Origin of artificial noises on broadband seismograms and possible prescription to remove them

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Abstract Artificial noise, which was generated simultaneously as a data storage's hard disc drive started up, has been recorded in STS-1 broadband seismometers' output at two seismic stations where were established over western Pacific Ocean. If this periodical noise is included in the data, it may disturb our analyses of long period ground motions. For this reason, we conducted the experiments under several conditions to find the origin of this noise and to remove it. As a result, the noise wasn't generated by separating a ground line for frame ground from that for power return in the laboratory and the station, which means that the noise was generated by adding some impedance to the ground line for power return. We also propose some ideas to improve the instrument so that this noise may be not generated even if we short the ground line for frame ground and that for power return.

Keywords: STS-1 broadband seismometer, power supply, artificial noise, grounding

1. Introduction

We have been operating terrestrial broadband seismograph observation network in the western Pacific region, which was established during the Ocean Hemisphere Project[1)]. Currently we are using the same configuration of the instruments at nine stations to measure ground motions. We found that, at two stations of them, BAG station (Baguio, Republic of the Philippines) and PATS station (Ponape, Federated States of Micronesia), step-like noise has been recorded in the up-down component of the seismometer (Fig.1). This noise cannot be distinguishable in raw data sampled at 20Hz, but it becomes apparent after filtering since its amplitude is much smaller than that of background noise. We found that this noise is generated simultaneously as a rush current flow and successive sudden drop of the supplied voltage in the power line, especially a startup of data storage's hard disc drive (PB-14). In addition, the frequency of PB-14's startup depends on

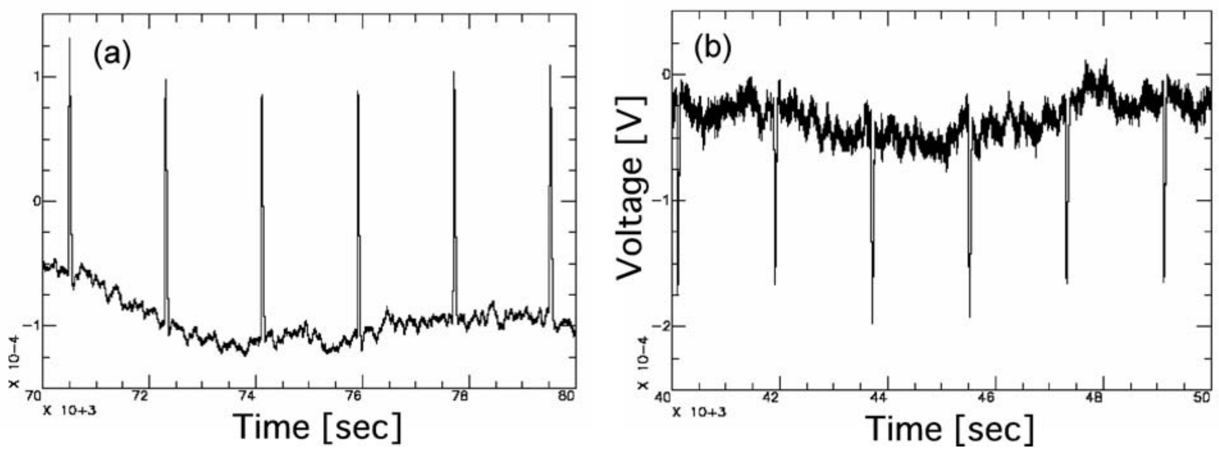

Figure 1: (a) The wave of STS-1 Up-Down seismometer at BAG sampled at 20 Hz and filtered with band-pass filter between 100-10000sec. (b) The wave of STS-1 Up-Down seismometer at PATS. The data was sampled at 20 Hz and filtered with band-pass filter between 100 and 10000sec. A division of the horizontal axis is 500 sec.

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the version of its firmware; PB-14 starts up every 30 minutes with the version bellow 1.87 and it does 15-20 times every 30 minutes intermittently with the version of 1.87 or above (Fig.2). If this noise is included in a seismometer's record, it may not be negligible when we analyze very small and long ground motion, especially the earth's background free oscillations whose amplitude are the order of 10-6V in STS-1 broadband seismometer's output. To make matters worse, it is difficult to use some filtering to remove this noise from raw data since this noise forms step-like shape. Here, we show the result of our simulation how the noise can be generated in the laboratory and how we can remove the noise. We also propose a future work how we can protect ground motions recorded by seismometers from some artificial noise

2. Instrumental configuration of measuring ground motions

We have observed ground motions, using three Streckeisen STS-1 broadband seismometers[2] (Up-Down, North-South and East-West axes), the data logger Quanterra Q330 and the hard disc PB-14 manufactured by Kinemetrics Inc. with the power supply PSC150[3] manufactured by T&F, Inc.. A STS-1 seismometer converts single axis of ground velocity to the voltage with a transducer coil, and then sends it to Q330 as a pair of differential signal. The Q330 has three channels of 24bit A/D demodulator in one input connector, measuring three pairs of differential signals from STS-1 seismometers; The PB-14 is Q330's exclusive hard disc, restoring measured values as files with maximum capacity of 20GB. The PSC150 was specially produced in order to supply power to STS-1, Q330 and PB-14, and send the signals from STS-1 seismometers to Q330 after binding three signal cables from STS-1 seismometers into one cable. In addition, stable power supply can be realized because a battery connected outside PSC150 supplies the power to the instruments in case of a power failure. According to the design specifications of PSC150 (Fig.3), the AC-DC converter (LDA50F-15-YSN manufactured by COSEL Co., Ltd.) supplies +12VDC (+9~18VDC) to Q330 and PB-14 and then DC-DC converter (AQD12-15D0.8A manufactured by Asia Electronics Ind. Co.,Ltd.) supplies ±5VDC to STS-1 seismometers (Fig.4). Incidentally, when we measured the voltage of power supply to Q330&PB-14 (+12VDC) and STS-1 (+15VDC), it was found that +12VDC dropped at the same time as PB-14 started running; on the other hand, +15VDC was constant even if PB-14 started running (Fig.5). As for the ground lines of the entire system, once all instruments are connected to each other, the ground lines for AC-DC and DC-DC converter are connected to the Q330's ground terminal (GND terminal); meanwhile, the aluminum plate at the bottom of PSC150, the chassis of AC-DC converter and the shield coatings of cables are connected to PSC150's frame ground terminal (FG terminal) (Fig.4). Additionally, since GND and FG terminals are insulated, we have grounded them in two ways; one way is to short two terminals with the ground line whose cross section of conductor is 1.25mm^2 and ground one of them (common grounding); the other is to ground two terminals at the same ground point respectively (single point grounding).

3. Simulation of the noise generation

First, to reproduce the noise, which seems to be generated simultaneously as the startup of PB-14, in our labora-

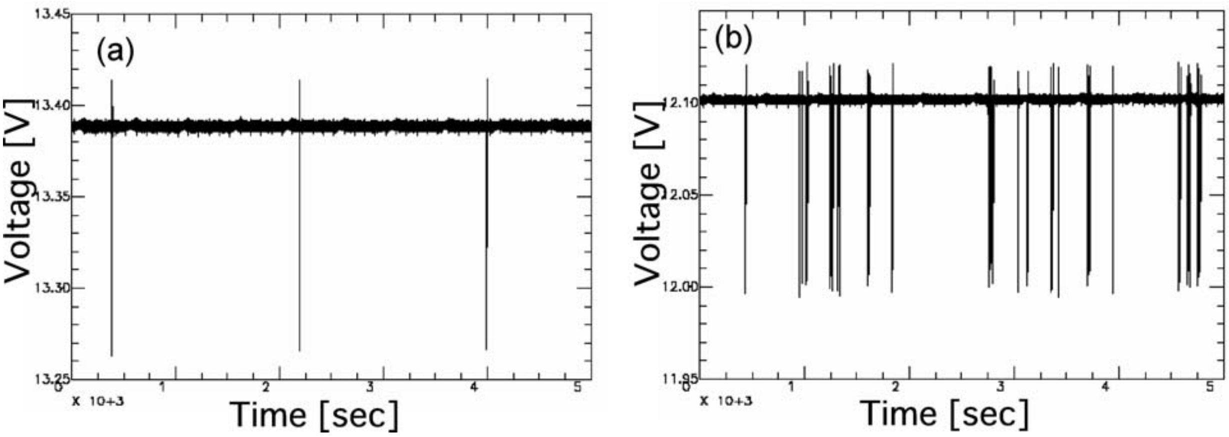

Figure 2: (a) The voltage of power supplied to Q330 and PB-14 whose firmware is below version 1.87. The data was sampled at 20 Hz. (b) The voltage of power supplied to Q330 and PB-14 whose firmware is 1.87 or above. The data was sampled at 20 Hz. A division of the horizontal axis is 250 sec.

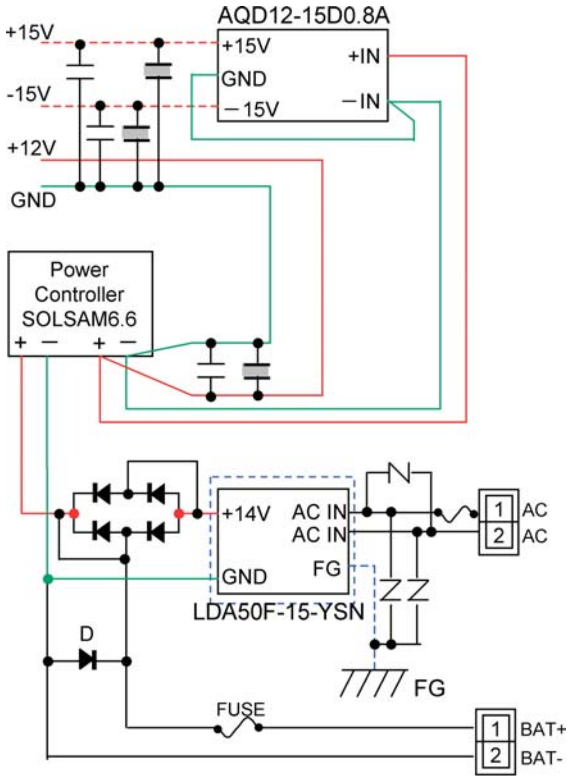

Figure 3: The design specifications of PSC150 which we devised for the sake of convenience. Red solid and dashed lines illustrate the power lines of +12VDC (+9-18VDC) and ±15VDC respectively. Green Solid and blue dashed lines illustrate the ground lines of power return and frame ground respectively.

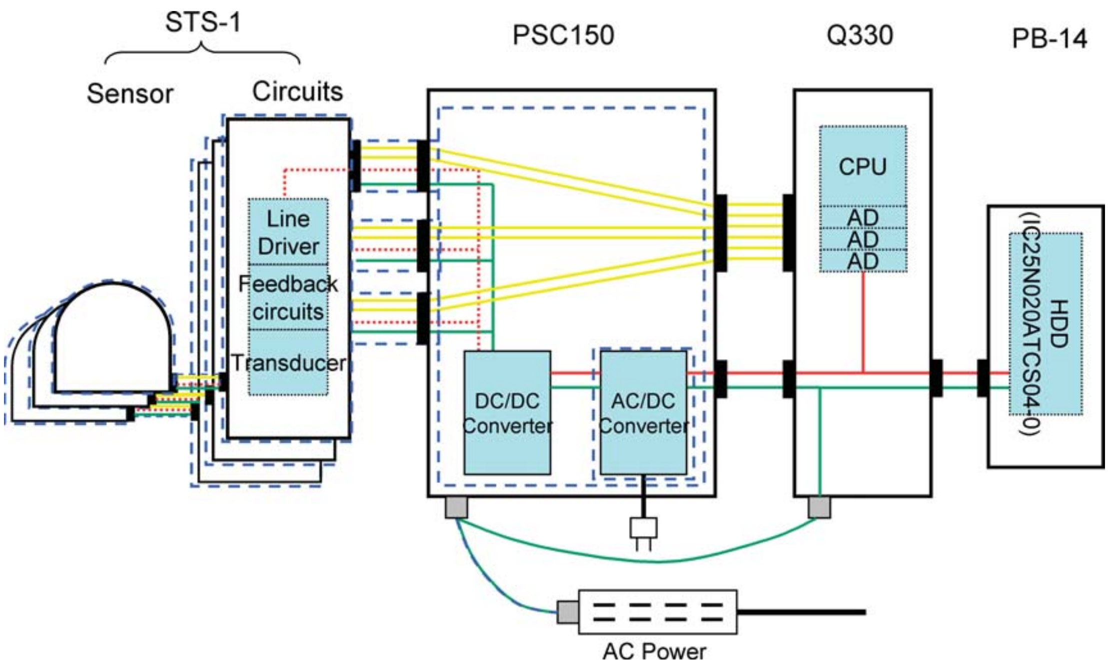

Figure 4: The wiring diagram of STS-1 seismometers, Q330, PB-14 and PSC150. Yellow solid lines illustrate the signal lines. Red solid and dashed lines illustrate the power lines of +12VDC (+9-18VDC) and ±15VDC respectively. Green Solid and blue dashed lines illustrate the ground lines of power return and frame ground respectively.

tory, we have set up the same configuration of observation system as our field station, using one STS-1 seismometer (Up-Down axis), Q330, PB-14 and PSC150 (Fig.6a). In this experiment, we used the same cable between STS-1 and PSC150 as we have used at BAG, and applied common grounding, regarding a ground point as a ground terminal of AC power outlet. As a result, we couldn't distinguish the noise which was recurred in BAG's and PATS's data, even if any filter had been applied to the data (Fig.6b). We suppose that this result is attributed to the fact that the amplitude of background noise at the laboratory is 30 to 50 times as large as that at BAG and PATS. Therefore, we tried to remove the STS-1 seismometer and short a pair of the differential signal inputs on Q330 to remove the background noise (Fig.7a). However the noise wasn't still generated in the shorted channel (Fig.7b). This result suggests that we need to input very small differential signals to Q330 instead of STS-1's signals. We prepared an oscillator and made the equivalent circuit of STS-1's line driver circuit (LD circuit) which turns an input signal into a pair of differential signals (Fig.8), and then connected an oscillator through LD circuit (Fig.9a). As a result, the noise was generated even if LD circuit, whose inputs were shorted, was only connected without an oscillator (Fig.9b). However, the amplitude of this noise generated at the laboratory was much smaller than that at BAG and PATS. This difference of the amplitudes may be due to the difference of oscillator which inputs signal to Q330, because STS-1 seismometers, especially Up-Down component, have an amplifier with so large gain, which makes this noise remarkable. Thus, we may assume that the noise of LD circuit and STS-1 seismometers at BAG and PATS are generated by the same mechanism. In the following section, we use LD circuit as a input source and tried to remove the noise in the laboratory. In addition, we had used only one input channel of Q330 to conduct these experiments, assuming that three input channels of Q330 are equivalent since the signal from LD circuit generated this noise in any channel.

4. Removal of the noise

4.1 Separating the power supplies

We had conducted several experiments with various conditions to investigate the cause of the noise in the signal line and find the countermeasures how to remove or reduce the noise. First, we supplied the power to Q330

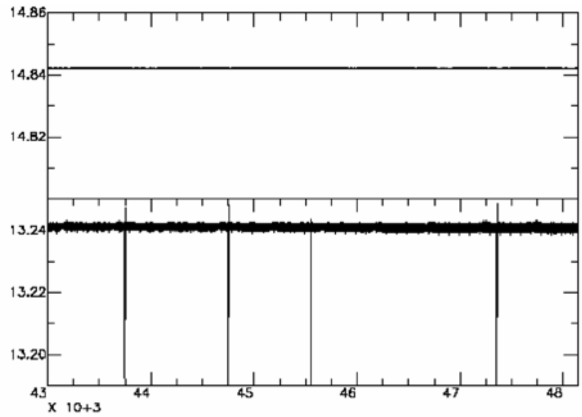

Figure5: The sudden voltage drop of PSC150. Top figure illustrates the voltage +15V supplied to STS-1 seismometer. The data was sampled at 20 Hz. Bottom figure illustrates the voltage +12V supplied to Q330 and PB-14. The data was sampled at 20 Hz. A division of the horizontal axis is 250 sec.

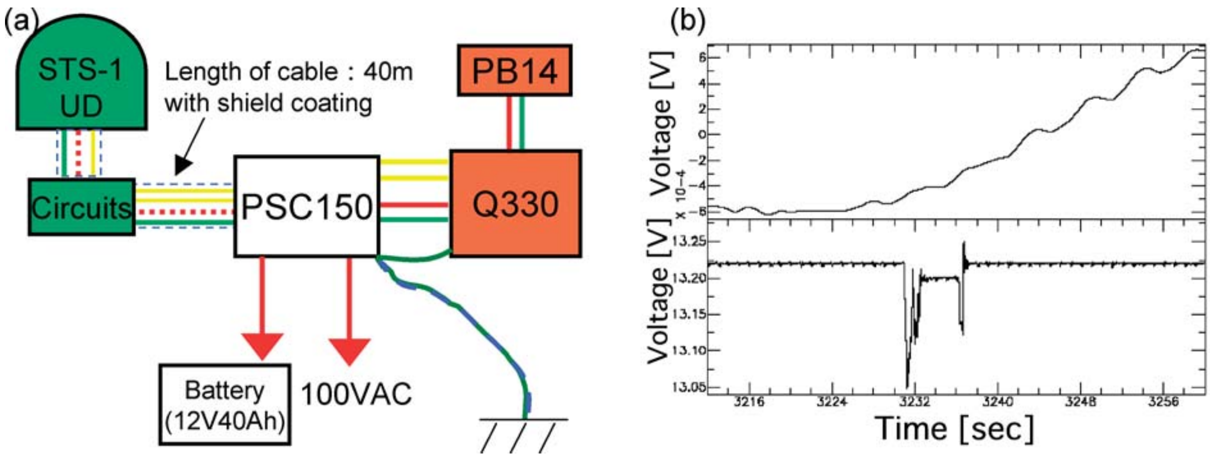

Figure6: (a) The diagram of instrumental configuration which imitates that at BAG. The meanings of line's colors are same as Fig.4. (b) Top figure illustrates the output of STS-1 seismometer sampled at 20 Hz and filtered with band-pass filter between 100 and 10000sec. Bottom figure illustrates the voltage supplied to Q330 and PB-14. The data was sampled at 20 Hz. A division of the horizontal axis is 2 sec.

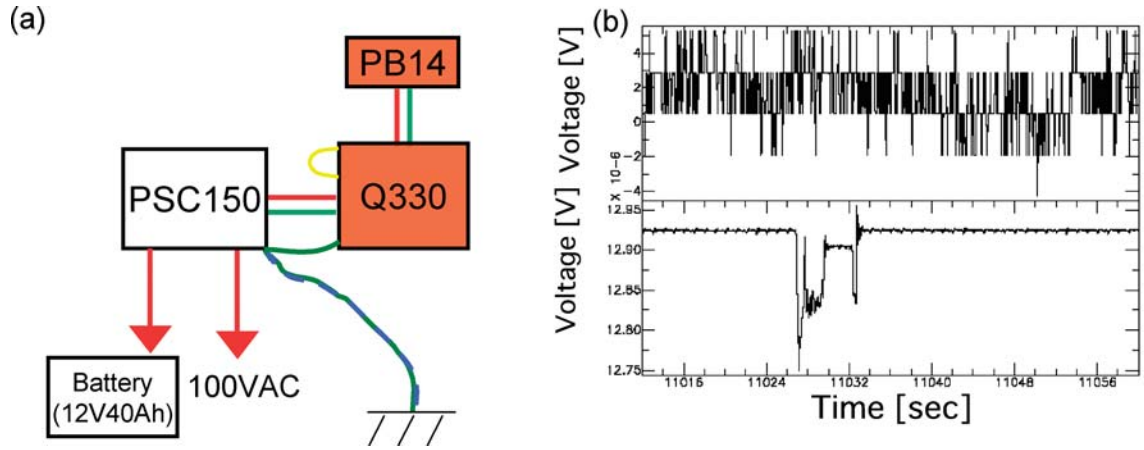

Figure7: (a) The diagram of instrumental configuration without the input to Q330. (b) Top figure illustrates the output of Q330 shorted its differential inputs. The data was sampled at 20 Hz. Bottom figure illustrates the voltage supplied to Q330 and PB-14. The data was sampled at 20 Hz. A division of the horizontal axis is 2 sec.

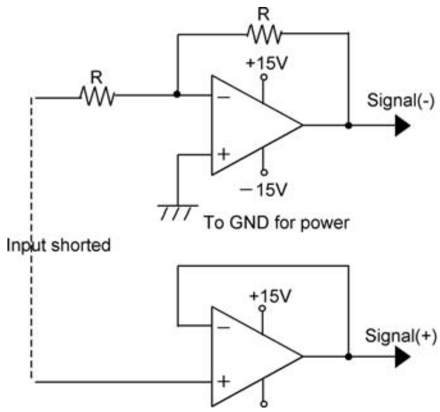

Figure8: The design diagram of the equivalent circuit of STS-1's line driver (LD circuit).

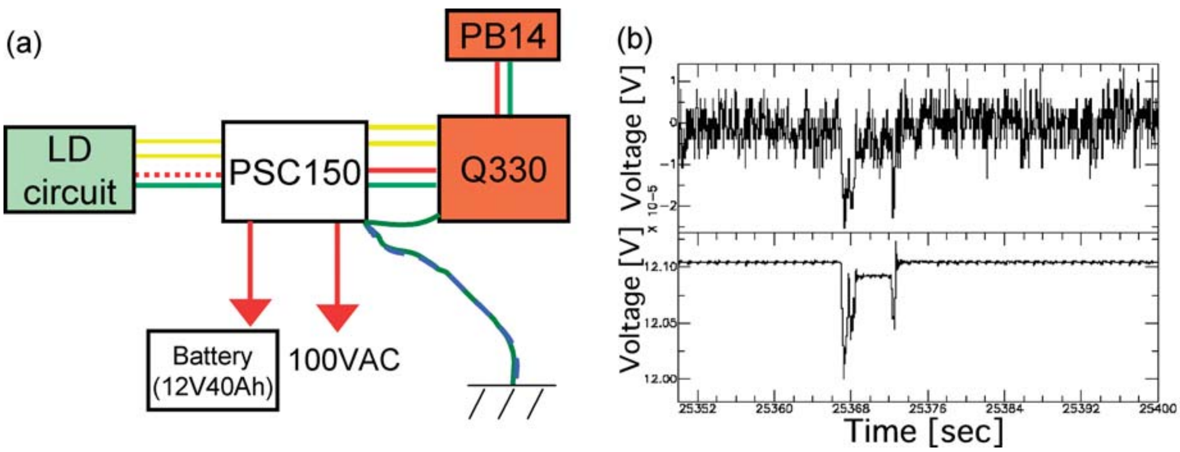

Figure9: (a) The diagram of instrumental configuration with LD circuit as input. (b) Top figure illustrates the output of LD circuit sampled at 20 Hz. Bottom figure illustrates the voltage supplied to Q330 and PB-14. The data was sampled at 20 Hz. A division of the horizontal axis is 2 sec.

and PB-14 by another device because it is likely that the energy capacity of PSC150 isn't enough to compensate for all instruments although PSC150 has enough energy capacity theoretically. The power of LD circuit was supplied from PSC150; on the other hand, the power of Q330 and PB-14 was supplied from AD-740U-1138 which was the attachment for Q330 (Fig.10a). The result shows that the noise was slightly generated in the signal from LD circuit but not significant (Fig.10b), which indicates the lack of PSC150's capacity doesn't cause the noise of the LD circuit's signal.

4.2 Direct input of the signals to Q330

PSC150 is very small in the size of 250×175×100mm since PSC150 was produced with the requirement of portability. Because of the size limitation, signal lines from STS-1 seismometers, power lines and ground lines in PSC150 are tied together to some parts. There is a possibility that these tied lines might generate the noise in the signal lines (crosstalk) when the power is fluctuating sharply. For this reason, we connected the signal lines from LD circuit to Q330 directly not through PSC150 (Fig.11a). However, the noise was still generated in the signal from LD circuit (Fig.11b), which means that the noise doesn't result from the crosstalk between the signal line and the power line.

4.3 Changing the way of grounding

We had conducted those experiments that were shown in the previous sections under the same condition of common grounding. Next, we tried to apply single point grounding which is generally known as the best way of grounding (Fig.12a). The result of this experiment shows that the noise was generated with the amplitude of more than 10 times larger than the occations with the common grounding (Fig.12b). This result indicates that the behavior of the noise strongly depends on the way of grounding (Fig.9, 12); therefore, we selected the length of the ground line between GND terminal and the ground point (=1m) such as 2m or 4m (Fig.13a). As a result, the noise was generated with reverse phase to that of the supplied voltage drop in case of 2m or 4m (Fig.13b), whereas it was done with the same phase as that of the supplied voltage drop in case of 1m (Fig.12b). In addition, even though we changed the diameter of this ground line, the behavior of the noise was almost comparable with any diameter. As the results of above experiments, we could reach the conclusion that we should remove the ground line from FG terminal on PSC150 and remain connecting the ground line from GND terminal to the ground point (Fig.14a). As a result, the noise wasn't generated in signal of LD circuit (Fig.14b).

4.4 Noise removal at BAG

Now that we have discovered the countermeasure, which is to disconnect the GND from FG terminal to remove the noise generated by a rush current in the power line, we applied this countermeasure to BAG station. We have confirmed that the noise of STS-1 seismometer wasn't generated (Fig.15). This result indicates that this countermeasure is effective against the noise, and also that our assumption, that the noise of LD circuit at the laboratory and STS-1 seismometers at BAG can be generated under same mechanism, is appropriate.

5. Discussion & Conclusion

As was shown above, without connecting the ground line between GND and FG terminal, the noise which synchronizes with PB-14's startup wasn't generated both in the laboratory and BAG. Additionally, based on the results of the above experiments, we could conclude that the noise is generated by adding the impeadance, such as PSC150's frame to a flow of current between GND terminal and the ground point. The ground line from GND terminal need to be idealistically shorted to the ground without impedance since it is connected with the return lines of the power (=0V). However, some impedance can be generated between GND terminal and the ground, once GND and FG terminal are connected (Fig.16a). In this case, if a rush current flows by PB-14's startup, the current can flow in the ground line and then the electric potential difference (=V_{gnd}) can be generated between the GND terminal and the ground (Fig.16b). We think that the noise is generated in signal line owing to this electric potential difference in the ground line. In addition, we also think that the different behaviors of the noise, appeared in the experiments, with various ground line or the way of grounding FG and GND terminal are caused by the difference of impedance between GND terminal and the ground, which proves the fact that the noise is generated at some stations but isn't at the other stations. However, under the above conclusion, there is a possibility that the noise will be generated if the length of ground line is extremely long, that is, the impedance is extremely high between GND terminal and the ground. In this case, disconnecting the ground line between GND and FG terminal may not remove the noise but just reduce it. However, disconnecting FG terminal to the ground also may cause the problem that it cannot protect perfectly the signal lines against the noise with high frequency, such as a hum noise. It is because the shield coatings of cables are connected to FG terminal.

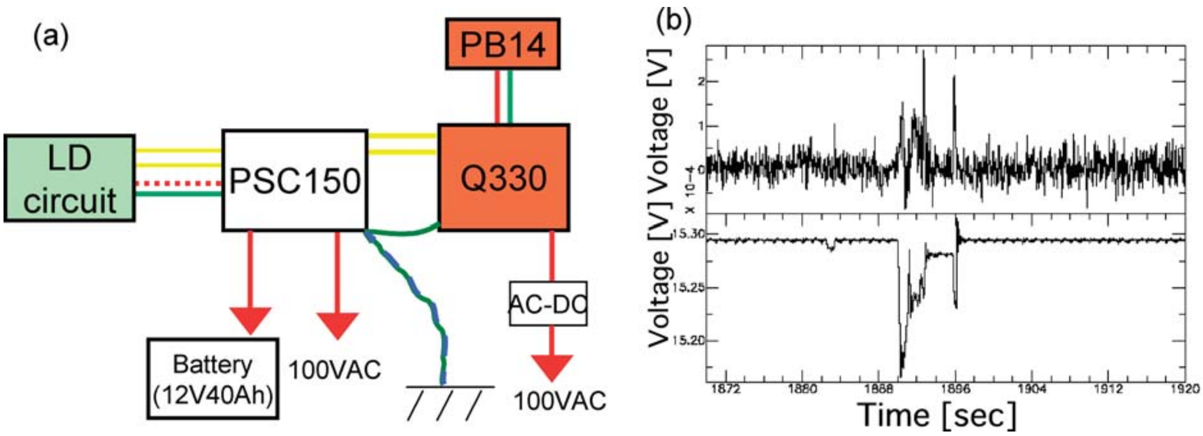

Figure10: (a) The diagram of instrumental configuration on the condition of separating the power supply of Q330 and PB-14 from PSC150. (b) Top figure illustrates the output of LD circuit sampled at 20 Hz. Bottom figure illustrates the voltage supplied to Q330 and PB-14. The data was sampled at 20 Hz. A division of the horizontal axis is 2 sec.

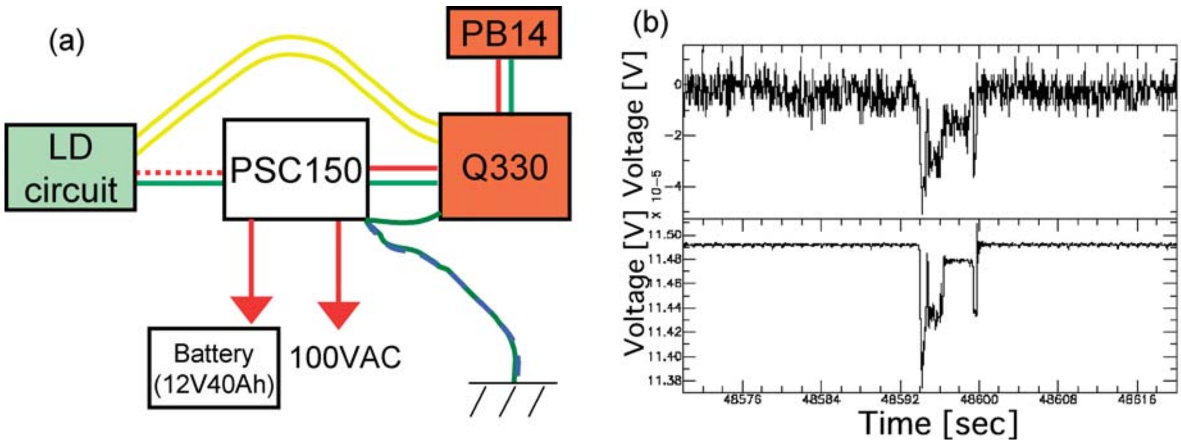

Figure11: (a) The diagram of instrumental configuration on the condition of sending the signals of LD circuit to Q330 not through PSC150. (b) Top figure illustrates the output of LD circuit sampled at 20 Hz. Bottom figure illustrates the voltage supplied to Q330 and PB-14. The data was sampled at 20 Hz. A division of the horizontal axis is 2 sec.

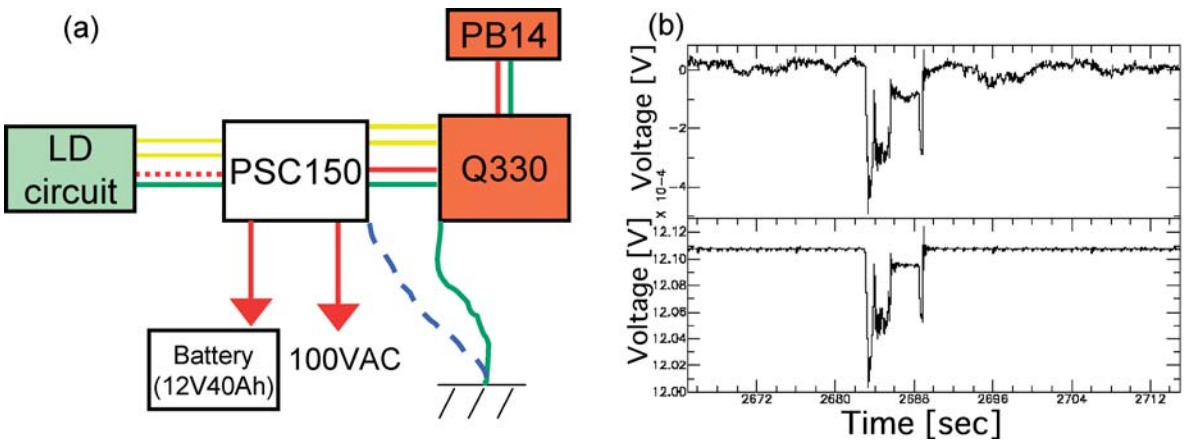

Figure12: (a) The diagram of instrumental configuration with single point grounding. (b) Top figure illustrates the output of LD circuit sampled at 20 Hz. Bottom figure illustrates the voltage supplied to Q330 and PB-14. The data was sampled at 20 Hz. A division of the horizontal axis is 2 sec.

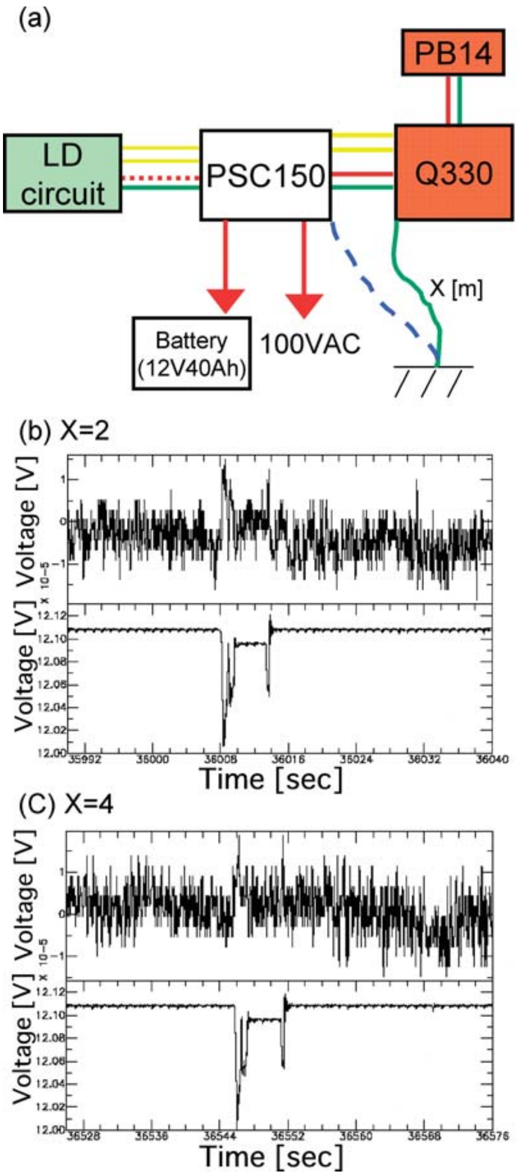

Figure13: (a) The diagram of instrumental configuration with various length (=X) of line between Q330's GND terminal and the ground point. (b) Top figure illustrates the output of LD circuit sampled at 20 Hz with X=2. Bottom figure illustrates the voltage supplied to Q330 and PB-14. The data was sampled at 20 Hz. (c) Top figure illustrates the output of LD circuit sampled at 20 Hz with X=4. Bottom figure illustrates the voltage supplied to Q330 and PB-14. The data was sampled at 20 Hz. A division of the horizontal axis is 2 sec.

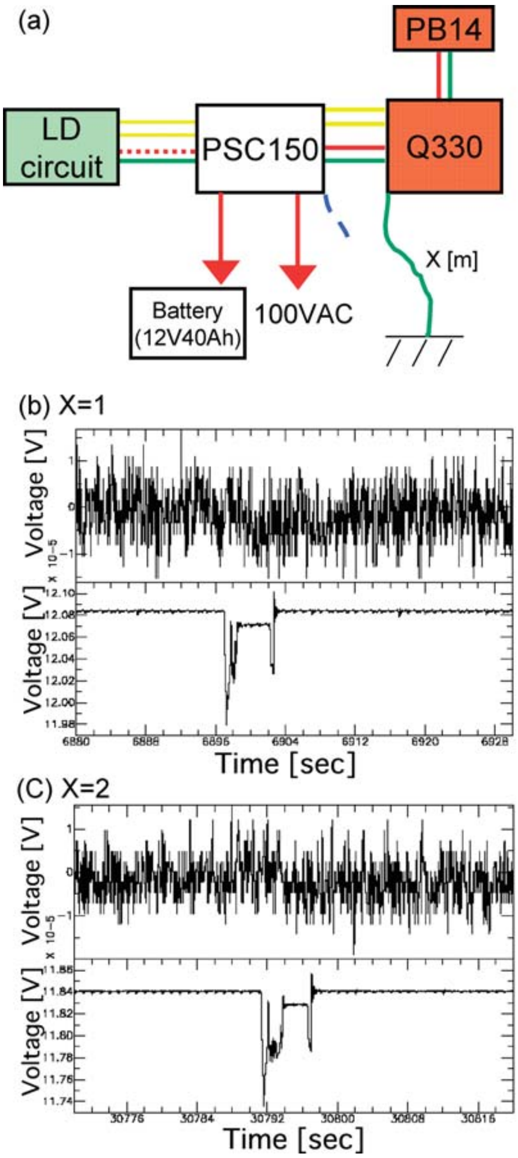

Figure14: (a) The diagram of instrumental configuration on the condition of disconnecting the ground line between FG and GND terminals with various length (=X) of line between Q330's GND terminal and the ground point. (b) Top figure illustrates the output of LD circuit sampled at 20 Hz. with X=1. Bottom figure illustrates the voltage supplied to Q330 and PB-14. The data was sampled at 20 Hz. (c) Top figure illustrates the output of LD circuit sampled at 20 Hz with X=2. Bottom figure illustrates the voltage supplied to Q330 and PB-14. The data was sampled at 20 Hz. A division of the horizontal axis is 2 sec.

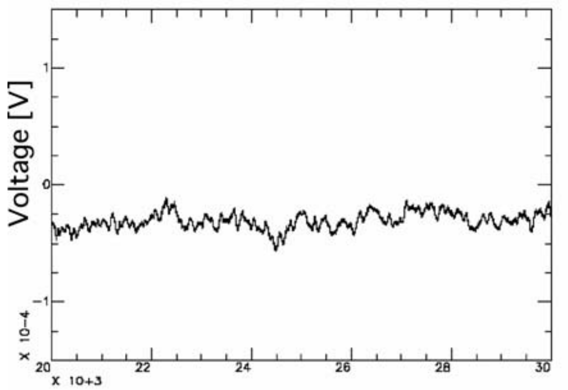

Figure15: The wave of STS-1 Up-Down seismometer at BAG sampled at 20 Hz and filtered between 100 and 10000sec without the ground line between FG and GND terminals. A division of the horizontal axis is 500 sec.

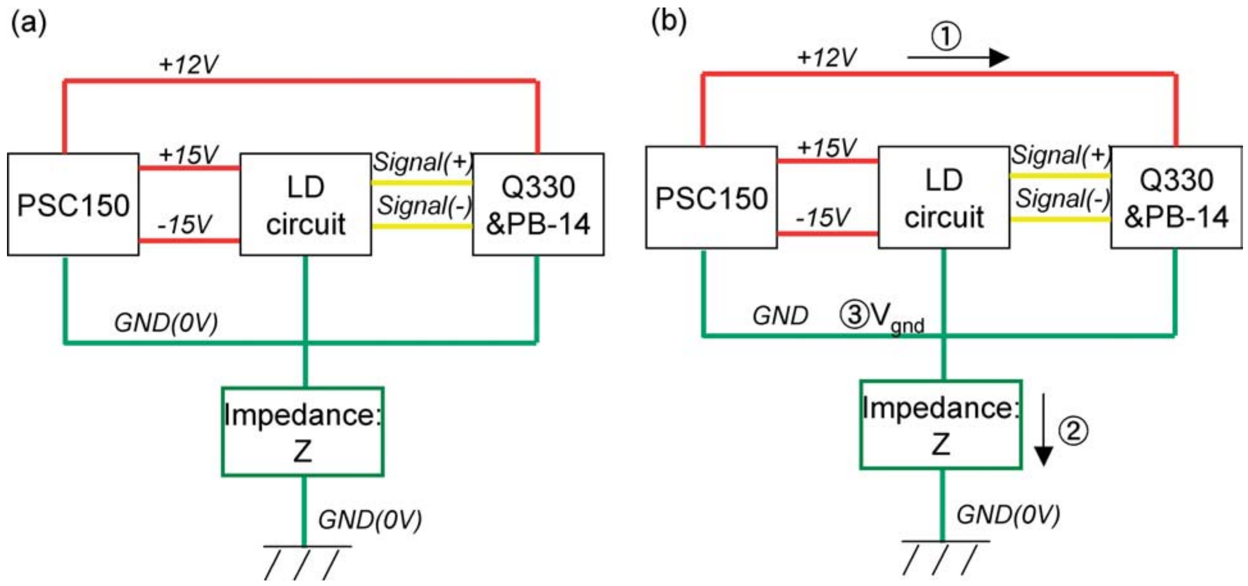

Figure16: The conceptual diagram of the noise generation. (a) Some impedance (=Z) can be generated by connecting FG and GND terminals. (b) If a rush current flows in the power line (=①), some current flows into the impedance (=②) and then some voltage is generated in the ground line (=③).

Therefore, when FG terminal isn't connected to the ground, it is necessary to take countermeasures for protecting the signal lines against high-frequency noise, by connecting, for example, the FG terminal to the aluminum or copper plate which has an equipotential surface in stead of the ground.

So far we have discussed how we can remove the noise without improving the instruments. Meanwhile, we will propose two ideas to improve PSC150 so as not to generate the noise in the signal lines even if GND and FG terminals are shorted. One proposal is to make much higher impedance of the signal lines than that of ground lines. For example, equipping the differential signal lines with the common mode choke coils protects them against the noise equally generated in both differential signal lines, such as an impulsive or step-like noise (Fig.17). The other proposal is to reduce the current in the ground line. For example, equipping the loop of the power and ground line with the ferrite beads absorbs the noise generated by a rush current (Fig.17). To ascertain whether these improvement of PSC150 are effective in removing the noise or not, we will conduct some experiments in the future.

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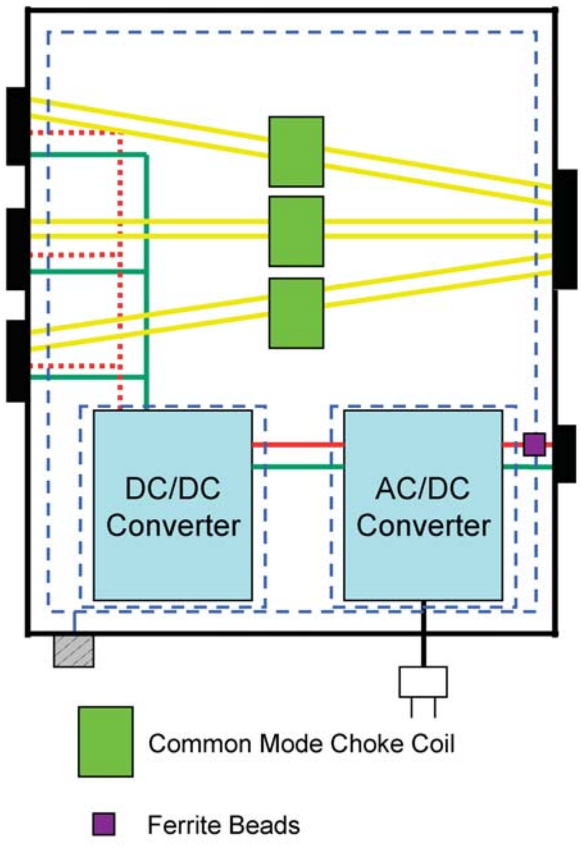

Figure17: Our proposal for new PSC150 to protect the signal lines against the artificial noise. One improvement of it is to connect the common mode choke coils to the signal lines against common mode noise. The other is to connect the ferrite beads to the power lines against normal mode noise.division of the horizontal axis is 500 sec.