PATENT SPECIFICATION

(11) 1 562 698

1 562 698

(21) Application No. 50399/76 (22) Filed 3 Dec. 1976
(31) Convention Application No. 7537893
(32) Filed 10 Dec. 1975 in
(33) France (FR)
(44) Complete Specification published 12 March 1980
(51) INT CL³ G01P 5/00
(52) Index at acceptance
G1G 1H 4A3 PJ
G4G 2B1 2B2 2F1 3A10 3A2 3A8A RC

(19)

(72) Inventors JEAN-MAX MURAZ
MICHEL PAYRE and
PIERRE RAMPIN

(54) DEVICE FOR MEASURING THE FLOW SPEED OF A FLUID

(71) We, CROUZET, a French body corporate of 128 avenue de la République, 75011 Paris—France, do hereby declare the invention, for which we pray that a patent may be granted to us, and the method by which it is to be performed, to be particularly described in and by the following statement:—

The present invention relates to devices for measuring the flow speed of a fluid by means of sound waves.

In the already known devices of this type, such as that disclosed in French Patent No. 69.41 949 (2,070,438) of December 4th 1969, to P. Alais and J. Girves, two sound wave transmitting-receiving transducers are placed opposite one another in the fluid flow whose speed is to be measured. Generating means are used to simultaneously transmit a succession of sound waves from both transducers for a period less than the time needed by the waves to travel the distance separating both transducers, after which the transducers are used as receiving transducers in order to measure the phase difference between the received signals detected by the transducers.

An aim of the present invention is to provide improved means for processing signals received by the transducers in order on the one hand to increase the accuracy of the measurements by compensating the sound speed and on the other hand to enable the calculation of a fluid speed on various channels by multiplexing the calculation system on a plurality of pairs of transducers, without increasing the data processing means as was necessary in French Patent No. 69.41 949 (2,070,438).

With this aim in view the present invention provides a device for measuring the flow speed of a fluid, comprising at least one pair of electroacoustic transducers placed in the fluid, means operative to generate a pulse train for triggering said transducers, each operating as a transmitting transducer, to transmit simultaneously a succession of acoustic waves during a time interval shorter than the time interval taken by the acoustic waves to travel between said transducers, transforming means for processing respectively the received electric signals delivered by each of said transducers operating as receiving transducers, in order to get information representing the phase difference between the received signals delivered by one of said receiving transducers and the received signals delivered by the other receiving transducer, said transforming means comprising: a first integrator which integrates a reference voltage between instants 0, corresponding to the beginning of the transmission time interval, and t_1, or t_2 if $t_2<t_1$, t_1 and t_2 representing the propagation times of the acoustic waves from one probe to the other in respective directions, said reference voltage being switched to the input of said first integrator by an analog switch; a second integrator which integrates the output voltage of said first integrator switched to the input of said second integrator by analog switches between 0 and t_1, or t_2 if $t_2<t_1$ with a time constant

$$\frac{\tau}{2}$$

and between t_1 and t_2, or t_2 and t_1 if $t_2<t_1$, with a time constant τ; a third integrator

which integrates the output voltage of said second integrator switched to the input of said third integrator by analog switches between 0 and t_1, or t_2 if $t_2<t_1$, with a time constant τ_1, between t_1 and t_2, or t_2 and t_1 if $t_2<t_1$, with a time constant τ_2, and until instant θ with a time constant τ_3, where instant θ is determined by the comparison of the output voltage of said third integrator with a reference voltage by a comparator, the time constants τ_1, τ_2, τ_3, being chosen so as to cancel at the output of said third integrator the terms in t_1^3 and $t_1t_2^2$, or t_2^3 and $t_2t_1^2$ if $t_2<t_1$, and to keep the terms in $t_1t_2\ \theta$; a trigger circuit for developing a square wave pulse of life time 0—θ; a fourth integrator which integrates a reference voltage between instants 0 and θ and develops an output voltage proportional to

$$\frac{K}{t_1t_2}$$

a memory unit for storing the output of said fourth integrator after time lag greater than the maximum duration of 0—θ; a fifth integrator which receives square wave pulses modulated in amplitude by the output of said fourth integrator stored in said memory unit and in width by $\Delta t=t_2-t_1$, or t_1-t_2 if $t_2<t_1$, and which supplies an output voltage proportioned to the product

$$K\frac{\Delta t}{t_1t_2}$$

an amplifier responsive to the output from said fifth integrator for performing a scaling operation which, after a time greater than the maximum propagation time, is sampled and stored on an output corresponding to a measuring channel for one of said transducer pairs.

In order to measure the fluid flow speed along two perpendicular axes OX and OY, such as is the case in the manufacture of a current-meter, the device may comprise two pairs of transducers X_1X_2 and Y_1Y_2 whose alignments are at right angles.

An associated magnetic compass may be used to provide information on the orientation of said axes in relation to North.

A "programmer" clock enables such transducer of the transducer pairs X_1X_2 and Y_1Y_2 to deliver synchronous pulse trains whose total duration is less than the sound propagation time in the space separating the transducers. After emission of the pulse pairs the transducers operate as receivers and for each pair of transducers the sound propagation times (t_1, t_2) in the two directions between the transducers are compared.

For a given measuring axis X_1X_2, if α is the angle formed by vector V representing the flow speed of a fluid in relation to said axis, and if the speed to be measured is small compared to the speed of sound C in the fluid medium, the following equation applies:

$$V\cos\alpha=\frac{C^2}{2d}\Delta t$$

where $\Delta t=t_2-t_1$ is the propagation time difference for the two pulse trains detected by transducers X_1 and X_2 operating as receivers, and d is the distance between the transducers. Clearly the accuracy with which the speed of sound c is known will play a major part in determining the accuracy with which V is measured if the above formula is used. Therefore the device employs an electronic computing circuit operative to calculate the fluid speed V from the following equation:

$$V\cos\alpha=-\frac{d}{2}\frac{\Delta t}{t_1\,t_2}$$

wherein term c does not appear and the influence of variations of c on the measurement of V may be eliminated.

The present invention will hereinafter be further described by way of example with reference to the accompanying drawings in which:

Figure 1 is a vector diagram for the resolution of the fluid speed V in relation with the axis of a pair of probes X_1X_2;

Figure 2 is a block schematic diagram of a current-meter according to the invention;

Figure 3 is an electric circuit diagram of the computing circuit of the current meter;

Figure 4 is a complementary electric circuit diagram for three measuring channels;

Figure 5 is a transmission, reception and control chronogram, and

Figure 6 is a chronogram illustrating the measurement of a number (m) of individual time differences t.

On Figure 1, the transmitting-receiving probes X_1 and X_2, spaced apart by a distance d=20 cm about, determined the X-axis. Vector V represents the flow speed and direction of a fluid forming an angle with the X-axis. If t_1 and t_2 are the transit times of the sound wave from one probe to the other in respective directions, Δt represents the difference t_2-t_1.

Using formula:

$$V \cos\alpha = \frac{d}{2} \frac{\Delta t}{t_1 t_2}$$

the calculation of V $\cos\alpha$ may be made in three stages:

1) Calculation of

$$\frac{K}{t_1 t_2};$$

2) Summation of m elementary measurements of Δt;

3) Calculation of

$$\frac{K}{t_1 t_2} m.\Delta t.$$

To this effect, the "current-meter" device comprises two pairs of probes X_1 X_2 and Y_1 Y_2 placed at a distance sufficient from a lead-free stainless steel box 1 (Figure 2) containing the electronic equipment, to render interference negligible.

This box contains the various electronic circuits necessary for the generation and processing of the electrical signals such as:

2. Transmission-reception circuit;
3. Programming circuit;
4. Supply circuit;
5. Analog calculation circuit.

The measurements are performed in succession on the various pairs of probes by multiplexing switches 6 and 7.

The elimination of the speed of sound factor is done by creating a square wave crenel of width

$$\theta = \frac{K}{t_1 t_2}$$

then a voltage

$$V = \frac{K'}{t_1 t_2}$$

by means of a circuit shown in Figure 3.

Square wave crenels $0-t_1$ and $0-t_2$ are created by known means by trigger circuits put in state 1 at moment 0 by starting high frequency SHF, and put back to state 0 in the fore front of the reception signals.

Supposing for instance $(0-t_1)<(0-t_2)$, voltage Vref is integrated from 0 to t_1 (signal t_1 t_2), and signal V_1 is obtained in the form

$$\frac{V\ Ref}{\tau}.\ t,$$

with a final value of

$$\frac{V\ Ref}{\tau}t_1.$$

A voltage proportional to t_1 t_2 is created in the following manner:

From 0 to t_1, both switches Sw2 and Sw3 are in their lower position. Resistors R2 and R3 are then parallel. V_1 is then integrated from 0 to t_1 with a time constant $\tau/2$.

The final value at moment t_1 is:

$$V'_2=\frac{2}{\tau}\int_0^{t_1}\frac{V\ ref}{\tau}t.\ dt=\frac{V\ ref}{\tau^2}t_1^2.$$

Between t_1 and t_2, constant

$$V\ ref\frac{t_1}{\tau}$$

is integrated with time constant τ.

$$V''_2=\frac{1}{\tau}\int_{t_1}^{t_2}V\ ref\frac{t_1}{\tau}\ dt=\frac{V\ ref}{\tau^2}t_1\ (t_2-t_1)$$

at moment t_2, the position is then

$$V'_2+v''_2=\frac{V\ ref}{\tau^2}t_1\ t_2.$$

A square wave crenel of width θ is created in the following manner:

Trigger circuit 0–θ A_5 is put at 0 at moment 0 (beginning of the transmission) and V_2 is thereby connected through Sw6.

From 0 to t_1, V_2 is integrated with a time constant τ_1, (R_4, R_5, R_6 in parallel).

From t_1 to t_2, V_2 is integrated with a time constant τ_2, (R_5 and R_6 in parallel).

From t_2 to θ, V_2 is integrated with a time constant τ_3 (R_6 alone).

The output voltage of the integrator is compared with a reference. When this threshold has been reached, the comparator is on +V max. The trigger circuit shifts to state 1 and stops the integration (Sw6 in the upper position).

Voltage V_3 at moment θ has following shape:

$$(a-b)t_1^3+(c-d)t_1t_2^2+e\ .\ t_1\ t_2\theta.$$

An appropriate choice of the time constants τ_1, τ_2, τ_3 allows the terms in t_1^3 and in t_1 t_2^2 to be cancelled in order to keep only the term in t_1 $t_2\theta$. The result is then: t_1 $t_2\theta$=constant, and therefore

$$\theta=\frac{K}{t_1\ t_2}$$

Figure 5 is a transmission-reception and control chronogram wherein:

a is the transmission signal,

b is the back to zero signal for A_1, A_2, A_3, A_6 (at the lower level) and the initialization signal for trigger circuit A_5 (positive front t=0),

c is the back to zero signal for A_8 (at the lower level), the positive portion determining the minimum propagation time,

d, e are the reception signals,
g is the sampling control for the scale factor (PSC).
A voltage proportional to

$$\frac{K}{t_1\ t_2}$$

is created in the following manner:

Square wave crenel θ is integrated by amplifier A_6. The sampling signal PSC permits storing of the final result of the integration. Voltage V_6 represents therefore factor

$$\frac{K}{t_1\ t_2}$$

The same result is obtained with voltage V_7 maintained by amplifier A_7 and capacitor C.

After storing this scale factor, integrators A_1, A_2, A_3 and A_6 are put back to zero.

Δt is determined and m individual measurements of t are summed as follows (Figure 6):

Δt: phase shift between the two received wave trains.

After dividing the frequency of these wave trains by a number 2n, and shifting the phase of one of the signals in relation to the other, signals S_1 and S_2 are obtained:

S_1; m square wave crenels of width

$$\frac{nT}{2}-\Delta t$$

S_2: m square wave crenels of width

$$\frac{nT}{2}+\Delta t$$

The periodicity of S_1 and S_2 is therefore 2 nT.

Parameters m and n are determined by a counting operation with known means such as those cited in French Patent No 2,070,348.

Integration (analog calculation circuit;

Let us call "moment 0" the beginning of square wave crenel

$$\frac{nT}{2}-\Delta t$$

and let us determine the shape of the integrator input signal obtained by resistors R_8 and R_9.

Before moment 0, S_1 and S_2 are at 0,

Between 0 and

$$\frac{nT}{2}-\Delta t$$

Sw8 is in the higher position and Sw9 is in the lower position

Between

$$\frac{nT}{2}-\Delta t$$

and nT, Sw8 is in the lower position and Sw9 is in the higher position. R_8 and R_9 perform a summation.

After a time nT, the result is:

$$V_8 = \frac{1}{\tau}\int_0^{\frac{nT}{2}-\Delta t} -V_7 dt + \frac{1}{\tau}\int_{\frac{nT}{2}-\Delta t}^{nT} +V_7 dt$$

$$= \frac{V_7}{\tau}\left(-\frac{nT}{2}+\Delta t+nT-\frac{nT}{2}+\Delta t\right) = \frac{V_7}{\tau}(2\Delta t)$$

Integration on m periods:

The integration of m signals gives

$$\frac{2V_7}{\tau}m.$$

t which is in the form

$$\frac{k\Delta t}{t_1 t_2}$$

and represents therefore the V cosα speed required.

During PSDx, signal sampling on channel x, the integrator output voltage (after A_9) is stored in capacitor Cx to give signal Sx.

During PSDy, signal sampling on channel y, the output voltage is stored in capacitor Cy to give signal Sy.

Amplifiers A_{10} and A_{11} provide output signals Sx and Sy under low impedance.

The calculation on each channel of scale factor

$$\frac{K}{t_1 t_2}$$

and its application on switch A_8 to the following measurement on the same channel provides separation of the measurements on the various channels. The only imperative is that the propagation times occuring during the various measurements be of the same order of magnitude. With this system, it is possible, in fluid flow-metering for instance, to operate measurements by multiplexing on n channels with one calculation circuit only.

Figure 4 is a diagram, by way of example, of n=3 measurement channels.

In this case, the result of the calculation of the scale factor made on one measuring channel (x for instance) is taken out and stored in an intermediate memory A_{14} by a switch Sw14 whereas simultaneously, the scale factor previously calculated on channel y is kept stored in memory A_{16} until then and transferred into memory A_7 by Sw17. The calculation made at the next cycle by integrator A_8 on the channel y takes therefore account of the scale factor previously calculated from the same channel. During the latter cycle, the scale factor calculated on channel y is taken out by Sw16 and stored in memory A_{16}, whereas the scale factor of the next channel z is transferred on A_7 by Sw19 for the calculation of the next cycle on channel z.

The device according to the invention provides possibility to measure the flow speed of a fluid with a high accuracy independently of sound speed variations in said fluid.

WHAT WE CLAIM IS:—

1. A device for measuring the flow speed of a fluid, comprising at least one pair of electro-acoustic transducers placed in the fluid, means operative to generate a

pulse train for triggering said transducers, each operating as a transmitting transducer, to transmit simultaneously a succession of acoustic waves during a time interval shorter than the time interval taken by the acoustic waves to travel between said transducers, transforming means for processing respectively the received electric signals delivered by each of said transducers operating as receiving transducers, in order to get information representing the phase difference between the received signals delivered by one of said receiving transducers and the received signals delivered by the other receiving transducer, said transforming means comprising a first integrator which integrates a reference voltage between instants 0, corresponding to the beginning of the transmission time interval, and t_1, or t_2 if $t_2<t_1$, t_1 and t_2 representing the propagation times of the acoustic waves from one probe to the other in respective directions, said reference voltage being switched to the input of said first integrator by an analog switch; a second integrator which integrates the output voltage of said first integrator switched to the input of said second integrator by analog switches between 0 and t_1, or t_2 if $t_2<t_1$ with a time constant

$$\frac{\tau}{2}$$

and between t_1 and t_2, or t_2 and t_1 if $t_2<t_1$, with a time constant τ; a third integrator which integrates the output voltage of said second integrator switched to the input of said third integrator by analog switches between 0 and t_1, or t_2 if $t_2<t_1$, with a time constant τ_1, between t_1 and t_2, or t_2 and t_1 if $t_2<t_1$, with a time constant τ_2, and until instant θ with a time constant τ_3, where instant θ is determined by the comparison of the output voltage of said third integrator with a reference voltage by a comparator, the time constants τ_1, τ_2, τ_3, being chosen so as to cancel at the output of said third integrator the terms in t_1^3 and $t_1t_2^2$, or t_2^3 and $t_2t_1^2$ if $t_2<t_1$, and to keep the terms in $t_1t_2\theta$; a trigger circuit for devleoping a square wave pulse of life time $0-\theta$; a fourth integrator which integrates a reference voltage between instants 0 and θ and develops an output voltage proportional to

$$\frac{K}{t_1t_2}$$

a memory unit for storing the output of said fourth integrator after a time lag greater than the maximum duration of $0-\theta$; a fifth integrator which receives square wave pulses modulated in amplitude by the output of said fourth integrator stored in said memory unit and in width by $\Delta t=t_2-t_1$, or t_1-t_2 if $t_2<t_1$, and which supplies an output voltage proportioned to the product

$$K\frac{\Delta t}{t_1\ t_2}$$

an amplifier responsive to the output from said fifth integrator for performing a scaling operation which, after a time greater than the maximum propagation time, is sampled and stored on an output corresponding to a measuring channel for one of said transducer pairs.

2. A device as claimed in claim 1, comprising a plurality of pairs of electro-acoustic transducers, a plurality of corresponding pulse train generating means and having a plurality of circuits connected in parallel between said fourth integrator and said memory unit, each of said circuits comprising an analog switch and an intermediate memory, thus allowing the measuring of the flow speeds on a plurality of channels with a single measuring device.

3. A device for measuring the flow speed of a fluid, substantially as hereinbefore described with reference to and as illustrated in the accompanying drawings.

For the Applicants,
BARLOW, GILLET & PERCIVAL,
Chartered Patent Agents,
94, Market Street,
Manchester, 1.
and
20, Tooks Court,
Cursitor Street,
London, E.C.4.

Printed for Her Majesty's Stationery Office, by the Courier Press, Leamington Spa, 1980
Published by The Patent Office, 25 Southampton Buildings, London, WC2A 1AY, from which copies may be obtained.

1562698 COMPLETE SPECIFICATION

4 SHEETS *This drawing is a reproduction of the Original on a reduced scale*

Sheet 1

Fig: 1

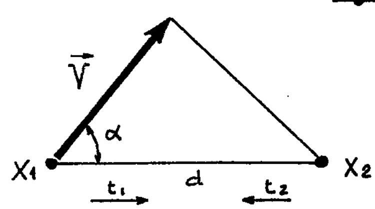
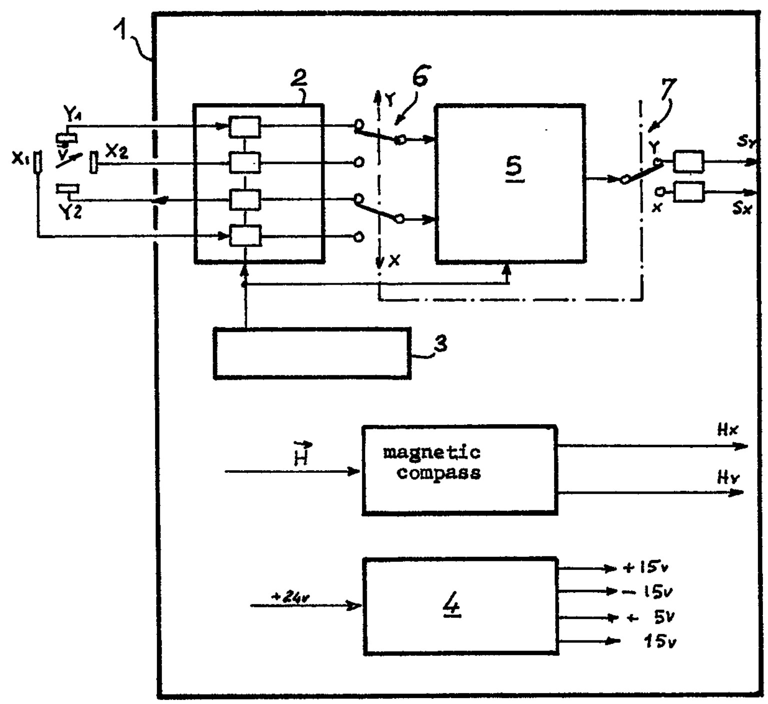


Fig: 2



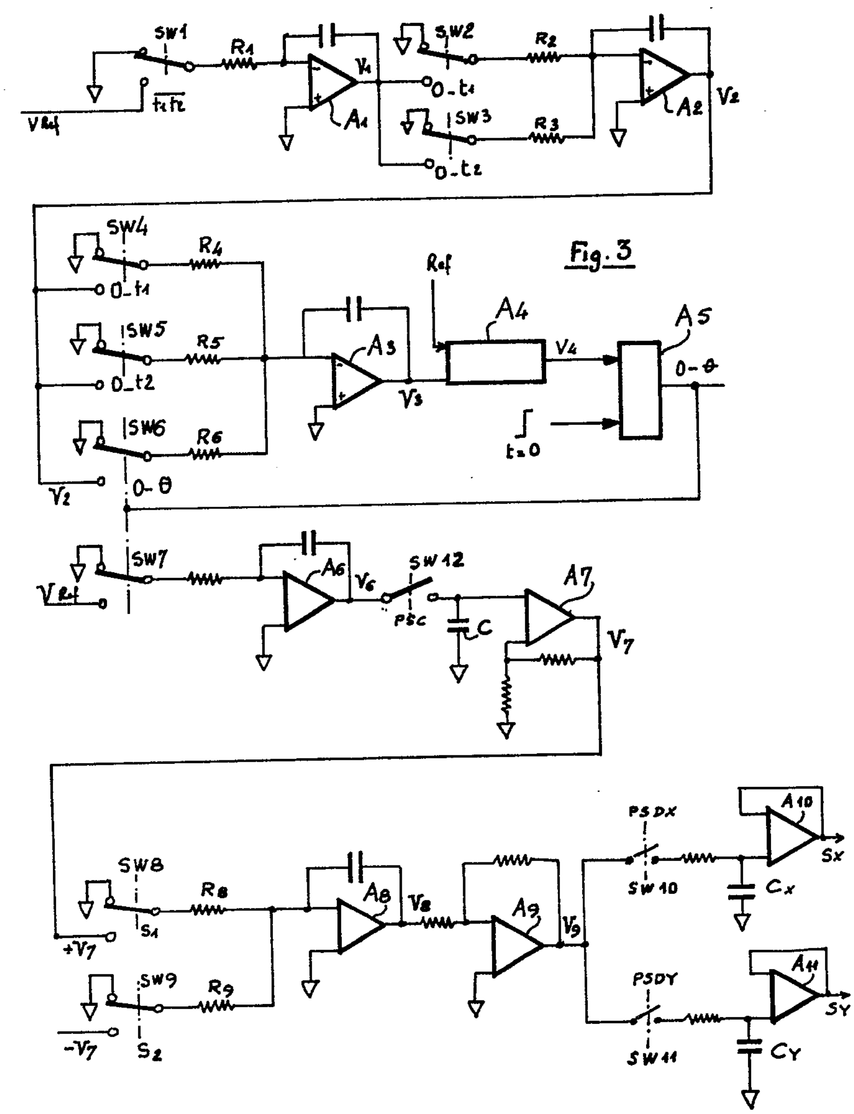

SW1
R1
A1
V1
SW2
0-t1
R2
SW3
R3
0-t2
A2
V2
VRef
Fig. 3
SW4
R4
0-t1
SW5
R5
0-t2
SW6
R6
V2
0-θ
A3
V3
Ref
A4
V4
A5
0-θ
t=0
SW7
VRef
A6
V6
SW12
PSC
C
A7
V7
SW8
R8
S1
+V7
SW9
R9
-V7
S2
A8
V8
A9
V9
PSDX
SW10
A10
Sx
Cx
PSDY
SW11
A11
SY
CY

FIG. 4

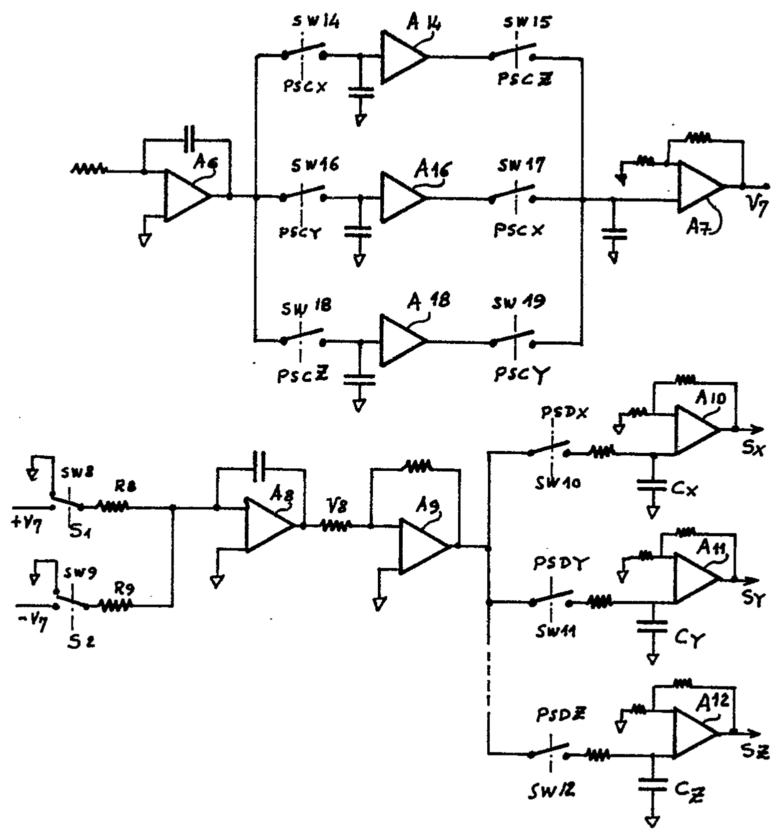

SW14
A14
SW15
PSCX
PSCZ
A6
SW16
A16
SW17
PSCY
PSCX
A7
V7
SW18
A18
SW19
PSCZ
PSCY
PSDX
A10
SX
SW10
CX
SW8
R8
A8
V8
A9
+V7
S1
PSDY
A11
SY
SW9
R9
-V7
S2
SW11
CY
PSDZ
A12
SZ
SW12
CZ

FIG. 5

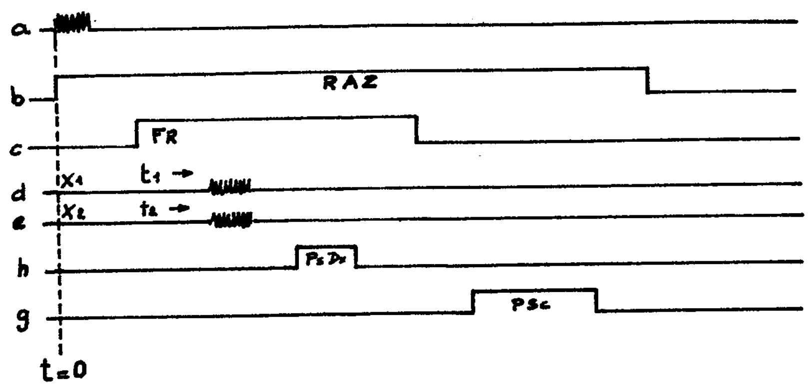


FIG. 6