

The present invention relates to a radar device for measuring the distance "h" separating it from a surface, which device includes emission means for emitting towards the said surface a frequency-modulated wave produced by an oscillator equipped with a frequency control, reception means for receiving this wave reflected by the said surface, a mixer circuit for providing a beat wave from the emitted wave and received wave, and a processing circuit including a circuit for digitizing the beat wave, a time/frequency transformation operator for providing frequency components from which the distance "h" is established, an autocorrelation operator for performing an autocorrelation of the beat wave before applying it to the time/frequency transformation means.

Such a radar device finds important applications in particular in the field of radionavigation where it can be used as a radio altimeter. The United States of America Patent No. 4 568 938 may also be consulted. The French Patent 2 552 905 describes a similar device, however this known device is not very suited to the measurement of altitude; the processing mentioned therein relates to the processing of a multitude of targets travelling at different speeds. The frequency components bound to each target form a narrow spectrum from which it is easy to obtain the distance.

It is different when the target is an extended surface, the various points of which are situated continuously at various distances from the device. The spectrum is then wide.

The Applicant has taken note that, although the altitude is related to the lowest component, it was not easy to determine, either because the noise swamps this component, or because parasitic phenomena falsify the value of this component. This is especially obvious for small distances "h" and when there is relative motion between the radar device and the surface. It will be shown subsequently in the present exposition that the spectrum of the beat wave is widened by a function

"sin x/x" where x is a variable depending on "h" and on the duration of the variation in frequency of the oscillator. It follows that the lowest frequency component does not necessarily represent the distance "h". Moreover, the spectrum of the beat wave may be further widened by the Doppler phenomenon when there is relative motion between the device and the surface.

In order to improve resistance to noise, the use of the autocorrelation technique is known. In this regard the work by M. I. SKOLNIK: "Introduction to radar systems", 1962, pages 420-422, McGraw Hill Book Co., Inc., New York, US., can also be consulted.

The invention proposes means for determining the frequency of the component which gives the altitude.

To do this, a device of the kind mentioned is notable in that the processing circuit also includes spectrum processing means for determining the frequency giving the distance "h" from the value of a plurality of frequency components, and in that these processing means operate in at least one of the following ways:

- the spectrum processing means determine the frequency "fb" which provides the distance "h":

$$fb = \frac{\sum_{n=k}^{k+m} c_n \cdot f_n}{\sum_{n=k}^{k+m} c_n}$$

where c_n are the amplitude values of the spectrum provided by the time/frequency transformation operator and f_n are the frequency values relating to these amplitudes (n an integer varying from k to k + m),

- the spectrum processing means operate on the amplitude values c_n for frequencies f_n according to the following procedure:

- the value "i" which gives the maximum absolute value of $c_n - c_{n-1}$ is determined, that is to say: $c_i - c_{i-1}$

- that one of the components c_i or c_{i-1} having the higher amplitude is determined, from which the frequency fb :

$fb = f_i$ or f_{i-1} according as $c_i > c_{i-1}$ or $c_{i-1} > c_i$

5 (n an integer varying from k to k+m).

- the spectrum processing means operate on amplitude values c_n for frequencies f_n according to the following procedure:

- f_b^2 is computed through the formula:

$$10 \quad \begin{array}{c} k+m \\ \Sigma c_n \cdot f_n^2 \\ n=k \end{array}$$
$$f_b^2 = \frac{\quad}{15 \quad \begin{array}{c} k+m \\ \Sigma c_n \\ n=k \end{array}}$$

- the value "h" is determined by the value fb , the square root of the above quantity (n an integer varying from k to k+m),

- 20 - the spectrum processing means operate on amplitude values c_n for frequencies f_n in order to determine the value "i" such that c_i is the largest of the components and the frequency "fb" giving "h" then being $fb = f_i$ (n an integer varying from k to k+m).

25 The following description, accompanied by the attached drawings, the whole given by way of non-limiting example, will clearly elucidate the manner in which the invention can be embodied.

30 Figure 1 represents the radar device according to the invention.

Figure 2 represents, as a function of time, the shape of a few signals from the device of Figure 1.

Figure 3 represents the shape of the spectrum of the signals of Figure 2.

35 In Figure 1, reference 1 indicates the device of the invention intended for measuring the distance "h" which separates it from a plane surface 2. The example described is set in the context of radionavigation in which the device 1 is on board an aircraft whilst the

plane surface is none other than the ground and the distance "h" is therefore the altitude.

The device 1 includes an emission antenna 5 from which a wave $E(t)$ is emitted towards the ground, and a reception antenna 7 for picking up the reflected wave $R(t)$ from the ground 2. A mixer circuit 10 performs the mixing of the reflected wave with a part of the emitted wave tapped off by means of a coupler 12 connected near the input of the emission antenna 5. The emitted wave is produced by means of a microwave oscillator 14 oscillating upwards of a frequency f_0 of the order of 4 GHz. Its frequency is controlled by a sawtooth signal generator 16. Thus, the emitted wave is frequency-modulated over a frequency range ΔF and can be written:

$$(1) \quad E(t) = A \cos \left[2\pi \left(f_0 + \frac{\Delta F}{T} t \right) t \right]$$

for t varying within the time spans T in which the sawtooth occurs.

A is a constant defining the amplitude of the wave. The wave $R(t)$ received after reflection from the ground (2) can be written:

$$R(t) = B \cos \left[2\pi \left(f_0 + \frac{\Delta F}{T} (t-\tau) \right) t \right]$$

where B is a constant defining the received level and τ represents the delay between the emitted wave and the reflected wave.

The purpose of the mixer circuit 10 is to yield at its output a signal:

$$(2) \quad M(t) = C \cos \left[2\pi \frac{\Delta F}{T} \tau t \right]$$

where C represents a constant.

The distance "h" is deduced from the frequency "fb" of the signal $M(t)$:

$$fb = \tau \frac{\Delta F}{T} \quad \text{where} \quad \tau = \frac{2h}{c}$$

(c = speed of light)

whence:

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$$h = \frac{fb \cdot c}{2\Delta F} T$$

10 The processing circuit 20 therefore performs a processing on the output signal from the mixer circuit 10 after amplification effected by an amplifier 22. This processing is performed on digital samples obtained through an analog/digital converter 25. A time/frequency transformation operation, a Fourier transformation for example, 27, is used to determine the frequency "fb" so that the distance "h" is displayed by an indicator 30.

15 According to the invention, the processing circuit 20 includes, furthermore, an autocorrelation operator 31 in order to perform an autocorrelation of the beat wave digitized by the analog/digital converter 25 before undergoing the time/frequency transformation operation executed by the operator 27. Moreover, the
20 circuit 20 includes spectrum processing means 32 for determining, from the spectrum obtained through the said time/frequency transformation, the frequency "fb" corresponding to the distance "h".

25 The functioning of the device of the invention relies upon the following considerations. In order to simplify the explanations, the case is considered in which the surface 2 behaves as a perfectly reflecting surface (specular reflection).

30 In Figure 2 in a are represented the shape of the variation in frequency of the emitted wave E(t) with a single line and the received wave R(t) with a double line. These frequencies vary linearly in frequency during a time T and with a period TR. The beat signal M(t) therefore has the shape represented in b; this signal
35 therefore takes the form of sinusoidal trains. This breaks down into a rectangular signal RT(t) shown in c and a sinusoid Si(t) shown in d (the phase breaks have been neglected here).

Figure 3 shows the shape of the various spectra

relating to these signals.

- in a is represented the spectrum $SP[RT(t)]$ of the rectangular signal. This signal being periodic, its spectrum is formed of discrete lines spaced $1/T_r$ apart. The envelope of the amplitudes of these components is the function $[\sin x/x]^2$.
- in b is represented the spectrum $SP[Si(t)]$ of the signal $Si(t)$ which is formed of two components at the frequencies "fb" and "-fb"; only the component at "fb" is represented.
- in c is lastly the spectrum of the signal $SP[M(t)]$ of $M(t)$ which is given by the convolution product of the two above spectra:
$$SP[M(t)] = SP[Si(t)] * SP[RT(t)]$$

that is to say, this spectrum is that of the signal $RT(t)$ shifted by the frequency fb.

It is therefore appreciated that the frequency components of lowest frequency do not correspond very precisely to the frequency "fb".

Although having argued hitherto regarding the spectrum of the signal at the output of the mixer 10, the argument applies also to the autocorrelation function of this same signal. Since the spectrum of a signal and the spectrum of its autocorrelation function have lines at the same frequencies, the autocorrelation operation allows the transformation effected by the operator 27 to be performed on a signal which possesses a better signal/noise ratio and hence better accuracy is thus obtained.

The means 32 for processing spectra process the various lines delivered by the operator 27. According to one embodiment of the invention, the means 27 determine the barycentre of the spectrum. Thus, for a spectrum whose components have amplitudes c_n ($n = k, k+1, \dots, k+m$) spreading over frequencies f_n , the frequency "fb" is determined from:

$$fb = \frac{\sum_{n=k}^{k+m} c_n \cdot f_n}{\sum_{n=k}^{k+m} c_n}$$

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According to a second embodiment, the means 32 use the following procedure:

10 the value "i" which gives the maximum absolute value of $c_n - c_{n-1}$ is determined, that is to say: $c_i - c_{i-1}$, that one of the components c_i or c_{i-1} having the higher amplitude is determined, from which the frequency fb:

15 $fb = f_i$ or f_{i-1} according as $c_i > c_{i-1}$ or $c_{i-1} > c_i$.

According to a third embodiment, the means 27 use the following procedure:

f_b^2 is computed through the formula

$$f_b^2 = \frac{\sum_{n=k}^{k+m} c_n \cdot f_n^2}{\sum_{n=k}^{k+m} c_n}$$

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fb is determined next by computing the square root of the above quantity.

These other embodiments are not incompatible with the fourth embodiment which consists in taking for fb the maximum value of the components c_n .

30 The value n is then determined, namely i which is such that c_i is a maximum, whence $fb = f_i$.

In practice these spectrum processing means 32 advantageously consist of a microprocessor assembly; it will be easy for those skilled in the art to programme the procedures alluded to in order to obtain the value "fb".

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CLAIMS

1. Radar device for measuring the distance "h" separating it from a surface, which device includes emission means (5) for emitting towards the said surface a frequency-modulated wave produced by an oscillator (14) equipped with a frequency control, the said emitted wave $E(t)$ being frequency-modulated over a frequency range ΔF so that $E(t) = A \cos[2\pi(f_0 + \Delta F \cdot t) \cdot t]$, reception means (7) for receiving this wave reflected by the said surface, a mixer circuit (10) for providing a beat wave from the emitted wave and received wave, and a processing circuit (20) including a circuit (25) for digitizing the beat wave, a time/frequency transformation operator (27) for providing frequency components from which the distance "h" is established, an autocorrelation operator (31) for performing an autocorrelation of the beat wave before applying it to the time/frequency transformation means (27), characterized in that the processing circuit also includes spectrum processing means (32) for determining the frequency f_b giving the distance "h" from the value of a plurality of frequency components, where $f_b = \tau \Delta F$, τ representing the delay between the emitted wave and the reflected wave, and in that these processing means operate in at least one of the following ways:
- the spectrum processing means determine the frequency "fb" which provides the distance "h":

$$f_b = \frac{\sum_{n=k}^{k+m} c_n \cdot f_n}{\sum_{n=k}^{k+m} c_n}$$

- where c_n are the amplitude values of the spectrum provided by the time/frequency transformation operator and f_n are the frequency values relating to these amplitudes (n an integer varying from k to k + m),



- the spectrum processing means operate on the amplitude values c_n for frequencies f_n according to the following procedure:
 - the value "i" which gives the maximum absolute value of $c_n - c_{n-1}$ is determined, that is to say:

$$c_i - c_{i-1}$$
 - that one of the components c_i or c_{i-1} having the higher amplitude is determined, from which the frequency fb:

$$fb = f_i \text{ or } f_{i-1} \text{ according as } c_i > c_{i-1} \text{ or } c_{i-1} > c_i$$
 (n an integer varying from k to k+m).
- the spectrum processing means operate on amplitude values c_n for frequencies f_n according to the following procedure:
 - f_b^2 is computed through the formula:

$$f_b^2 = \frac{\sum_{n=k}^{k+m} c_n \cdot f_n^2}{\sum_{n=k}^{k+m} c_n}$$
 - the value "h" is determined by the value fb, the square root of the above quantity (n an integer varying from k to k+m),
- the spectrum processing means operate on amplitude values c_n for frequencies f_n in order to determine the value "i" such that c_i is the largest of the components and the frequency "fb" giving "h" then being $fb = f_i$ (n an integer varying from k to k+m).