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A NEW SEISMOGRAPH RECORDER WITH TRANSISTOR AMPLIFIERS

by

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Abstract

A seismograph recording system consisting of a transistor amplifier, a moving-coil pen unit, and a smoked-paper recorder is described. The amplifier has four directly coupled differential stages, and its power gain is 64 dB with an input impendence of 10 kΩ and output impendance of 1 kΩ.

Introduction

The different types of earth waves generated by earthquakes are detected by means of seismographs. Most seismographs used at present are based on electromagnetic induction, i.e. the voltage induced on a coil by the relative motion between the coil and a permanent magnet. The usual recording system consists of a mirror galvanometer that deflects a light spot projected on photosensitive paper.

This system is fairly simple in principle, but several practical drawbacks limit its usefulness. It is often difficult to obtain good focussing, since the trace produced either becomes too thick or tends to disappear during larger shocks. Also the delay in obtaining the records, which frequently amounts to 24 hours or more, is often inconvenient and the consumption and cost of the photographic material, developers, etc. is relatively high.

To overcome these drawbacks, a new system has been developed, consisting of a transistor amplifier that directly drives the recording pen writing on smoked paper or other suitable material. The requirements imposed on such amplifiers become clear when it is recalled that most seismologically interesting phenomena are observed at frequencies below one C.P.S. (in the region 1—0.01 C.P.S.) and that the equipment must run continuously. A D.C. amplifier is required, and transistors are superior to electron tubes by virtue of their small power consumption, long life, and small size. To replace the D.C. amplifier with a more conventional A.C. type it would be necessary to employ a seismometer with a fundamentally different principle of operation.

The Amplifiers

Sacks [3] has developed a transistor preamplifier for the purpose of improving the sensitivity of seismographs. It consists of a directly coupled two-stage differential amplifier in which all transistors are of the type OC 70.

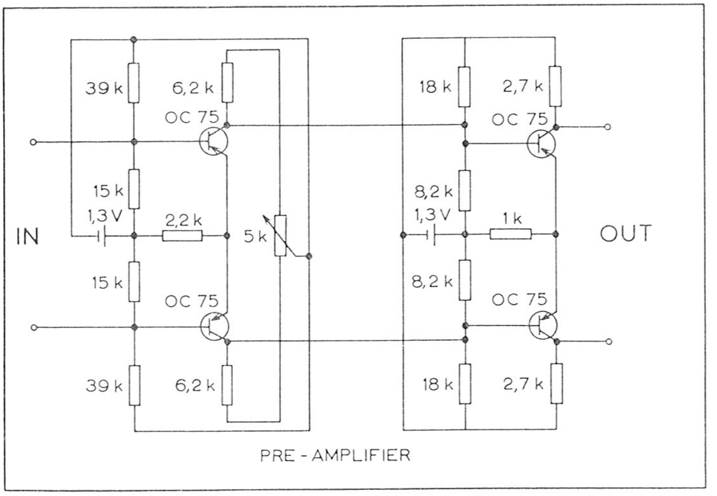
The design is optimised for small noise, the peak value of which is $1.66 \cdot 10^{-7}$ volts at a frequency band 4 c.p.s. — 35 c.p.s. referred to input. This is achieved at a collector voltage of —0.11 volts, collector current of 20 μA, and base bias of 50 mV in the input stage. The second stage operates at slightly higher current but is coupled in a similar way. With open-circuited output the voltage gain of the amplifier is about 200, and the second stage is driven to saturation when the input signal to the amplifier exceeds 3 mV.

Experiments aimed at developing new seismological instruments at the Seismological Station of the University of Helsinki (Nurmia, [1]) clearly revealed the drawbacks of the usual method of photographic recording, and most of the new instruments were consequently designed to be used in connexion with a transistorized recorder.

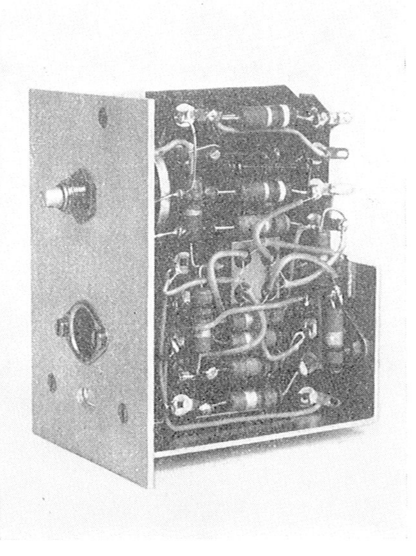
The amplifier designed for this purpose consists of two parts, the preamplifier and the final amplifier.

A circuit diagram of the preamplifier is given in Fig. 1. It contains two pairs of OC 75's in a directly coupled differential amplifier. The operating points for the first stage are: base current $+3.5$ μA, collector current -75 μA, and collector voltage -0.5 V, and for the second stage respectively $+2$ μA, -200 μA, and -0.4 V.

The working points are stabilised in the usual way by means of emitter



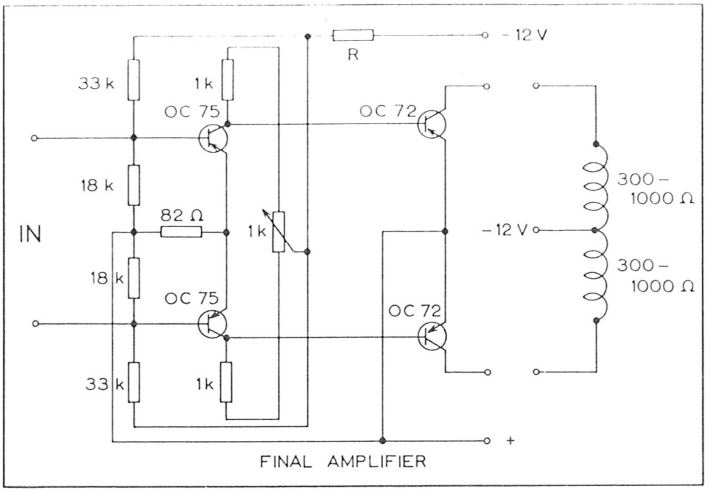
a.



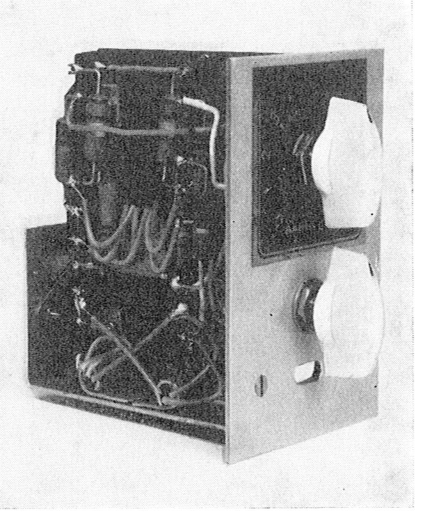
b.

Fig. 1. a) Circuit diagram of the preamplifier.
b) The preamplifier.

resistors and voltage dividers inserted into the base circuit. A part of the collector resistance of the first stage is formed by a potentiometer, which is used to adjust the balance of the amplifier. The current for each stage



a.



b.

Fig. 2. a) Circuit diagram of the final amplifier.
b) The final amplifier.

is supplied by a 1.3-volt mercury cell (Type RM 4), which lasts for several months in continuous function.

The final amplifier (Fig. 2) contains a pair of OC 75's as the first stage and a pair of OC 72's (supplied as matched pairs under the designation

2—OC 72) as the output stage. The collector current of the former is about 0.5 mA, whereas the collector current of the final stage is adjusted by means of the resistor R to such a value that approximately half the supply voltage appears across the load resistance. The current will thus be set to 10—30 mA if the load resistance is between 700 and 250 ohms. The current to the final amplifier is taken from a 12-volt storage battery.

To eliminate drifts due to temperature variations, all transistors are mounted in brass blocks.

The gain achieved with these amplifiers varies appreciably owing to the large spread in transistor characteristics, but a typical value for a complete amplifier is a power gain of 64 dB with a generator resistance of 10 kΩ and load resistance of 1 kΩ. This is a rather modest value for a four-stage amplifier, but it should be noted that the design is aimed at stability, small noise, and small power consumption in preference to high gain. The noise in the present amplifier is of the same order of magnitude as in the type described by SACKS.

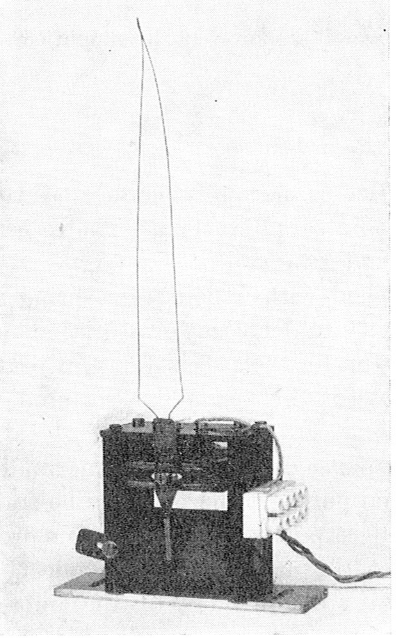


Fig. 3. The moving-coil pen unit.

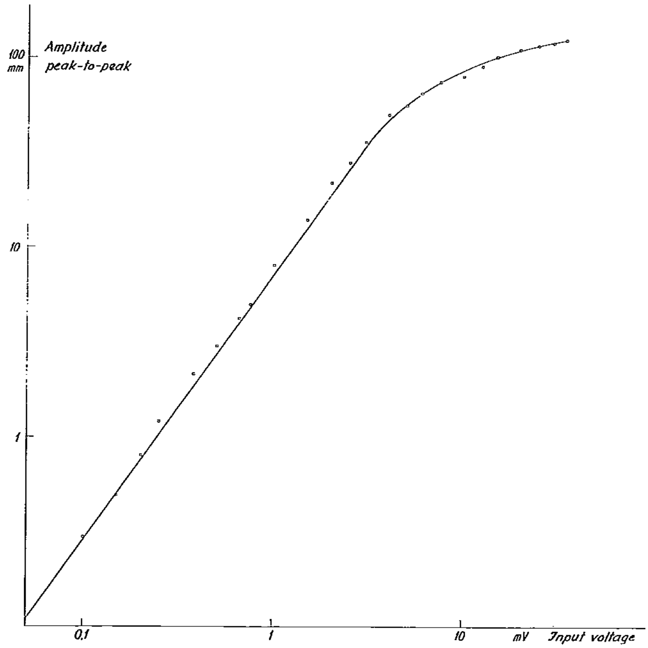


Fig. 4. The overall response of the amplifiers and the pen unit.

The Pen Units and Recorders

The final amplifier is normally connected to a moving-coil pen (Fig. 3) equipped with a sapphire stylus. The resistance of the standard coil is 1500 ohms, center-tapped.

The pen is furnished with a nonlinear spring system which causes its deflection sensitivity to decrease toward large amplitudes. The maximum amplitude written by the pen is 120 mm peak-to-peak. An amplitude calibration curve of the pen and associated amplifier is given in Fig. 4.

The frequency response of the system is normally flat between 0 and 7 c.p.s., but for special purposes the pen may be equipped with a heavier spring whereby a flat response to 30 c.p.s. or more can be obtained. It should be noted that the maximum amplitude covered by the pen is limited by mechanical stops and not by the amount of drive available from the amplifier. By this means a considerably better transient response than that indicated by the above frequencies can be achieved.

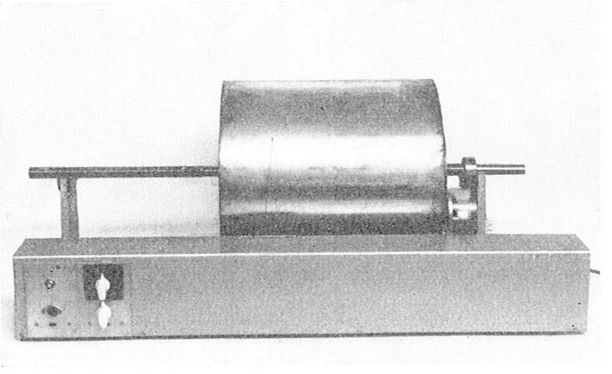


Fig. 5. The smoked-paper recorder with amplifiers in place. Mechanical part has been designed by M. Nurmia and M. Hakkinen.

The pen writes on a sheet of smoked paper attached on a revolving drum driven by a small synchronous motor at a speed set between 30 and 300 millimeters per minute. The time signals are produced by using the chronometer contacts to insert a resistance of 10—15 kΩ in parallel with one half of the pen winding.

A complete recorder with amplifiers in place is shown in Fig. 5.

The line drawn by the sapphire stylus on a properly smoked paper is only a few hundredths of a millimeter in width, and as the maximum amplitude covered by the pen corresponds to a signal that would give an amplitude of 500 millimeters if the pen were linear, the dynamic range available for amplitude measurements is of the order of 10,000 to 1. This fact, together with the constant width of the trace, which does not disappear even in strong shocks, constitutes the main advantage of this method over the photographic one. The immediate visibility of the record and the associated economic saving make it especially suitable for research purposes where a large amount of high-resolution material is needed. The amplifiers have proved very reliable in use, and normally a zero adjustment need only be made at intervals of several weeks. It has been found advisable to insert small radio-frequency chokes in series with both preamplifier input leads to eliminate effects due to stray r.f. fields in certain locations where long cables are needed between seismometers and amplifiers. In these cases a 0.2 microfarad paper condenser is further connected across the input terminals to filter away the interference sometimes caused by nearby A.C. apparatus.

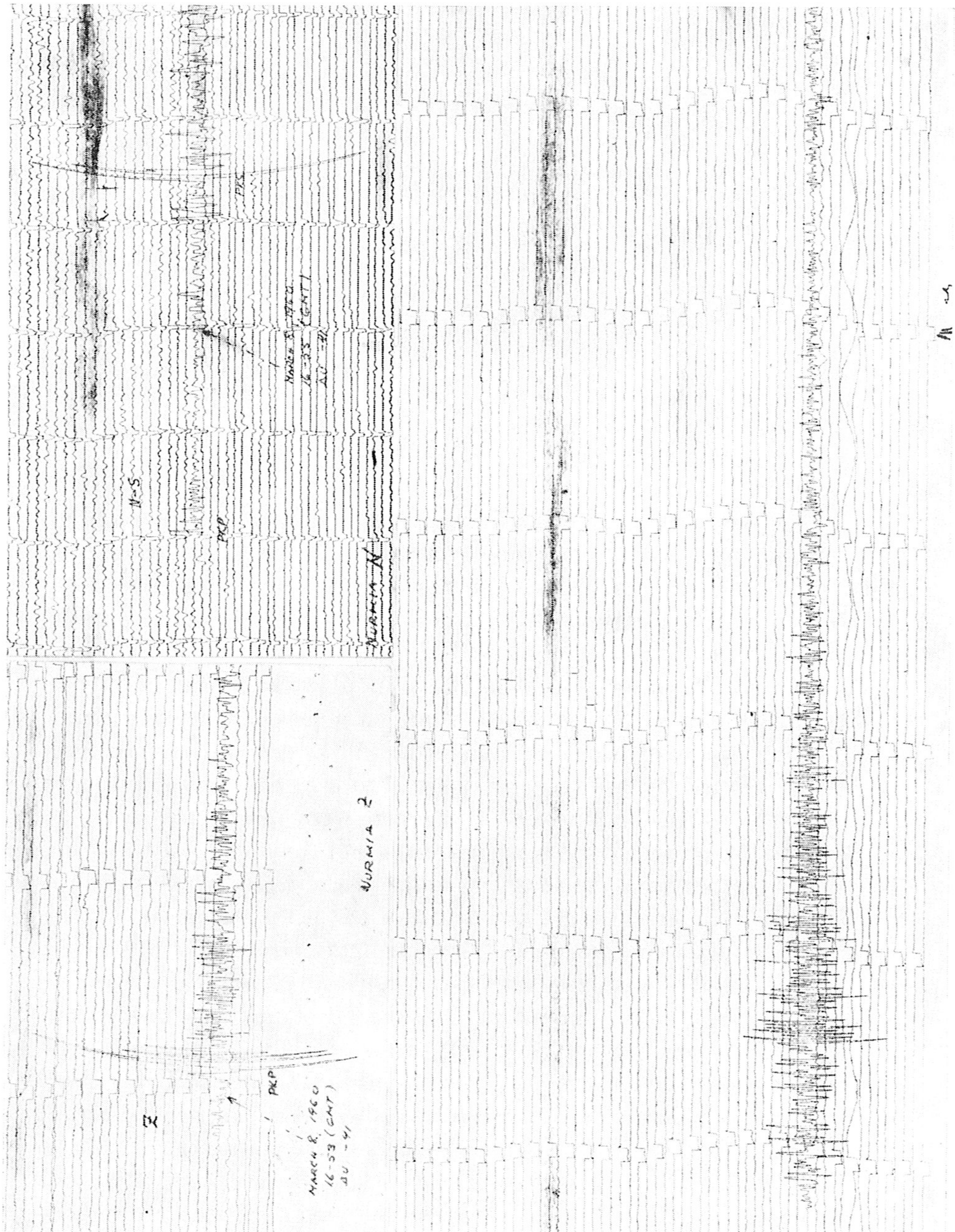


Fig. 7. Above PKP and PKS of the earthquake March 08, H: 16—33—38, 16 ½°S, 168 ½°E (USCGS) recorded in Helsinki. Below the beginning of the record in Helsinki of the earthquake March 20, H: 17—07—30, 40°N, 143 ½°E (USCGS).

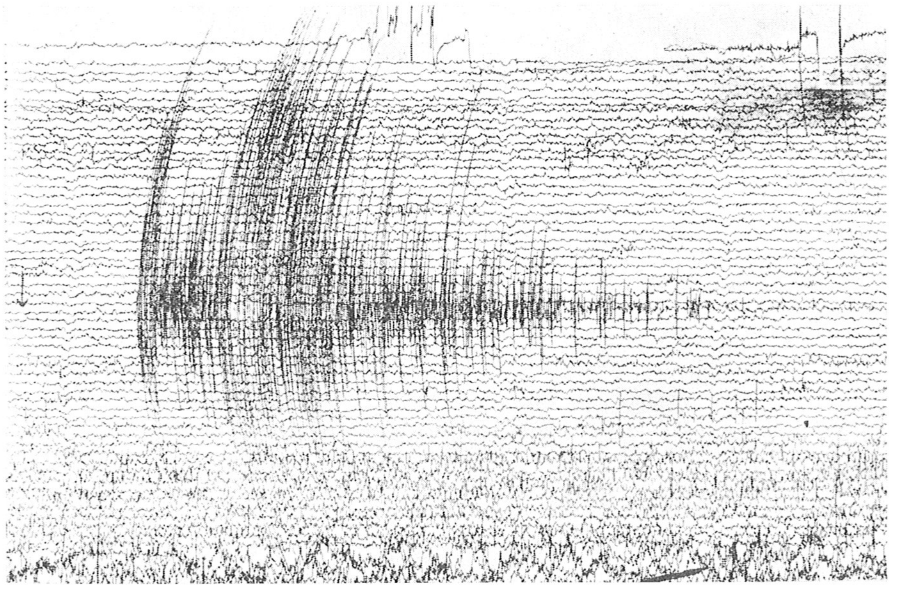


Fig. 6. The local earthquake in Finland Feb. 20, 1960 recorded at the station of Oulu ($\Delta = 1.88°$).

In seismically noisy locations and also for special purposes, i.e. study of long-period waves, the high-frequency response of the pen can conveniently be varied by connecting low-voltage electrolytic condensers of from one to several thousand microfarads in parallel with each half of the pen coil. These amplifiers are also being employed in telemeter recording where the output of the final amplifier is sent over telephone lines to another location for recording. This has been successfully done over distances of more than 100 kilometers (PENTTILÄ and others, [2]).

Figures 6 and 7 give examples fo records obtained with the apparatus described above.

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