Developing a Thin-film Low-noise Hall Element for Use in Current Probes

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***Abstract*—The Clamp On Probe 3273-50 and 3276 are current probes that are capable of measuring a wide band of frequencies from DC to several megahertz to facilitate observation of current waveforms with an oscilloscope. In this project, Hioki developed a thin-film low-noise Hall element ("Hall element"), which is a key device in current probes, to accommodate market demand for improved low-current measurement capability. This paper describes the general property and the characteristics of the Hall element.**

I. Introduction

The Clamp On Probe 3273-50 and 3276 are current probes that can observe current waveforms with an oscilloscope. Their most remarkable feature is their wideband frequency characteristics, which enable them to measure targets ranging from DC to AC currents at 50 MHz (−3 dB, 3273-50) or 100 MHz (−3 dB, 3276). Thanks to this capability, these sensors are utilized in a wide range of applications, including measurement of high-speed switching waveforms and transient response waveforms[1].

These probes use a Hall element Hioki manufactured to detect the magnetic flux passing through a magnetic core (see Fig. 1). By using a thin-film Hall element, the ability to minimize the gap between the magnetic core is achieved, which improves the S/N ratio[1].

The need to measure minute electric current has been increasing in recent years, requiring the development of increasingly high-sensitivity Hall elements. To fulfill this need, Hioki developed a Hall element that reduces 1/*f* noise to 1/10 the level of legacy models.

II. Requirements

The following describes the element characteristics and production requirements associated with Hall elements designed for use in current probes:

A. Requirements: Element Characteristics

1) Relationship between electron mobility and element characteristics

As shown in (1), the electron mobility μ, which indicates the performance of a Hall element, can be expressed as relation between the resistance R and the sensitivity K_H. In

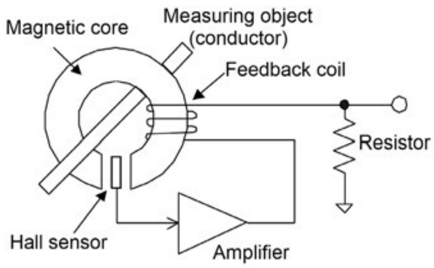

Fig. 1. Current Probe Structure

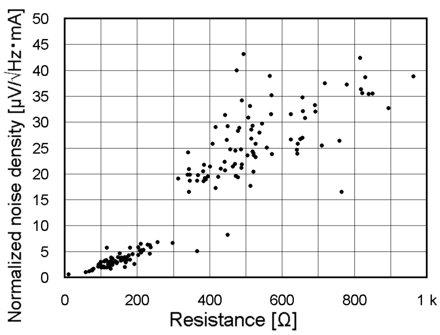

Fig. 2. Noise Density at 10 Hz

(1), A is a constant derived from the element shape and other factors.

$$\mu = A \cdot \frac{K_H}{R} \left[\mathrm{m^2/V{\cdot}s}\right] \quad (1)$$

As indicated in (1), smaller resistance and higher sensitivity result in greater electron mobility, boosting the S/N ratio of the Hall element in question.

2) Relationship between resistance and noise

The amount of 1/*f* noise increases as the frequency decreases. In this case, 1/*f* noise was evaluated using the noise density at 10 Hz.

Fig. 2 provides a graph in which normalized noise of a Hall element at 10 Hz is plotted versus resistance. Normalized noise is calculated by normalizing the noise density after eliminating the effects of individual differences between elements so that multiple Hall elements can be compared.

Fig. 2 shows that lower Hall element resistance yield lower noise density.

B. Requirements: Production Factors

Molecular beam epitaxy (MBE) is a standard method for producing Hall elements with the low noise characteristics described in Section II-*A* above, but Hioki found that relative to the production capacity provided, the extremely high cost of deploying the equipment precluded its use in producing Hall elements for current probes.

Hioki has a three-temperature method vacuum evaporation system for use in producing Hall elements for current probes, and have determined that developing a coating formation and processing method using that system was the most reasonable solution from a production standpoint.

The company developed Hall elements that satisfy the requirements described above.

III. Example Characteristics

This section compares the characteristics of the Hall element used by the 3273-50 and 3276 current probes (“conventional sensor”) and the Hall element developed in this project (“newly developed sensor”).

A. Comparison of Resistance and Sensitivity

For conventional sensors, standard characteristics are a resistance value of 800 Ω and a sensitivity value of 1.5 V/A·T. By contrast, the corresponding values for the newly developed sensor are 100 Ω and 1.0 V/A·T.

Assuming identical composition, a 50% reduction in the resistance would ordinarily result in a 50% reduction in sensitivity. However, despite a dramatic reduction in resistance, which is the cause of 1/*f* noise, Hioki succeeded in limiting the decrease in sensitivity.

B. Comparison of Noise Density

Fig. 3 provides a comparison of noise density in the low-frequency region up to 500 Hz between the conventional sensor and the newly developed sensor, while Fig. 4 compares the sensors by converting the results shown in Fig. 3 into normalized noise.

Fig. 3 shows the noise density for the newly developed sensor in the region of less than 10 Hz is the same as the measuring instrument noise. This level indicates how dramatically the newly developed sensor’s 1/*f* noise has been reduced. Fig. 4 shows a comparison of normalized noise density reveals that the newly developed sensor’s noise density is 1/10 that of the conventional sensor.

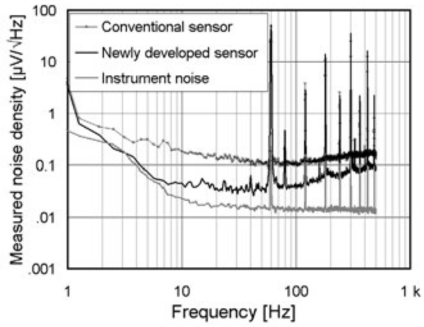

Fig. 3. Hall Element Noise Characteristics

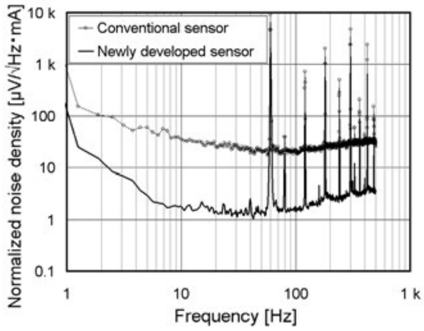

Fig. 4. Normalized Noise of Each Sensor

Figs. 3 and 4 show an increased noise component at high frequencies at and above 100 Hz. That noise is caused by downstream circuitry.

In this way, the newly developed sensor delivers reduced 1/*f* noise and an improved S/N ratio. This sensor is capable of use in current probes that are suitable for measurement of minuscule currents.

IV. Conclusion

Hioki succeeded in developing a more sensitive Hall element—an impasse that had been preventing the development of more sensitive current probes—by dramatically reducing the amount of 1/*f* noise. It plans to use this sensor to develop current probes capable of measuring minuscule currents.

Hioki would like to take this opportunity to express its heartfelt gratitude for the technical guidance provided by the late Hideo Oura of the Engineering Department at Toei Scientific Industrial Co., Ltd.

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Reference

[1] Hirabayashi, A. 3276 Clamp On Probe. Hioki Giho. 2004, vol. 25, no. 1, pp. 47-64. (Japanese).

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