobes are -27dB at 25° and deep nulls are formed.

In both cases, the sidelobes have been suppressed 10dB or greater. This is most significant in the case of the near in sidelobe which is critical to clutter and jamming concerns.

Fig. 3a shows an embodiment of the present invention wherein a center section of the elements are selectively excluded in generating the difference patterns. Fig. 3b shows a sum and difference network for providing the desired sum and difference signals. The circuit of Fig. 3b has the advantage of using only five hybrids, which is of high utility for applications where space is very important (i.e., missile radar systems, etc.). Data for the embodiment shown in Figs. 3a and 3b is comparable to that for the embodiment shown in Fig. 2a and Fig. 2b.

Thus, it can be seen that the embodiment of European patent application 87 907 265, by selectively excluding a vertical strip of elements along the azimuth axis, can reduce the sidelobes for the azimuth difference pattern and, by selectively excluding a horizontal strip of elements along the elevation axis, can reduce the sidelobes for the elevation difference pattern.

It can also be seen that, according to the present invention, excluding other predetermined cross section patterns of the aperture may permit further optimization of the signals, i.e., permit other combinations for reducing the sidelobes in the difference patterns while minimizing circuit complexity and maintaining sum signal quality.

## Claims

1. An antenna system adapted for radar application using sum and difference signals for tracking a target including:

   a) a monopulse antenna (10) having

   a1) a cross sectional area for transmitting energy toward a target and receiving return energy;

   a2) an array of excitable elements (20) symmetrically disposed about azimuth and elevation axes;

   b) circuit means coupled to said excitable elements (20), said circuit means generating a sum signal and azimuth and elevation difference signals using return energy from said excitable elements (20),

   **characterized in that**

   c) said cross sectional area is divided into four quadrants (A,B,C,D) and a center section (E),

   d) said circuit means provide

   d1) said sum signal as the sum of the return energy of all said excitable elements (20) in said four quadrants (A,B,C,D) and said center section (E),

   d2) said azimuth difference signal as the difference between

   d2.1) the sum of the return energy of the excitable elements (20) in the left-hand two of said quadrants (A,D) and

   d2.2) the sum of the return energy of the excitable elements (20) in the right-hand two of said quadrants (B,C),

   d3) said elevation difference signal as the difference between

   d3.1) the sum of the return energy of the excitable elements (20) in the upper two of said quadrants (A,B) and

   d3.2) the sum of the return energy of the excitable elements (20) in the lower two of said quadrants (D,C).

2. An antenna system according to claim 1, characterized in that said circuit means comprises a hybrid network (81,82; 91,92; 101).

3. Method of operating an antenna system adapted for radar application using sum and difference signals for tracking a target including the steps of:

   a) transmitting energy toward said target and receiving return energy with a monopulse antenna (10), said monopulse antenna comprising a cross sectional area with an array of excitable elements (20) symmetrically disposed about azimuth and elevation axes;

   b) coupling return energy from said monopulse antenna (10) to circuit means,

   c) generating with said circuit means a sum signal and azimuth and elevation difference signals,

   **characterized by the steps of:**

   d) dividing said cross sectional area into four quadrants (A,B,C,D) and a center section (E),

   e) generating said sum signal as the sum of the return energy of all said excitable elements (20) in said four quadrants (A,B,C,D) and said center section (E),

   f) generating said azimuth difference signal as the difference between

   f1) the sum of the return energy of the excitable elements (20) in the left-hand two of said quadrants (A,D) and

   f2) the sum of the return energy of the excitable elements (20) in the right-hand two of said quadrants (B,C),

g) generating said elevation difference signal as the difference between

g1) the sum of the return energy of the excitable elements (20) in the upper two of said quadrants (A,B) and

g2) the sum of the return energy of the excitable elements (20) in the lower two of said quadrants (D,C).

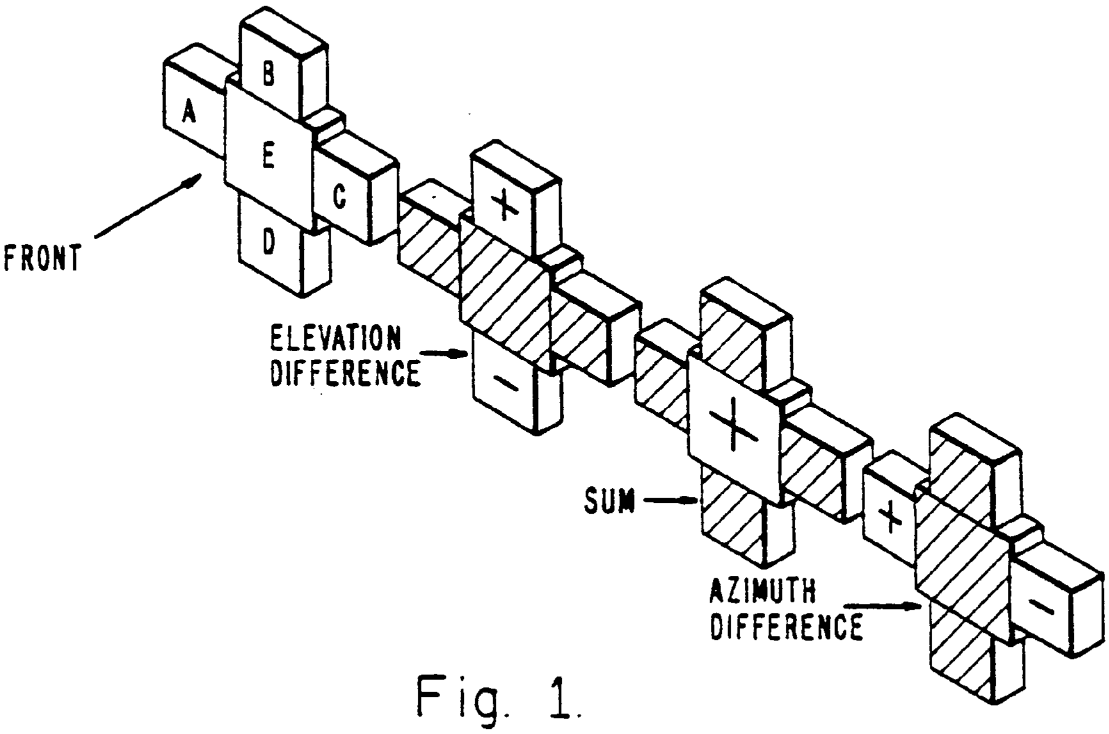



Fig. 1.

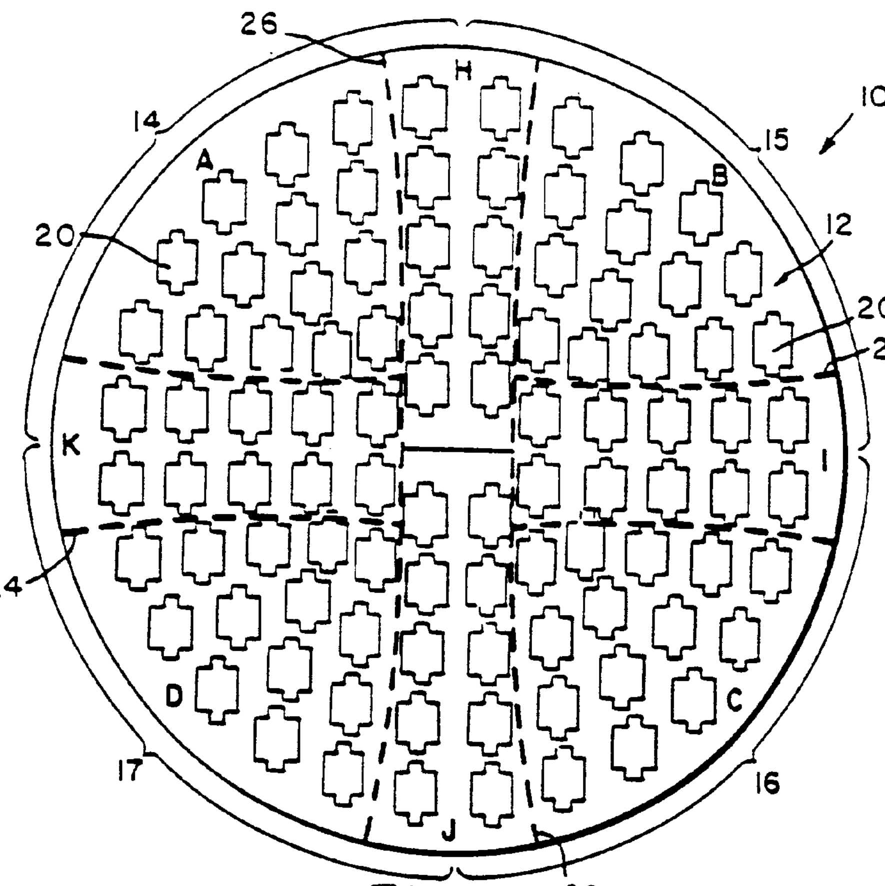

26
H
14
10
15
A
B
20
12
20
24
K
I
24
D
C
17
16
J
26

Fig. 2a.

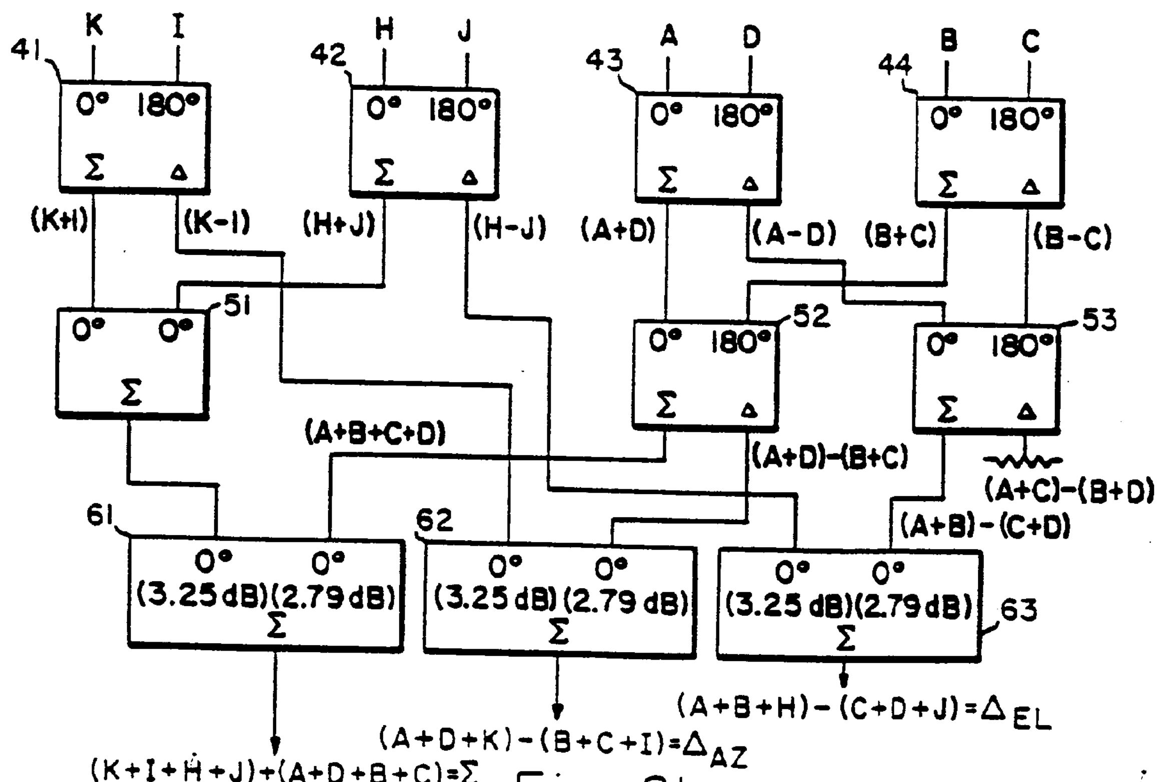

K
I
41
0° 180°
Σ Δ
H
J
42
0° 180°
Σ Δ
A
D
43
0° 180°
Σ Δ
B
C
44
0° 180°
Σ Δ
(K+I)
(K-I)
(H+J)
(H-J)
(A+D)
(A-D)
(B+C)
(B-C)
0° 0°
Σ
51
0° 180°
Σ Δ
52
0° 180°
Σ Δ
53
(A+B+C+D)
(A+D)-(B+C)
(A+C)-(B+D)
(A+B)-(C+D)
61
0° 0°
(3.25 dB)(2.79 dB)
Σ
62
0° 0°
(3.25 dB)(2.79 dB)
Σ
0° 0°
(3.25 dB)(2.79 dB)
Σ
63
(A+B+H)-(C+D+J)=ΔEL
(A+D+K)-(B+C+I)=ΔAZ
(K+I+H+J)+(A+D+B+C)=Σ

Fig. 2b.

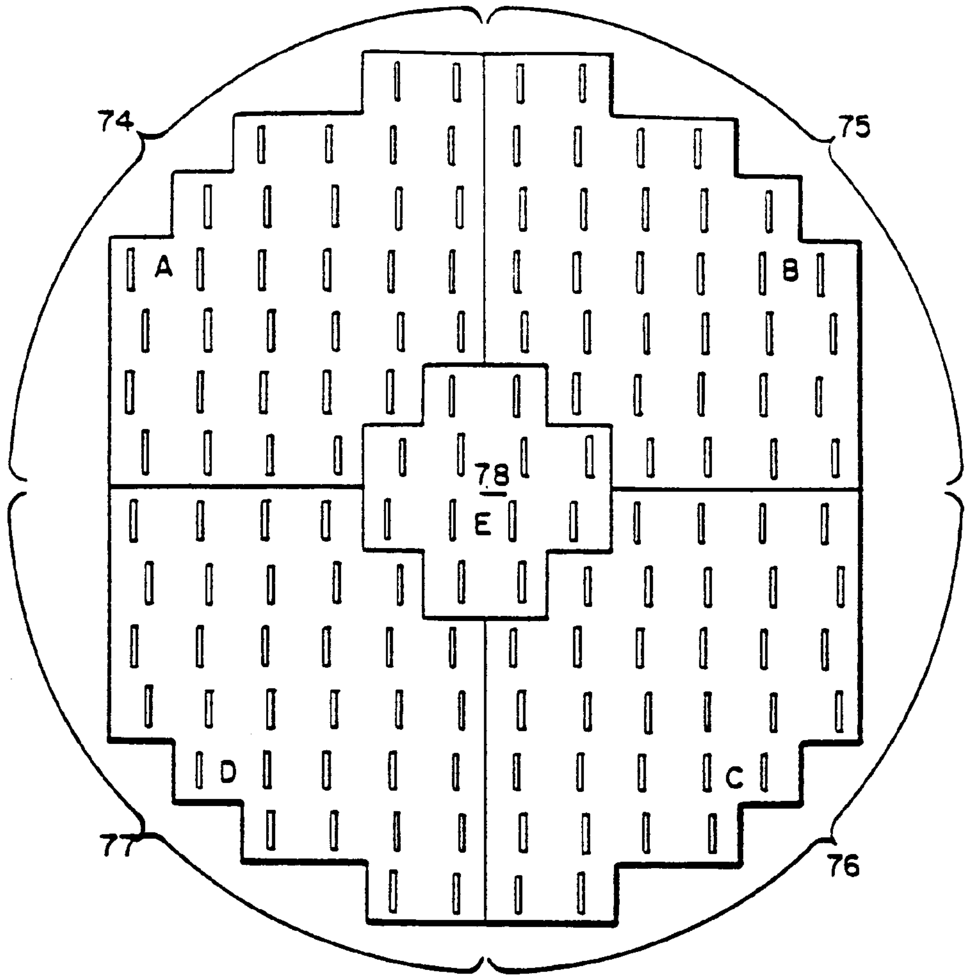
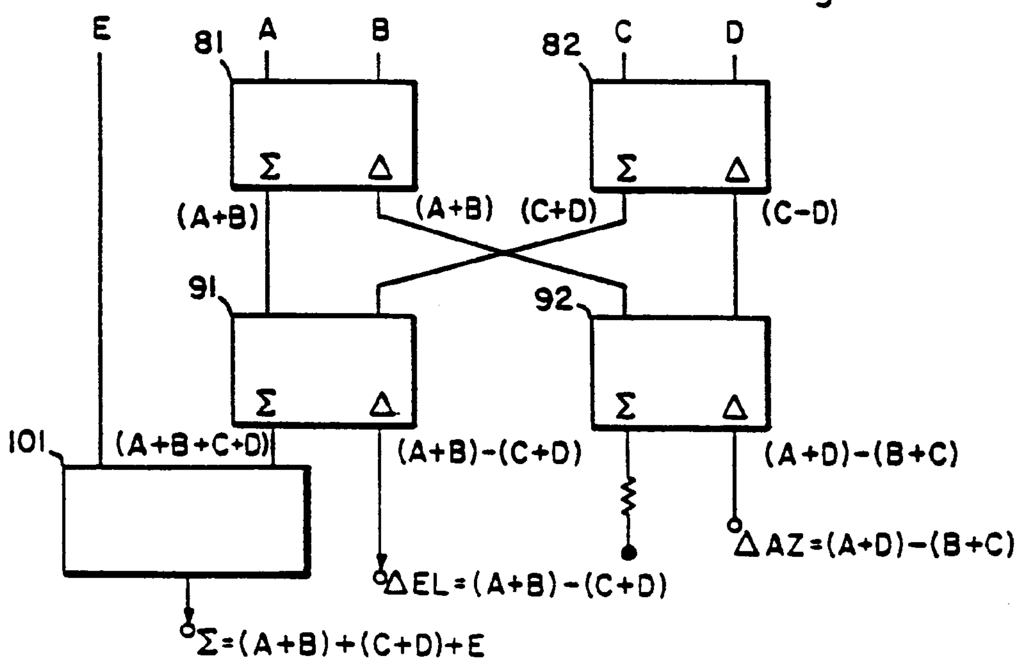

74
75
A
B
78
E
D
C
77
76

Fig. 3a.

Fig. 3b.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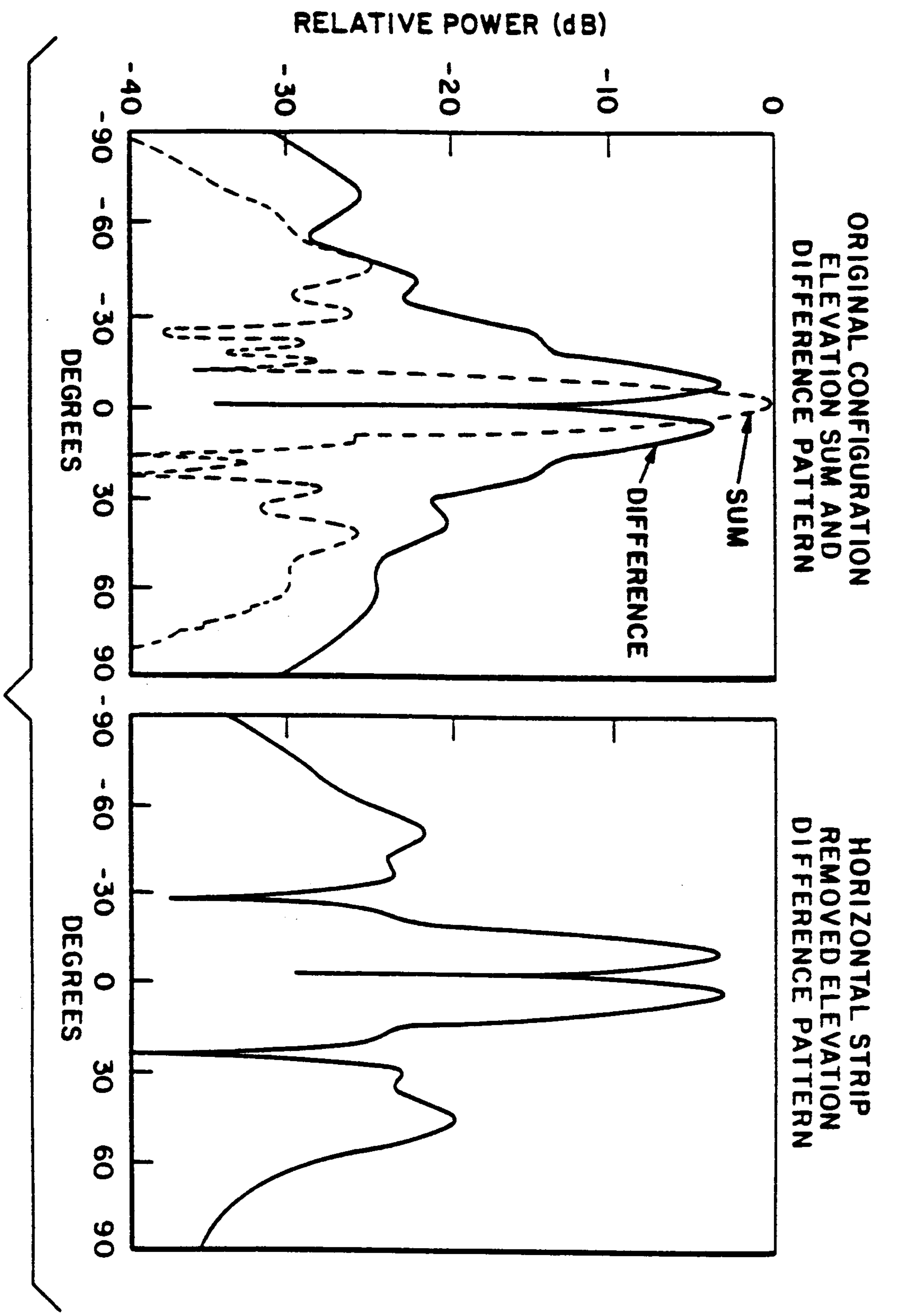
A
B
82
C
D
Σ
Δ
Σ
Δ
(A+B)
(A+B)
(C+D)
(C-D)
91
92
Σ
Δ
Σ
Δ
101
(A+B+C+D)
(A+B)-(C+D)
(A+D)-(B+C)
ΔEL=(A+B)-(C+D)
ΔAZ=(A+D)-(B+C)
Σ=(A+B)+(C+D)+E


RELATIVE POWER (dB)
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-10
-20
-30
-40
ORIGINAL CONFIGURATION ELEVATION SUM AND DIFFERENCE PATTERN
SUM
DIFFERENCE
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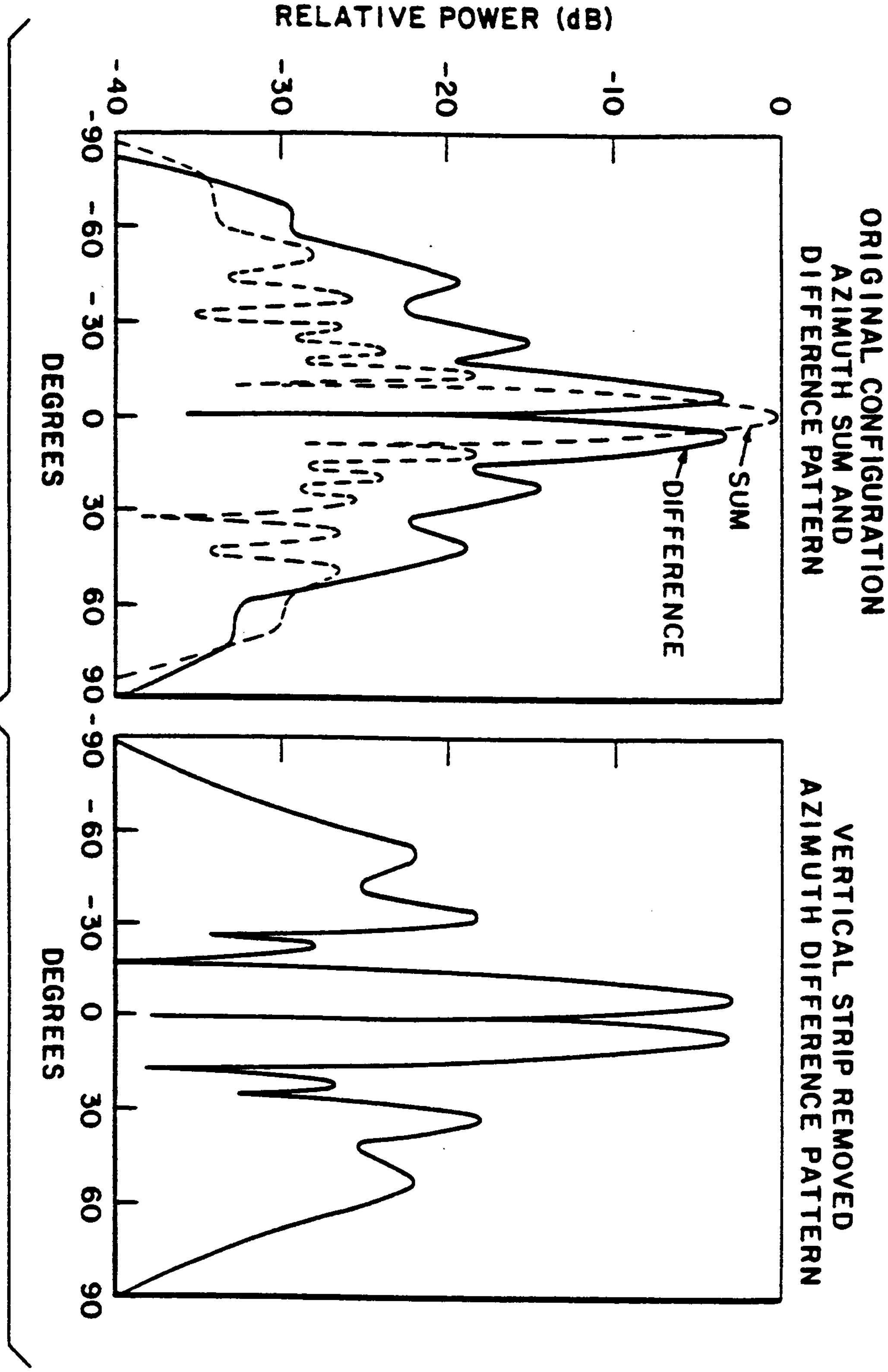
-60
-30
0
30
60
90
DEGREES
HORIZONTAL STRIP REMOVED ELEVATION DIFFERENCE PATTERN
-90
-60
-30
0
30
60
90
DEGREES

Fig. 4a.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AZIMUTH SUM AND
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-60
-30
0
30
60
90
DEGREES
VERTICAL STRIP REMOVED
AZIMUTH DIFFERENCE PATTERN
-90
-60
-30
0
30
60
90
DEGREES

Fig. 4b.

European Patent Office

# EUROPEAN SEARCH REPORT

Application Number

EP 92 11 6842

## 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 ) |
|---|---|---|---|
| X<br><br><br><br>D | WO-A-8 804 109 (HUGHES AIRCRAFT)<br>* page 3, line 10 - line 16 *<br>* page 8, line 25 - page 9, line 16; figures 3A,B *<br>& EP-A-0 289 553<br>----- | 1-3 | H01Q25/02 |
| | | | TECHNICAL FIELDS SEARCHED (Int. Cl.4 ) |
| | | | H01Q |

The present search report has been drawn up for all claims

| Place of search | Date of completion of the search | Examiner |
|---|---|---|
| THE HAGUE | 30 OCTOBER 1992 | ANGRABEIT F.F.K. |

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