INSTRUCTIONS

(a) If Convention application insert "Convention"

CONVENTION (a) 653290

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/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) Radar apparatus

(f) Insert Names of actual Inventors.

[72] Names of Actual Inventors (f)

Albert Groenenboom

Bernard Jozef Reits

[74] Address for Service:

PHILLIPS ORMONDE AND FITZPATRICK
Patent and Trade Mark Attorneys
367 Collins Street
Melbourne, Australia 3000
Attorney Code: PO

(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
	9200837	Netherlands	NL	12-05-92

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

(i) Insert date of signing

(j) Corporate seal if any

(j) HOLLANDSE SIGNAALAPPARATEN B.V.

Note: No legalization or other witness required

(h) Signature of Applicant

22 April 1993

(i) Date

PHILLIPS ORMONDE AND FITZPATRICK
Patent and Trade Mark Attorneys
367 Collins Street
Melbourne, Australia

P17/5/91

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NOTICE OF ENTITLEMENT

INSTRUCTIONS
(a) Name of person making statement.
(b) Position of that person.
(c) Name of applicant
(d) Address of applicant
(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,

(b) Authorised Representative of 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 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 assignees 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) 22 April 1993

(j) _____
B.J. Reits

Note: No legalization or other witness required

To: The Commissioner of Patents

PHILLIPS ORMONDE AND FITZPATRICK
Patent and Trade Mark Attorneys
367 Collins Street
Melbourne, Australia

P18/3/91

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(12) PATENT ABRIDGMENT (11) Document No. AU-B-38313/93
(19) AUSTRALIAN PATENT OFFICE (10) Acceptance No. 653290

(54) Title
RADAR APPARATUS

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(71) Applicant(s)
HOLLANDSE SIGNAALAPPARATEN B.V.

(72) Inventor(s)
ALBERT GROENENBOOM; BERNARD JOZEF REITS

(74) Attorney or Agent
PHILLIPS ORMONDE & FITZPATRICK , 367 Collins Street, MELBOURNE VIC 3000

(56) Prior Art Documents
US 5023618
US 4912472

(57) Claim

1. Radar apparatus comprising transmitter means provided with a transmit generator for generating a transmitter pulse modulated at a frequency sweep rate and a reference signal modulated at the same frequency sweep rate; receiver means provided with a mixer stage for generating a heterodyne signal from the reflected transmitter pulse and the reference signal, a dispersive delay element for the frequency-dependent delay of the heterodyne signal; and a Fourier transformation unit provided with a weighting function for transforming the delayed heterodyne signal, characterised in that correction means have been provided for correcting distortion of the heterodyne signal.

AUSTRALIA

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COMPLETE SPECIFICATION
(ORIGINAL)

Class Int. Class

Application Number:
Lodged:

Complete Specification Lodged:
Accepted:
Published:

Priority

Related Art:

Name of Applicant:

Hollandse Signaalapparaten B.V.

Actual Inventor(s):

Bernard Jozef Reits
Albert Groenenboom

Address for Service:

PHILLIPS ORMONDE & FITZPATRICK
Patent and Trade Mark Attorneys
367 Collins Street
Melbourne 3000 AUSTRALIA

Invention Title:

RADAR APPARATUS

Our Ref : 326912
POF Code: 1399/1399

The following statement is a full description of this invention, including the best method of performing it known to applicant(s):

Radar apparatus

The invention relates to a radar apparatus comprising transmitter means provided with a transmit generator for generating a transmitter pulse modulated at a frequency sweep rate and a reference signal modulated at the same frequency sweep rate; receiver means provided with a mixer stage for generating a heterodyne signal from the reflected transmitter pulse and the reference signal, a dispersive delay element for the frequency-dependent delay of the heterodyne signal; and a Fourier transformer unit provided with a weighting function for transforming the delayed heterodyne signal.

Such a radar apparatus is known from patent specification US-A 4,912,472. This specification relates to a radar apparatus which linearly transmits frequency-modulated pulses at a 50% duty cycle, the received echo pulses being processed as is customary in a FMCW radar by mixing them in receiver means with a reference signal and subsequently digitizing, weighting and Fourier-transforming the resulting heterodyne signal. A non-simultaneous arrival of received echo pulses as a result of propagation time differences is solved by incorporating a dispersive delay element in the receiver means. Since both the echo pulse propagation time and the frequency of the heterodyne signal linearly depend on the distance between the radar apparatus and the target producing the echo pulse, a dispersive delay element of a suitably chosen dispersiveness is undoubtedly capable of compensating any propagation time differences.

A drawback of the signal processing in said radar apparatus is that any distortion of the heterodyne signal, wherever caused, may give rise, after Fourier analysis, to spurious targets.

The radar apparatus according to the invention aims at obviating this drawback and is characterised in that correction means have been provided for correcting distortion of the heterodyne signal.

Said distortion is mainly found to be caused by the heterodyne signal passing through the dispersive delay element. The distortion is entirely predictable, however, and merely depends on the pulse length, the degree of dispersiveness of the dispersive delay element and on a tapering, applied to the transmitter pulse.

A first favourable embodiment of the radar apparatus according to the invention is thereto characterised in that the correction means comprise a division of the weighting function by a first function which describes the distortion of the heterodyne signal in the dispersive delay element.

A second, most favourable embodiment of the radar apparatus according to the invention is characterised in that the correction means comprise a division of the weighting function by a second function which describes the distortion of the transmitter pulse in the transmitter means and of the heterodyne signal in the dispersive delay element. The underlying idea of the invention is that the required incorporation of the correction means may conveniently serve to eliminate the transmitter pulse distortion. Since latter distortion can be influenced by time-dependent parameters, for instance the temperature of the transmitter means, this embodiment is further characterised in that means have been provided for analysing a signal distorted in the transmitter means and the dispersive element in order to obtain the second function.

The invention will now be further described with reference to the following figures, of which:

Fig. 1 represents a block diagram of a radar apparatus according to the invention;

Fig. 2 represents a possible transmitter pulse and a possible reference signal in a radar apparatus according to the invention;

Fig. 3 represents a block diagram of a radar apparatus according to the invention in which calibration means are provided for correction of the transmitter pulse distortion.

In a pulse radar apparatus, the distance to the target is determined in the time domain, as a delay between a transmitted pulse and a received echo pulse. In a linear FMCW radar apparatus this distance is determined in the frequency domain, as a frequency difference between a transmitted signal and a received echo signal. Fourier transformation of this heterodyne signal yields a radar signal which practically corresponds with the radar signal of a pulse radar apparatus and which is suitable for driving a pulse radar-specific radar display or a track computer.

Fig. 1 represents a block diagram of a radar apparatus according to the invention which combines features of an FMCW radar apparatus and a pulse radar apparatus. A transmit generator 1 generates a transmitter pulse which is applied to antenna means 2. The transmitter pulse has a duration T_p and a linear frequency modulation of a bandwidth B. Transmit generator 1 also generates a reference signal with a linear frequency modulation, the frequency sweep rate of which corresponds with that of the transmitter pulse, which reference signal is applied to a first input of mixer stage 3. Echo signals are received by antenna means 2 and applied to a second input of mixer stage 3. The reference signal has a duration T' with $T_p' = kT$, $k > 1$ and a bandwidth $B' = kB$. Transmitter pulse and reference signal are periodically generated and will always start simultaneously. Heterodyne signals at the output of mixer stage 3 will also reveal features of both a pulse radar apparatus and an FMCW radar apparatus.

Thus, the time delay will cause a heterodyne signal to contain the distance to the target, although this information will also be contained in the frequency of the echo signal. If transmitter pulse and reference signal are substantially identical and only the

reference signal is of a longer duration, both the time delay and the frequency are proportional to the distance.

According to the state of the art referred to in the introduction, it is advantageous to pass the heterodyne signals through a dispersive delay element 4, the dispersiveness of which has been selected such that time delays for different echo signals are compensated. All echo signals will then simultaneously leave the dispersive delay element 4 to be subsequently applied to Fourier transformation unit 5 provided with a weighting function. Thus, a type of processing inherent in an FMCW radar apparatus is used in a pulse radar apparatus. The resulting radar signal is however found to be less suitable for driving a radar display or a track computer on account of this signal being afflicted with time sidelobes, which cause false echoes on the display screen. This phenomenon is chiefly due to distortion of the heterodyne signal in dispersive delay element 4.

Supposing the input signal of the dispersive delay element is a signal f(t) with an angular frequency ω^* and a pulse length T_p, then

$$f(t) = p_\sigma(t)\, e^{j\omega^* t} \tag{1}$$

where

$$p_\sigma(t) = w_\sigma^* \, p_0 \tag{2}$$

In this formula

$$w_\sigma(t) = \frac{1}{\sigma\sqrt{2\pi}}\, e^{-\frac{1}{2}(t/\sigma)^2} \tag{3}$$

represents the tapering and the following applies

$$P_0(t) = \begin{cases} 1 \text{ if } |t| \leq \frac{1}{2}T_p \\ 0 \text{ if } |t| > \frac{1}{2}T_p \end{cases} \tag{4}$$

The spectrum of this pulse is

$$\hat{f}(\omega) = \hat{P}_0(\omega-\omega^*)\, \hat{w}_\sigma(\omega-\omega^*) \tag{5}$$

where

$$\hat{P}_0(\omega) = 2\, T_p\, \mathrm{sinc}(\omega T_p) \tag{6}$$

and

$$\hat{w}_\sigma(\omega) = e^{-\frac{1}{2}\omega^2\sigma^2} \tag{7}$$

The input signal can now be represented as

$$f(t) = \frac{1}{2\pi} \int_{-\infty}^{\infty} \hat{f}(\omega)\, e^{j\omega t} d\omega \tag{8}$$

For the dispersive delay element 4 we assume that a harmonic input signal with an angular frequency ω will experience a delay of $\frac{1}{2}\alpha\omega$, α representing the dispersiveness of dispersive delay element 4.

An input signal $e^{j\omega t}$ consequently yields an output signal $e^{j\omega(t-\frac{1}{2}\alpha\omega)}$. Our input signal f(t) then results in an output signal

$$f^*(t) = \frac{1}{2\pi} \int_{-\infty}^{\infty} \hat{f}(\omega)\, e^{j\omega(t-\frac{1}{2}\alpha\omega)} d\omega \tag{9}$$

$$= e^{-\frac{1}{2}\alpha(\omega^*)^2} q_\sigma\,(t-\alpha\omega)\, e^{j\omega^* t}$$

where

$$q_\sigma(t) = \frac{1}{2\pi} \int_{-\infty}^{\infty} \hat{p}_\sigma\,(\omega)\, e^{-\frac{1}{2}\alpha\omega^2}\, e^{j\omega t} d\omega \tag{10}$$

If we compare (1) and (9) we find

i) a phase shift of $\frac{1}{2}\alpha(\omega^*)^2$

ii) the pulse form p_σ changing into q_σ

iii) a delay of $\alpha\omega^*$.

The first effect is irrelevant. The third effect is the intended effect. The second effect entails a ripple which adversely affects the pulse compression.

A simple calculation reveals that:

$$q_\sigma(t) = \tfrac{1}{2}\sqrt{2}\, e^{-j\frac{4}{\pi}} \left[F\left[\frac{t + \tfrac{1}{2}T_p}{\sqrt{\pi(\alpha - 2j\sigma^2)}} \right] - F\left[\frac{t - \tfrac{1}{2}T_p}{\sqrt{\pi(\alpha - 2j\sigma^2)}} \right] \right] \qquad (11)$$

where F represents the Fresnel integral

$$F(z) = \sqrt{\frac{2}{\pi}} \int_0^z e^{jt^2} dt, \quad z \in C \qquad (12)$$

Consequently, the ripple is a so-called Fresnel ripple.

From (11) it follows that the ripple only depends on the pulse length, on the dispersiveness of dispersive delay element 4 and possibly on a tapering of the transmitter pulse. It is therefore possible to obtain a radar signal which is suitable for driving a radar display or a track computer by making a correction for this ripple. A particularly opportune moment for this correction is during the weighting of the echo signals before they are applied to Fourier transformation unit 5. To this end, the weighting function can be divided by $q_\sigma(t)$.

In a first favourable embodiment of a radar apparatus according to the invention, a transmitter pulse is emitted with a frequency sweep of 1 Mc/s in 100 μsec. The start frequency of the reference signal is selected 16 Mc/s lower than the start frequency of the transmitter pulse, the frequency sweep is 7 Mc/s in 700 μsec. This is illustrated in Fig. 2.

Targets at a very short range will then produce heterodyne signals of 16 Mc/s, at 15 km distance 15 Mc/s, at 30 km distance 14 Mc/s, etc. A dispersive delay element 4 can be implemented according to the well-known imcon technology, on the basis of the parameters:

bandwidth	5 Mc/s
dispersiveness	500 μsec
centre frequency	12.5 Mc/s
weighting	none

If said heterodyne signals are applied to this dispersive delay element 4, echoes of targets between 15 and 90 km will simultaneously appear at the output of the dispersive delay element 4, in a time window of 100 μsec. By means of a quadrature detector, incorporated in Fourier transformation unit 5, provided with a 12.5 Mc/s reference signal, a quadrature video is produced and sampled at a clock frequency of 5 Mc/s. The 500 resulting complex samples are then weighted with a $\cos^2$ weighting, provided with an inverse Fresnel ripple calculated by means of formula (11) using the above-mentioned parameters. Subsequently, a 512-point FFT is performed, resulting in 512 range quants.

The radar apparatus can be provided with an STC, as is usual in a pulse radar apparatus. This STC will inevitably cause pulse distortion and consequently time sidelobes. A more favourable solution is to apply the STC in the frequency domain, as is usual in an FMCW radar apparatus. To this effect the frequency characteristic of an amplifier, for instance incorporated between mixer stage 3 and dispersive delay element 4 may be selected such that an attenuation for close, consequently high-frequency targets is obtained. Another possibility is to provide the dispersive delay element 4 with a weighting which realises the STC in the frequency domain.

A second favourable embodiment of the radar apparatus is represented in Fig. 3 and has for its object to provide an application of the invention which also corrects the transmitter pulse distortion. The transmitter pulse will generally show droop and ripple and will moreover often provide a tapering for the transmitter pulse which depends on the degree of saturation of a transmitter output stage in transmit generator 1.

To this end, the radar apparatus is equipped with a switch S1 which during operation connects antenna means 2 and mixer stage 3, but which during system calibration applies a calibration pulse originating from transmit generator 1 to mixer stage 3. The

calibration pulse is derived from the transmitter pulse and is attenuated such as to prevent overload of mixer stage 3. During system calibration, the start frequency of the transmitter pulse is moreover reduced to such an extent that the derived heterodyne signal will be within the pass-band of dispersive delay element 4. Thus, the calibration pulse generates an artificial target. In this embodiment the Fourier transformation unit is provided with a digital signal processor, which also performs the weighting; an embodiment well-known in the art. An exceptional aspect is, however, that during system calibration, the signal processor runs a calibration program which determines the distortion of the heterodyne signal originating from the calibration pulse and generates a weighting function which eliminates this distortion. This is possible since the distortion is on the one hand caused by the transmit generator and is therefore identical for all targets; on the other hand the distortion is caused by the dispersive delay element 4 and will, according to formula (11), also be identical for all targets. By thus periodical system calibration results in a radar apparatus with favourable time sidelobes which is suitable for driving a radar dsiplay or a track computer.

For applications which require the radar apparatus to be Doppler-tolerant, it is important to reduce the Fresnel ripple, since a heterodyne signal originating from a moving target leaves the dispersive delay element somewhat shifted in time, so that Fresnel ripple and inverse Fresnel ripple do not fully match. As shown in formula (11), a tapering of the transmitter pulse will then be the obvious means.

The claims defining the invention are as follows:

1. Radar apparatus comprising transmitter means provided with a transmit generator for generating a transmitter pulse modulated at a frequency sweep rate and a reference signal modulated at the same frequency sweep rate; receiver means provided with a mixer stage for generating a heterodyne signal from the reflected transmitter pulse and the reference signal, a dispersive delay element for the frequency-dependent delay of the heterodyne signal; and a Fourier transformation unit provided with a weighting function for transforming the delayed heterodyne signal, characterised in that correction means have been provided for correcting distortion of the heterodyne signal.

2. Radar apparatus as claimed in claim 1, characterised in that the correction means comprise a modification of the weighting function.

3. Radar apparatus as claimed in claim 2, characterised in that the correction means comprise a division of the weighting function by a first function which describes the distortion of the heterodyne signal in the dispersive delay element.

4. Radar apparatus as claimed in claim 2, characterised in that the correction means comprise a division of the weighting function by a second function which describes the distortion of the transmitter pulse in the transmitter means and of the heterodyne signal in the dispersive delay element.

5. Radar apparatus as claimed in claim 4, characterised in that means have been provided for analysing a signal distorted in the transmitter means and the dispersive delay element in order to obtain the second function.

6. Radar apparatus as claimed in claim 5, the Fourier transformation unit being provided with a digital signal processor, characterised in that the digital signal processor constitutes the means for analysing a distorted signal.

7. Radar apparatus as claimed in claims 5 or 6, characterised in that the transmitter means are provided with means for generating a calibration pulse and the receiver means have been provided with an input device for injecting the calibration pulse.

8. Radar apparatus as claimed in claim 7, characterised in that the frequency of the calibration pulse has been selected such that the frequency of a heterodyne signal originating from the calibration pulse will be within the pass-band of the dispersive delay element.

9. Radar apparatus as claimed in claim 8, characterised in that the means for analysing a distorted signal are activated concurrently with the calibration pulse.

10. Radar apparatus as claimed in one of the claims 1-9, characterised in that the receiver means are provided with an STC, realised in the frequency domain.

11. Radar apparatus as claimed in one of the claims 1-10, characterised in that the transmitter pulse is provided with a tapering.

DATED: 29 April, 1993
PHILLIPS ORMONDE & FITZPATRICK
Attorneys for:
HOLLANDSE SIGNAALAPPARATEN B.V.

Abstract

Radar apparatus provided with a transmit generator (1) and antenna means (2) for the transmission of comparatively long, linearly frequency-modulated transmitter pulses. Echo signals are received by antenna means (2) and a heterodyne signal is generated in mixer stage (3). Propagation time differences for different echo pulses are compensated by means of a dispersive delay element (4) incorporated in the radar receiver. Distortion of the echo pulses in the dispersive delay element is corrected on the basis of a Fresnel ripple correction. A Fourier transformation unit (5) transfers the corrected echo pulses to time domain video with low sidelobes.

Fig. 1

30 04 93 38313.

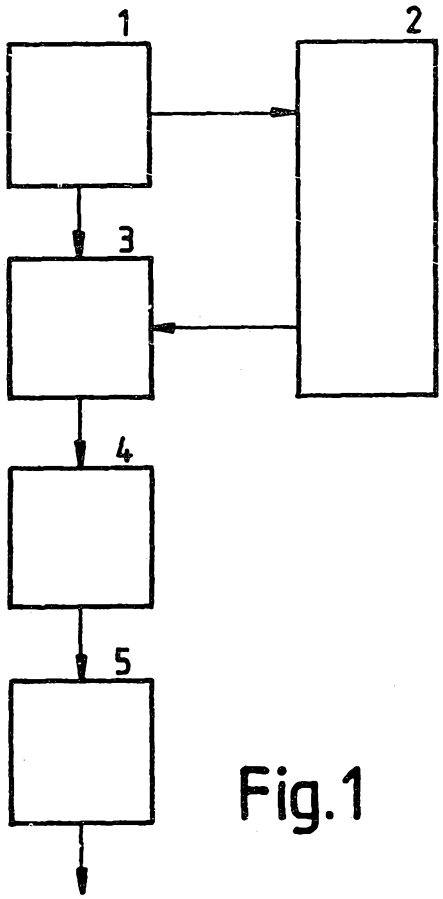


Fig.1

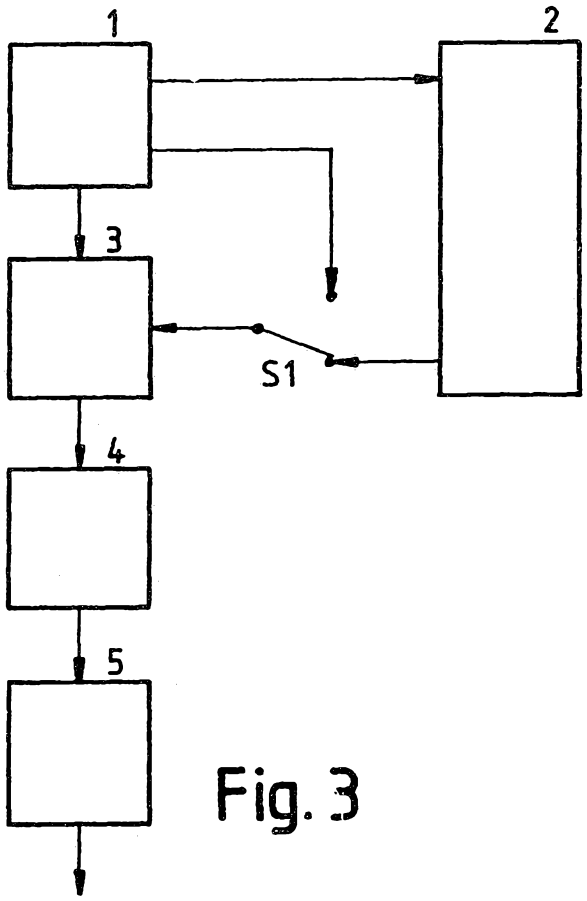


Fig. 3

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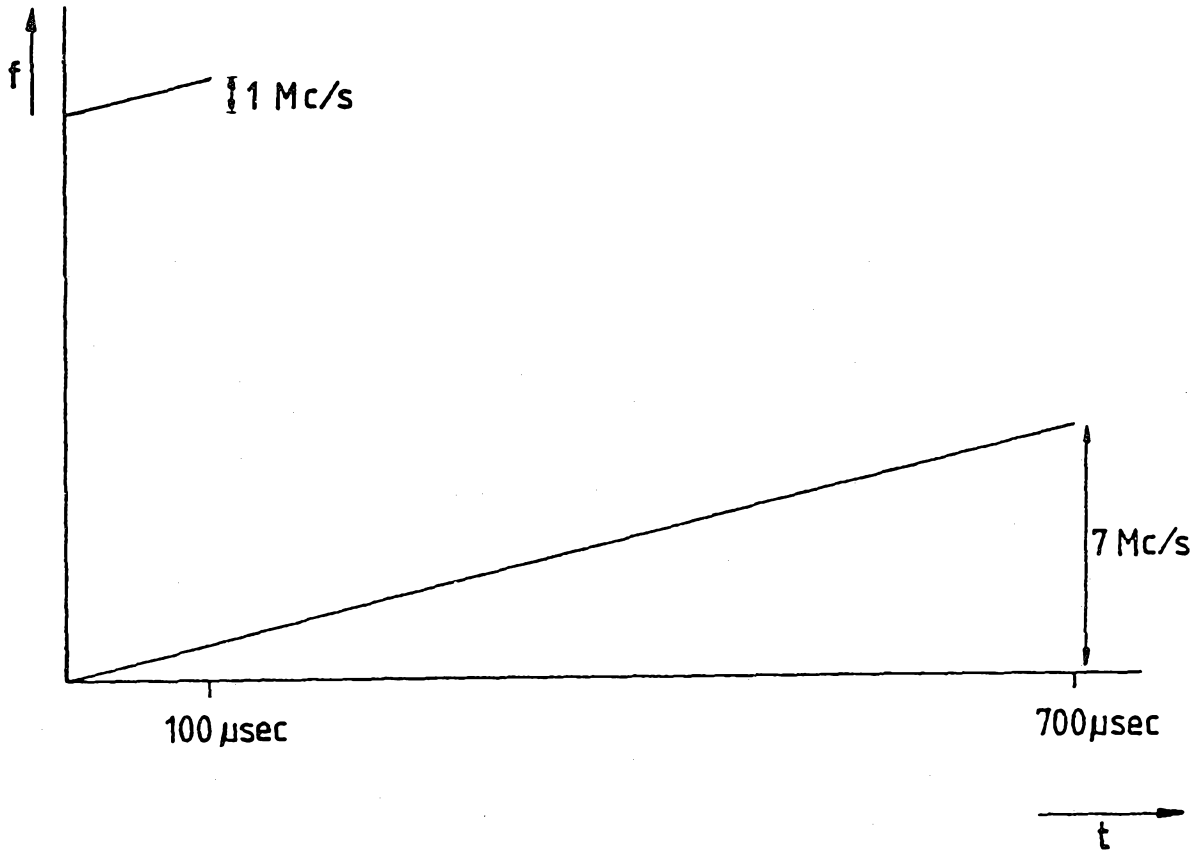


Fig. 2