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A TELERECORDING SEISMOGRAPH

by

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Abstract

A description is given of a telerecording seismograph working on the FM principle. A solid-state voltage-variable capacitor is used in the frequency modulator, the long-term stability is remarkably good, and the equipment contains the minimum of electronic circuitry. The carrier frequency is in the audio range, and conventional telephone lines are used. The telerecording method described is practical up to a line attenuation of 4 to 5 nepers with 1 mW transmitting power.

Introduction

A direct application of telephone lines between the amplifier and recorder was experimentally adopted in connection with an explosion seismic operation organized by the Seismological Laboratory of the University of Helsinki (PENTTILÄ, KARRAS, NURMIA, SIIVOLA, VESANEN [1]). For routine observations, however, this method is unsatisfactory because of the background noise and variations in transmission properties found in most telephone channels. To overcome these difficulties, it seems logical to use a suitable application of the frequency modulation and detection principle. GANE, LOGIE and STEPHEN [2] were the first to introduce such a system having a frequency-modulated subcarrier in their VHF radio seismograph. MIYAMURA, MATUMOTO and TSUJIURA [3, 4] have published different designs utilizing similar principles. At the Seismological Laboratory of the University of Helsinki, another version has been developed to meet the urgent need for a simpler system.

General

Owing to a recent development in the field of the semiconductor industry, there are available a growing variety of solid-state devices which have the property of acting as voltage-variable capacitances. The semiconductor capacitor is actually a junction diode operated in the reverse bias region. It works on the controlled width of the junction, which in turn depends on the magnitude of the biasing voltage; the capacitance is inversely proportional to the bias and reaches a minimum at the breakdown point.

Unlike many properties of a semiconductor, the capacitance across the depletion layer shows little temperature dependence. This is due to the fact that the carrier mobilities cancel out in the equation for the width of the layer (GIACOLETTO, O'CONNEL [5]). It is largely because of this that such a unit was incorporated in the frequency-modulated oscillator, to give the stable and simple configuration.

Because the aim was to have only one information channel per station, no subcarriers were used. The carrier frequency was selected to be sufficiently above the harmonic frequencies generated by the power systems, and, on the other hand, not to suffer too much from attenuation in the regular telephone channels. As a compromise, 880 c/s was taken, which also eases the field adjustments, allowing the use of a mere standard tuning fork.

The Transmitter

The most important part of the transmitter is the frequency-modulated oscillator. This is of the phase-shift type. The oscillation occurs on the frequency that undergoes a 180° phase-shift from plate to grid through the phase-shifting network. By varying the reactance of the elements in the network, variations in the frequency can be produced, and considerable variation in frequency can be caused by adjusting the reactance of one element only.

The silicon capacitor is introduced into the network as one of the elements. Hughes HC 7001 is selected for the purpose. It is sufficiently biased to prevent most of the clipping and self-biasing effects due to the A.C. voltages appearing across the network. The network is so constructed that the carrier frequency with the selected bias is produced. The final adjustments are made by tuning the trimmer capacitor in one of the other branches of the network.

The plot of the frequency vs. biasing voltage, as obtainable by the voltage-tuned oscillator, is shown in Fig. 1. There is a slight distortion from the linear law. The maximum frequency deviation for F.S.D. is $\pm$ 60 c/s, which is a compromise between the distortion and relative requirement for the frequency stability. This is covered by the voltage swing of $\pm$ 6 volts, superimposed on the selected D.C. bias of + 10 volts, which corresponds to the carrier frequency 880 c/s. The oscillator produces an almost sinusoidal output waveform and has not more than $\pm 10\%$ amplitude variation with the full-scale frequency excursion.

The circuit diagram of the oscillator is seen in Fig. 2. The phase-shift oscillator is easy to construct for a reasonable frequency stability, if care and well-selected parts are used. The stabilization of the operating point of the oscillator tube by a large feedback in its cathode lead does away with most of the need for precise heater regulation.

The amplifier, the circuit diagram of which is also seen in Fig. 2, delivers the control voltage for the oscillator. The amplifier has a D.C.-connected output part and a low output impedance to feed the balancing

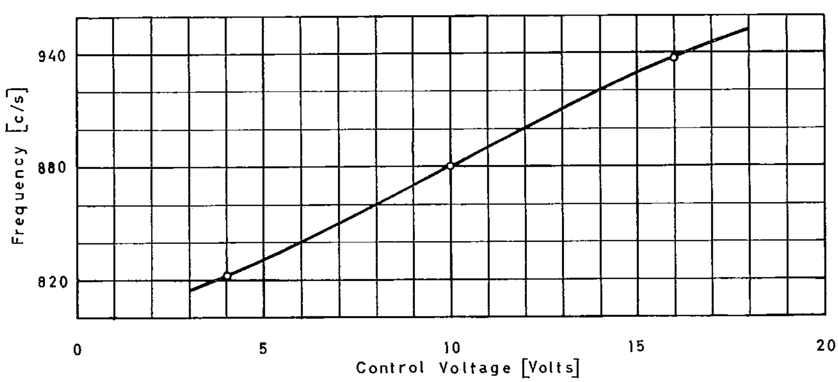

Fig. 1. The frequency-voltage characteristic of the voltage-tuned audio oscillator used in the transmission system.

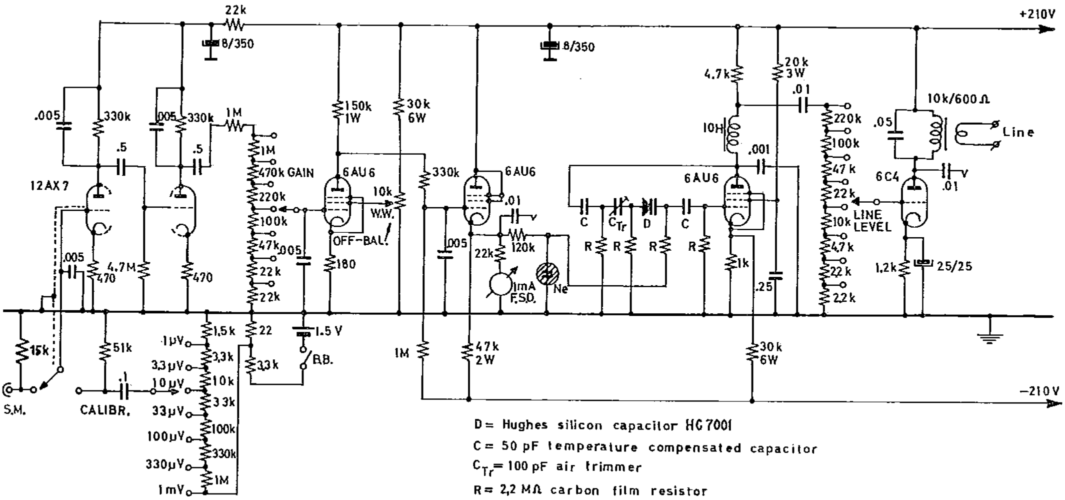

Fig. 2. The circuit diagram of the transmitter, including the amplifier, oscillator and output stage.

meter. By adjusting the screen voltage of the final amplifier pentode, the output part is properly off-balanced to + 10 volts with respect to ground, with no signal applied for the zero frequency deviation. The input part of the amplifier is A.C. connected. This is necessary because only very little drift in the output voltage can be tolerated, and no other measures have been taken to stabilize a complete D.C. amplifier. Most of the small amount of drift in the output voltage, present even in this configuration, can be eliminated by properly pre-aging the two output tubes. The 3 db cut-off at the low-frequency end is at about 0.5 c/s, which will not matter much if short-period seismometers are used.

On account of the low-frequency response of the amplifier and with the high values of gain, a considerable amount of heater regulation is required. A transistorized heater regulator is actually used for the whole transmitter. The D.C. supplies are also regulated.

The Receiver

The circuit diagram of the receiver is shown in Fig. 3. It consists of a voltage amplifier, power amplifier, F.M. detector and differential cathode follower output stage.

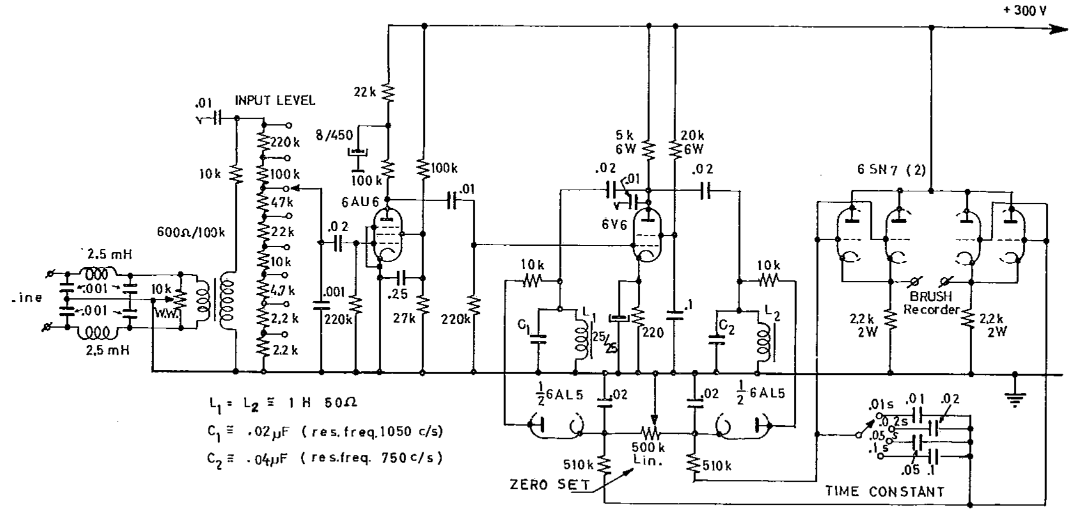

Fig. 3. The circuit diagram of the receiver.

The suitable input level is 0.2 volts R.M.S. on the high side of the step-up transformer. With this level, variations in the input level of $\pm$ 6 db will result in a zero shift of not more than 3% of the F.S.D. and sensitivity variations of not more than 4%. The two resonant circuits are tuned to about 750 and 1050 c/s and have a Q of about 5. Because of the Brush penmotor type BL-959 adopted, considerable power amplification is needed. The amplitude linearity of the transmission system is shown in Fig. 4. If a different recorder requiring less driving power could be used, the cathode resistances in the output stage could be increased and returned to the — 210 V supply for somewhat better linearity.

The stability of the receiver is very good. It will not even produce a deflection without an audio signal in the suitable frequency range. The power regulation required is also relatively small.

Discussion

Experience indicates that the transmitter requires very little care in field use. The oscillator itself has an extremely good frequency stability over long periods of time. A typical frequency drift is less than 1% over a period of 6 months of continuous operation. There is more tendency in the control voltage to drift and off-set.

The system works up to 5 nepers of line attenuation with a transmitting power of 1 mW and has a good discrimination against background noise. For longer ranges, repeaters should be used.

As seismometers, medium-impedance Nurmia-Z type of units (NURMIA [6]) have been temporarily adopted. They will later be replaced by high-impedance Willmore instruments.

The recording is made with large drums and a chart speed of 120 mm/min. Ink writing with the Brush pen units is adopted exclusively. Future plans include the use of the tape recorder because the frequency-modulated 880 c/s carrier gives less serious requirements for the bandwidth, noise and distortion qualifications of the tape-recording apparatus. Preliminary experiments show that a rather low tape speed may be used, but that the requirement for the maximum permissible peak-to-peak value of the flutter and wow is very stringent.

A sample recording is seen in Fig. 5 and Figs 6 and 7 show the appearance of the equipment.

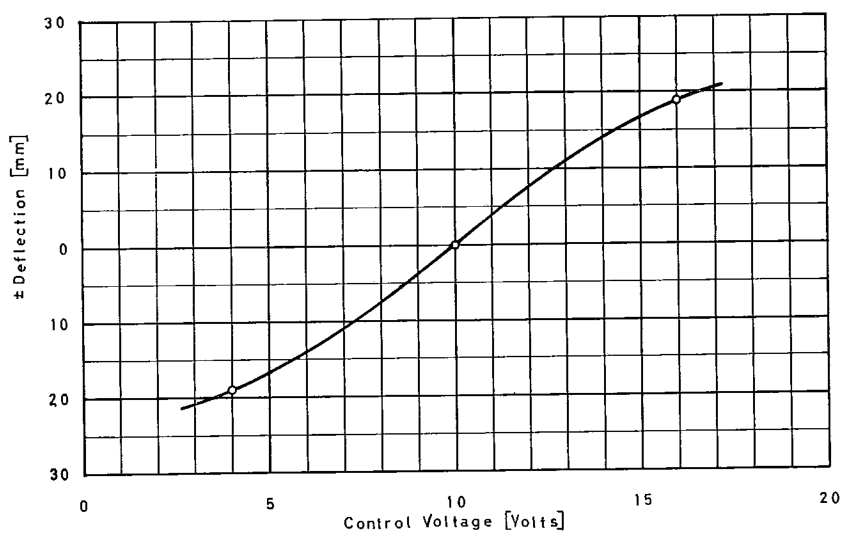

Fig. 4. The recorder deflection as a function of the oscillator control voltage in the transmission system.

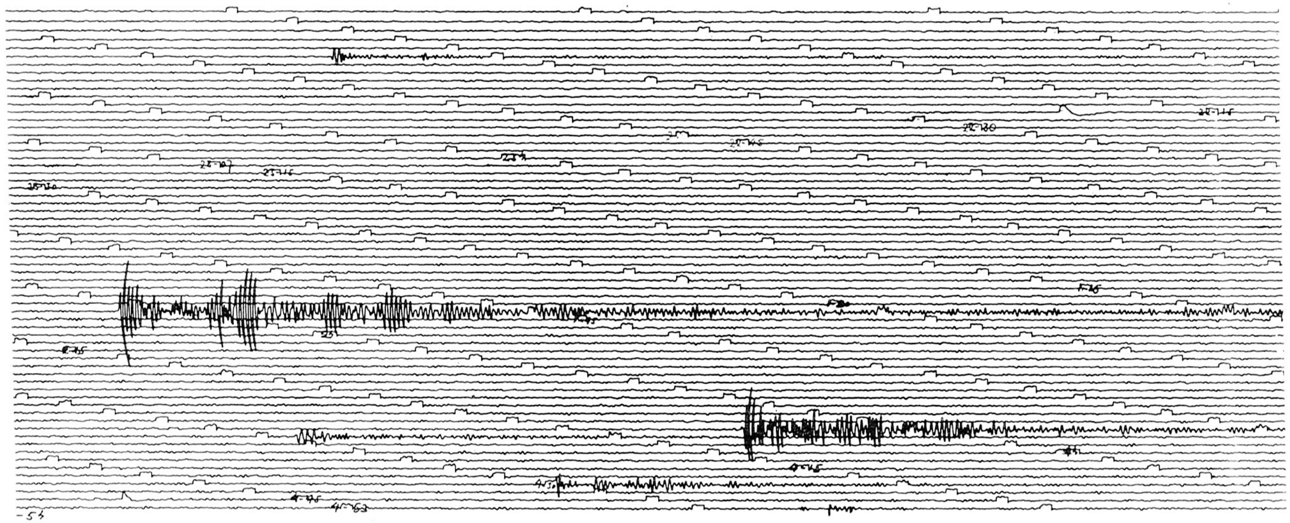

Fig. 5. A sample telerecorded seismogram as transmitted on Sept. 28, 1961 over a cable having a total attenuation of 3 nepers. The transmitting power is 1 mW. Recording made by the ink recorder at 120 mm/min chart speed. Magnification is about 100 000. The seismometer used is Nurmia-Z. Following iP phases, read from up to down, are seen on the figure ($\Delta t = + 52$ s.):

Sept. 27 21 h 18 m 25 s	Ryukyu Islands
» 28 01 » 36 » 44 »	Sumatra
» 28 03 » 36 » 24 »	South of Honshu
» 28 03 » 42 » 59 »	Unknown locality
» 28 04 » 30 » 53 »	South of Honshu

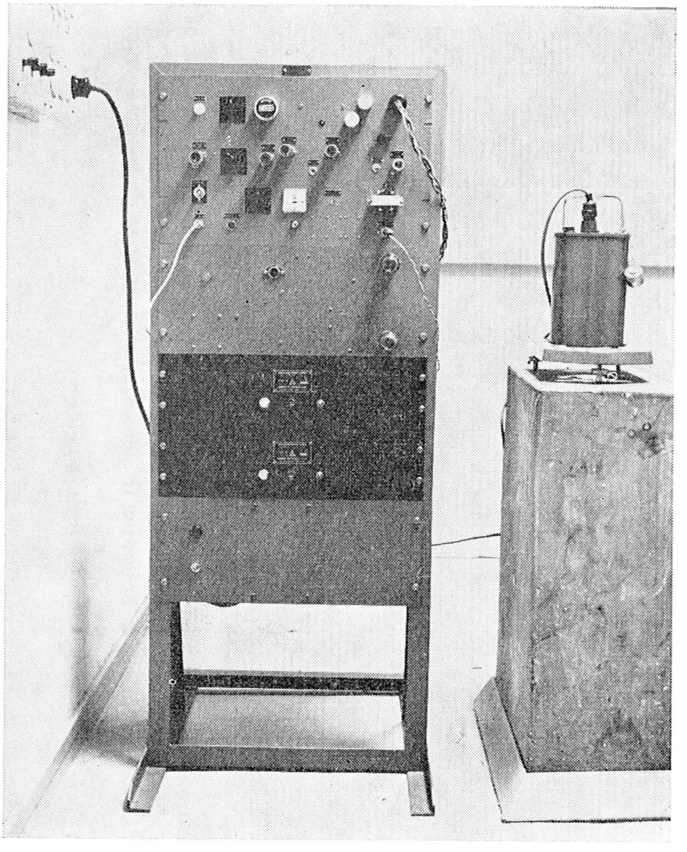

Fig. 6. The appearance of a transmitter.

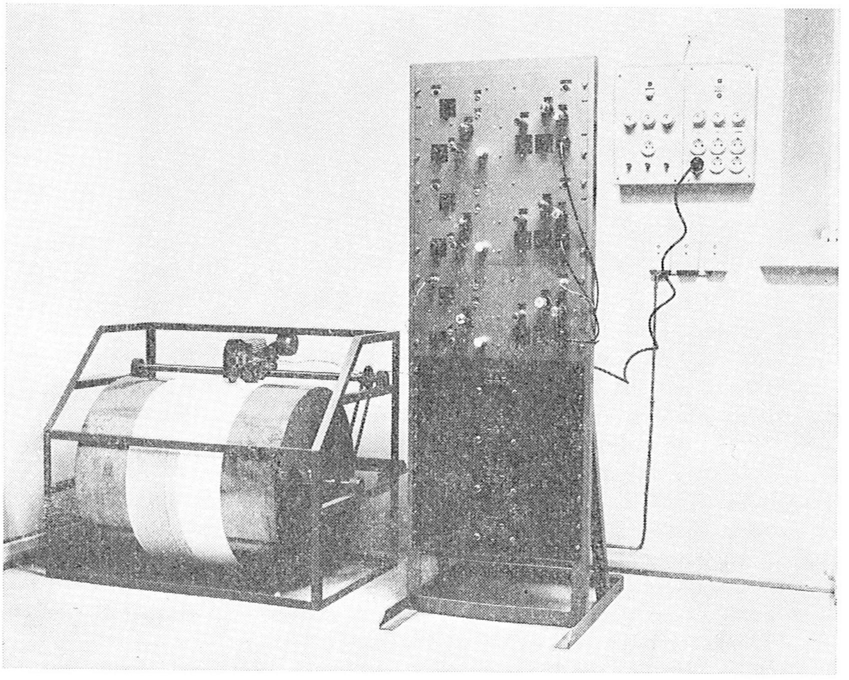

Fig. 7. The appearance of the multiple receiver and an ink recorder.

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