Office de la Propriété Intellectuelle du Canada
Un organisme d'Industrie Canada

Canadian Intellectual Property Office
An agency of Industry Canada

CA 2157368 C 2004/12/07

(11)(21) 2 157 368

(12) BREVET CANADIEN
CANADIAN PATENT

(13) C

(86) Date de dépôt PCT/PCT Filing Date: 1993/03/04
(87) Date publication PCT/PCT Publication Date: 1994/09/15
(45) Date de délivrance/Issue Date: 2004/12/07
(85) Entrée phase nationale/National Entry: 1995/08/31
(86) N° demande PCT/PCT Application No.: US 1993/002234
(87) N° publication PCT/PCT Publication No.: 1994/020926

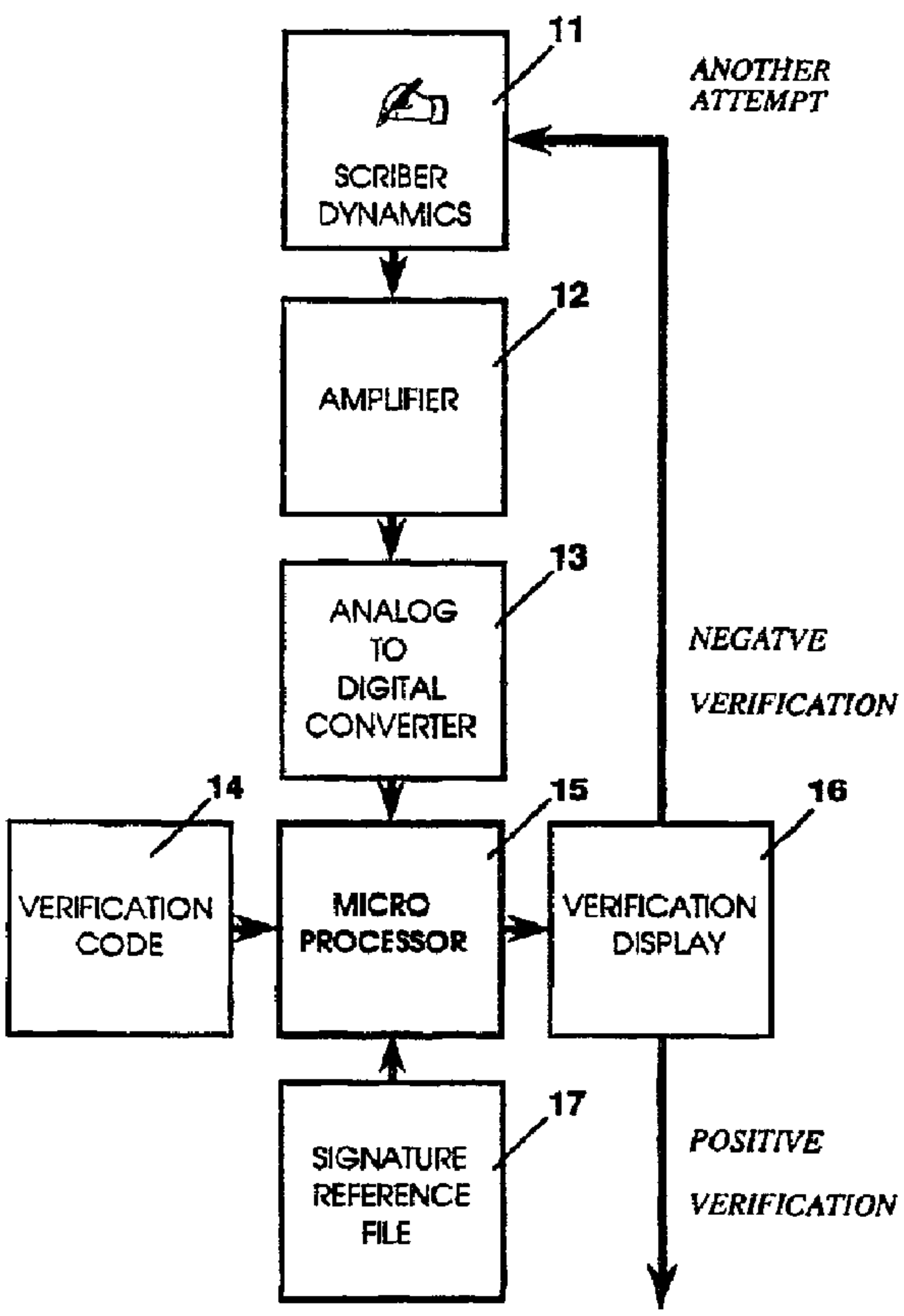
(51) Cl.Int.^{6}/Int.Cl.^{6} G06K 9/64

(72) Inventeurs/Inventors:
LIVSHITZ, ALEXANDER, US;
SHRAIRMAN, RUTH, US

(73) Propriétaires/Owners:
LIVSHITZ, ALEXANDER, US;
SHRAIRMAN, RUTH, US

(74) Agent: BORDEN LADNER GERVAIS LLP

(54) Titre : SYSTEME DE VERIFICATION DYNAMIQUE DE SIGNATURES EN LIGNE DE HAUTE PRECISION
(54) Title: HIGH PRECISION ON-LINE DYNAMIC SIGNATURE VERIFICATION SYSTEM



(57) Abrégé/Abstract:
A method for on-line handwritten data verification based on the comparison of the dynamics of sample (31 or 32) and reference data (21 or 22) by implementation of correlation function analysis. Reference dynamic data concerning scriber (11) movement during data formation is recorded and converted to digital form (13). Prior to evaluation to-be-verified data, both the reference and to-be-verified data dynamic digital signals are pre-processed to eliminate time distortions. A "sliding window" mechanism is used to

(57) Abrégé(suite)/Abstract(continued):
establish the mapping between phase coincident regions of the reference and of the to-be-verified signals. Then multi-dimensional cross-correlation function analysis is applied to the pair of indivisible stationary signals. The resulting measures of similarity are then compared with thresholds that have been selected to determine acceptance or rejection of the to-be-verified signals. The method and the apparatus can be applied to data authentication in a wide variety of applications like security for physical mess, for credit card authentication, electronic voting, and the like.

PCT

WORLD INTELLECTUAL PROPERTY ORGANIZATION
International Bureau

INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

(51) International Patent Classification 5 : G06K 9/00, 9/46, 9/36, 9/66

A1

(11) International Publication Number: WO 94/20926

(43) International Publication Date: 15 September 1994 (15.09.94)

2157368

(21) International Application Number: PCT/US93/02234

(22) International Filing Date: 4 March 1993 (04.03.93)

(71)(72) Applicants and Inventors: LIVSHITZ, Alexander [IL/US]; 1475 Folsom Avenue, Apartment 378, Boulder, CO 80303 (US). SHRAIRMAN, Ruth [IL/US]; 1475 Folsom Avenue, Apartment 378, Boulder, CO 80303 (US).

(74) Agent: MARGOLIS, Donald, W.; 3405 Penrose Place, Suite 105, Boulder, CO 80301-1819 (US).

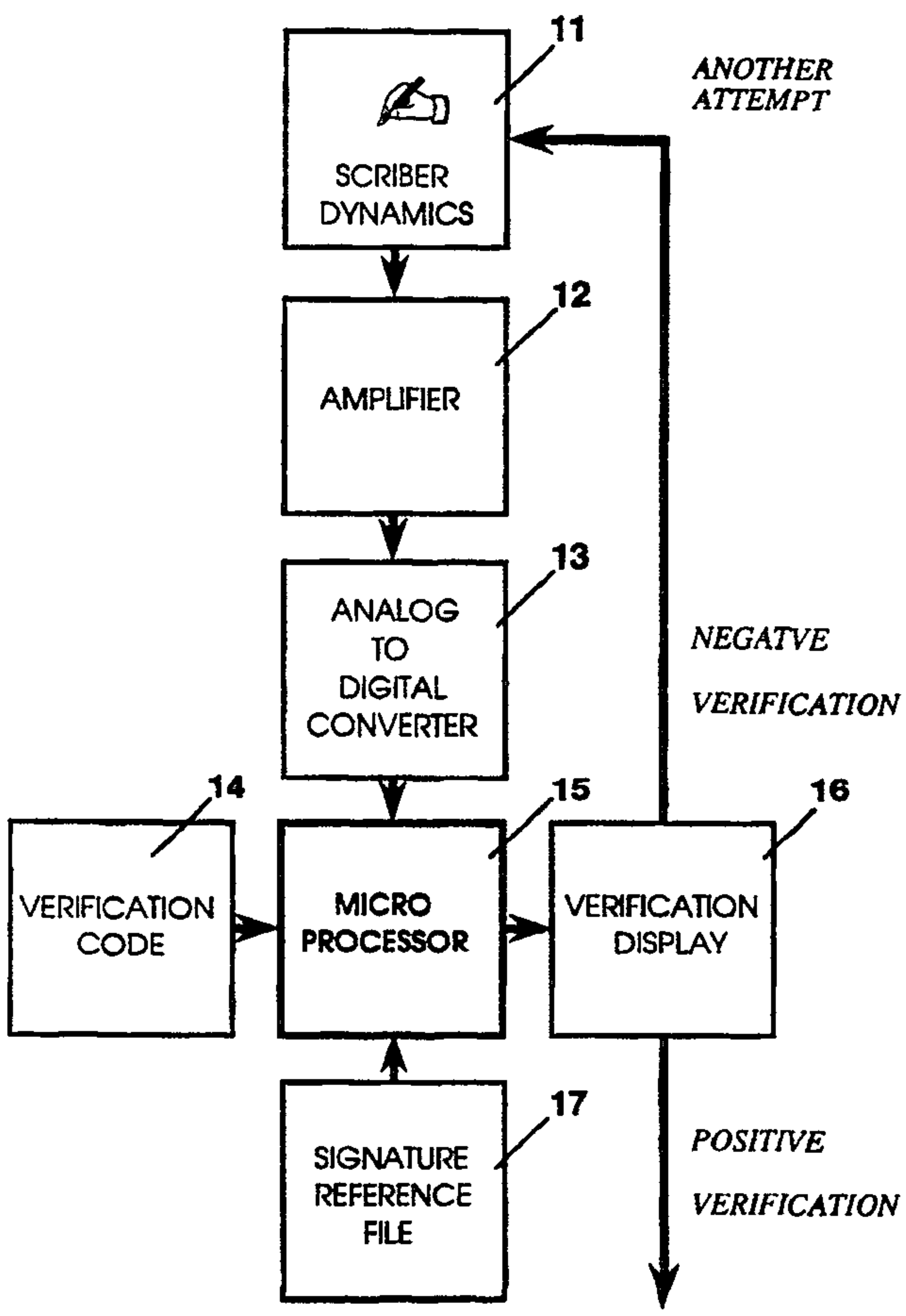
(81) Designated States: AU, CA, JP, European patent (AT, BE, CH, DE, DK, ES, FR, GB, GR, IE, IT, LU, MC, NL, PT, SE).

Published
With international search report.

(54) Title: HIGH PRECISION ON-LINE DYNAMIC SIGNATURE VERIFICATION SYSTEM

(57) Abstract

A method for on-line handwritten data verification based on the comparison of the dynamics of sample (31 or 32) and reference data (21 or 22) by implementation of correlation function analysis. Reference dynamic data concerning scriber (11) movement during data formation is recorded and converted to digital form (13). Prior to evaluation to-be-verified data, both the reference and to-be-verified data dynamic digital signals are pre-processed to eliminate time distortions. A "sliding window" mechanism is used to establish the mapping between phase coincident regions of the reference and of the to-be-verified signals. Then multi-dimensional cross-correlation function analysis is applied to the pair of indivisible stationary signals. The resulting measures of similarity are then compared with thresholds that have been selected to determine acceptance or rejection of the to-be-verified signals. The method and the apparatus can be applied to data authentication in a wide variety of applications like security for physical access, for credit card authentication, electronic voting, and the like.



2157368

Title: HIGH PRECISION ON-LINE DYNAMIC SIGNATURE VERIFICATION SYSTEM

a.) Technical Field

This invention relates to an automated on-line hand written data verification system, for example for high accuracy signature verification, based on scriber movement and data analysis using digital data comparison. More particularly, it relates to an verification system using hand written data, and which takes into account evaluation of the maximum value of cross-correlation function between to-be-verified and reference signature signals, as well as analysis of phase histograms related to such signals.

b.) Background Art

The dictionary defines a signature as the name of a person written with his own hand. It is the oldest means used by people to signify authenticity, and still remains the primary means of authorization approval and authentication. The current electronic environment of computer networks, facsimile machines, and on-line data bases, coupled with the movement towards a moneyless, paperless, faceless society requires new and innovative ways to guarantee the authenticity and validity of money and document transactions. One way to protect information is encryption which provides a certain amount of security. Modern encryption systems use a pair of encryption keys, a public encryption key and private secret decryption key. However, should the private decryption key of an individual be learned by an unauthorized person, the system loses its security.

In the art, two basic approaches to signature verification process are known, the "method of templets" and the "correlation analysis method."

The method of templets uses a set of chosen features values represented together with their tolerance levels and with corresponding weight coefficients. The features that represent the signature of a person usually exploit such characteristics as the average number of peaks, the position of the highest peak, the number of cross-overs at the zero reference, and the like, that is an image of the average signature dynamics as it is used in the pattern recognition approach. Since the signature of a person is a highly variable, it is very hard to find its invariant. This fact results in a reliability problem when using the method of templets for verification.

The correlation analysis method is more appropriate to the nature of the problem of comparison of signature dynamic signals. However, the correlation analysis method runs into difficulties because of the short length of the signals and the non-stationary character of the signals. Application of the correlation analysis method for signature verification is the substance of Herbst, et al. U.S. Patents 3,983,535 and 4,128, 829; and Gundersen U.S. Patent 4,736,445, all of IBM. Each of these patents uses the regional correlation approach, in order to eliminate "distortions of signals in the time axis", for example, see Gundersen U.S. Patent 4,736,445, at Col. 1, lines 52-54. The method of the signal segmentation for cross-correlation analysis was first introduced by Herbst, et al. U.S. Patent

3,983,535, and was modified and supplemented by elements of spectrum analysis by Gundersen U.S. Patent 4,736,445. In the latter references, the evaluation of cross-correlation functions are done between small segments of corresponding to-be-verified and reference signature signals.

The segmentation in its last modification by Gundersen is implemented by dividing the time signal segments between scriber lifts into short subsegments, each subsegment being at most 0.7 second in length, with the cross-correlation function being evaluated between preassigned pairs of subsegments of a to-be-verified and of a reference signature signals. Similarity of the signals is measured by integral characteristics evaluated by using maximum correlation coefficients for all of the subsegments pairs, with special weight functions being used for penalizing any abnormal correlations within the very small overlapped areas.

Such a segmentation analysis method has serious shortcomings. Splitting signals into segments of very short length results in the considerable loss of useful authentic information. Computation of correlation functions on such short overlapping pieces of these subsegments can not result in reliable evaluation and makes this measure statistically unstable. Furthermore, the subdivision of segments into very short subsegments does not eliminate time distortions as it does not necessarily result in generation of phase-coincidental pairs of sub-segments from the reference signature and from the to-be-verified signature signals.

DISCLOSURE OF THE INVENTION

The present invention discloses a method and apparatus for use in on-line hand written data verification, such as a signature, based on the comparison of the dynamics of a to-be-verified (sample) signature and of a reference signature by use of a new method for the implementation of correlation function analysis. In the practice of the present invention, the dynamic data concerning forces, accelerations, velocities and the like, of a scriber, such as a pen, during the process of reference signature making is first recorded and then converted to digital form. This dynamic data can then be used as random signal vectors during the verification process, as taught herein below. Prior to the correlation function analysis for evaluating signal matching, both the reference dynamic data and the to-be-verified dynamic data signals are pre-processed to eliminate different kinds of time distortions, so that the signals can be compared as though both sets of data were stationary signals. More particularly, the compared signals are reduced to the same time scale or to the same average velocity and by this to adjust a frequency coincidence between the signals. In order to eliminate phase shifts, a special "sliding window", method, has been developed, as detailed below, which can be used to establish the mapping between phase coincident points of the reference and of the to-be-verified signals.

Additionally, the sliding window method allows to determine a portion of first order differences of window shifts for each axis and differences of such shifts for any compared pair of axes which values are in the zero neighborhood which determination is appeared to be two powerful criteria to distinguish authentic and forged signatures.

Then cross-correlation function analysis is applied to the pair of indivisible apparently stationary, frequency and phase coincident signals. Such analysis may be implemented either for each vector component of written data signal separately, or for multidimensional signal. In the former implementation, the maximum of cross-correlation function evaluated for each vector component is used to determine and measure similarity. In the latter, using multidimensional vectors, a norm or a trace of the cross-correlation matrix is used to determine and measure similarity.

The resulting measure of similarity as determined by either such method of cross-correlation analysis, is then compared with a threshold that has been selected to determine acceptance or rejection of the signature; this criterion will be referred to as Cr_1. As more precisely set forth below, verification criteria are calculated by evaluating complex criteria with regard for phase shift histograms and estimation of maximum value of cross-correlation function between to-be-verified and reference signals which both have been pre-processed to a corresponding pair of effectively stationary signals with frequency and phase adjustment. Phase shift analysis and correlation function analysis can be implemented either sequentially or in parallel.

The method and the apparatus of the present invention can be applied for signature authentication in a wide variety of applications, such as security for physical access, computer network access, facsimile legalization, smart card industry, and many others.

These and other objects of the present invention will become apparent to those skilled in the art from the following detailed description, showing the contemplated invention as herein described, and more particularly defined by the appended claims, it being understood that changes in the precise embodiments of the herein disclosed invention are meant to be included as coming within the scope of the claims, except insofar as they may be precluded by the prior art.

BRIEF DESCRIPTION OF DRAWINGS

The accompanying drawings illustrate complete preferred embodiments of the present invention according to the best modes presently devised for the practical application of the principles thereof, and in which:

FIG. 1 is a schematic diagram showing the elements of the signature verification system of the present invention;

FIG. 2 shows a pictorial representation of two samples of an authentic signature, 22 and 23 which have been written by the same person at two different times;

FIG. 3 shows a pictorial representation of an authentic signature, 31 as in FIG. 2, and of free hand forgery 32 of that signature which has been written by another person;

FIG. 4 shows the magnitude of acceleration during the process of scriber movement 41 and 42 for the two authentic signatures in FIG. 2;

FIG. 5 shows magnitude of acceleration during the process of scriber movement, 51 and 52 respectively, for the authentic signature 31 and for the forged signature 32, shown in FIG. 3;

FIGS. 6a and 6b show graphs of the sliding window shift for the magnitude of acceleration with respect to the window number given for the pair of authentic signature signals in FIG.4, and for the pair of a true and forged signature signals in FIG. 5, respectively;

FIG. 6c shows the sliding window shift for both cases in the same scale along the shift axis;

FIGS. 7a and 7b show histograms of the first order difference, $\Delta\tau_{max}$ for the pair of authentic signatures shown in FIG. 4, and for the pair of the true signature and the free hand forgery in FIG. 5, respectively;

FIGS. 8a and 8b show window shift difference between components X and Y of acceleration with respect to the window number for the pair of authentic signatures in FIG. 2, and for the pair of the authentic and forged signatures in FIG. 3, respectively;

FIG. 8c shows shift difference for both cases in the same scale along the shift axis;

FIGS. 9a and 9b show histograms of the shift difference $[\Delta\tau^{xy}]_{max}$ between window shifts determined for X and Y components of scriber acceleration for the pair of authentic signatures shown in FIG. 2, and for the pair of the authentic and the forged signatures in FIG. 3, respectively;

FIG. 10 shows behavioral matching of the phase shifts 61 given in FIG. 6a, and maximum values of window cross-correlation function 91 with respect to the window number for the authentic signatures in FIG. 2.

BEST MODE FOR CARRYING OUT THE INVENTION AND INDUSTRIAL APPLICABILITY

The present invention proposes a method by which a digitized code of the signal picked up in the process of signature making can be considered as a personnel key which is both unique and cannot be lost or forgotten. As used herein, a "signature" shall mean any specific hand written text, or hieroglyph, or the like.

As it is shown in FIG. 1, in the process of signature making, or writing other data, a scriber 11 with enclosed sensors, not shown, produces analog signals, which are amplified by amplifier 12 and converted to digital signals by converter 13. The digital signals then go to processor 15 where, if they are original reference signals they are pre-processed and stored in the reference file 17. If the digital signals are from a to-be-verified sample signature they are compared with reference signature signals stored in reference file 17 by use of a verification code 14, as set forth in detail below. The result of the verification comparison is displayed on a verification display 16, and informs the writer or the person administering the test that either access is granted (in the case of positive verification), or request the writer to provide another signature (in the case of negative verification). In the practice of the present invention, no pictorial representation is needed, thereby avoiding even the basis for a forgery attempt of the signature.

The signal that represents the information of the signature making is a time multivariable function of the force transmitted from the hand to the scriber and, in practice, is provided by sensors of pressure and acceleration or velocity along coordinate axes. It has been noted that the signals of the signatures of the same person appear to vary in time and suffer from time distortions. It is a premise of the present invention that the time distortions of signals must be eliminated prior to correlation function analysis to establish signal matching. This is accomplished by using a number of steps.

First of all, the to-be-compared and reference signatures, or other written data signals, are reduced to the same time scale to achieve the same average velocity of signing. In this case, the compared signals are considered on the same time scale for the scriber-media contact period.

Secondly, the time distortions related to the phase shifts are eliminated by using the "sliding window" method. As detailed herein, so called "sliding window" is used to localize time distortions. In order to understand the "sliding window" method, and without loss of generality, suppose we take a window of Δt_W size on the reference signal, and move that window along the to-be-verified signal for an appropriate interval, usually $\pm$ 15% of the window size, computing the cross-correlation function between the window and the corresponding part of the to-be-verified signal called "shadow" until the position of the maximum value of cross-correlation function is found. In the experiments detailed herein, a window of 0.5 sec. equal to 100 points of signal length was used, with a step of 0.05 sec. (10 points) length.

The cross-correlation function $W_j(\tau)$ is defined as follows:

$$W_j(\tau) = 1/\sqrt{(D_W * D_S)} * \sum_{j}^{j_w} v_W(t) * v_S(t+\tau),$$

where:

D_W and D_S are dispersions of a window and of its shadow , correspondingly;

$v_W(t)$ - value of the reference signal at the moment "t" taken on the current window W;

$v_s(t+\tau)$ - value of the to-be-verified signal at the moment "$t+\tau$" taken on the shadow;

$j_w=j+\Delta t_w-1$, where Δt_w is the window size;

$j=1,2,\ldots,n$, is the window number.

This unique method of sliding window makes it possible to establish the mapping between coincidental regions of the reference signal and of the to-be-verified signal in order to eliminate relative phase shifts between parts of the considered pair of signals.

Thus mapping is used as a procedure to establish correspondence between set of points of a reference signal and its counterpart on the to-be-verified signal with respect to phase distortions.

The mapping is done, for example, as follows. Each difference between shifts of two sequential windows is compensated by cutting out the number of points equal to this difference of the corresponding window or shadow. In the case of increasing shift, the corresponding piece of the signal is ignored on the to-be-verified signal, and in the case of decreasing shift, the corresponding piece of the reference signal is ignored. It is noted that sharp changes in the shift value indicate regions of time distortion.

Now, after compensation of both frequency and phase distortions, the correlation function analysis can be applied to the pair of stationary signals.

The cross-correlation function $\Phi(\tau)$ is evaluated as follows:

$$\Phi(\tau)=1/\sqrt{(D_r*D_s)}*\sum_{0}^{L} v_r(t+t_b)*v_s(t+\tau),$$

where:

D_r and D_s are dispersions of reference and to-be-verified signals, correspondingly;

$v_r(t+t_b)$ and $v_s(t+\tau)$ are centered reference and to-be-verified signals, correspondingly;

t_b and t_e are the parameters of reference signal vector.

$L=t_e-t_b$ is length of pre-processed reference signal.

Shown in FIG. 2 are two signatures 22 and 23 of the same person. The corresponding signals of these two signatures are shown in FIG. 4. The signals represent magnitudes of the scriber acceleration:

$$v(t)=\sqrt{[a_x(t)]^2+[a_y(t)]^2},$$

where

$a_x(t)$ and $a_y(t)$ are accelerations along axis X and Y, respectively.

Elimination of time distortions results in an essential increase of maximum value of cross-correlation function. For the signatures in FIG.4 it increases from 0.69 before elimination up to 0.92 after that. It is one of the premises of the present invention that the elimination of such time distortions provides an essential improvement in the level of verification reliability.

The sliding window technique of the present invention provides a powerful method for signature verification, as well as for forgery detection and rejection. FIGS. 6a and 6b show the shift of sliding window relatively to its shadow as a functions of the window number for the pair of authentic signatures and for the pair of authentic and a corresponding free hand forgery.

The oscillating character of the graph in FIG. 6b compared to the flat graph in 6a shows that the signals from the signatures of the authentic person and the forger have absolutely different dynamics. FIG. 6c, where the both graphs 6a, and 6b are plotted in the same shift scale exposes clearly this difference.

This visual perception can be easily formalized by computing a histogram of the first order differences normalized to the window step, which characterizes quantitatively differences of shifts for each pair of adjoined windows as follows:

$$\Delta\tau_{max}=1/\Delta t_{wstep}*[\tau_{max}(j+1)-\tau_{max}(j)],$$

where:

$\tau_{max}(j)$ - shift of window j at which its shadow is found;

Δt_{wstep} - window step.

For the pair of authentic signatures of the same signer, the histogram, in FIG. 7a shows that about 90% of all $\Delta\tau_{max}$ concentrate in the very narrow interval, around zero or neighborhood:

$$-3 \leq \Delta\tau \leq +3$$

For the case of the forgery, the histogram shown in FIG. 7b has a relatively spread character with less than 20% of all $\Delta\tau_{max}$ concentrated in the zero neighborhood. It is thus shown that the portion of $\Delta\tau_{max}$ values in the zero neighborhood is a criterion referred to as Cr_2, and can be used as a measure for establishing authenticity of a signature or other written material by comparing it with a predetermined threshold value.

Another powerful criterion for forgery detection which is provided by the sliding window technique of the present invention is a measure of conformity between the window phase shifts for the different vector components of the signal pair. That is, the relative window phase shifts should conform with each other for two different vector components of signature signals, say for acceleration along axis X and acceleration along axis Y.

As it is known in the art, the true signature and the forgery, being very similar in pictorial representation, differ significantly in thickness of the signed lines which reflects considerably different dynamics with respect to differences in horizontal and vertical movements in the case of true signature making and forgery making. This information is partially used by experts for visual examination of signature authenticity. The present invention utilizes this dynamic information in full and guarantees by then the reliable examination of signature authenticity. These differences become easily apparent by using the conformity measure between the window phase shifts for different components of the signal vector. In the case of the comparison of two authentic signatures, given for instance accelerations along axes X and Y, the graphs of phase shift differences along axes X and Y mostly coincide, see FIG. 8a while for the pair of authentic and forged signatures, the graph demonstrates essential and chaotic differences, see, FIG. 8b. FIG. 8c shows both graphs in the same scale.

The histogram which is used as a part of verification algorithm represents the distribution of differences of the window shift along axes X and Y:

$$[\Delta\tau^{xy}]_{max}=[\tau^{x}]_{max}-[\tau^{y}]_{max}$$

where:

$[\tau^{x}]_{max}$ is a shift of a window at which its shadow is found for X component of vector;

$[\tau^{y}]_{max}$ is a shift of a window at which its shadow is found for Y component of vector.

Here, the present invention exploits the fact that time distortions identified by the sliding window method should coincide with each other along all the axes the signature signals of the same person a represented, and would be expected to differ significantly in the case of forgery. There is a high rate coincidence, the typical histogram is shown in FIG. 9a, which is again characterized by high density of $[\Delta\tau^{xy}]_{max}$ in the zero neighborhood . In this region, there are about 95% of all the shifts for the pair of authentic signatures. By comparison, for a forgery, there is less than 4% of shift coincidence for the pair of authentic and forged signatures, as shown in FIG.9b.

The histogram for shift differences provides another criterion that referred to as Cr_3, which measures the portion of shift differences between any pair of axes in the zero neighborhood, Cr_3 is used as another measure for establishing signature authenticity by comparing it with the corresponding threshold value.

Criteria Cr_2 and Cr_3, which are based on two kinds of shift histograms, and the cross-correlation function criterion applied to the pair of indivisible reference and to-be-verified signature signals pre-processed to a stationary pair with the frequency and the phase coincidence represent two faces of signature verification algorithm.

Analysis of the histograms for $\Delta\tau_{max}$ and for $[\Delta\tau^{xy}]_{max}$ and the cross-correlation function analysis can be implemented sequentially as a system of implications, or in parallel as a conjunction of the conditions, for different applications.

In both cases, whether a parallel or sequential approach is used, signature verification is positive when an assigned combination of the criteria is satisfied. Otherwise verification is negative and authenticity of the signer is rejected.

In addition to use of correlation analysis for single signal components we exploit correlation function determination applied for multidimensional random signals as well.

In this case, cross-correlation function for two random signals with components $x_r(t)$, $y_r(t)$, $z_r(t)$ for reference signature signals, and $x_s(t)$, $y_s(t)$, $z_s(t)$ components for the to-be-verified signature signals is represented by square cross-correlation matrix K_{rs}:

$$K_{rs} = \begin{matrix} K_{xx} & K_{xy} & K_{xz} \\ K_{yx} & K_{yy} & K_{yz} \\ K_{zx} & K_{zy} & K_{zz} \end{matrix}$$

where K_{ij} is a cross-correlation function evaluated for "i" component of the reference vector and "j" component of the to-be-verified vector, and i = x,y,z ; j = x,y,z.

This functional matrix is reduced to the numerical one by substituting each function by its maximum value. A choice of a norm of the matrix or a trace of the matrix is allowed as a similarity measure to establish authenticity of the signature. The to-be-verified signature is accepted or rejected depending on the similarity measure is over or under the appropriate threshold.

While the invention has been particularly shown, described and illustrated in detail with reference to preferred embodiments and modifications thereof, it should be understood by those skilled in art that the foregoing and other modifications are exemplary only, and that equivalent changes in form and detail may be made therein without departing from the true spirit and scope of the invention as claimed, except as precluded by the prior art.

CLAIMS:

1. Apparatus for use in on-line handwritten data verification using movement dynamics of a scriber in a hand of a writer while recording reference and a to-be-verified data signals in accordance with one or more selected threshold values, the apparatus comprising:

a. a scriber;

b. means for gathering a set of reference and to-be-verified analog dynamic signals related to movement of the scriber during a process of reference data making and during a process of to-be-verified data making, such signals being selected from the group consisting of forces transmitted from the hand of the writer to the scriber, including a longitudinal force applied along the scriber to a writing surface, scriber acceleration, scriber velocity, and mixtures thereof, all said signals being measured or calculated as a function of time;

c. means for converting the reference and to-be-verified analog dynamic signals from analog to digital form;

d. means for storing the resulting reference digital signals in a file of reference digital signals;

e. means for providing a data pair composed of the digital data of the to-be-verified signal and the digital data of one of the reference file signals;

f. means for processing the data pair of digital signals to eliminate phase shifts which are time distortions between them, utilizing the steps of:

i. using a sliding window to find the phase shifts, and thereby establishing a mapping between phase coincident areas of the reference digital signal and of the to-be-verified digital signal, wherein each phase shift represents a difference in positioning of the sliding window and a shadow of the sliding window in a time scale, and wherein the sliding window is a piece of one of the reference digital signal and the to-be-verified digital signal which is moved along the one of the reference digital signal and the to-be-verified digital signal with a predetermined step of a size which is less than a size of the window, and which is used to find for each window the shadow, the shadow being a corresponding piece of the other of the reference digital signal and the to-be-verified digital signal having a maximum value of a cross-correlation function with the window;

ii. eliminating the phase shifts between the reference digital signal and the to-be-verified digital signal by the use of the mapping procedure of step f.i.;

iii. differentiating differences in positioning of windows and their shadows along one axis with respect to the counterpart differences along another axis;

g. means for determining a statistical similarity of the pair of reference and to-be-verified data using a criterion Cr.1 only, or combined with a criterion Cr.2 or a criterion Cr.3, or with both, wherein Cr_1 is determined by:

i. evaluating a cross-correlation matrix K_{rs} based on data from step f.ii., with each element representing a maximum value of the corresponding cross-correlation function for each pair of X, Y and Z components of digital signal vectors

$$K_{rs} = \begin{matrix} K_{xx} & K_{xy} & K_{xz} \\ K_{yx} & K_{yy} & K_{yz} \\ K_{zx} & K_{zy} & K_{zz} \end{matrix} ;$$

ii. producing a measure from the matrix, said measure being produced using a method selected from a method of calculating a norm of the matrix and a method of calculating a trace of the matrix;

iii. comparing the measure as determined in previous step g.ii., with an appropriate threshold in order to produce a non-rejection or rejection signal of an authenticity of the to-be-verified data, as the criterion Cr_1; wherein Cr_2 is determined by:

iv. determining distribution of phase shifts for windows by constructing a histogram of the first order shift differences between positions of windows and their shadows obtained from the application of the sliding window method in step f.i.;

v. utilizing said first order shift differences histogram to produce a measure which characterizes the portion of the first order shift differences in a zero neighbourhood, which is determined as a narrow time interval including a few data samples;

vi. comparing the measure determined in previous step v. with an appropriate threshold in order to produce a signal of non-rejection or rejection of authenticity of the to-be-verified data as the criterion Cr_2; wherein Cr_3 is determined by:

vii. determining coincidence of phase shifts for two different components of the data signal vectors pairs chosen from X, Y and Z by constructing a histogram of the shift differences obtained from the application of sliding window means in step f.iii;

viii. utilizing said shift differences histogram to produce a measure which characterizes the portion of the shift differences for the two considered vector components of the data signal which values are in the zero neighbourhood, which is determined as a narrow time interval including a few data samples;

ix. comparing the measure determined in previous step viii. with an appropriate threshold in order to produce a signal of non-rejection or rejection of authenticity of the to-be-verified data as the criterion Cr_3; and

h. means for using the determination of statistical similarity of signals from g., to produce a signal of approval or rejection of the authenticity of the to-be-verified data.

2. A machine method of on-line handwritten data verification using movement dynamics of a scriber in a hand of a writer while recording a reference data and a to-be-verified data in accordance with one or more selected threshold values, including the steps of:

a. gathering a set of analog dynamic reference signals related to movement of the scriber for producing handwritten reference data during a process of reference data making, such signals being selected from the group consisting of forces transmitted from the hand of the writer to the scriber, including a longitudinal force applied along the scriber to a writing surface, scriber acceleration, scriber velocity, and mixtures thereof, all said signals being measured or calculated as functions of time;

b. converting the reference analog dynamic signals from analog to digital form, and storing the resulting reference digital signals in a file of reference digital signals for retrieval therefrom;

c. gathering a set of to-be-verified analog dynamic data signals related to movement of said scriber during the process of to-be-verified data making, such signals to be selected from the group consisting of forces transmitted from the hand of the writer to the scriber, including a force applied along the scriber body to the writing surface, scriber acceleration, scriber velocity, and mixtures thereof, all said signals being measured or calculated as functions of time;

d. converting the to-be-verified analog dynamic data signals to digital form;

e. providing a pair of digital signals, said digital signal pair being composed of the to-be-verified digital signal and one of the reference digital signals taken from the reference signal file;

f. processing the pair of digital signals to eliminate time distortions between them, utilizing the steps of:

i. using a sliding window to find the phase shifts, and thereby establishing a mapping between phase coincident areas of the reference digital signal and of the to-be-verified digital signal, wherein the phase shifts represent a difference in positioning of the sliding window and a shadow of the sliding window in a time scale, and wherein the sliding window is a piece of one of the reference digital signal and the to-be-verified digital signal which is moved along the one of the reference digital signal and the to-be-verified digital signal with a predetermined step of a size which is less than a size of the window, and which is used to find for each window the shadow, the shadow being a corresponding piece of the other of the reference digital signal and the to-be-verified digital signal having a maximum value of a cross-correlation function with the window;

ii. eliminating the phase shifts between the reference digital signal and the to-be-verified digital signal by the use of the mapping procedure of step f.i.;

iii. differentiating differences in positioning of said windows and their shadows along one axis with respect to the counterpart differences along another axis;

g. determining a statistical similarity of the pair of reference and to-be-verified data using a criterion Cr.1 only, or combined with a criterion Cr.2 or a criterion Cr.3, or with both, wherein Cr_1 is determined by:

i. evaluating a cross-correlation matrix K_{rs} based on data from step f.ii., with each element representing a maximum value of the corresponding cross-correlation function for each pair of X, Y and Z components of digital signal vectors:

$$K_{rs} = \begin{matrix} K_{xx} & K_{xy} & K_{xz} \\ K_{yx} & K_{yy} & K_{yz} \\ K_{zx} & K_{zy} & K_{zz} \end{matrix} \;;$$

ii. producing a measure from the matrix, said measure being produced using a method selected from a method of calculating a norm of the matrix and a method of calculating a trace of the matrix;

iii. comparing the measure as determined by previous step g.ii. with an appropriate threshold in order to produce a signal of non-rejection or rejection of an authenticity of the to-be-verified data, as the criterion Cr_1; wherein Cr_2 is determined by:

iv. determining distribution of phase shifts for windows by constructing a histogram of the first order shift differences between positions of windows and their shadows obtained from the application of the sliding window method in step f.i.;

v. utilizing said first order shift differences histogram to produce a measure which characterizes the portion of the first order shift differences in a predefined zero neighbourhood, which is determined as a narrow time interval including a few data sample;

vi. using the measure determined in previous step v. and comparing it with an appropriate threshold in order to produce a signal of non-rejection or rejection of authenticity of the to-be-verified data, as the criterion Cr_2; wherein Cr_3 is determined by:

vii. determining coincidence of phase shifts for pairs of the different components of the data signal vectors: X, Y and Z by constructing a histogram of the shift differences obtained from the application of the sliding window method in step f.iii.;

viii. utilizing said shift differences histogram to produce a measure which characterizes the portion of the shift differences in the predefined zero neighbourhood, which is determined as a narrow time interval including a few data samples;

ix. comparing the measure determined in previous step viii. with an appropriate threshold in order to produce a signal of non-rejection or rejection of authenticity of the to-be-verified data as the criterion Cr_3; and then

h. using the determination of statistical similarity of signals from g. to produce a signal of approval or rejection of the authenticity of the to-be-verified data.

3. The method of claim 2 wherein the correlation analysis utilizes a sub-matrix in step g.i. of criterion Cr_1.

4. The method of claim 2 wherein the information in said matrix is utilized in step g.ii. of criterion Cr_1 to determine a trace of the matrix.

5. The method of claim 2 wherein the information in said matrix is utilized in step g.ii. of criterion Cr_1 to determine a norm of the matrix.

6. The method of claim 2 wherein determination of the statistical similarity of signal data is based on evaluation of cross-correlation function for a selected component of the data signals.

7. The method of claim 2 wherein correlation analysis is utilized by evaluating cross-correlation function for a magnitude of selected components of the data signals.

8. The method of claim 2 wherein the verification result of step g. is computed by determining a conjunction of measures Cr_1, Cr_2 and Cr_3.

2157368

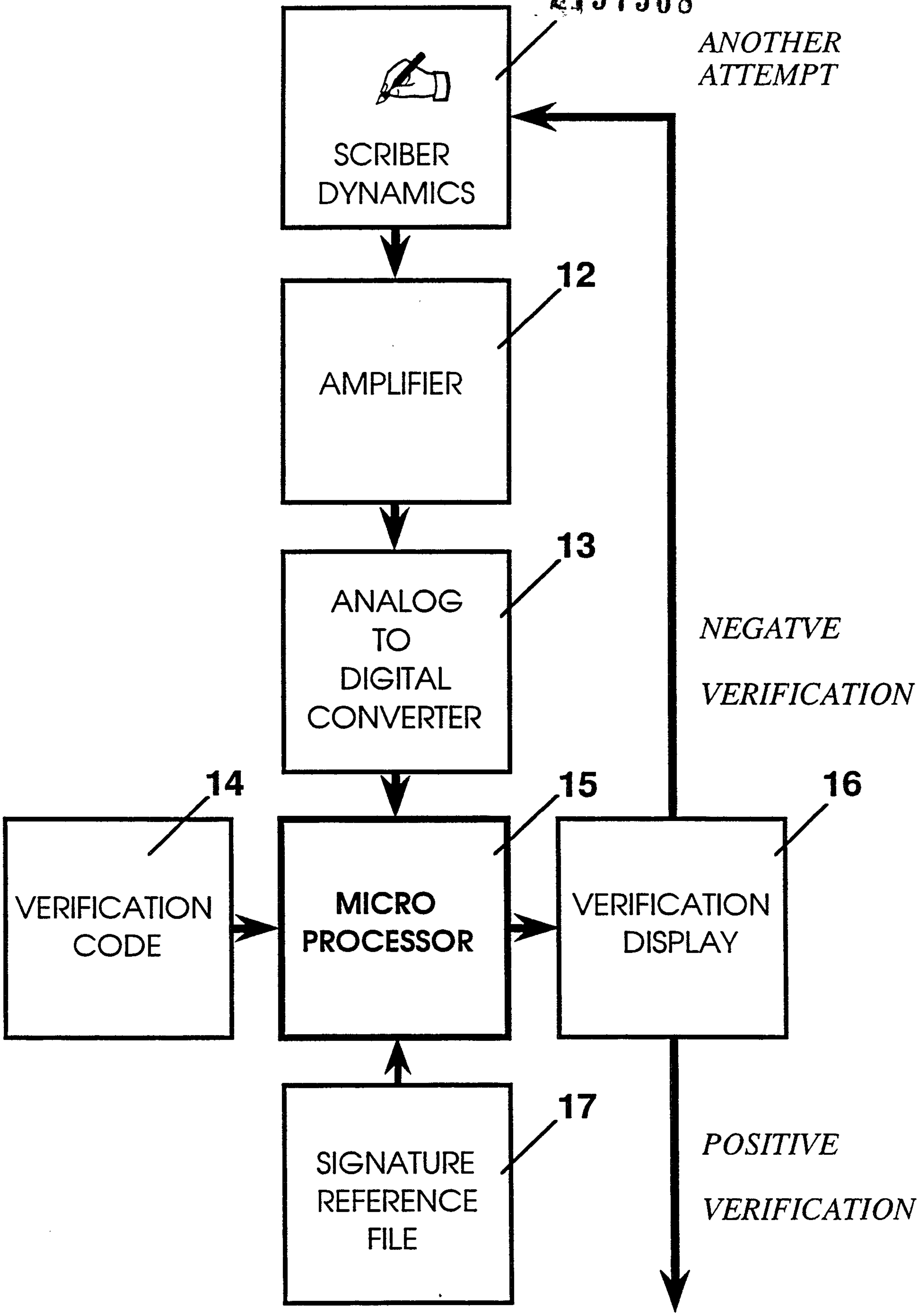


Fig. 1

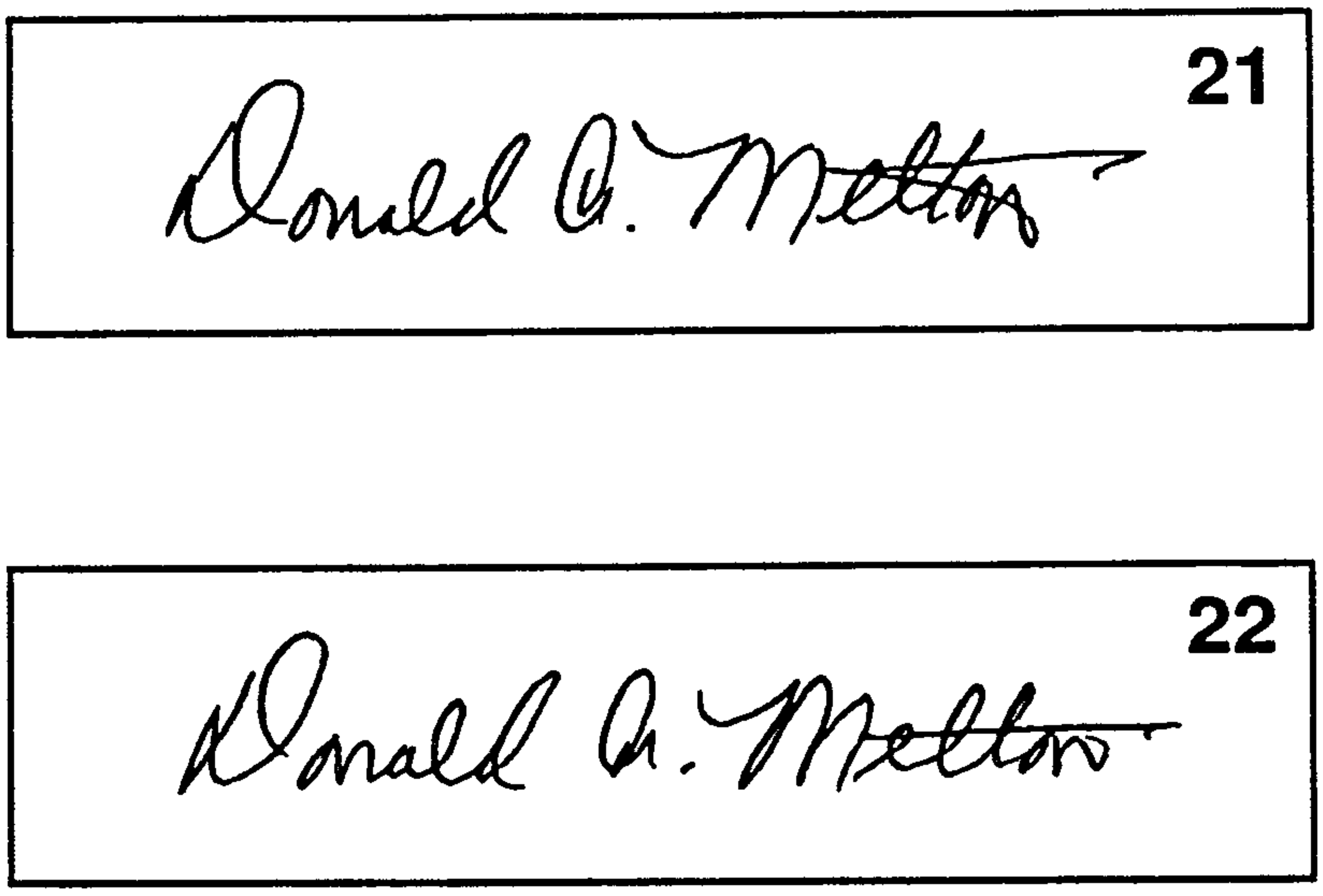


Fig. 2

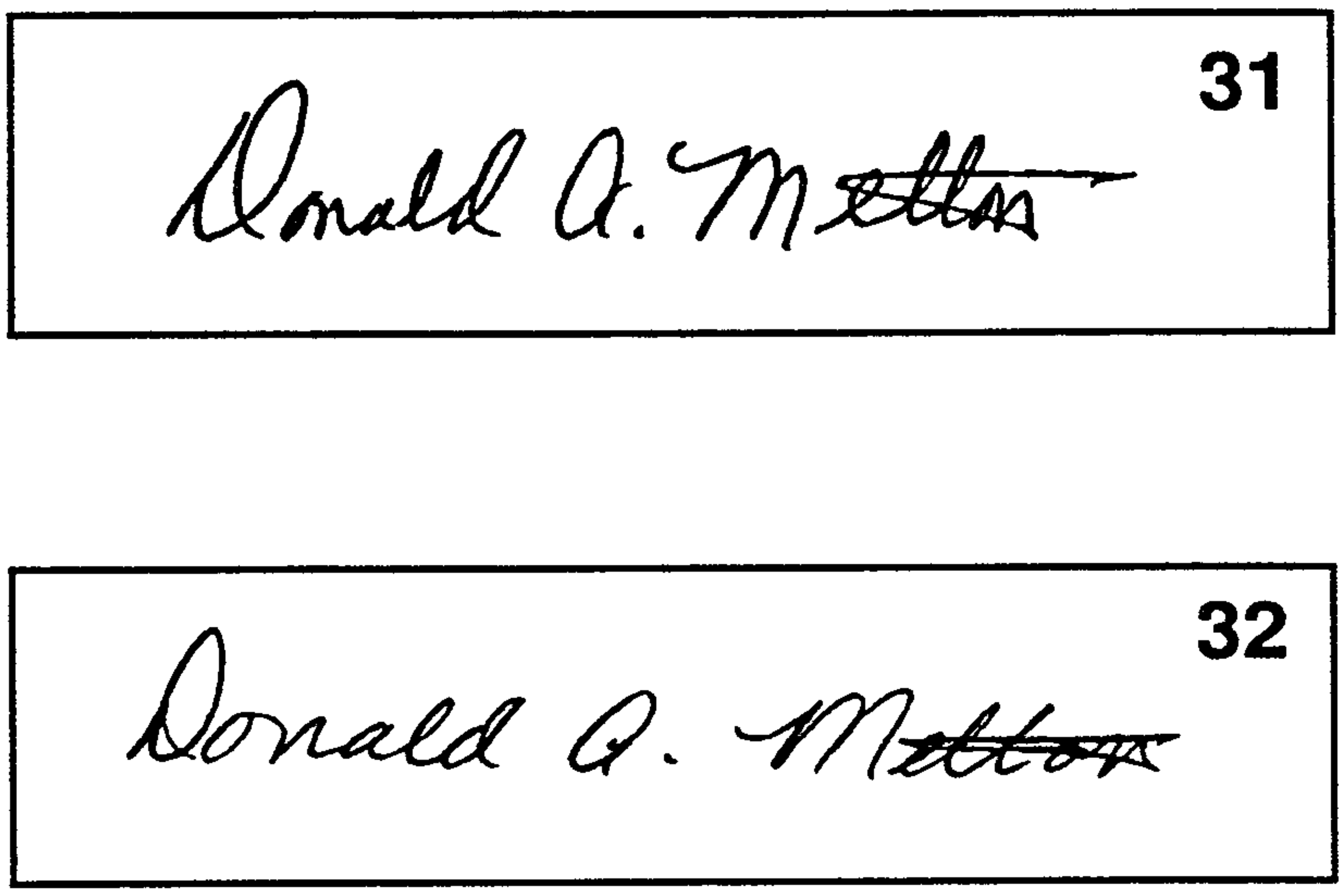


Fig. 3

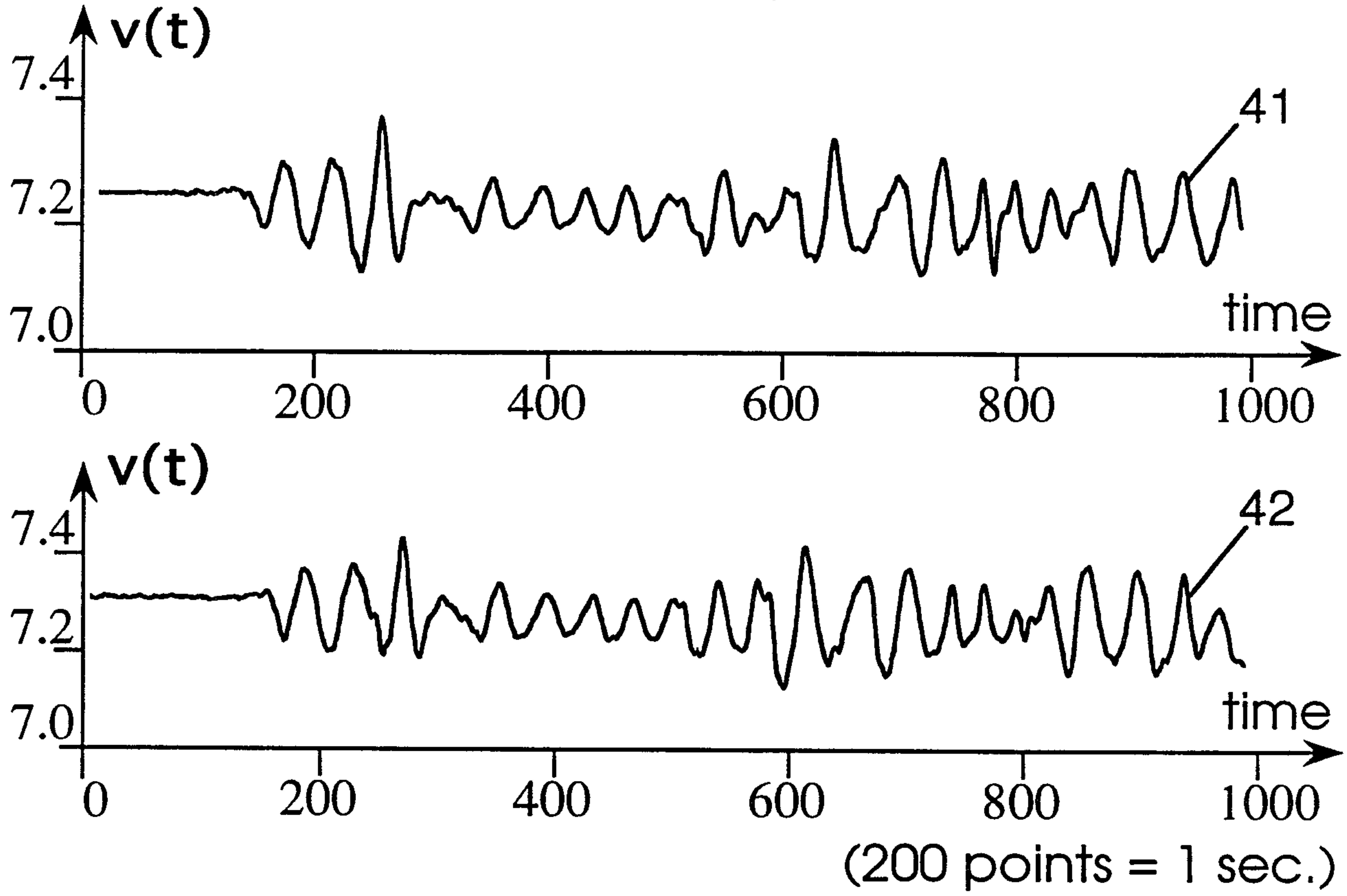

v(t)
7.4
7.2
7.0
41
time
0
200
400
600
800
1000
v(t)
7.4
7.2
7.0
42
time
0
200
400
600
800
1000
(200 points = 1 sec.)

Fig. 4

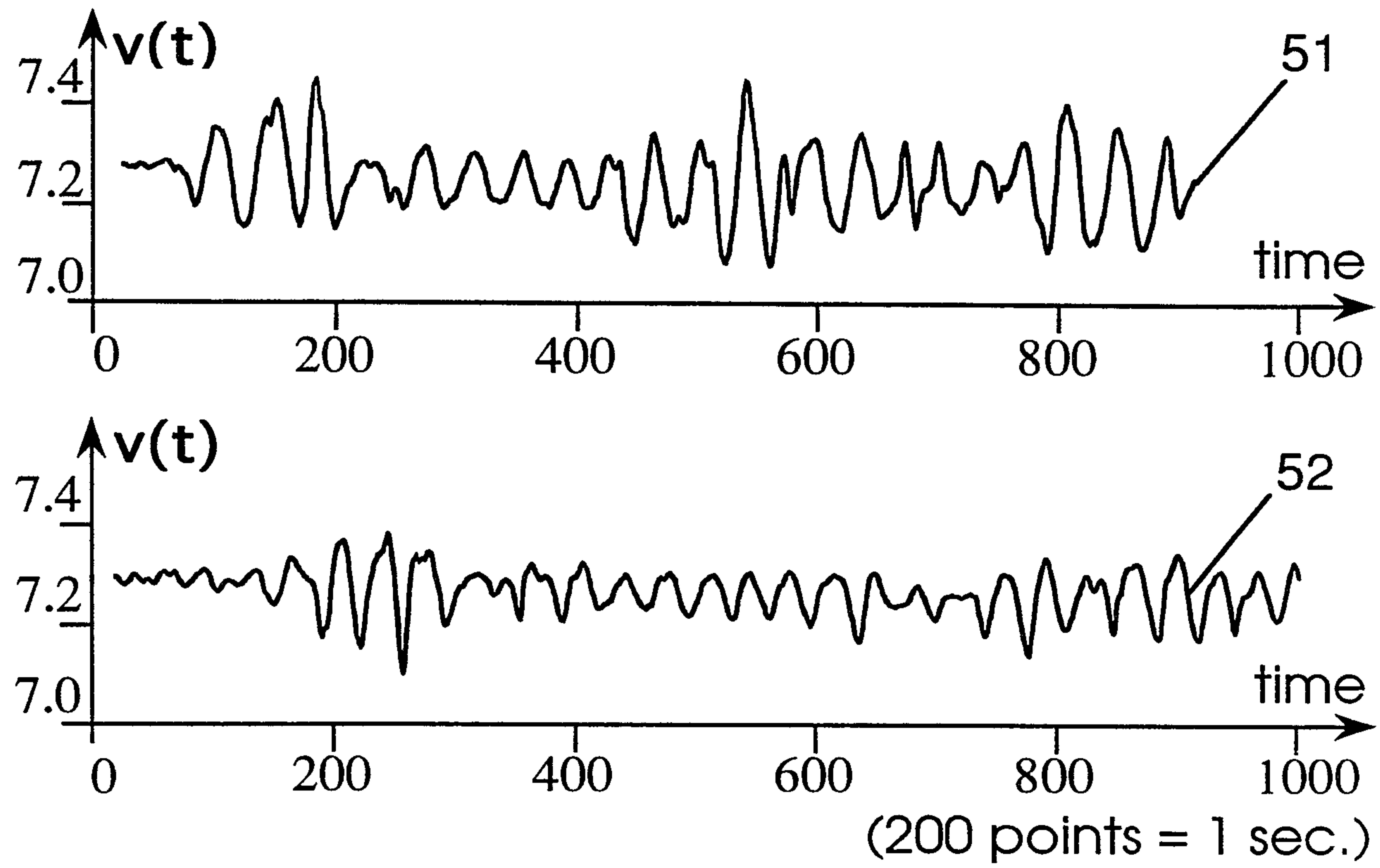

v(t)
7.4
7.2
7.0
51
time
0
200
400
600
800
1000
v(t)
7.4
7.2
7.0
52
time
0
200
400
600
800
1000
(200 points = 1 sec.)

Fig. 5

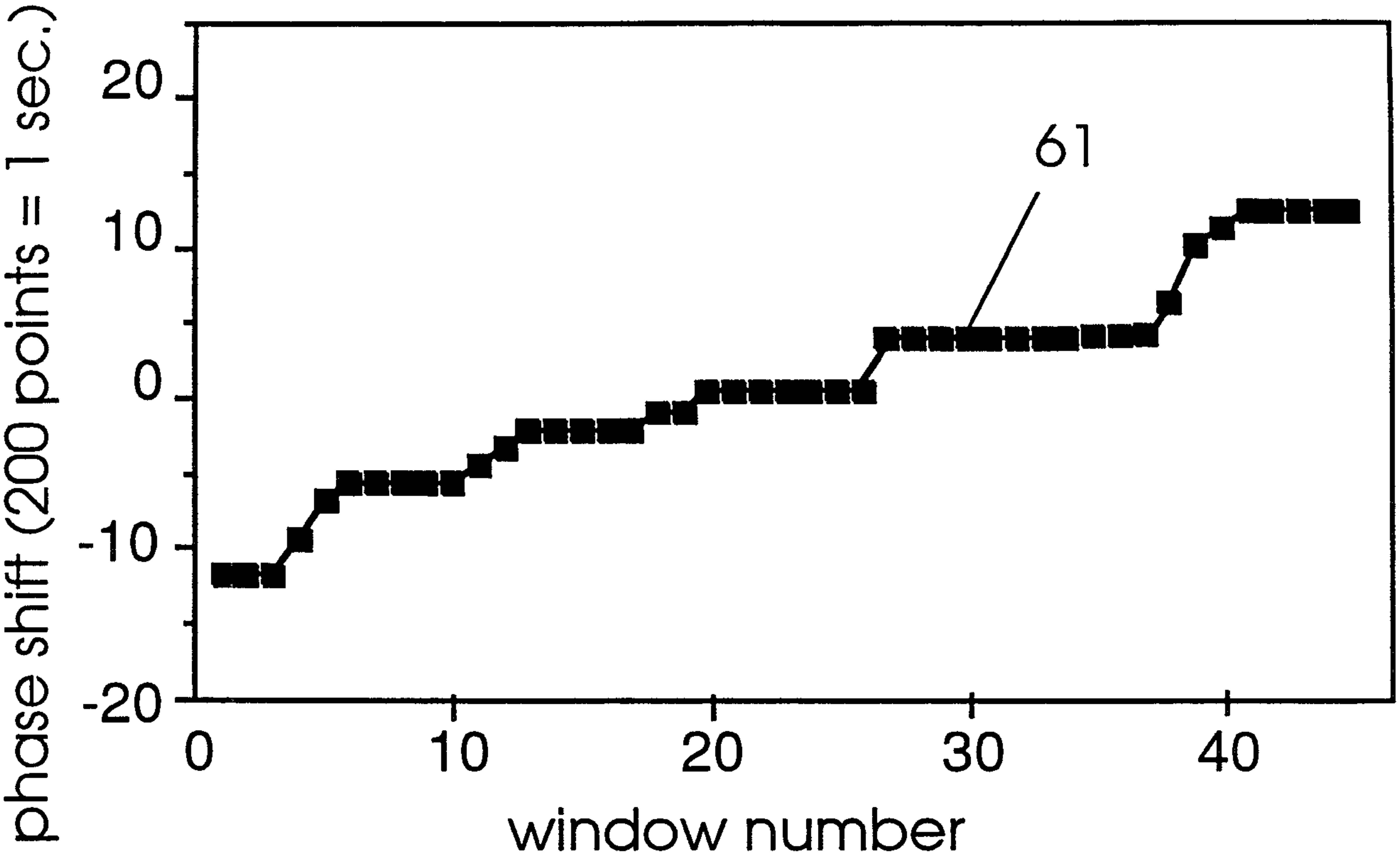

phase shift (200 points = 1 sec.)
20
10
0
-10
-20
0
10
20
30
40
window number
61

Fig. 6a

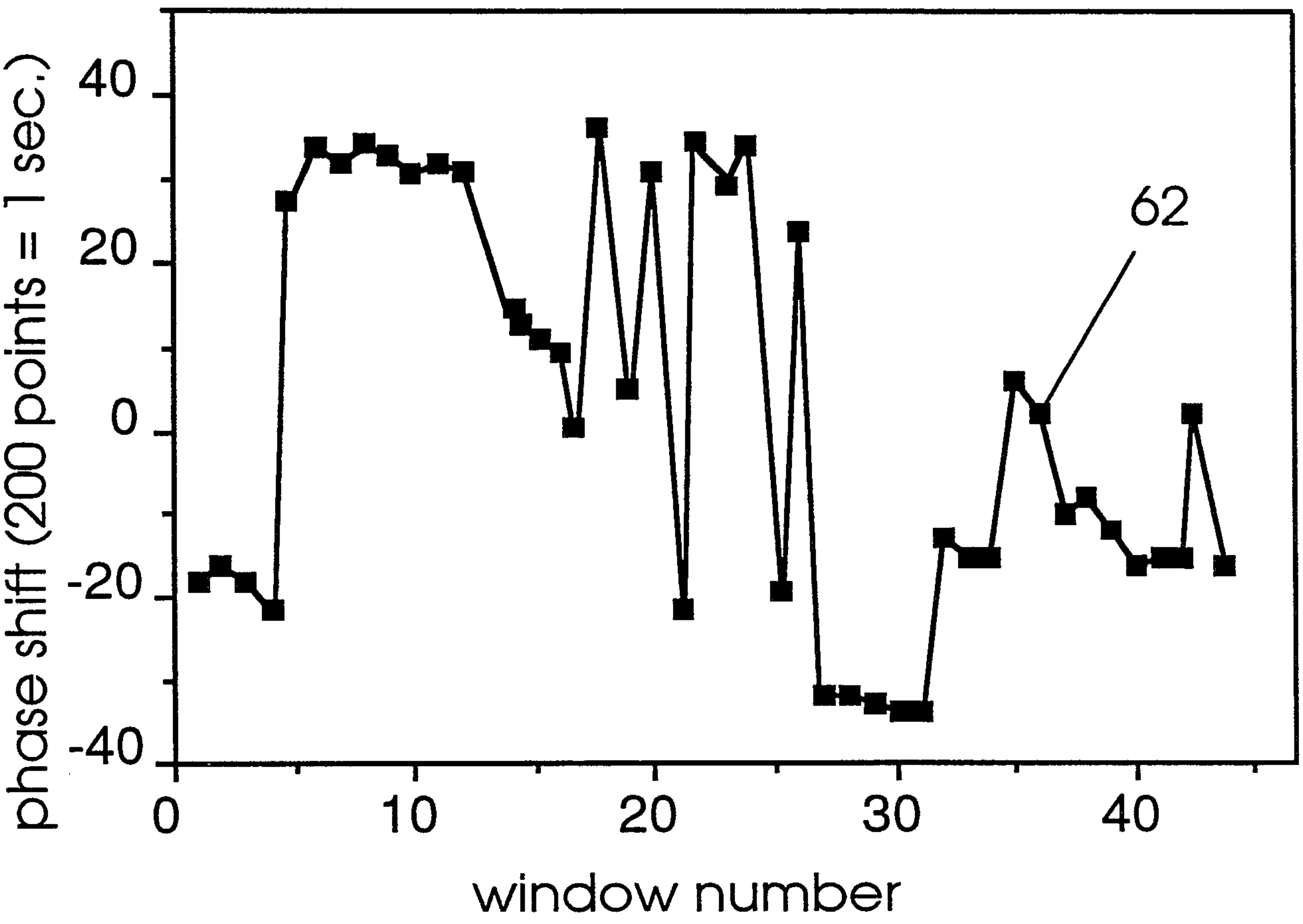

phase shift (200 points = 1 sec.)
40
20
0
-20
-40
0
10
20
30
40
window number
62

Fig. 6b

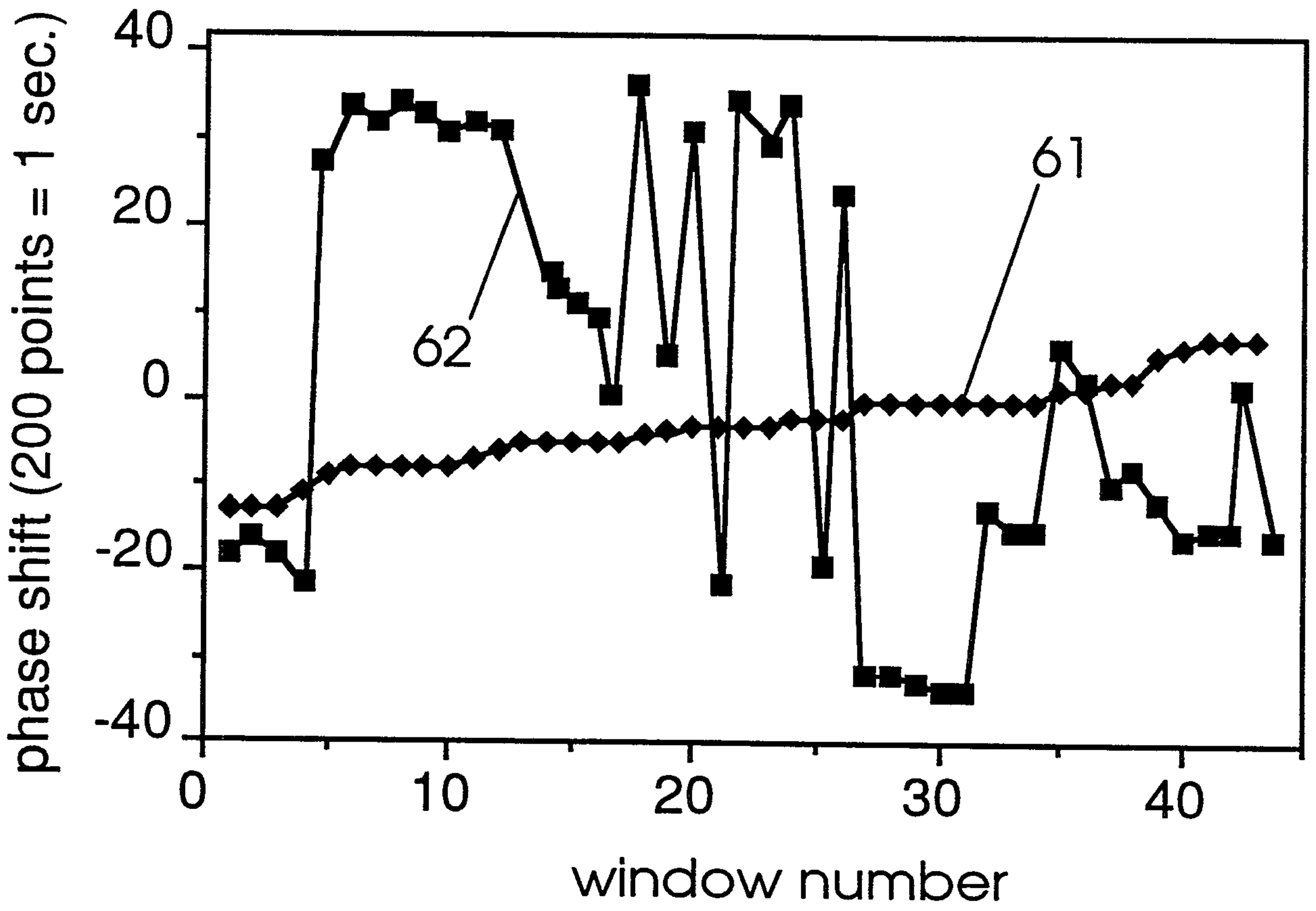

phase shift (200 points = 1 sec.)
40
20
0
-20
-40
0
10
20
30
40
window number
61
62

Fig. 6c

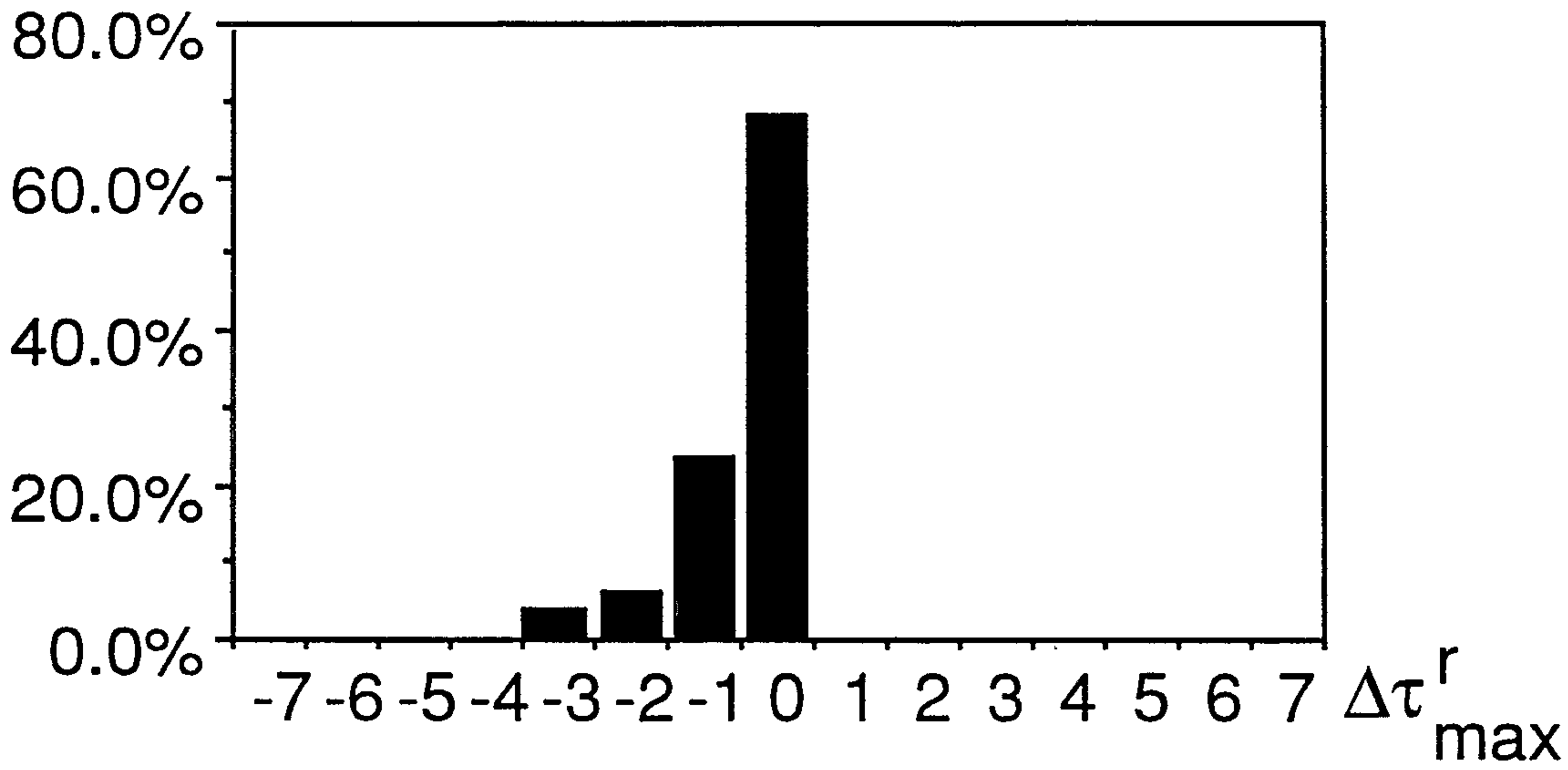

80.0%
60.0%
40.0%
20.0%
0.0%
-7 -6 -5 -4 -3 -2 -1 0 1 2 3 4 5 6 7 $\Delta\tau^{r}_{max}$

Fig. 7a

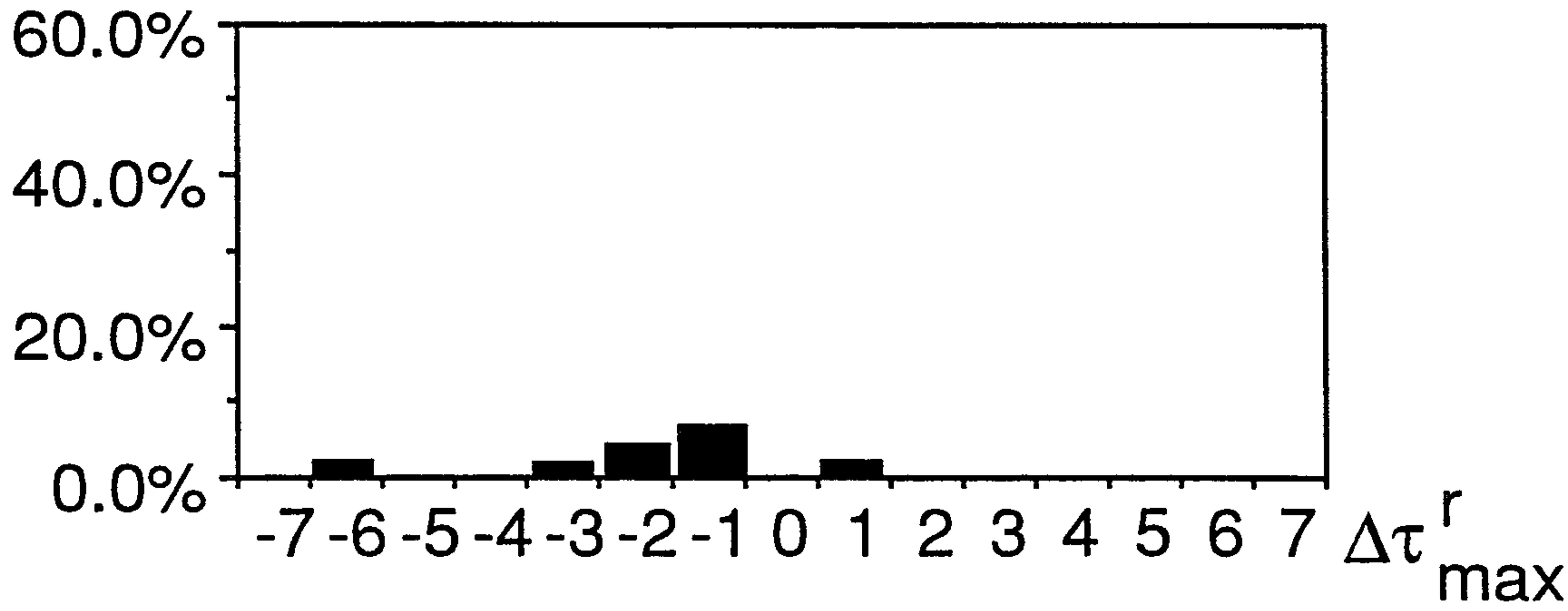
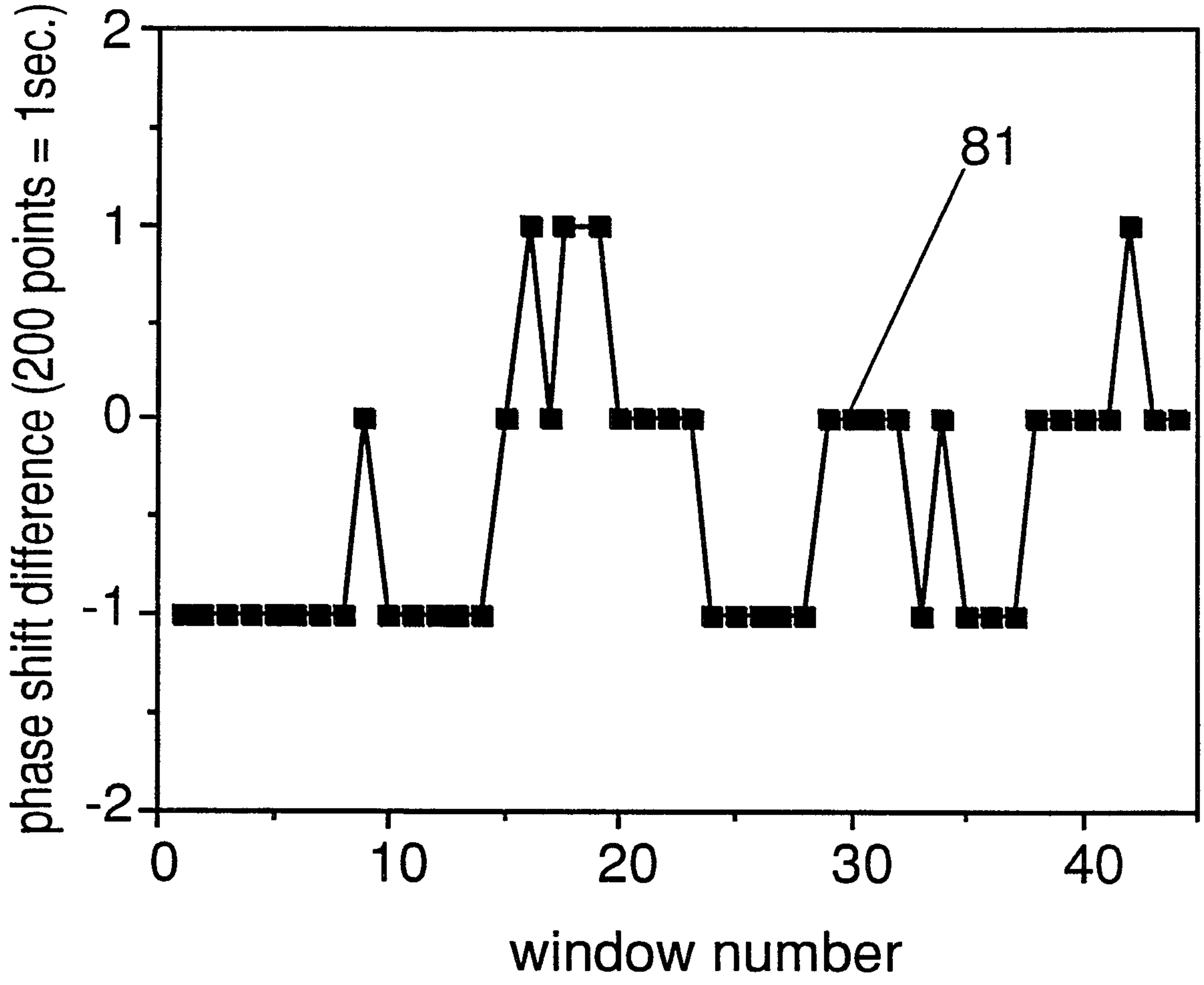

60.0%
40.0%
20.0%
0.0%
-7 -6 -5 -4 -3 -2 -1 0 1 2 3 4 5 6 7 $\Delta\tau^{r}_{max}$

Fig. 7b



phase shift difference (200 points = 1sec.)
2
1
0
-1
-2
81
0
10
20
30
40
window number

Fig. 8a

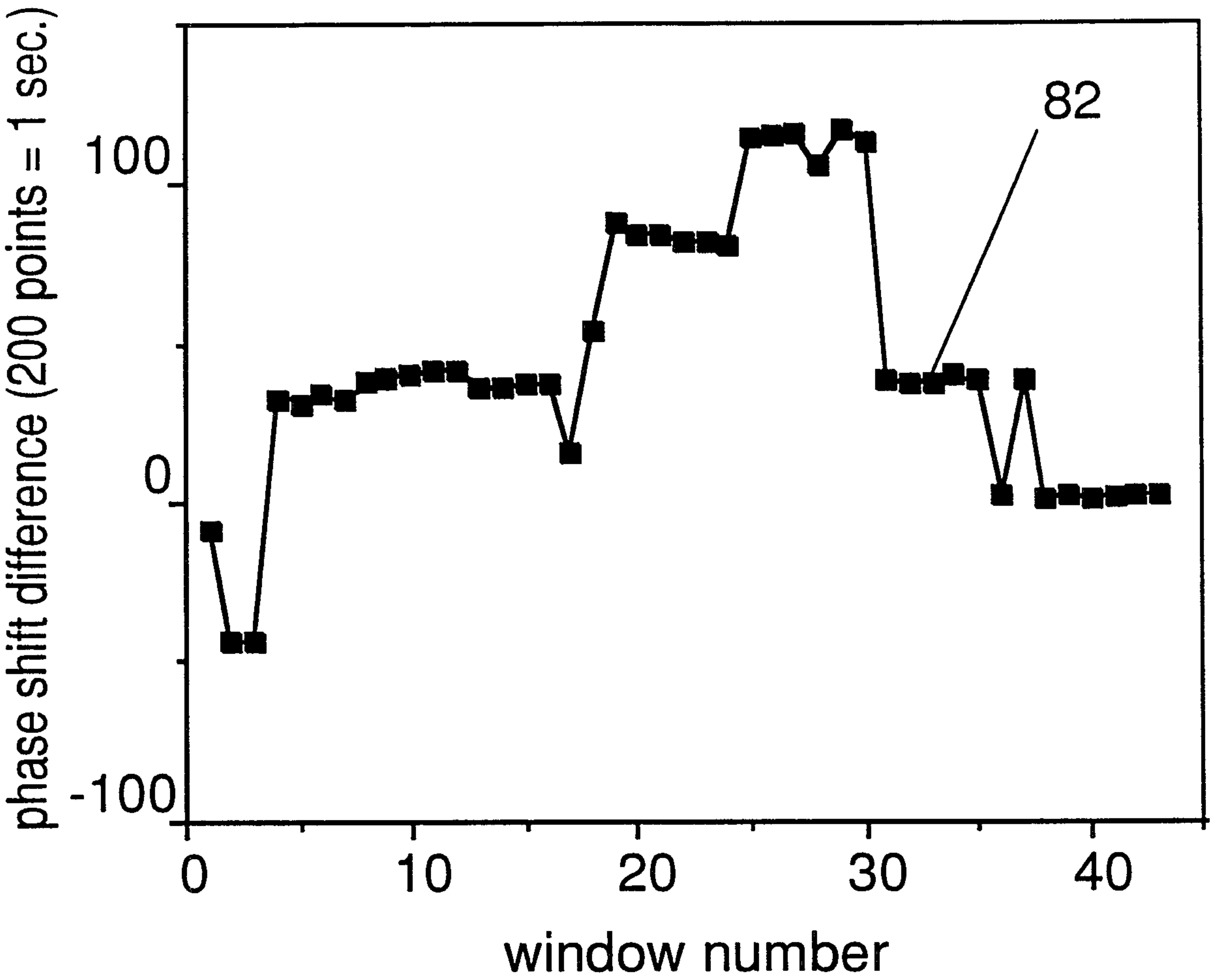

82
100
0
-100
phase shift difference (200 points = 1 sec.)
0
10
20
30
40
window number

Fig. 8b

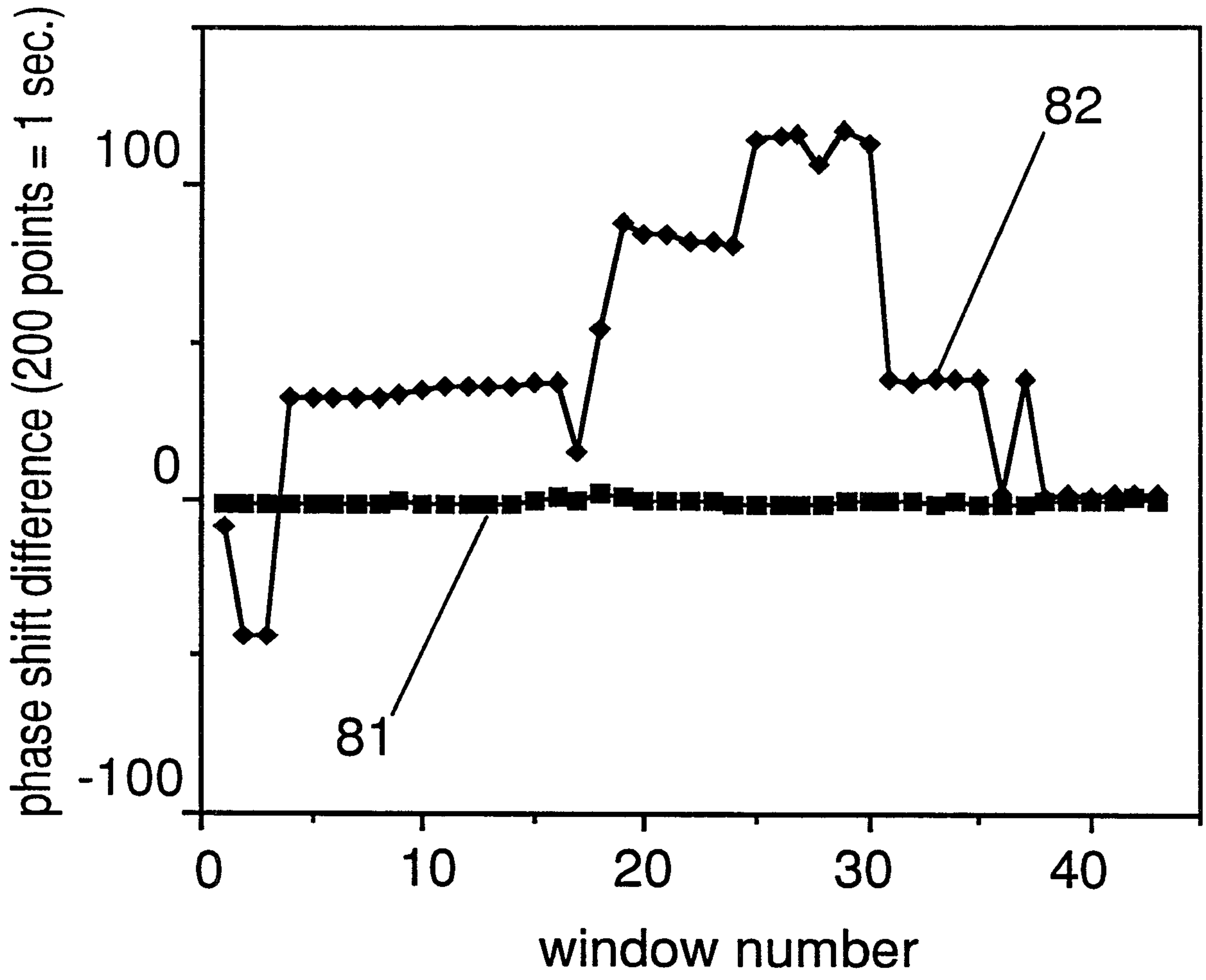

phase shift difference (200 points = 1 sec.)
100
0
-100
0
10
20
30
40
window number
82
81

Fig. 8c

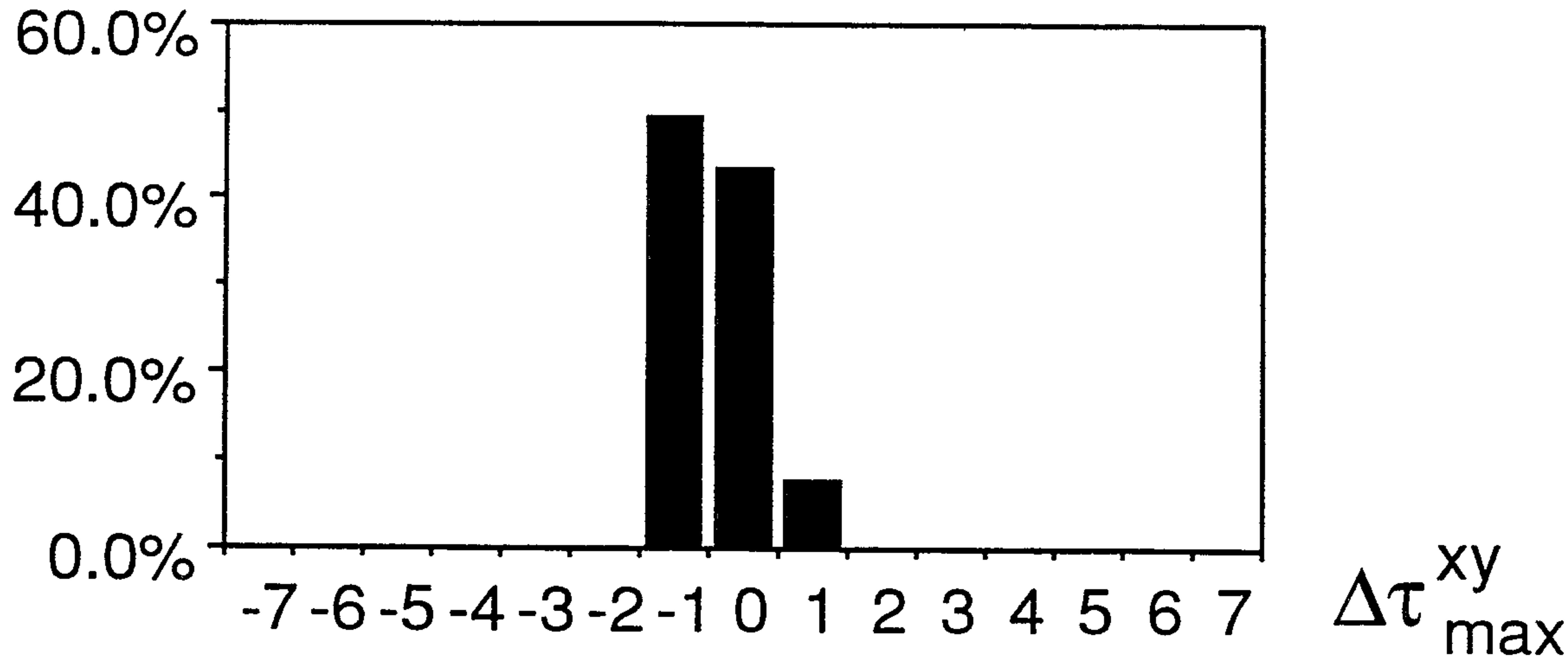

60.0%
40.0%
20.0%
0.0%
-7 -6 -5 -4 -3 -2 -1 0 1 2 3 4 5 6 7
$\Delta\tau^{xy}_{max}$

Fig. 9a

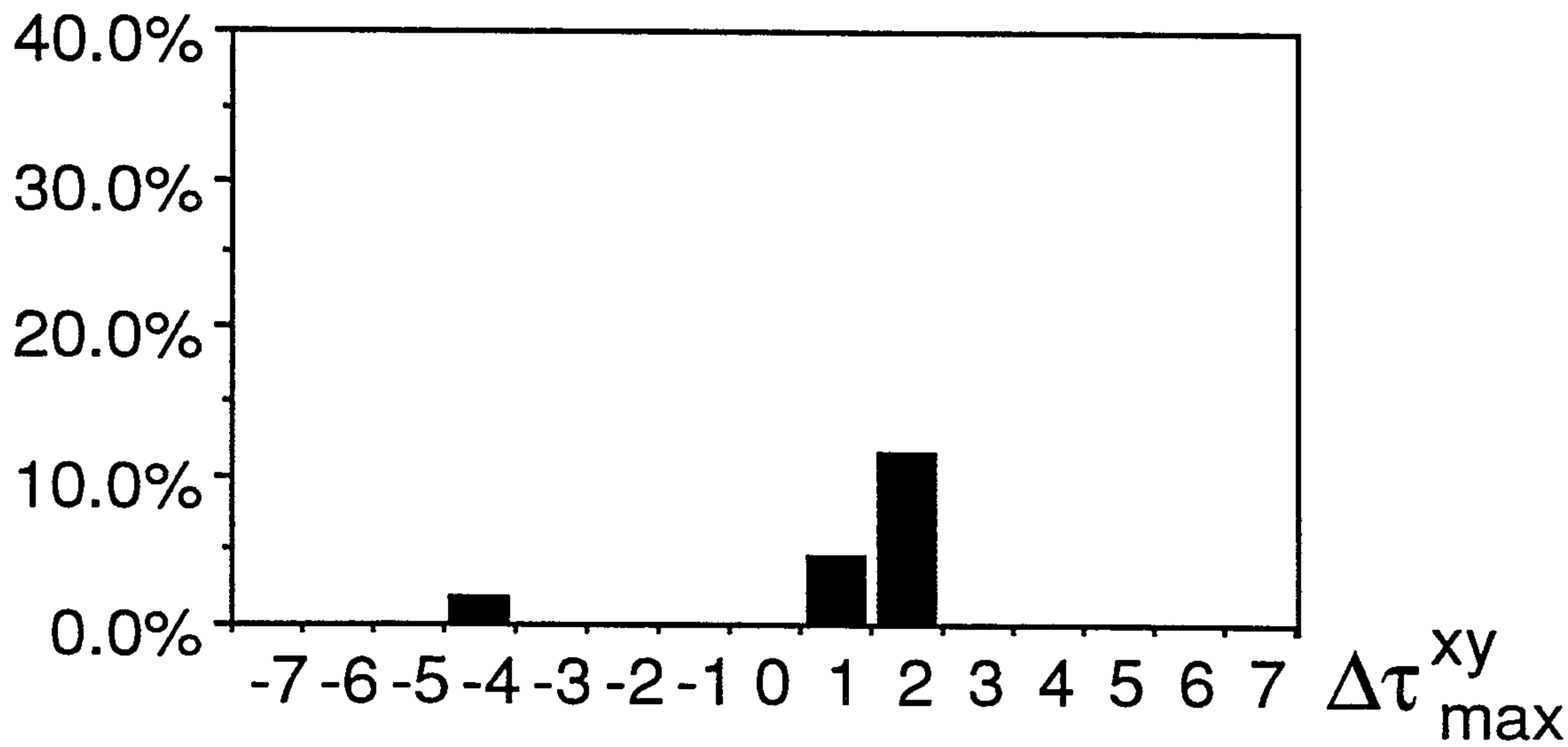
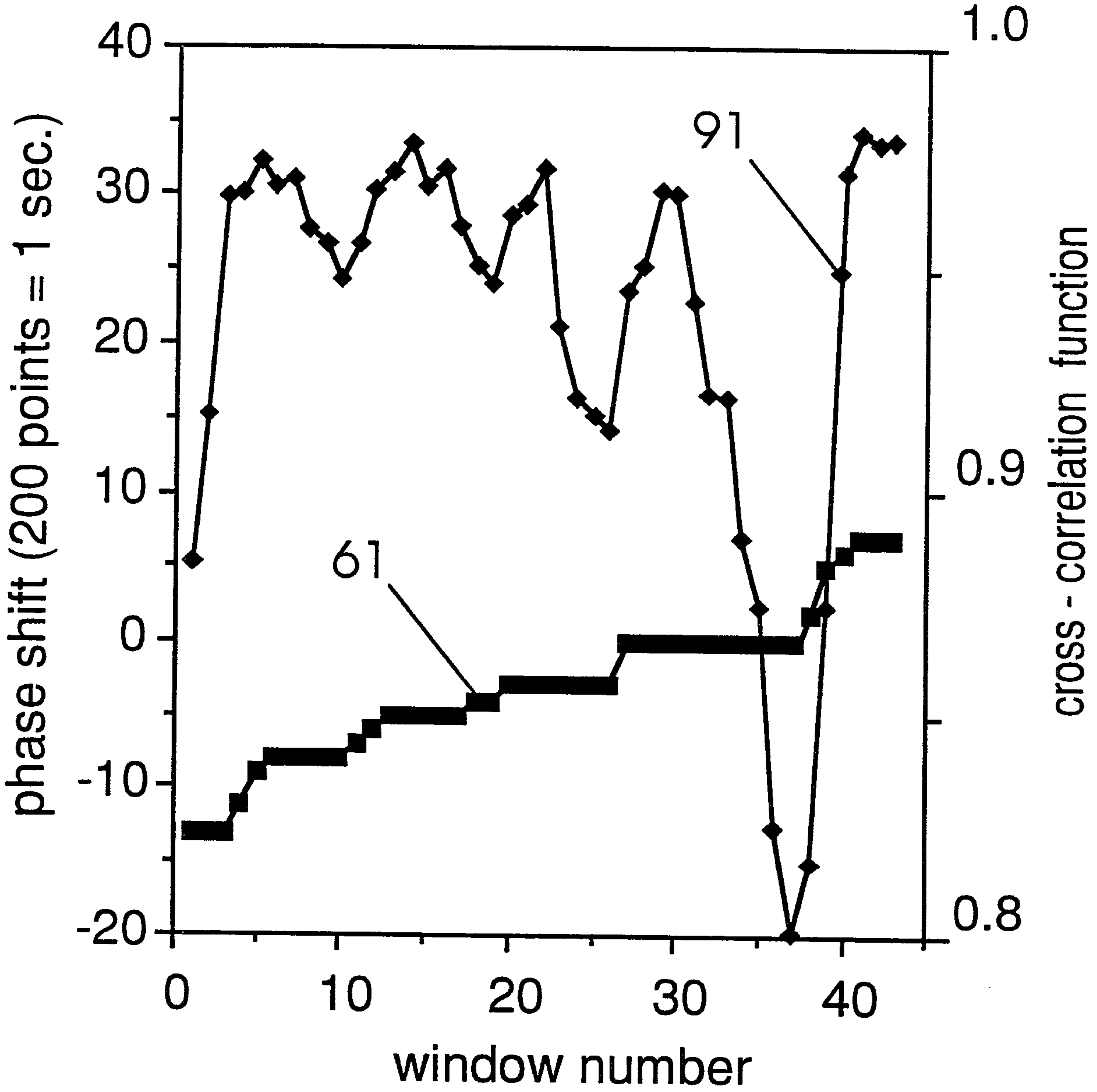
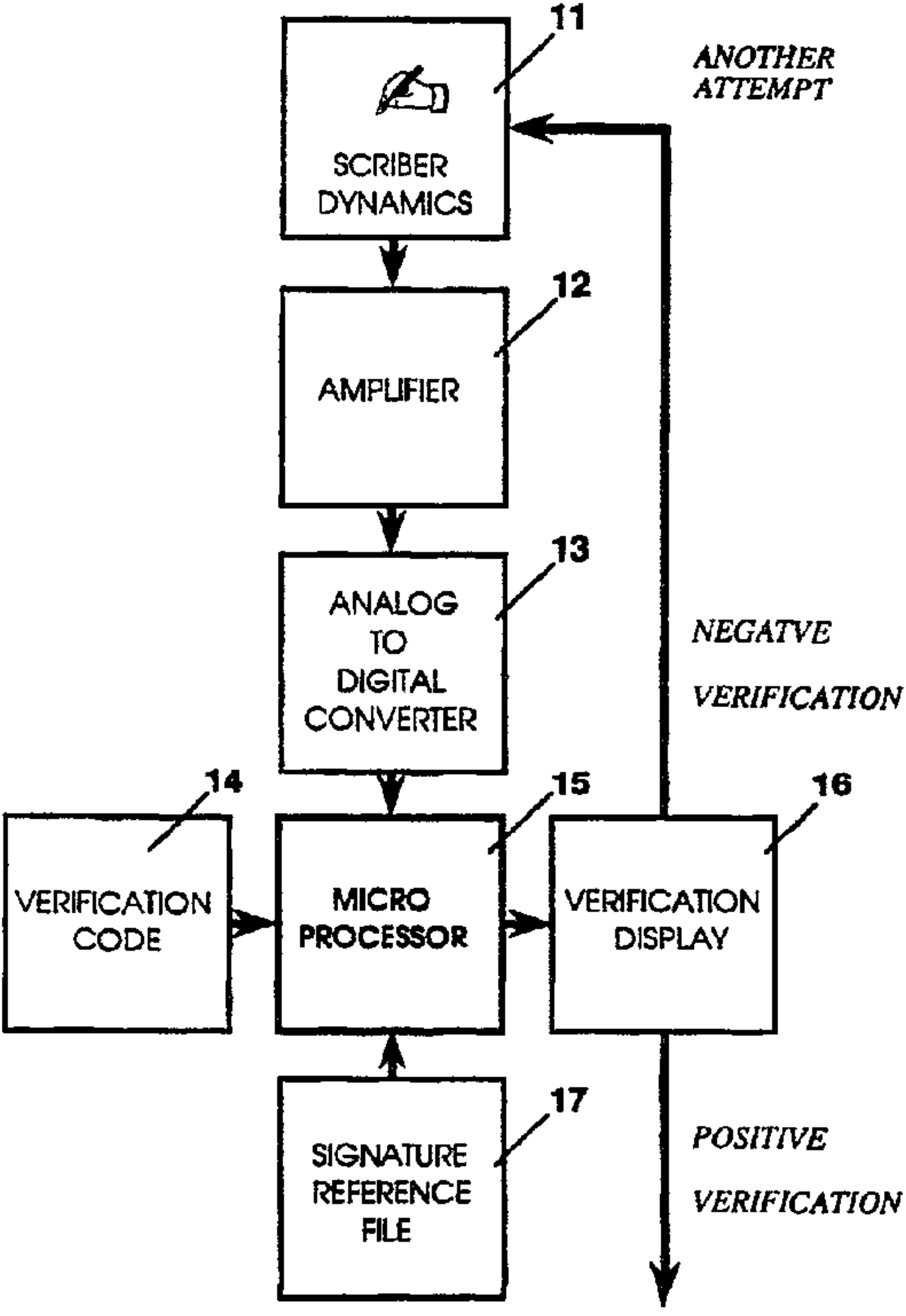

40.0%
30.0%
20.0%
10.0%
0.0%
-7 -6 -5 -4 -3 -2 -1 0 1 2 3 4 5 6 7
$\Delta\tau^{xy}_{max}$

Fig. 9b



phase shift (200 points = 1 sec.)
cross - correlation function
40
30
20
10
0
-10
-20
1.0
0.9
0.8
0
10
20
30
40
window number
91
61

Fig. 10


11
SCRIBER DYNAMICS
ANOTHER ATTEMPT
12
AMPLIFIER
13
ANALOG TO DIGITAL CONVERTER
NEGATVE VERIFICATION
14
VERIFICATION CODE
15
MICRO PROCESSOR
16
VERIFICATION DISPLAY
17
SIGNATURE REFERENCE FILE
POSITIVE VERIFICATION