COMMUNICATION

DEVELOPMENT OF A SIDE BAND MODULATION AND ELECTRONIC DAMPING SEISMOMETER

OCTAVIO LOZANO CARDIEL*

RESUMEN

El Departamento de Instrumentación Atmosférica del Centro de Ciencias de la Atmósfera, ha desarrollado un sismómetro de campo con detección óptica de desplazamiento y modulación en banda lateral mediante el uso de diodos emisores y fototransistores que trabajan en el rango del espectro de luz cercano al infrarrojo, permitiendo la utilización de grandes amplificaciones electrónicas. Por otra parte, se emplea un sistema de amortiguamiento electrónico y corrección de equilibrio con métodos de retroalimentación, lo que en esta forma optimiza las características del sismómetro.

ABSTRACT

The Instrumentation Department of the Atmospheric Sciences Center has been developing a seismometer with optical displacement detection and side band modulation using LEDS and phototransistors matched at the near infrared wavelength, allowing the use of high electronic gains. An electronic damping system and a feedback method for positioning and correcting is used to optimize the seismometer characteristics.

* *Centro de Ciencias de la Atmósfera, UNAM.*

INTRODUCTION

The progress obtained in the seismological and vulcanological field has been assisted and complemented as a whole by the development of the modern techniques and measurements devices implemented day by day, owing to the electronic technology that we actually have.

In this paper, it is proposed a displacement detection method that improves the gain characteristics, band width and linearity of the different systems utilized until now, by the modulation of the data obtained in an optical detector and the introduction of a new electronic damping method.

PROPOSED SYSTEM

One of the main problems encontered in seismometers is the gain of their direct current amplifiers that produces a drift at the output essentially as a function of the temperature and the aging of their components. It can be corrected by the use of a side band modulated system (B.L.) which has the advantage to eliminate the carrier signal allowing the information to be transferred with a zero reference level independently of the modulation index, given at the same time the possibility of isolating the direct current components by means of capacitors.

There are several kinds of seismometers that work on the same principles of operation and in general its behavior can be represented with a differential equation of second order.

Figure 1 shows the schematic arrangement of such seismometers, whose representative equation is:

$$\ddot{x} + \frac{c}{m}\dot{x} + \frac{k}{m}x = \ddot{y} \tag{1}$$

Where:

$\ddot{y}$ - acceleration of the ground
c - mechanic impedance
k - spring's restitution constant
m - accelerometer's mass
x - displacement of the mass
$\dot{x}$ - velocity of the mass
$\ddot{x}$ - acceleration of the mass

Solving the equation by Laplace tranform one obtains the following transfer function:

$$A_o(s) = \frac{X(s)}{A(s)} = \frac{1}{1 + \frac{c}{k} s + \frac{k}{m} s^2} \qquad (2)$$

In such a way that the response to sinusoidal movements will be given by the following equation:

$$A_o(j\omega) = \frac{X(j\omega)}{A(j\omega)} = \frac{1}{1 + j2b\frac{\omega}{\omega_o} - (\frac{\omega}{\omega_o})^2} \qquad (3)$$

Where:

$b = \frac{c}{2\sqrt{mk}}$ damping index

$\omega_o = \sqrt{\frac{k}{m}}$ seismometer's proper frequency

Its representation is given in normalized Bode plots as shown in Figure 2.

The output can be linearized by selecting a value for the damping index "b" of 0.707 for a bandwidth equal to "ω_o".

A usual method for obtaining the mechanical impedance and get this index, is based in the introduction of a coil inside a magnetic field with flux density B, with its terminals closed through an electric resistance R, as shown in Figure 3.

The electric current "i" flowing through the coil is:

$$i = \frac{B\ell\dot{x}}{R} \tag{4}$$

Where:

- B - Magnetic flux density
- ℓ - length of the coil
- v - velocity associated to the motion of the coil
- R - Total resistance associated to the circuit of the coil.

The force "f" opposing the motion is

$$f = B\ell i \tag{5}$$

From: (4) and (5)

$$f = \frac{B^2 \ell^2 \dot{x}}{R} = c\dot{x}$$

(6)

$$c = \frac{B^2 \ell^2}{R}$$

c = mechanical impedance.

One gets as a result a mechanical impedance just as required by the mechanical analysis.

In this paper use is made of electronic amplifiers to magnify a potential difference from an optical sensor which is processed obtaining the velocity component and fed back at a proper stage.

Displacement detection and side band modulation is fulfilled with a pair of phototransistors in a differential configuration, both illuminated by the same LED and a thin wire attached to the mass interfering the light beam of the phototransistors.

Figure 4 shows the proposed circuit and its mechanical scheme. The ligth emitting diode is fed with a two components current, one is a direct current and the other a sinusoidally varying current which frequency is ω_p (carrier frequency) greater than the maximum modulating frequency (event's frequency) ω_m of the seismometer.

The incident irradiance upon each phototransistor is:

$$H = ax = a\,(X_o + X_m \cos \omega_m t) \tag{7}$$

Where:

H – irradiance upon each phototransistor in $\frac{\text{Watts}}{m^2}$

a – irradiance transfer function per unit length variation of the mechanical arrangements in $\frac{\text{Watts}}{m^2 - m}$

X_o – mean amplitude of x (reference amplitud)

ω_m – frequency of the motion (event)

On the other hand:

$$a = A_o + A_p \cos \omega_p t$$

$$a = A_o \left(1 + \frac{A_p}{A_o} \cos \omega_p t \right) \tag{8}$$

Where:

A_o – mean irradiance per unit length variation

A_p – maximum carrier irradiance per unit length variation

ω_p – carrier frequency

From (7) to (8) one obtáins:

$$H = A_o X_o \left(1 + \frac{X_m}{X_o} \cos \omega_m t \right) + X_o A_p \left(1 + \frac{X_m}{X_o} \cos \omega_m t \right) \cos \omega_p t \tag{9}$$

The output voltage of each phototransistor is:

$$v_c = A_o X_o \beta \left(1 + \frac{X_m}{X_o} \cos \omega_m t \right) + A_p X_o \beta \left(1 + \frac{X_m}{X_o} \cos \omega_m t \right) \cos \omega_p t \tag{10}$$

Where: β represents the linear phototransistor transfer function in

$$\frac{\text{Volts} - m^2}{\text{Watts}}$$

This equation shows the low frequency component that corresponds to the signal and a high frequency component that corresponds to the side band modulated information in such a way that if one couple each phototransistor through and RC network as shown in Figure 5, one can obtain for the low frequency component its derivative and the undamped displacement for the side band modulated signal.

One obtains as output of the capacitive coupling device:

$$e_c = -K_c \beta A_o X_m \omega_m \operatorname{sen} \omega t + A_p X_o \left(1 + \frac{X_m}{X_o} \cos \omega_m t\right) \cos \omega_p t \tag{11}$$

Where:

e_c – output voltage of the capacitive coupling
K_c – constant of proportionality of the differentiation circuit.

The differential output of both couplers cancels the components of a common mode giving a differential voltage value as shown:

$$\begin{aligned} e_d = & \mp 2K_c \beta A_o X_m \operatorname{sen} \omega_m t \\ & \pm \beta A_p X_m [\cos(\omega_p - \omega_m) t + \cos(\omega_p + \omega_m) t] \end{aligned} \tag{12}$$

Writing:

$$e_v = 2K_c \beta A_o X_m \operatorname{sen} \omega_m t \tag{13}$$

$$e_{BL} = \beta A_p X_m [\cos(\omega_p - \omega_m) t + \cos(\omega_p + \omega_m) t] \tag{14}$$

to represent the side band modulated displacement and velocity components respectively, one finally obtains:

$$e_d = \mp e_v \pm e_{BL} \tag{15}$$

The positive and negative signs represent the sense of motion.

Figure 6 shows the differential output an that of its components. This voltage is applied to a damping coil located in the seismometer to generate a force proportional to the velocity as required by the analysis of the mechanical system.

Figure 7 shows the block diagram of the seismometer.

CONCLUSIONS

The method proposed in this paper has allowed the construction of an experimental prototype, after a careful circuit selection. Once the laboratory's observations have been done, this permits to affirm that the behaviour of the equipment by itself fulfils with the linearity and stability characteristics assigned during its designs. On the other hand, due to the fact that the material used in its construction can be obtained easily in the market, we can say that economy is an important factor of this project.

A second dinamic set of observations should be done on a calibration table in order to fit the amplification and to obtain the appropriate transfer graphics.

ACKNOWLEDGMENTS

I thank sincerely to Roberto Domínguez for his valuable criticism and commentaries during the development of this paper, Manuel Perusquía del C., for his help in the construction of an experimental mechanical seismometer, Alfredo Gómez for his colaboration in the armed seismometer's electronic section and Francisco García for his cooperation in the confection of the graphics and drawings required in this paper.

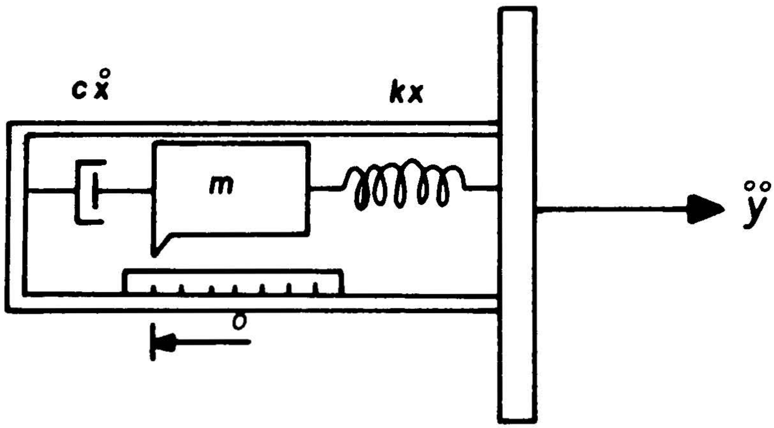


Fig. 1 ACCELEROMETER

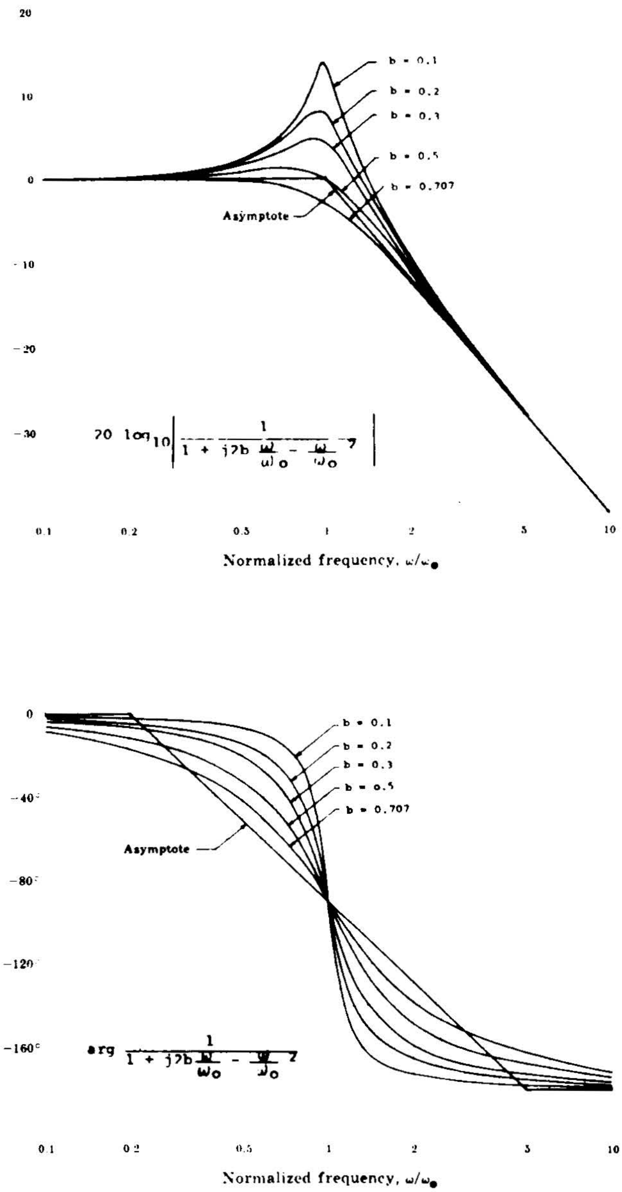


Fig. 2 BODE'S GRAPHIC FOR A_o (JW)

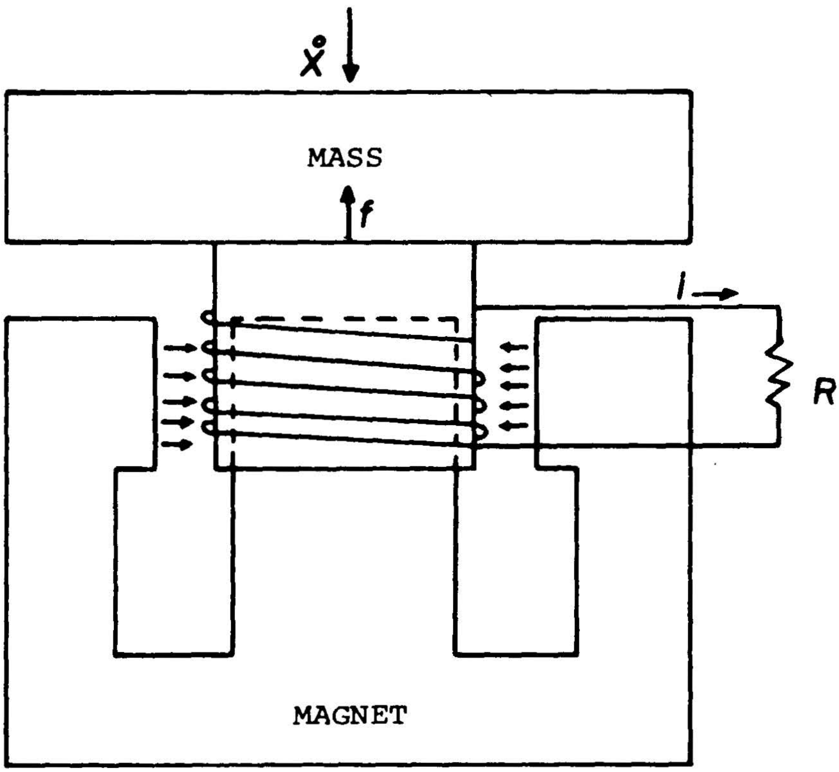


Fig. 3 DAMPING SYSTEM

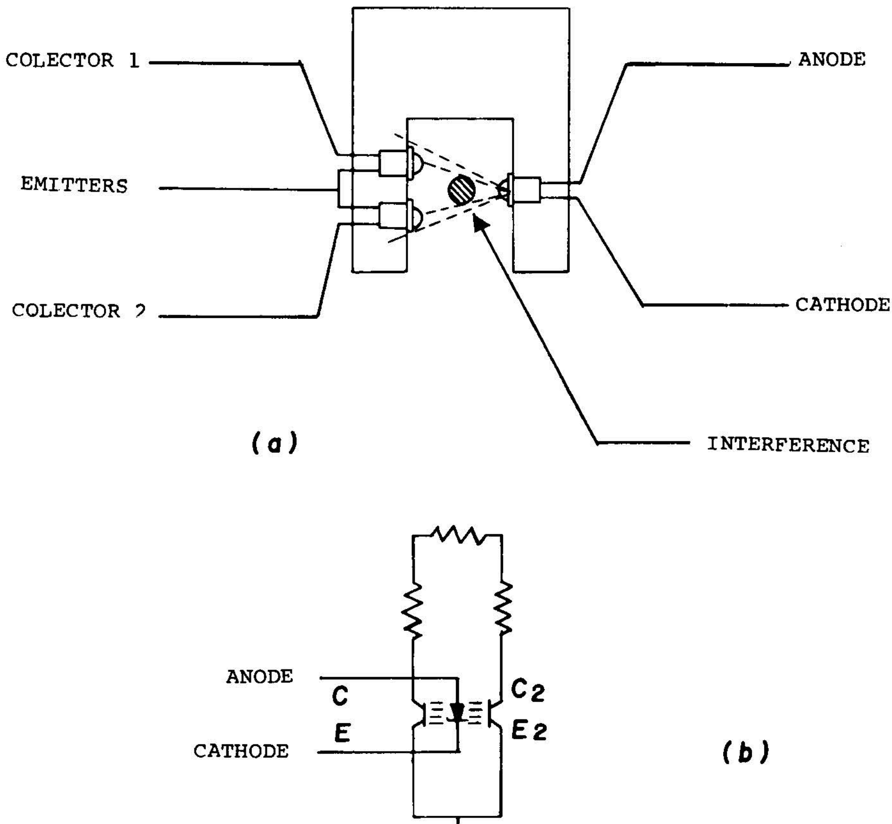


Fig. 4 DISPLACEMENT DETECTOR

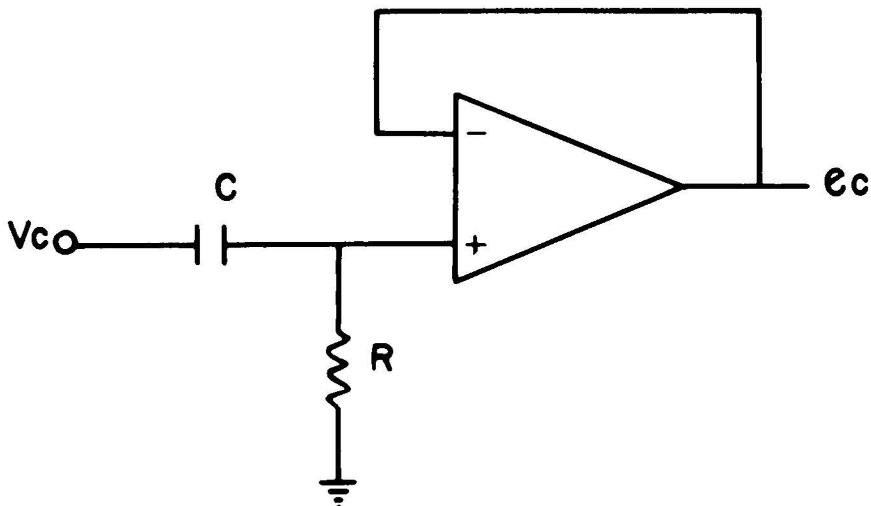


Fig. 5 DIFFERENTIATOR AND COUPLER

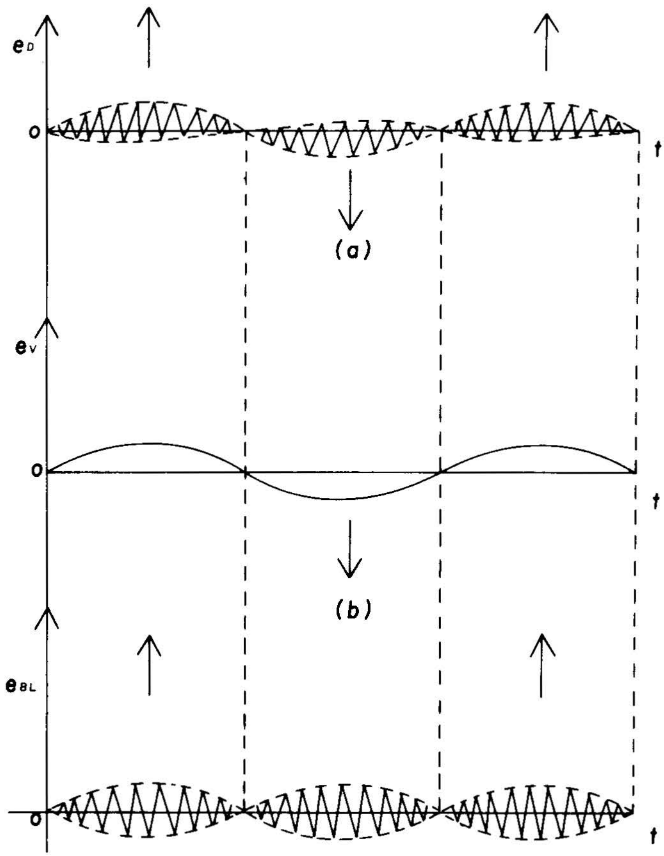


Fig. 6 SIDE BAND MODULATED DISPLACEMENT

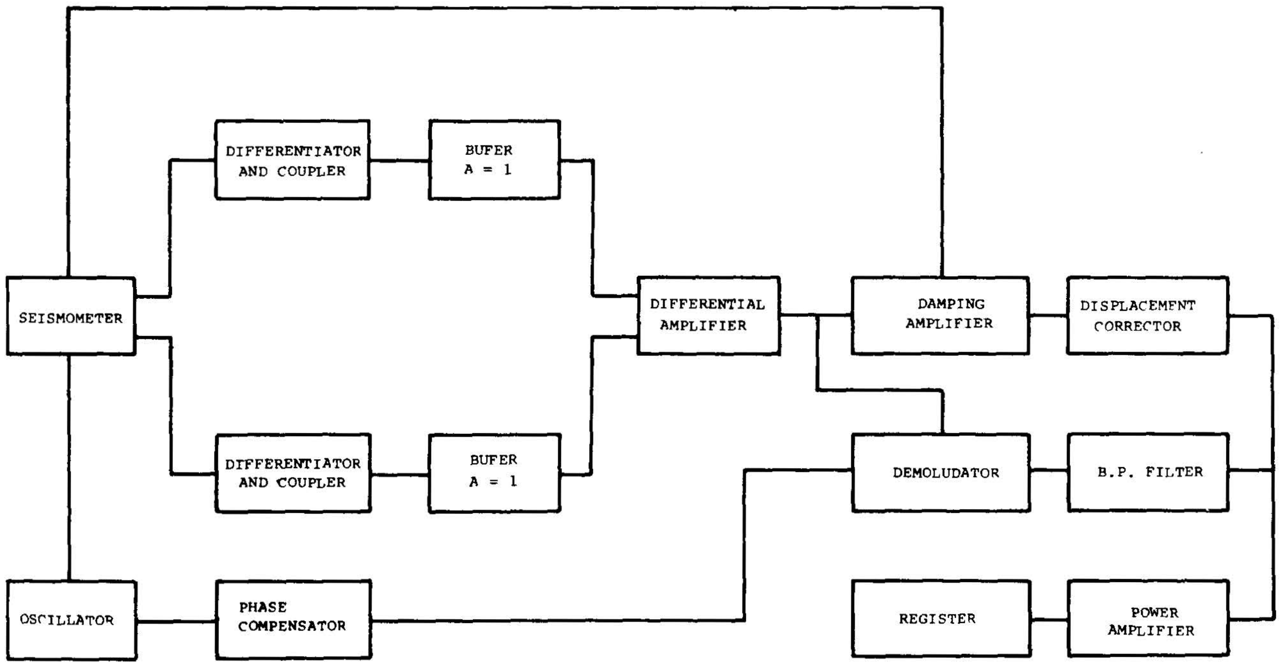


FIG. 7 SEISMOMETER BLOCK DIAGRAM

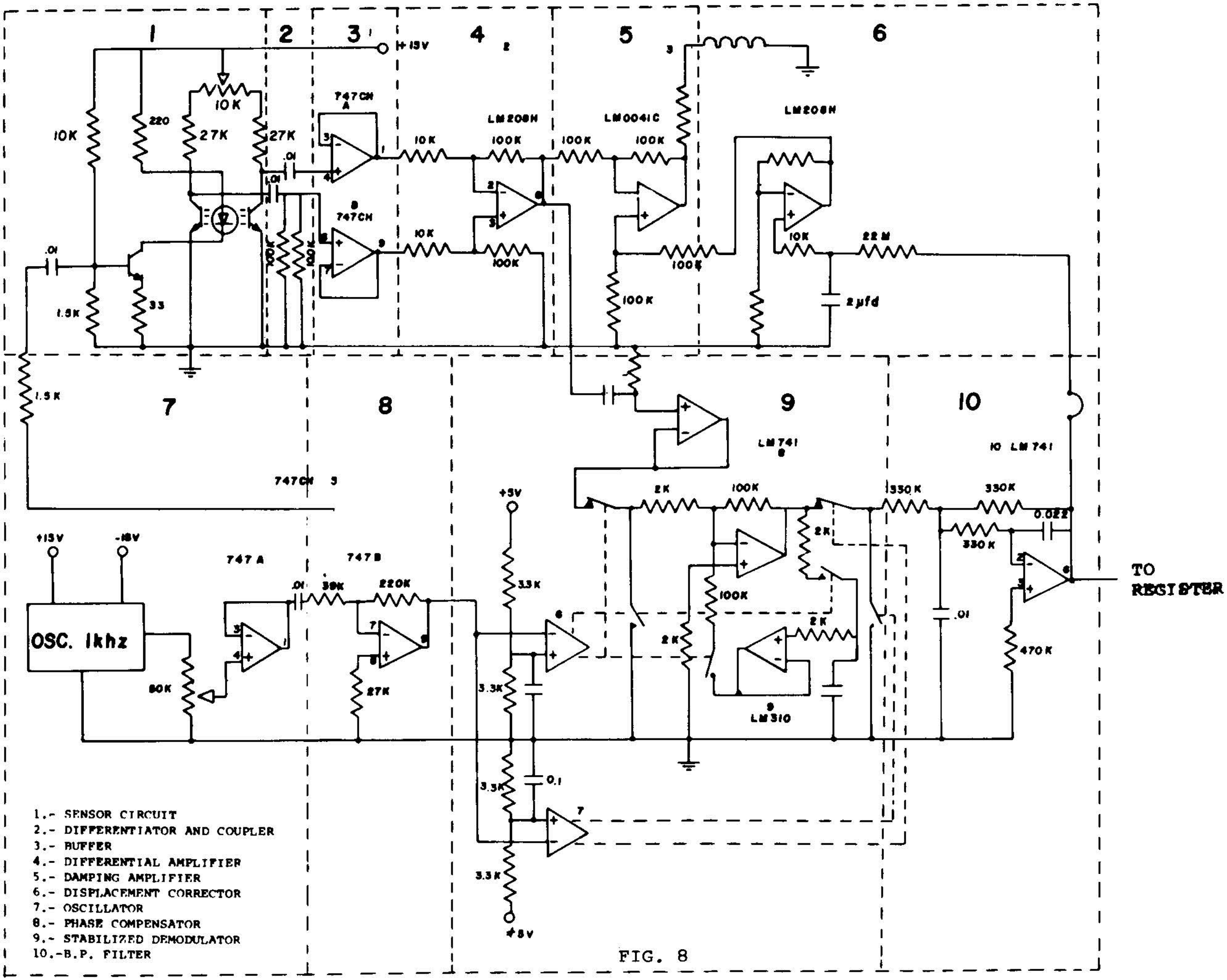
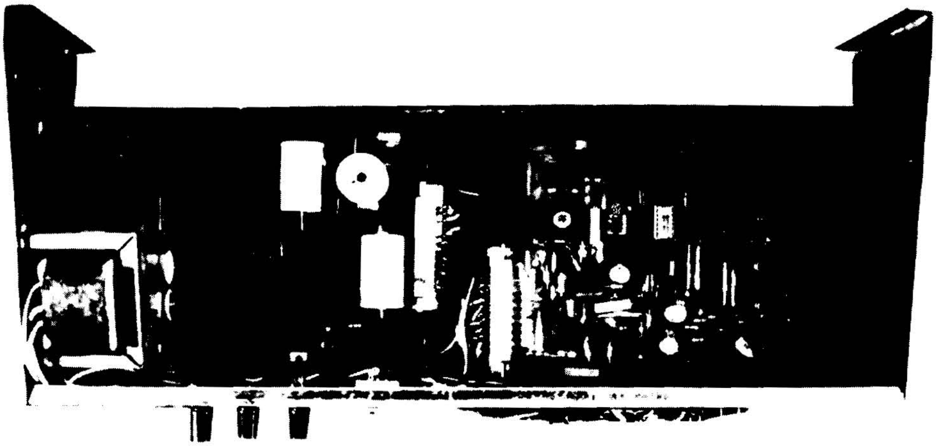

1
2
3
4
5
6
7
8
9
10
+15V
747CH A
747CH B
LM208H
LM0041C
10K
220
27K
.01
100K
22M
2μfd
1.5K
33
747CH 3
+15V
-15V
OSC. 1khz
747 A
747 B
39K
220K
50K
+5V
3.3K
0.1
2K
LM741
LM310
330K
0.022
470K
TO REGISTER
1.- SENSOR CIRCUIT
2.- DIFFERENTIATOR AND COUPLER
3.- BUFFER
4.- DIFFERENTIAL AMPLIFIER
5.- DAMPING AMPLIFIER
6.- DISPLACEMENT CORRECTOR
7.- OSCILLATOR
8.- PHASE COMPENSATOR
9.- STABILIZED DEMODULATOR
10.-B.P. FILTER

FIG. 8



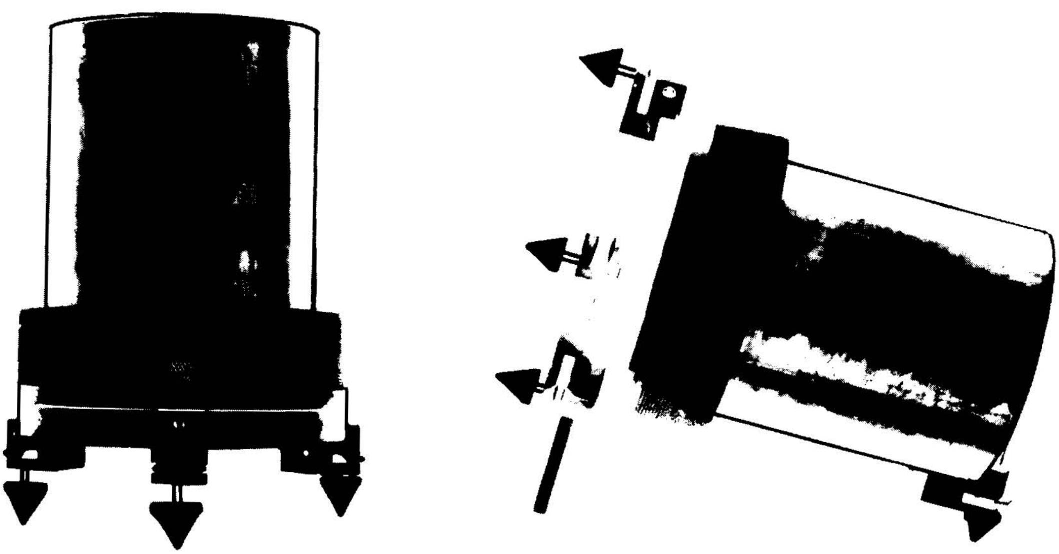


Fig. 9 SEISMOMETER