

**INSTRUCTIONS**

(a) If Convention application insert "Convention"

CONVENTION

653047

AUSTRALIA

Patents Act 1990

(b) Delete one

**REQUEST FOR A (b) STANDARD/~~PETTY~~ PATENT**

(c) Insert FULL name(s) of applicant(s)

I/We being the person(s) identified below as the Applicant, request the grant of a patent to the person identified below as the Nominated Person, for an invention described in the accompanying Standard/Petty (b) Complete Patent Specification.

I am/We are (b) not an opponent or eligible person described in Sections 33-36 of the Act.

[70,71] Applicant and Nominated Person (c): HOLLANDSE SIGNAALAPPARATEN B.V.

(d) Insert FULL address(es) of applicant(s)

of (d) Zuidelijke Havenweg 40, 7550-GD Hengelo, The Netherlands

(e) Insert TITLE of invention

[54] Invention Title (e) Method and apparatus for the determination of the height of a target

(f) Insert Names of actual Inventors.

[72] Names of Actual Inventors (f)

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(Note: The following applies only to Convention applications)

Basic Convention Application Details

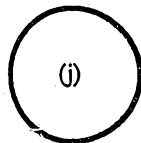
(g) Insert number, country and filing date for the/or each basic application

(g)	[31] Application No.	[33] Country	Country Code	[32] Date of Application
	9101394	Netherlands	NL	16-08-91

(h) Signature of applicant(s) (For body corporate see headnote\*)

(i) Insert date of signing

(j) Corporate seal if any



HOLLANDSE SIGNAALAPPARATEN B.V.

*[Handwritten signature]*

Note: No legalization or other witness required

15 July 1992

(h) Signature of Applicant

(i) Date

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AUSTRALIA

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NOTICE OF ENTITLEMENT

INSTRUCTIONS

(a) Name of person making statement.

(b) Position of that person.

(c) Name of applicant

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(e) Delete as necessary

(f) Insert details if not covered by (i) or (ii)

(g) Delete as necessary

(h) Delete for non-convention applications

(i) Insert DATE of signing

(j) Signature(s) of person making statement

I (a) B. J. Reits,

Authorised Representative of  
(b) Hollandse Signaalapparaten B.V.

of (c) HOLLANDSE SIGNAALAPPARATEN B.V.

of (d) Zuidelijke Havenweg 40, 7550-GD Hengelo, The Netherlands


State the following:-

1. The nominated person (applicant) is entitled to the grant of a patent  
(e) (i) ~~as an assignee of the actual inventor(s)~~  
(ii) by contract of employment of the actual inventor(s)  
or (iii) (f)

2. The nominated person (applicant) is entitled to claim priority from the basic convention application(s).  
(g) (i) as applicants of the said application(s)  
(ii) ~~as the assignee of the applicants of the said application(s)~~  
(iii) ~~with the consent of the applicants of the said application(s)~~

3. The basic convention application(s) was/were the first made in a Convention country in respect of the invention the subject of the application. (h)

Dated (i) 15 July 1992

(j)   
\_\_\_\_\_  
B. J. REITS  
\_\_\_\_\_

Note: No legalization or other witness required

To: The Commissioner of Patents

PHILLIPS ORMONDE AND FITZPATRICK  
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METHOD AND APPARATUS FOR THE DETERMINATION OF THE HEIGHT OF A TARGET
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- (71) Applicant(s)  
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- (56) Prior Art Documents  
US 4163975  
US 4084167  
FR 2408843
- (57) Radar apparatus for determining the height of a low-elevation target, the target being illuminated by a transmitter (7) and an antenna (3) via a TR-switch (6). Electromagnetic radiation reflected directly by the target and indirectly by the target via the earth surface is received by the antenna (3) and processed in a sum receiver (9, 10, 11), connected via the TR-switch (6) to the antenna (3), into complex sum signals, and in a difference receiver (12, 13, 14), into complex difference signals. A signal processor (15), receiving the complex sum signals and the complex difference signals, is provided with an algorithm which determines the height of the target. The algorithm enables the determination of the target height while the antenna remains directed at the target.

## CLAIM

1. Method for determining, by means of a radar apparatus, the height of a low-elevation target, the radar apparatus being provided with a transmitting and receiving unit to which are connected a transmitting and receiving antenna and a signal processing unit, whereby:
- the target is illuminated by electromagnetic radiation emitted by the transmitting unit and the transmitting antenna;

- the transmitted signal is reflected directly via the target and indirectly via the target and the earth surface in the direction of the receiving antenna;
  - by means of the receiving unit, complex sum signals  $\Sigma$  and complex elevation difference signals  $\Delta$  are derived from signals received by means of the receiving antenna;
  - by means of the signal processing unit, an algorithm is carried out for deriving the height of the target from the complex sum and elevation difference signals,
- wherein the transmitting and receiving antenna are substantially directed at the target, and whereby on the basis of the algorithm, the target range  $R$  and the complex elevation error voltage  $S = \Delta/\Sigma$  are derived from the complex signals  $\Sigma$  and  $\Delta$ , and wherein the height  $h_t$  of the target is determined by solving the equation:

$$\frac{d}{dt} \arg(S) = f(R, h_t, \operatorname{Re}(S)),$$

whereby  $\arg(S)$  equals the argument of  $S$  and  $\operatorname{Re}(S)$  equals the real part of  $S$ .

4. Apparatus for determining the height of a low-elevation target, including a radar apparatus provided with a transmitting unit to which a transmitting antenna is connected, a receiving antenna to which a receiving unit is connected, whereby the target is illuminated by electromagnetic radiation emitted by the transmitting unit and the transmitting antenna and the transmitted signal is reflected directly by the target and by the target via the earth surface in the direction of the receiving antenna and whereby, by means of the receiving unit, complex sum signals  $\Sigma$  and at least complex elevation difference signals  $\Delta$ , which are representative for the target, can be generated, a signal processor connected to the receiving unit, provided with an algorithm for determining the height of the target  $h_t$ , and means connected to the signal processor for directing the transmitting antenna and the receiving antenna at an aiming point, wherein the target and the aiming point at least substantially coincide and whereby from the signals  $\Sigma$  and  $\Delta$  the complex elevation

(11) AU-B-20797/92  
(10) 653047

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error voltage  $S = \Delta/\Sigma$ , and the target range  $R$  are derived,  
and wherein the algorithm solves the following  
equation:

$$\frac{d}{dt} \arg(S) = f(R, h_t, \operatorname{Re}(S)),$$

whereby  $\arg(S)$  equals the argument of  $S$  and  $\operatorname{Re}(S)$  equals  
the real part of  $S$ .



Method and apparatus for the determination of the height of a target.

The invention relates to a method for determining, by means  
5 of a radar apparatus, the height of a low-elevation target, the radar apparatus being provided with a transmitting and receiving unit to which are connected a transmitting and receiving antenna and a signal processing unit, whereby:

- the target is illuminated by electromagnetic radiation  
10 emitted by the transmitting unit and the transmitting antenna;
- the transmitted signal is reflected directly via the target and indirectly via the target and the earth surface in the direction of the receiving antenna;
- 15 - by means of the receiving unit, complex sum signals  $\Sigma$  and complex elevation difference signals  $\Delta$  are derived from signals received by means of the receiving antenna;
- by means of the signal processing unit, an algorithm is carried out for deriving the height of the target from  
20 the complex sum and elevation difference signals, wherein the transmitting and receiving antenna are substantially directed at the target, and whereby on the basis of the algorithm, the target range  $R$  and the complex elevation error voltage  $S = \Delta/\Sigma$  are derived from the complex  
25 signals  $\Sigma$  and  $\Delta$ .

The invention furthermore relates to an apparatus for determining the height of a low-elevation target, comprising a radar apparatus provided with a transmitting  
30 unit to which a transmitting antenna is connected, a receiving antenna to which a receiving unit is connected, whereby the target is illuminated by electromagnetic radiation emitted by the transmitting unit and the transmitting antenna and the transmitted signal is  
35 reflected directly by the target and by the target via the



earth surface in the direction of the receiving antenna and whereby, by means of the receiving unit, complex sum signals  $\Sigma$  and at least complex elevation difference signals  $\Delta$ , which are representative for the target, can be  
 5 generated, a signal processor connected to the receiving unit, provided with an algorithm for determining the height of the target  $h_t$ , and means connected to the signal processor for directing the transmitting antenna and the receiving antenna at an aiming point, wherein the target  
 10 and the aiming point at least substantially coincide and whereby from the signals  $\Sigma$  and  $\Delta$  the complex elevation error voltage  $S = \Delta/\Sigma$  and the target range  $R$  are derived.

The height of a target can be determined by means of a  
 15 monopulse radar apparatus. The monopulse principle is described in "Introduction to Radar Systems" by M.I. Skolnik, second edition, pages 160-190. A problem encountered in the determination of the height of a target which is flying at a low altitude above the sea surface  
 20 and, to a lesser extent, also the earth surface, is described on pages 172-176. This problem is due to the phenomenon that the radar apparatus not only receives echo signals directly from the target, but also target echoes reflected by the sea surface. Without the occurrence of  
 25 this multipath effect, the height of the target can be easily derived from the values of the target range  $R$  and the elevation error voltage  $E(\theta)$ , delivered by the monopulse radar apparatus. The multipath effect causes the elevation error voltage to assume a complex value which  
 30 renders an accurate determination of the target height impossible.

The occurrence of said multipath effect can only be avoided by selecting a radar antenna beamwidth which is narrow to  
 35 such an extent that only echo signals directly from the



target are received, thereby excluding unwanted target echoes reflected by the sea surface. This method has the drawback, however, that with such a narrow beam, a relatively long time might be required to acquire the  
5 target. The patent US-A 4,743,907 provides an elegant solution to obviate this drawback. By fully integrating two monopulse radar apparatuses, the first radar apparatus having a relatively large wavelength and a consequent wide beam, the second radar apparatus having a relatively small  
10 wavelength and a consequent narrow beam, it is possible to achieve an optimal performance in both the acquisition and tracking phases. Such a system, however, entails considerable cost.

15 A method for accurately determining target height, notwithstanding the occurrence of multipath, is described in the patent US-A 4,796,031. According to the method disclosed in this patent, the radar antenna is not directed at the actual target, but at a point in space exactly  
20 between the actual target and its image. By subsequently measuring with at least two different radar wavelengths, which bear a predetermined relation, a system of equations can be solved, from which several possible target heights can be derived. Thus, by successively comparing possible  
25 target heights derived on the basis of this method, the target height can be determined.

An alternative method for accurately determining the target height is described in patent EP-B 0.087.355. According to  
30 this method the antenna orientation is constantly varied. Using measuring values obtained at various antenna orientations, it will again be possible to solve systems of equations, from which the target height can be derived.



Both methods are cumbersome and have the drawback that the monopulse radar apparatus is directed at an aiming point which does not coincide with the target. For a monopulse radar apparatus, this misalignment is an evident suboptimal condition which, however, in light of the state of the art is required in order to obtain a solvable system of equations.

According to the invention the height of a target can be determined on the basis of a method which is characterised in that the height of the target  $h_t$  is determined by solving the following equation:

$$\frac{d}{dt} \arg(S) = f(R, h_t, \operatorname{Re}(S)).$$

The apparatus according to the invention is characterised in that the algorithm solves the following equation:

$$\frac{d}{dt} \arg(S) = f(R, h_t, \operatorname{Re}(S))$$

whereby  $\arg(S)$  equals the argument of  $S$  and  $\operatorname{Re}(S)$  equals the real part of  $S$ .



According to one aspect of the present invention there is provided a method for determining, by means of a radar apparatus, the height of a low-elevation target, the radar apparatus being provided with a transmitting and receiving unit to which are connected a transmitting and receiving antenna and a signal processing unit, whereby:

- the target is illuminated by electromagnetic radiation emitted by the transmitting unit and the transmitting antenna,
- the transmitted signal is reflected directly via the target and indirectly via the target and the earth surface in the direction of the receiving antenna;
- by means of the receiving unit, complex sum signals  $\Sigma$  and complex elevation difference signals  $\Delta$  are derived from signals received by means of the receiving antenna;
- by means of the signal processing unit, an algorithm is carried out for deriving the height of the target from the complex sum and elevation difference signals,

wherein the transmitting and receiving antenna are substantially directed at the target, and whereby on the basis of the algorithm, the target range  $R$  and the complex elevation error voltage  $S = \Delta/\Sigma$  are derived from the complex signals  $\Sigma$  and  $\Delta$ , and wherein the height  $h_t$  of the target is determined by solving the equation:

$$\frac{d}{dt} \arg(S) = f(R, h_t, \text{Re}(S)),$$

whereby  $\arg(S)$  equals the argument of  $S$  and  $\text{Re}(S)$  equals the real part of  $S$ .

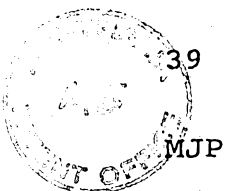
According to a further aspect of the present invention there is provided apparatus for determining the height of a low-elevation target, including a radar apparatus provided with a transmitting unit to which a transmitting antenna is connected, a receiving antenna to which a receiving unit is connected, whereby the target is illuminated by electromagnetic radiation emitted by the

transmitting unit and the transmitting antenna and the transmitted signal is reflected directly by the target and by the target via the earth surface in the direction of the receiving antenna and whereby, by means of the receiving unit, complex sum signals  $\Sigma$  and at least complex elevation difference signals  $\Delta$ , which are representative for the target, can be generated, a signal processor connected to the receiving unit, provided with an algorithm for determining the height of the target  $h_t$ , and means connected to the signal processor for directing the transmitting antenna and the receiving antenna at an aiming point, wherein the target and the aiming point at least substantially coincide and whereby from the signals  $\Sigma$  and  $\Delta$  the complex elevation error voltage  $S = \Delta/\Sigma$ , and the target range  $R$  are derived, and wherein the algorithm solves the following equation:

$$\frac{d}{dt} \arg(S) = f(R, h_t, \operatorname{Re}(S)),$$

whereby  $\arg(S)$  equals the argument of  $S$  and  $\operatorname{Re}(S)$  equals the real part of  $S$ .

A preferred embodiment of the present invention will now be described with reference to the accompanying drawings wherein:-



~~The apparatus according to the invention is characterized in that the target and the aiming point at least substantially coincide.~~

~~The invention will be further explained with reference to the following figures, of which:~~

Fig. 1 presents a diagram of a possible embodiment of a monopulse radar apparatus according to the invention;

Fig. 2 presents a possible elevation error voltage curve;

Fig. 3 illustrates the multipath effect.

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For accurately determining the height of a target flying at a low altitude above the sea or earth surface, a monopulse radar apparatus is used. In this situation, sum signals and elevation difference signals delivered by the radar apparatus assume complex values, which are to be further processed by a signal processor connected to the radar apparatus.

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Fig. 1 presents a diagram of a possible embodiment of a monopulse radar apparatus according to the invention. In order not to unnecessarily complicate the description, only the monopulse behaviour in elevation is included in the analysis.

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Two antenna elements 1, 2, one placed on top of the other, are connected to a conventional coupler 3, forming a sum channel 4 and a difference channel 5. A transmitter 7, which is controlled from a frequency and timing unit 8 and which transmits pulsed signals, is connected to the sum channel 4 via a TR-switch 6. Signals received via the sum channel are fed via TR-switch 6 to a mixer stage 9, which receives an LO signal from the frequency and timing unit 8. The resulting intermediate-frequency signal is amplified in intermediate-frequency amplifier 10 and converted into a digital, complex sum signal  $\Sigma$  by A/D converter and Hilbert filter 11. Signals received via the difference channel 5 are fed to a mixer stage 12, which also receives an LO channel from the frequency and timing

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unit 8. The resulting intermediate-frequency difference signal is amplified in intermediate-frequency amplifier 13 and converted into a digital, complex difference signal  $\Delta$  by A/D converter and Hilbert filter 14. Both signals are fed to a signal processor 15, by means of which an elevation error voltage  $S = \Delta/\Sigma$  is determined. The A/D converter and Hilbert filters 11, 14 may be replaced by phase-sensitive quadrature detectors plus A/D converters, but the embodiment described here is more satisfactory with regard to gain and offset stability.

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Assuming there is a single stationary target in the beam, the vectors  $\Sigma$  and  $\Delta$  will remain identical for each transmitted pulse and will have a fixed angle in the complex plane. For a single moving target in the beam, both vectors will rotate at the doppler frequency, but will retain the same fixed angle. It is common practice to apply a phase-alignment point in one of both channels, such that both vectors can be aligned. For a single target the elevation error voltage will then be real. The real elevation error voltage curve  $E(\theta)$  is represented in Fig. 2. It is noted that the elevation error voltage, notwithstanding its name, is dimensionless. Insofar as this is relevant, it is possible to linearize  $E(\theta)$  in signal processor 15, at least for small values of  $\theta$ ; this may be effected by means of a linearizing table. In that case  $E(\theta) = K\theta$  applies for small angles  $\theta$ . Furthermore, signal processor 15 may generate an AGC control signal for adjusting the gain of both intermediate-frequency amplifiers 10, 13 such that the amplitude of the target echo signal in the sum signal  $\Sigma$  is kept substantially constant. This results in less stringent requirements as regards the phase tracking of the sum channel and the difference channel; it allows the use of A/D converters with a limited dynamic range, and limits the size of the linearizing table.

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In general, signal processor 15 will perform several other functions which are of minor relevance to the invention described here. Thus,

a conventional time-gate function will be implemented in signal processor 15. Also, a form of MTI or MTD doppler processing will be applied to the values delivered by the A/D converters and Hilbert filters 11, 14. In addition, signal processor 15 will generate control signals for directing the transmitting antenna and the receiving antenna.

In the event of a single target in the beam, an echo of which is received directly and as a mirror image via the sea surface, as represented in Fig. 3,  $S$  proves to assume a complex value. In Fig. 3  $h_a$  represents the height of the antenna above the sea surface,  $h_t$  represents the height of the target above the sea surface,  $R$  represents the range from target to radar antenna and  $\theta_o$  represents the antenna elevation angle. For a moving target,  $S$  becomes a function of the target range  $R$ , the target height  $h_t$ , the radar transmitter wavelength  $\lambda$  and of several system constants. Our objective is to find an equation which incorporates these values and from which  $h_t$  can be derived. This equation will then constitute the basis for the claimed method and apparatus.

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For forming this equation we define:

- $h_a$  height of the antenna above the sea surface.
- $h_t$  height of the target above the sea surface.
- $R$  range from target to radar antenna.
- 25  $\theta_o$  antenna elevation angle.
- $\theta_t$  elevation error angle of the target.
- $\theta_m$  elevation error angle of the mirror image.
- $\rho$  reflection coefficient of the sea surface.
- $\Psi$  perturbation phase for the reflection on the sea surface.
- 30  $\phi$  phase difference between the reflections of target and mirror image.
- $G_{\Sigma}(\theta)$  antenna diagram of the elevation sum channel.
- $G_{\Delta}(\theta)$  antenna diagram of the elevation difference channel.
- $E(\theta)$  elevation error voltage curve.

The following approximations can now be derived:

$$\theta_t = \frac{h_t - h_a}{R} - \theta_o \quad (1)$$

$$5 \quad \theta_m = \frac{-h_t - h_a}{R} - \theta_o \quad (2)$$

$$\phi = \frac{4\pi h_t h_a}{\lambda R} + \Psi \quad (3)$$

Furthermore the following applies:

$$10 \quad E(\theta) = \frac{G_\Delta(\theta)}{G_\Sigma(\theta)} \quad (4)$$

$$\Sigma = G_\Sigma(\theta_t) - \rho G_\Sigma(\theta_m) \cdot e^{j\phi} \quad (5)$$

$$15 \quad \Delta = G_\Delta(\theta_t) - \rho G_\Delta(\theta_m) \cdot e^{j\phi} \quad (6)$$

$$S = \frac{\Delta}{\Sigma} = \frac{G_\Delta(\theta_t) - \rho G_\Delta(\theta_m) \cdot e^{j\phi}}{G_\Sigma(\theta_t) - \rho G_\Sigma(\theta_m) \cdot e^{j\phi}} \quad (7)$$

20 Subsequently we can define:

$$A = E(\theta_t) = E\left(\frac{h_t - h_a}{R} - \theta_o\right) \quad (8)$$

$$B = -E(\theta_m) = -E\left(\frac{-h_t - h_a}{R} - \theta_o\right) = E\left(\frac{h_t + h_a}{R} + \theta_o\right) \quad (9)$$

25 The last equation is based on the odd symmetry of  $E(\theta)$ .

We define a corrected reflection coefficient  $G$ , thereby considering that in case of a monopulse antenna directed at the target, the reflection of the mirror image is additionally attenuated by the

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antenna diagram:

$$G = \rho \frac{G_{\Sigma} \left( \frac{-h_t - h_a}{R} - \theta_o \right)}{G_{\Sigma} \left( \frac{h_t - h_a}{R} - \theta_o \right)} \quad (10)$$

Subsequently it follows from (3), (7), (8), (9) and (10) that:

$$S = A + \frac{e^{j\phi}}{1 - G e^{j\phi}} \cdot G \cdot (A + B) \quad (11)$$

During normal target tracking, the antenna is directed at the target, consequently  $A = 0$ :

$$S = \frac{e^{j\phi}}{1 - R e^{j\phi}} \cdot G \cdot B \quad (12)$$

The real part of  $S$  can be defined as follows:

$$\text{Re}(S) = \frac{\cos \phi - G}{1 + G^2 - 2G \cos \phi} \cdot G \cdot B \quad (13)$$

For the argument of  $S$ , the following applies:

$$\arg(S) = \phi + \text{arctg} \left( \frac{G \sin \phi}{1 - G \cos \phi} \right) \quad (14)$$

hence:

$$\frac{d}{dt} \arg(S) = \left( 1 + \frac{\cos \phi - G}{1 + G^2 - 2G \cos \phi} \right) \frac{d}{dt} \phi \quad (15)$$

A combination of (13) and (15) yields the desired equation:

$$\frac{d}{dt} \arg(S) = \left( 1 + \frac{\text{Re}(S)}{B} \right) \frac{d}{dt} \phi \quad (16)$$

A closer examination reveals that  $h_t$  and  $\Psi$  are the only unknowns in (16) in addition to several system parameters and measuring values.

For a smooth sea surface we may assume that:

$$\frac{d}{dt} \Psi = 0 \quad (17)$$

Together with (16) this yields:

$$\frac{d}{dt} \arg(S) = \frac{4\pi h_a h_t}{\lambda} \cdot \left(1 + \frac{\operatorname{Re}(S)}{E\left(\frac{h_a}{R} - \theta_o\right)}\right) \cdot \frac{d}{dt} \left(\frac{1}{R}\right) \quad (18)$$

10 Assuming that  $E(\theta)$  is linear for small values of  $\theta$ , this is a quadratic equation in  $h_t$ . If  $E(\theta)$  is not linear, the equation can be solved, for example following the Newton method. From a series of target height estimates, thus obtained in time, the best target height estimate is derived by a conventional filtering process with a time constant and a provision for eliminating extremely deviating estimates, a method well known in the art.

A second solution shall be selected, if the smooth sea surface condition does not apply, consequently if

$$20 \quad \frac{d}{dt} \Psi \neq 0.$$

We can then eliminate the unknown  $\Psi$  by measuring at two different wavelengths. The following can be derived from (16):

$$25 \quad \arg(S_2) - \arg(S_1) = \int_{\phi_1}^{\phi_2} \left(1 + \frac{\operatorname{Re}(S)}{B}\right) d\phi \quad (19)$$

For minor wavelength differences the following approximation can be used:

$$30 \quad \frac{1}{\phi_2 - \phi_1} \int_{\phi_1}^{\phi_2} \operatorname{Re}(S) d\phi = \frac{\operatorname{Re}(S_1) + \operatorname{Re}(S_2)}{2} \quad (20)$$

With (3), (9) and (19) this yields:

$$\arg(S_2) - \arg(S_1) = \frac{4\pi h_a h_t}{R} \left( \frac{1}{\lambda_2} - \frac{1}{\lambda_1} \right) \left( 1 + \frac{\operatorname{Re}(S_1) + \operatorname{Re}(S_2)}{2E \left( \frac{h_a + h_t}{R} - \theta_0 \right)} \right) \quad (21)$$

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This equation can be solved by means of one of the methods described under (18).

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The values of  $h_t$  thus obtained can be used for directing the transmitting antenna and the receiving antenna at the target. In this way an elevation error angle is realised which may show an improvement by an order of magnitude as compared against a monopulse radar apparatus where the imaginary part of the elevation error voltage is ignored. In addition, this method is comparatively

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insusceptible to perturbations, particularly  $A = 0$  proves to be a non-stringent condition.

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The claims defining the invention are as follows:

1. Method for determining, by means of a radar apparatus, the height of a low-elevation target, the radar apparatus being provided with a transmitting and receiving unit to which are connected a transmitting and receiving antenna and a signal processing unit, whereby:
- the target is illuminated by electromagnetic radiation emitted by the transmitting unit and the transmitting antenna;
  - the transmitted signal is reflected directly via the target and indirectly via the target and the earth surface in the direction of the receiving antenna;
  - by means of the receiving unit, complex sum signals  $\Sigma$  and complex elevation difference signals  $\Delta$  are derived from signals received by means of the receiving antenna;
  - by means of the signal processing unit, an algorithm is carried out for deriving the height of the target from the complex sum and elevation difference signals,
- wherein the transmitting and receiving antenna are substantially directed at the target, and whereby on the basis of the algorithm, the target range  $R$  and the complex elevation error voltage  $S = \Delta/\Sigma$  are derived from the complex signals  $\Sigma$  and  $\Delta$ , and wherein the height  $h_t$  of the target is determined by solving the equation:

$$\frac{d}{dt} \arg(S) = f(R, h_t, \operatorname{Re}(S)),$$

whereby  $\arg(S)$  equals the argument of  $S$  and  $\operatorname{Re}(S)$  equals the real part of  $S$ .

2. Method as claimed in claim 1, whereby, for the transmitting antenna, the receiving antenna and the receiving unit, a real error voltage curve  $E(\theta)$  is known for a target with an elevation error angle  $\theta$ , the transmitted signal has a wavelength  $\lambda$ , the receiving



antenna is positioned at a height  $h_a$  above the earth surface and makes an elevation angle  $\theta_0$  with the earth surface, characterised in that the equation

$$5 \quad \frac{d}{dt} \arg(S) = \frac{4\pi h_a h_t}{\lambda} \cdot \left(1 + \frac{\operatorname{Re}(S)}{E\left(\frac{h_a + h_t}{R} - \theta_0\right)}\right) \cdot \frac{d}{dt} \left(\frac{1}{R}\right)$$

is solved.

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3. Method as claimed in claim 1, whereby for the transmitting antenna, the receiving antenna and the receiving unit, a real elevation error curve  $E(\theta)$  is known for a target with an elevation angle  $\theta$ , the transmitting antenna successively transmits at least signals of wavelengths  $\lambda_1$  and  $\lambda_2$ , in which  $\lambda_1 \neq \lambda_2$ , the receiving antenna is positioned at a height  $h_a$  above the earth surface and makes an elevation angle  $\theta_0$  with the earth surface and whereby the values

$$20 \quad \Sigma_1, \Delta_1, S_1 = \frac{\Delta_1}{\Sigma_1}, \Sigma_2, \Delta_2 \text{ and } S_2 = \frac{\Delta_2}{\Sigma_2},$$

are determined, characterised in that for determining  $h_t$  the equation

$$25 \quad \operatorname{Arg}(S_2) - \operatorname{Arg}(S_1) = -\frac{4\pi h_a h_t}{R} \left(\frac{1}{\lambda_2} - \frac{1}{\lambda_1}\right) \left(1 + \frac{\operatorname{Re}(S_1) + \operatorname{Re}(S_2)}{2E\left(\frac{h_a + h_t}{R} - \theta_0\right)}\right)$$

30 is solved, wherein:

- $\lambda_i$  ( $i=1,2$ ) equals the wavelength of a transmitted signal;
- $\Sigma_i$  ( $i=1,2$ ) equals the complex sum signal corresponding to a transmitted signal with wavelength  $\lambda_i$ ;
- $\Delta_i$  ( $i=1,2$ ) equals the complex elevation error signal corresponding to a transmitted signal with wavelength  $\lambda_i$ ;
- 35  $S_i$  ( $i=1,2$ ) equals the complex elevation error signal.

4. Apparatus for determining the height of a low-elevation target, including a radar apparatus provided with a transmitting unit to which a transmitting antenna is connected, a receiving antenna to which a receiving unit is

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connected, whereby the target is illuminated by electro-  
 magnetic radiation emitted by the transmitting unit and the  
 transmitting antenna and the transmitted signal is  
 reflected directly by the target and by the target via the  
 5 earth surface in the direction of the receiving antenna and  
 whereby, by means of the receiving unit, complex sum  
 signals  $\Sigma$  and at least complex elevation difference signals  
 $\Delta$ , which are representative for the target, can be  
 generated, a signal processor connected to the receiving  
 10 unit, provided with an algorithm for determining the height  
 of the target  $h_t$ , and means connected to the signal  
 processor for directing the transmitting antenna and the  
 receiving antenna at an aiming point, wherein the target  
 and the aiming point at least substantially coincide and  
 15 whereby from the signals  $\Sigma$  and  $\Delta$  the complex elevation  
 error voltage  $S = \Delta/\Sigma$ , and the target range  $R$  are derived,  
 and wherein the algorithm solves the following  
 equation:

$$20 \quad \frac{d}{dt} \arg(S) = f(R, h_t, \operatorname{Re}(S)),$$

whereby  $\arg(S)$  equals the argument of  $S$  and  $\operatorname{Re}(S)$  equals  
 the real part of  $S$ .

25 5. Apparatus as claimed in claim 4, whereby for the  
 transmitting antenna, the receiving antenna and the  
 receiving unit, a real error voltage curve  $E(\theta)$  is known  
 for a target with an elevation error angle  $\theta$ , the  
 transmitted signal has a wavelength  $\lambda$ , the receiving  
 30 antenna is positioned at a height  $h_a$  above the earth surface  
 and makes an elevation angle  $\theta_0$  with the earth surface,  
 characterised in that

$$35 \quad \frac{d}{dt} \arg(S) = \frac{4\pi h_a h_t}{\lambda} \cdot \left(1 + \frac{\operatorname{Re}(S)}{E\left(\frac{h_a + h_t}{R} - \theta_0\right)}\right) \cdot \frac{d}{dt} \left(\frac{1}{R}\right)$$

is determined.



6. Apparatus as claimed in claim 5, whereby for the radar antenna, the receiving antenna and the receiving unit, a real error voltage curve  $E(\theta)$  is known for a target with an elevation angle  $\theta$ , the transmitting antenna being provided  
 5 with means for successively generating transmitter signals of wavelengths  $\lambda_1$  and  $\lambda_2$  in which  $\lambda_1 \neq \lambda_2$  and whereby the values

10  $\Sigma_1, \Delta_1, S_1 = \frac{\Delta_1}{\Sigma_1}, \Sigma_2, \Delta_2$  and  $S_2 = \frac{\Delta_2}{\Sigma_2},$

are determined, the receiving antenna is positioned at a height  $h_a$  above the earth surface and makes an elevation angle  $\theta_0$  with the earth surface, characterised in that the algorithm derives  $h_t$  from the following equation:

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$$\text{Arg}(S_2) - \text{Arg}(S_1) = \frac{4\pi h_a h_t}{R} \left( \frac{1}{\lambda_2} - \frac{1}{\lambda_1} \right) \left( 1 + \frac{\text{Re}(S_1) + \text{Re}(S_2)}{2E\left(\frac{h_a + h_t}{R} - \theta_0\right)} \right)$$

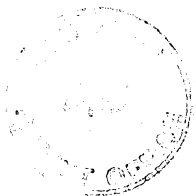
7. Method as claimed in claim 1 substantially as herein described with reference to the accompanying drawings.

8. Apparatus as claimed in claim 4 substantially as herein described with reference to the accompanying drawings.

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Abstract

Radar apparatus for determining the height of a low-elevation target, the target being illuminated by a transmitter (7) and an antenna (3) via a TR-switch (6). Electromagnetic radiation reflected directly by the target and indirectly by the target via the earth surface is received by the antenna (3) and processed in a sum receiver (9, 10, 11), connected via the TR-switch (6) to the antenna (3), into complex sum signals, and in a difference receiver (12, 13, 14), into complex difference signals. A signal processor (15), receiving the complex sum signals and the complex difference signals, is provided with an algorithm which determines the height of the target. The algorithm enables the determination of the target height while the antenna remains directed at the target.

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Fig. 1

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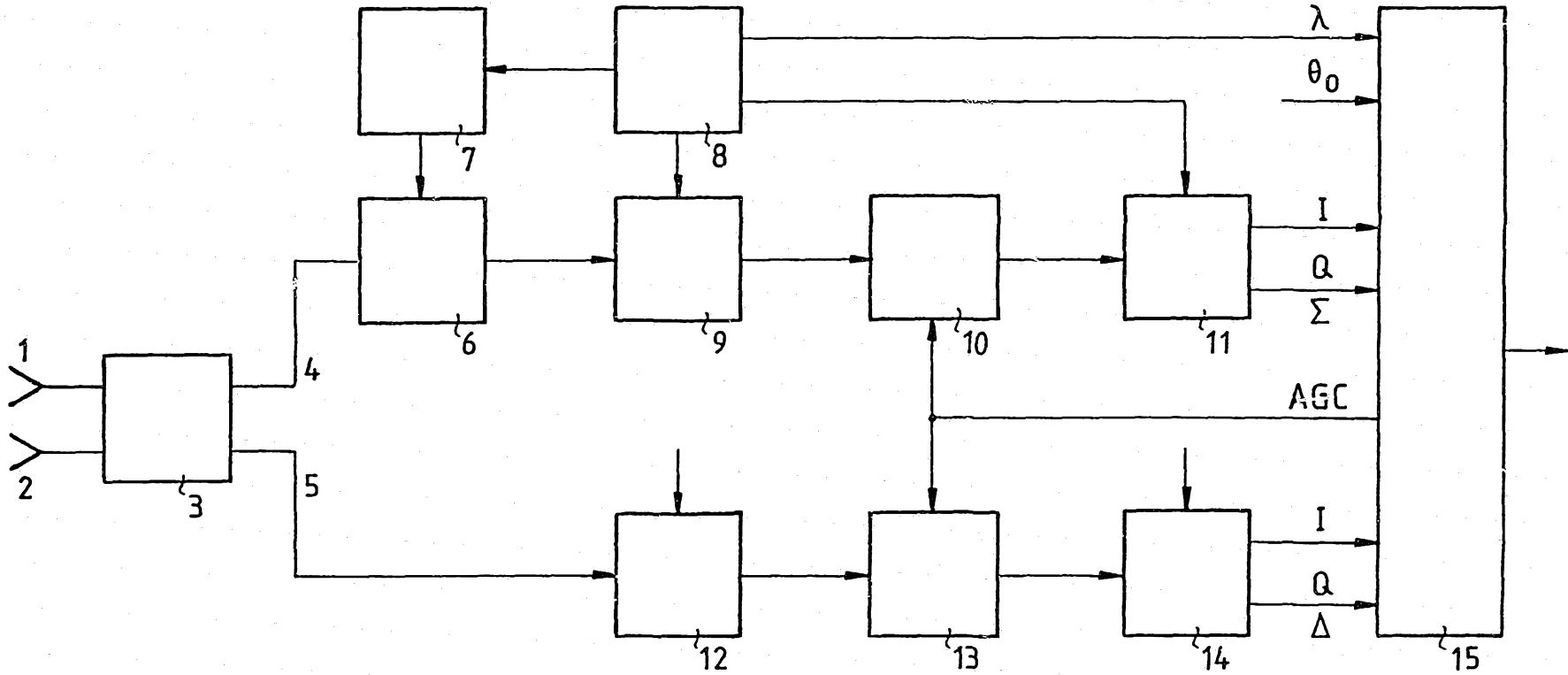


Fig. 1

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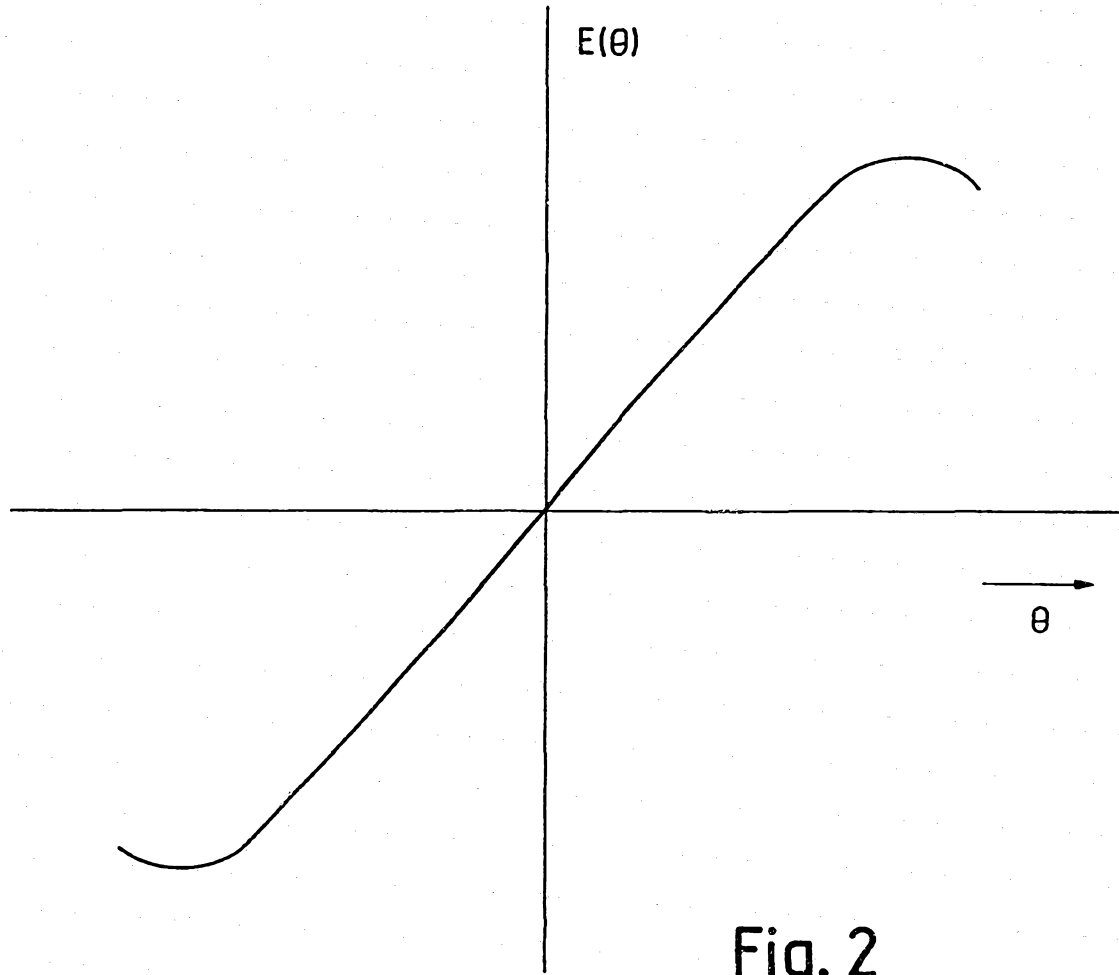


Fig. 2

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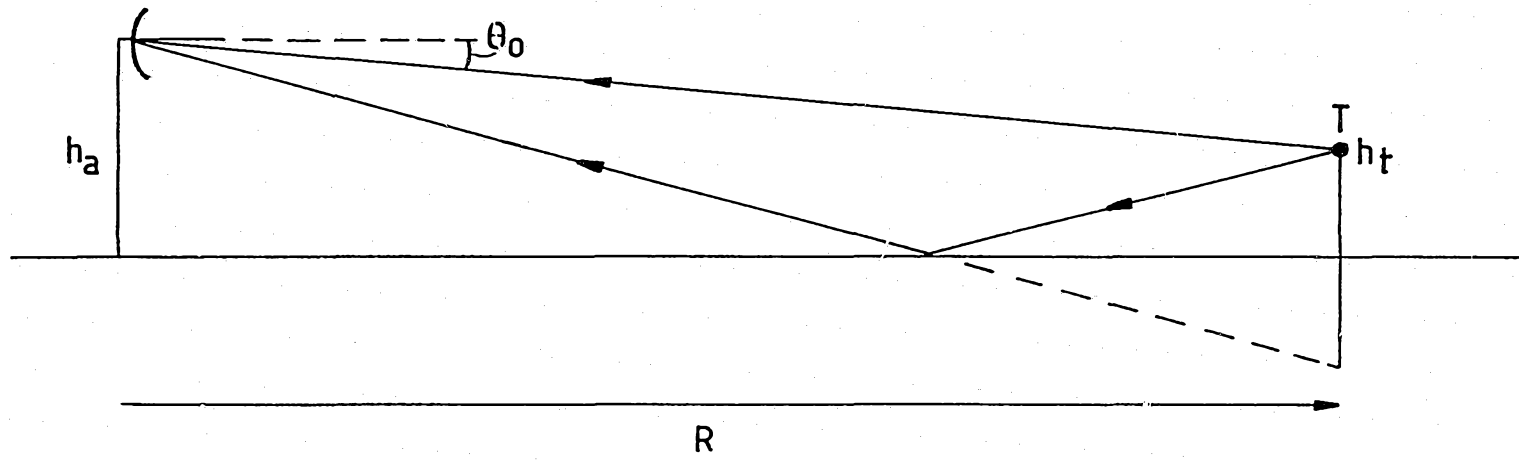


Fig. 3