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68. *Automatic Step-wise Gain Control of a Seismometer Amplifier for the Routine Observation of Small Earthquakes.*

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Abstract

In the observation of micro-earthquakes, the trace amplitude of the seismogram which is recorded with an ordinary highly sensitive seismograph very often reaches the limited amplitude range of the recorder, and consequently the information of amplitude or correctness of S phase identification are lost.

The quality of observation to give accurate data for the calculation of the hypocenter position and the determination of magnitude had been lowered by the trouble mentioned above.

In this paper, the author intends to describe one of the useful steps to expand the dynamic range of the seismograph without giving trouble in the operation of the instrument or in the quality of the seismogram.

1. Introduction

Several kinds of automatic gain control amplifiers were designed and have been utilized in the seismic observations, in order to extend the amplitude range of the recording which is ordinarily limited only within a dynamic range of 40db by the recorder.

Within the limited amplitude range of the recorder, we can record phenomena with wider dynamic range by making use of AGC amplifier as used in the exploration seismology.

But ordinarily, the precise information of amplitude is lost by using AGC amplifiers and the amplitude difference between the seismic phase and the waves registered before the phase becomes obscure.

The present author has explained the usefulness of a logarithmic compression AGC amplifier[1] for the determination of magnitude and

1) H. MATUMOTO, "Logarithmic Wide Amplitude Range Electronic Seismograph," *Bull. Earthq. Res. Inst.*, **37** (1959), 381-388.

arrival time of earthquakes.

However, the common defect of the AGC amplifier in amplitude measurement mentioned above did not allow us to discriminate the delicate amplitude difference in the seismograms and also in the logarithmic amplifier, the capability of the seismograph in the later phase identification becoming quite poor.

Usually some of the most important seismological information used to determine the position of hypocenter and the mechanism of the source is included in the S phase, but, as the S phase is not commonly isolated in the seismogram, the identification of S phase becomes difficult even when a slight change of amplitude is missed. Of course, we can obtain complete and sufficient data to calculate the position of the hypocenter by making use of the several kinds of seismographs with different magnifications at one station and/or at closely located stations.

Nevertheless, owing to economical and geographical considerations, the observatories are generally required to be equipped with facilities as simple as possible in order that they can be operated by none specialist observers, and the effective and accurate determination of hypocenters must be carried out by a minimum number of sub-stations. Thus a wide magnitude range should be observed without missing the S phase due to the amplitude satuation.

As the most suitable step to meet requirements the author adopted the step-wise gain control method instead of the conventional or logarithmic AGC.

2. Principle

The amplifier is constructed with main amplifier which provides the fixing potentiometer (now 1 : 10) and the amplitude discriminator with a relay switch.

The relay switch is driven by the discriminator and changes the potentiometer according to the in-put signal amplitude in the regular ratio. Where the hysterisis characteristics of the relay contribute to simplify the construction of the discriminator, because the ordinal seismic signals are constructed with gradual increase and decrease of signals in time series and the relay does not chatter according to the wave amplitude vibration or small level change when the relay is first set up.

For the same reason, the relay is also set up at high amplitude level and reset only at a facily lower level than the former.

Thus the switch keeps on by the over flow signal and keeps off only when the signal decreases as low as 1/3 amplitude of the former set up level, as if the discriminator can select the two levels automatically either set up or set off.

Thus we can control the amplifier gain by only one simple amplitude discriminator without reset timer or any other discriminator to detect the signal end. It is merit of the method to be able to operate the observatories as simply as possible.

3. Design and Construction

The first design of the amplifier was made in 1959, the newly constructed amplifier being installed experimentally[2] at Kainokawa, one of the observation stations of ERI in the Kii Peninsula, Central Japan.

The circuit diagram and the parts list of the first design are shown in Fig. 1, and a successful record sample obtained by the amplifier is shown in Fig. 4.

The circuit is constructed with push-pull connection and the gain change switch is put in the last stage of the amplifier, in order to suppress the switching noise as low as possible.

By introducing this device the ratio of the numbers of completely recorded earthquakes and incompletely recorded ones which lose precise information for maximum amplitude or correctness of S phase identification by the limited amplitude range of the recorder, decreased to less than 2% from the former value of over 10%.

For example the completely recorded earthquakes in Fig. 4 indicated by S are seismograms relieved by the method, which would have been saturated by the recorder range, if the ordinary linear amplifier had been used.

This means that the accuracy of hypocenter determination increases greatly, the number of determinable hypocenter also increasing 2 or 3 times more than the former stage when no AGC amplifier was used. This is because the adoptation of the method enabled us to give precise S arrival time at the station near the epicenter in cases of comparatively large earthquakes and to calculate the accurate hypocenter without any difficulty with phase identification due to the over flow signal.

During the experimental period, the usefulness of the method in extending the dynamic range and correcting the identification of S phase was thus clearly shown.

2) S. MIYAMURA, M. HORI and H. MATUMOTO, "Local Earthquakes in Kii Peninsula (Part 5)," *Bull. Earthq. Res. Inst.*, **44** (1966), 709-729.

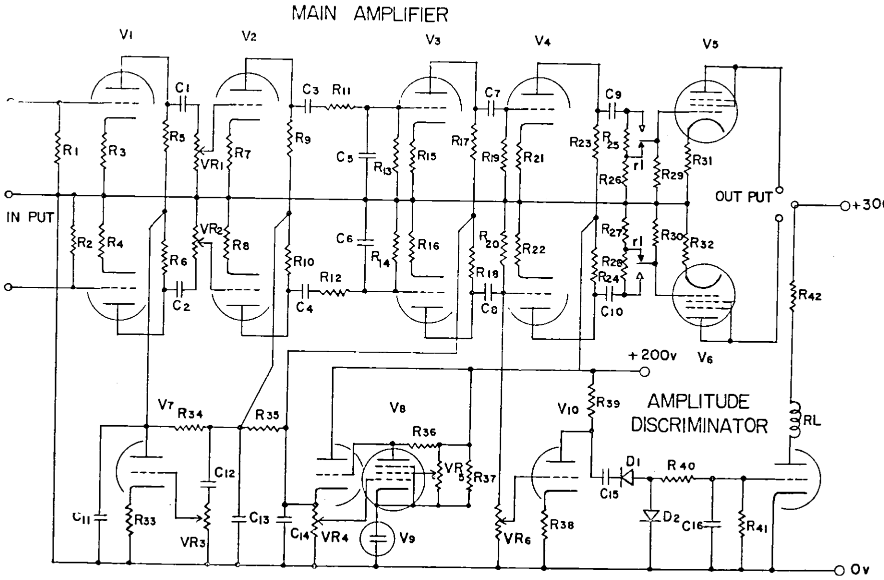

Fig. 1. Circuit diagram of the primarily designed amplifier.

$R_1R_2R_{13}R_{14}R_{19}R_{20}R_{25}R_{28}R_{29}R_{30}$	500 KΩ	$C_1C_2C_3C_4C_7C_8C_9C_{10}$	2 μF
R_3R_4	5 KΩ	C_5C_6	0.5 μF
$R_5R_6R_9R_{10}$	250 KΩ	$C_{11}C_{13}C_{14}$	20 μF
$R_7R_8R_{15}R_{16}R_{38}$	2 KΩ	$C_{12}C_{15}$	4 μF
$R_{11}R_{12}$	300 KΩ	C_{16}	1 μF
$R_{17}R_{18}R_{23}R_{24}$	100 KΩ	$VR_1VR_2VR_3VR_6$	500 KΩ
$R_{21}R_{22}R_{33}$	1 KΩ	VR_4	50 KΩ
$R_{26}R_{27}$	55 KΩ	VR_5	100 KΩ
$R_{31}R_{32}$	420 Ω	D_1D_2	1S112
$R_{34}R_{35}$	3 KΩ	$V_1V_2V_4$	6SL7
$R_{36}R_{41}$	1 MΩ	$V_3V_7V_{10}$	6SN7
R_{37}	30 KΩ	V_5V_6	6F6
R_{39}	50 KΩ	V_8	6SJ7
R_{40}	200 KΩ	V_9	5651
R_{42}	500 Ω	RL	FBV 151 01/1

The second design of the amplifier was developed in 1962, the constructed amplifiers being installed at Wakayama and Tottori Microearthquake Observatories and at all their substations.[3]

Fig. 2 shows the circuit diagram and the parts list, and Fig. 5 shows a sample of the seismogram obtained by the amplifier.

In the second design the gain change switch is put in the stage last

3) S. MIYAMURA and H. MATUMOTO, "The observation network in the southern part of the Kinki District," read at the 417th Monthly Meeting of the ERI, Jan. 28, 1964.

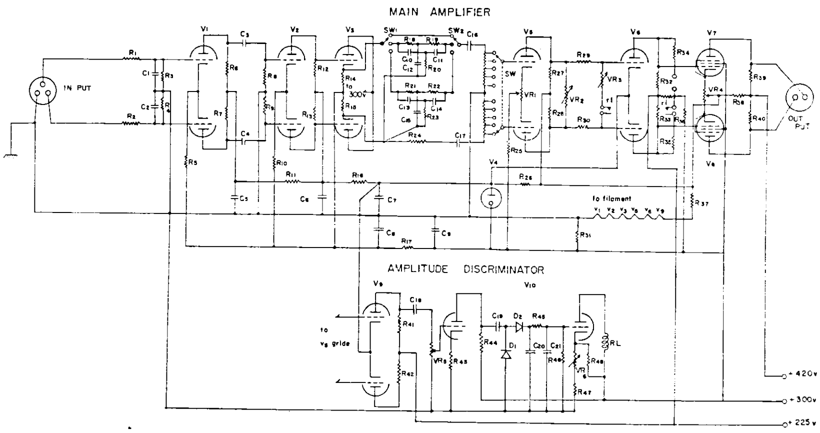

Fig. 2. Circuit diagram of the secondarily designed amplifier.

$R_1R_2R_{38}$	10 KΩ	$C_5C_6C_7C_8C_9$	60 μF
$R_3R_4R_{34}R_{35}$	5 KΩ	$C_{10}C_{11}C_{13}C_{14}$	0.02 μF
R_5R_{10}	4 MΩ	$C_{12}C_{15}$	0.04 μF
$R_6R_7R_{12}R_{13}$	300 KΩ	$C_{16}C_{17}$	3 μF
$R_8R_9R_{25}R_{27}R_{28}R_{29}R_{30}R_{32}R_{33}R_{46}$	1 MΩ	C_{18}	2 μF
$R_{11}R_{16}R_{17}R_{26}$	30 KΩ	C_{19}	1 μF
$R_{14}R_{15}$	100 KΩ	C_{20}	0.1 μF
$R_{18}R_{19}$	160 KΩ	C_{21}	0.5 μF
R_{20}	80 KΩ	VR_1	5 KΩ
$R_{21}R_{22}$	130 KΩ	VR_2	100 KΩ
R_{23}	65 KΩ	VR_3	500 KΩ
$R_{24}R_{36}$	200 KΩ	VR_4	30 Ω
$R_{31}R_{37}$	600 Ω	VR_5	1 MΩ
$R_{39}R_{49}$	2 KΩ	VR_6	3 KΩ
$R_{41}R_{42}R_{45}$	500 KΩ	D_1D_2	1S112
$R_{43}R_{47}$	1 KΩ	$V_1V_2V_5V_6V_9$	12AX7
R_{44}	80 KΩ	V_3V_{10}	12AU7
R_{48}	50 KΩ	V_7V_8	12GBS
C_1C_2	200 PF	V_4	VR-150
C_3C_4	4 μF	RL	FBV 151 01/1

but one, instead of the last stage as in the first design as shown in Fig. 1 and 2, in order to remove the distortion of signal waves and, moreover, to diminish circuit noise caused by the disturbance of the electric source which is induced by the saturation of the seismic signal.

However, in this case the DC balance of the 4th stage out-put must be adjusted more carefully in order to eliminate the switching noise in the record.

In both the first and second design, the valve of the relay driver

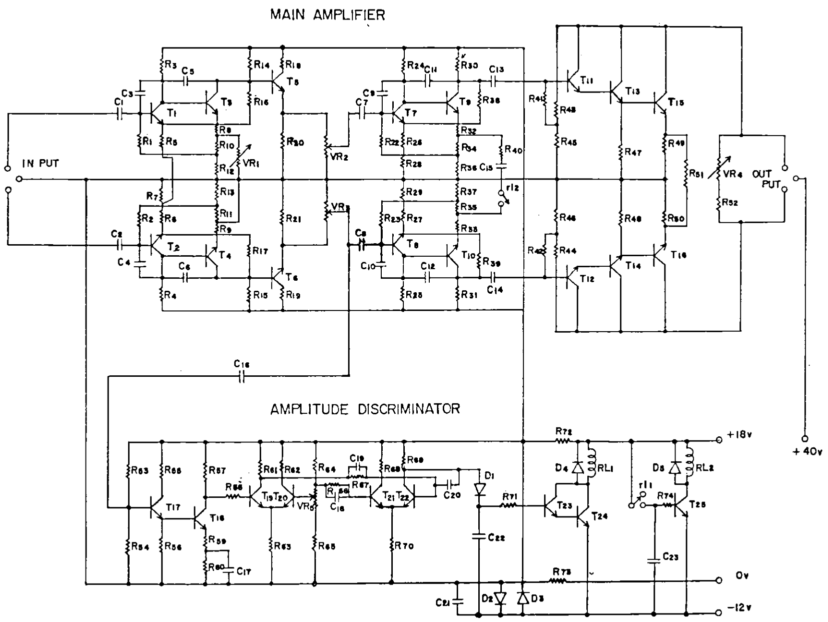

Fig. 3. Circuit diagram of the fourthly designed amplifier.

$R_1R_2R_{22}R_{23}R_{74}$	50 KΩ	$R_{66}R_{67}R_{71}$	20 KΩ
R_3R_4	96 KΩ	$C_1C_2C_7C_8C_{13}C_{14}$	200 μF
$R_5R_6R_{47}R_{48}R_{55}R_{58}$	1 KΩ	$C_3C_4C_5C_6C_9C_{10}C_{11}C_{12}C_{20}C_{21}$	0.01 μF
R_7	15 KΩ	$C_{15}C_{17}$	1000 μF
$R_8R_9R_{18}R_{19}R_{26}R_{27}R_{52}R_{72}$	500 Ω	C_{16}	10 μF
$R_{10}R_{11}$	4 KΩ	$C_{18}C_{19}$	0.001 μF
$R_{12}R_{13}$	5.5 KΩ	C_{22}	2 μF
$R_{14}R_{15}R_{20}R_{21}R_{24}R_{25}R_{56}R_{57}R_{64}R_{65}$	5 KΩ	C_{23}	100 μF
$R_{16}R_{17}$	300 KΩ	VR_1	10 KΩ
$R_{28}R_{29}R_{34}R_{35}$	1.5 KΩ	VR_2VR_3	50 KΩ
$R_{30}R_{31}R_{61}R_{62}R_{63}R_{68}R_{69}R_{70}$	2 KΩ	VR_4	1 KΩ
$R_{32}R_{33}R_{40}$	100 Ω	VR_5	5 KΩ
$R_{36}R_{37}R_{60}$	3 KΩ	$D_1D_4D_5$	SD46
$R_{38}R_{39}$	30 KΩ	D_2D_3	RD7A
$R_{41}R_{42}$	35 KΩ	$T_1T_2T_3T_4T_7T_8T_{17}T_{18}T_{19}$	
$R_{43}R_{44}$	80 KΩ	$T_{20}T_{21}T_{22}T_{23}T_{24}$	2SC266
$R_{45}R_{46}$	10 KΩ	T_5T_6	2SC267
$R_{49}R_{50}$	3 Ω	T_9T_{10}	2SC123
R_{51}	4 Ω	$T_{11}T_{12}T_{13}T_{14}$	2SC149
R_{53}	600 KΩ	$T_{15}T_{16}$	2SC245
R_{54}	500 KΩ	T_{25}	2SC268
$R_{59}R_{73}$	300 Ω	RL_1RL_2	FBV153 71/101

was constructed so as to keep the gain of the amplifier in ordinary state if and when it failed to function correctly, in order to remove the trouble in the gain change due to the relay driver.

Adoptation of the method in the equipment of the Micro-earthquake Observatories enabled us to observe the earthquakes of 4 magnitude range satisfactorily for all the earthquakes which occurred in their service areas.

The third design of the amplifier was effected with transistorized amplifier which is included in the movable Ultra-sensitive Seismometer Array System constructed in 1962 and described in the paper in 1965.[4]

The fourth design of the amplifier just completed is newly prepared for the long time continuous recorder, the maximum record time being 30 days by one roll of paper with width 40 cm length 40 m with 4 mm/sec paper speed. The circuit diagram and the parts list are shown in Fig. 3. The relay driver is constructed with two stages in order to remove the relay chatter as occurred in the 4th design which is induced by the decrement of the relay circuit time constant due to the transistor adoptation

Three kinds of electric source of the amplifier are used now, but in future they are expected to be unified to one kind, e.g. +12 V only instead of −12 V, +18 V and +40 V as now, by the development of highly sensitive high frequency pen galvanometer and highly sensitive relay in order to increase the movability of the amplifier.

4. Conclusion

Certification of the mutual relation between the P arrival time and the S-P time is the most useful measure to check the correctness of identification of P and S phases, and also S-P time alone is very convenient data to determine the hypocenter by as few stations as possible.

The duty of the micro-earthquake observatory[5] is, first of all, the determination of the magnitude and the location of micro-earthquakes with magnitude less than 3 which occurred in the service area.

The electronic seismographs with these AGC amplifiers increase the possibility of observing the S phase and the maximum amplitude of the

4) H. MATUMOTO, "A Mobile Ultra-Sensitive Seismograph Array System by Means of Magnetic Tape Recorder," *Bull. Earthq. Res. Inst.*, **43** (1965) 441-449.

5) C. TSUBOI, K. WADATI and T. HAGIWARA, "Prediction of Earthquake," Jan. 1962.

earthquake in complete form, the accuracy of observation and the determinable magnitude also increasing very much by making use of the step-wise gain control amplifier without giving any difficulty in operation or any change of the quality of the seismic recording.

Acknowledgement

This work was initiated and supervised by Prof. S. Miyamura, to whom the author's thanks are due. The author thanks Mr. T. Hirai and Mr. O. Kawamoto of Iwai Denki Co., Ltd. the manufacturer of the amplifiers.

The contribution of many persons attached to the Wakayama Micro-earthquake Observatory for the certification of the amplifier by the operation is also greatly acknowledged.

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68. 微小地震常時観測のための地震計増幅器の階段的利得自動切換

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地震活動度研究室では紀伊半島における微小地震調査の経験から微小地震常時観測にたいする能率的観測態勢を確立した.

1つは観測点配置について，1つは装置についてであるが本文では使用する増幅器について開発された装置を紹介する.

微小地震観測所には地震予知計画にもとづいてその分担地域がきめられ，分担地域内に発生した0から3までのマグニチュードの地震についてその活動度を調査する任務が課せられている.

この任務を遂行するにあたり，観測点相互の距離と小規模地震の波動減衰の問題との影響で普通のダイナミックレンジで記録を実施していたのではS波の同定や最大振幅の検測に問題がおおく効果的観測は期待できない.

装置の拡張および特別な保守を必要とせず，しかも検測が容易であるダイナミックレンジ拡張法として階段的利得切換をおこなうことが微小地震常時観測に最適だとおもわれるので順次装置を開発した.

第1第2の設計は真空管で第3第4はトランジスターで設計をおこない構成された増幅器は初期の目的を満足させ確実に動作している.

これまでの使用結果によりアナログの可視記録法では微小地震観測装置の増幅器にこの方法を採用することがよい観測結果をもたらすことを確認したので報告する次第である.

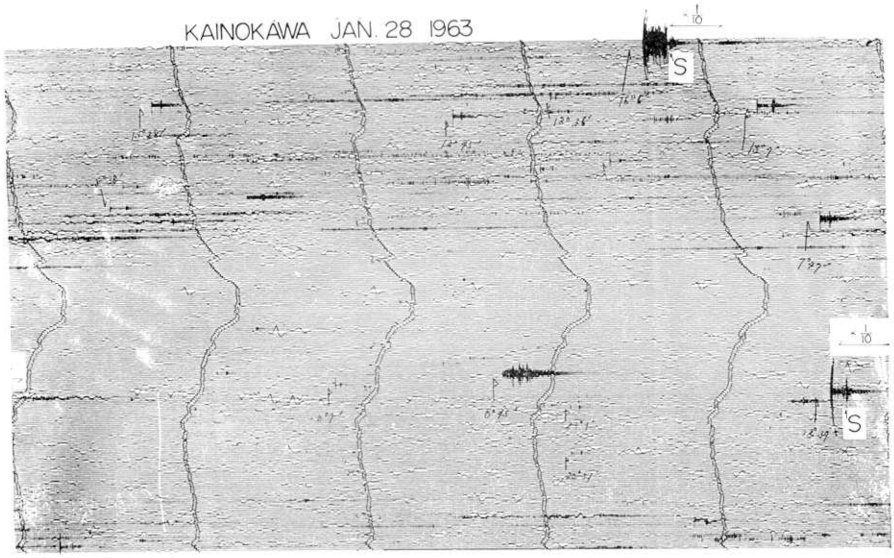

Fig. 4. A sample of the seismogram obtained by the primarily designed amplifier, in which successful records of AGC are indicated by S.

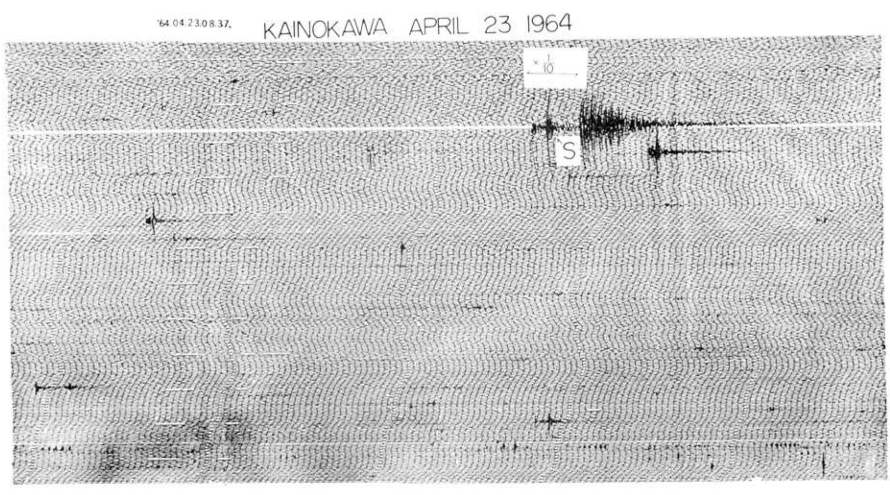

Fig. 5. A sample of the seismogram obtained by the secondarily designed amplifier. The successful records of AGC are indicated by S in the seismogram.

(震研彙報 第四十四号 図版 松本)