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Vector current viewer for electric current visualization

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ABSTRACT: This paper proposes a vector current viewer sensor as a mean of current visualizing tool. The vector current viewer has two-arc shape sensing coils set them up in orthogonal ways to each other. The arc-shape of the sensors enhances a focusing function of the line current generating magnetic field. By using our vector current viewer, existence as well as flowing path of the current can be visualized by Lissajous diagrams. Their horizontal- and vertical- axes respectively correspond to the sensor output voltages of the *x*- and *y*- axes. This paper demonstrates the current flowing path tracing on a simple circuit board by the developed vector current viewer.

1 INTRODUCTION

The integrated circuit technology of the semiconductor realizes a MPU (Micro Processing Unit), which is one of the essential elements for the modern electrical apparatus. Therefore it is possible to stimulate their downsizing. Another factor of this downsizing is that assembling the semiconductor elements is accomplished by employing printed circuits board (PCB). Modern PCBs have dramatically improved the density of integration and cost upon conventional wire assembling. On the other hand, because of the complex substrate structure it is difficult for human eyes to check up the fault and destroyed parts. In most cases, changing the PCB without any inspection is common due to cost performance. However, if such fault parts can be identified, the device could be repaired efficiently, and also, PCB obtains further reliability. Our final purpose is to develop the electric current visualizing sensors that enable us to carry out nondestructive inspection to the highly integrated PCB.

The paper proposes a vector current viewer, which makes it possible to visualize the current distribution. The vector current viewer is one of the magnetic sensors based on the Rogowski coil. In order to scan on a two-dimensional plane of the PCB, the sensor has two arc-shape coils. The arc-shape coil has focusing function of the current generating magnetic field. Further, two arc-shape sensing coils are crossed in orthogonal ways each other. In this case, existence as well as flowing path of the current can be visualized by means of Lissajous diagram, which horizontal- and vertical- axes respectively correspond to the sensor output voltages of *x*- and *y*- axes. Thereby, the vector current viewer enables us to trace/visualize the current flowing path with an oscilloscope in real time. As an example result, this paper demonstrates the visualization of a current distribution by the developed vector current viewer.

2 VECTOR CURRENT VIEWER

2.1 Structure of vector current viewer

To carry out current visualization on PCB without any decomposition, employing of magnetic field sensor is one of the methods. Previously, the vector current viewer has been proposed as shown in Fig.1 [1]. The current viewer is a modified Rogowski coil, which has been used for the alternative current measurements in lumped electric circuits. The vector current viewer proposed in this paper has two current viewers as shown in Fig.2.

Fig. 1. Current viewer [1]

Fig. 2. Vector current viewer

2.2 Operating principle

The principal idea of the Rogowski coil follows Ampere's law. Therefore, the arc shape winding effectively picks up the magnetic field H generated by the line current I illustrated in Fig. 3. This realizes a focusing function to the line current I. The current viewer shown in Fig. 1 is a single coil sensor. On the other hand, our vector current viewer shown in Fig. 2 is composed of two current viewers in order to carry out the real time visualization of the two dimensional current distribution. The two current viewers are crossed in orthogonal ways each other. The Lissajous diagram obtained from the horizontal- and vertical- axes of the respective sensor output voltages enables us to visualize the current flowing path as well as the existence on the oscilloscope screen.

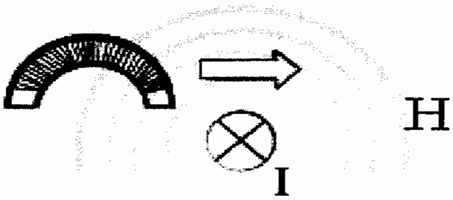


Fig. 3. Current searching by current viewer

2.3 Output of vector current viewer

The vector current viewer is composed of two current viewers crossed each other. Thereby, let us consider the output voltages of the current viewer, when an electric current I is flowing in a straight-line conductor with infinite length as shown in Fig. 4. Magnetic flux $d\varphi$ linked to small cross-sectional area dS of the sensor is obtained by solving for

$$d\phi = \mu_0 H dS. \tag{1}$$

where μ_0 is the permeability of the air. Ampere's law gives the magnetic field H in Eq. (1) at the distance r from the straight-line current

$$H = \frac{I}{2\pi r}. \tag{2}$$

Consider the coil length l is in parallel to the current, then the small cross-sectional area dS in

Eq. (1) is rewritten by small distance ***dr*** from **the straight-line conductor** as $ds = l \bullet dr$. This reduces Eq. (1) into Eq. (3)

$$d\phi = \frac{\mu_0 Il}{2\pi r} dr . \qquad (3)$$

In Fig. 4, let the lengths a and b be of the coil thickness and the internal radius of the current located at the center of sensor, respectively. Then the integral operation to Eq. (3) yields the linkage magnetic flux at a rectangular turn winding

$$\Phi = \int_b^{b+a} d\phi = \int_b^{b+a} \frac{\mu_0 Il}{2\pi r} dr . \qquad (4)$$

When the sensor is located at the center of the current, then the total linkage flux of sensor having N turns becomes $N\Phi$. Thus, in this case, Faraday's law gives the sensor output voltage v.

$$v = -N\frac{d\Phi}{dt} . \qquad (5)$$

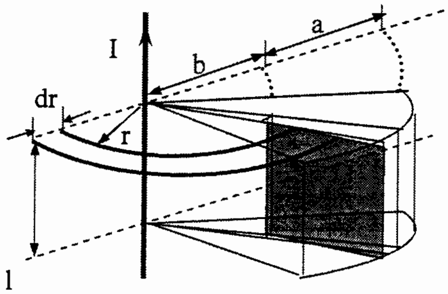


Fig.4. Various constants of current viewer for sensor output calculation

3 EXPERIMENTAL VERIFICATION

3.1 Tested vector current viewer

Table 1 lists the specification of a tested current viewer. The vector current viewer is composed of the same two current viewers.

Table 1 Specification of one of the tested current viewers

Radius b [mm]	Thickness a [mm]	Length l [mm]	Number of turns N [turns]
20.0	3.5	16.5	200

3.2 Spatial resolution

At first, we have examined spatial resolution characteristics of the vector current viewer. Fig. 5 illustrates a schematic diagram of the experiment. The sensor has been shifted in a vertical to the line current with 1cm intervals measuring each of sensor output voltages. The line current in Fig. 5 is at 10kHz, 0.5A. Fig. 6 shows the characteristics of the sensor position vs. output voltages. The x- and y-curves in Fig.6 correspond to the output voltages of orthogonal- and parallel- current viewers to the line current, respectively. Moreover, the prime ′ refers to the measured results when the angle of this sensor turns to 90°. When the sensor locates at the center the current, the output voltages of x and x' become maximum. On the other hand, the output voltages of y and y' are approximately constants. This is because y

and y' are the output voltages induced in the coils located in parallel to the line current.

To define the spatial resolution characteristics, let us introduce a figure of sharpness, which is defined as a width between both 3dB down points from the maximum peak as shown in Fig. 7. In the case of our tested vector current viewer, this figure of sharpness is about 4cm.

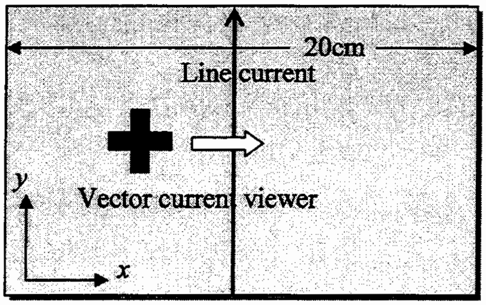


Fig.5. Experimental verification for spatial resolution of vector current viewer

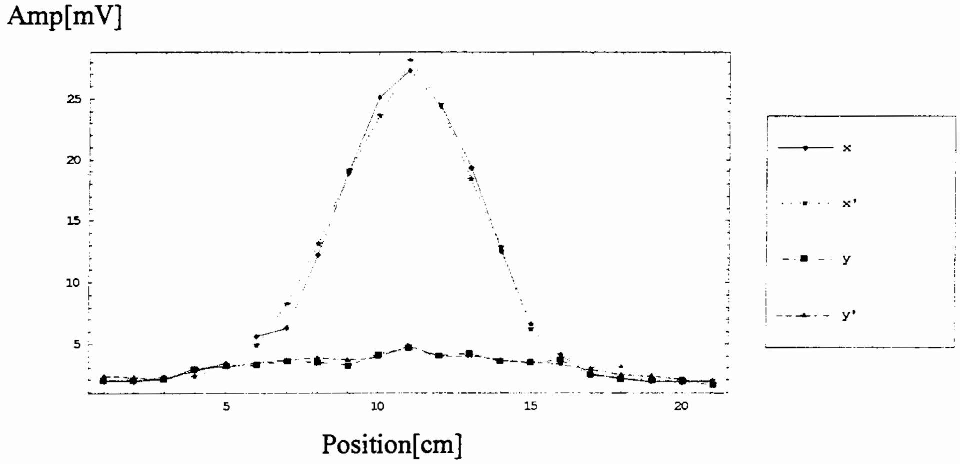


Fig.6. Spatial characteristics (10 kHz, 0.5A)

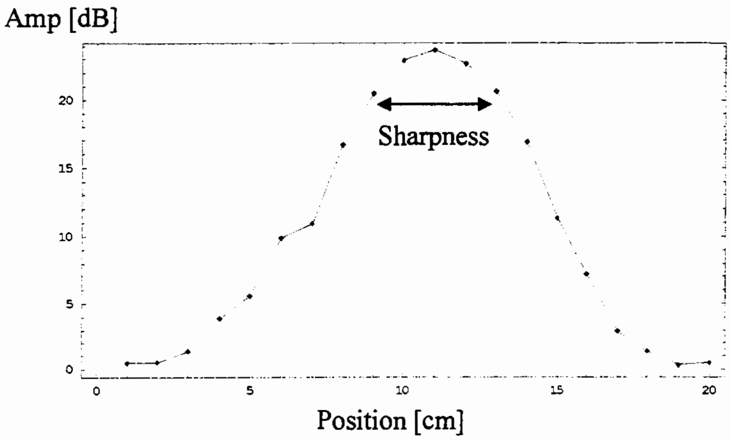
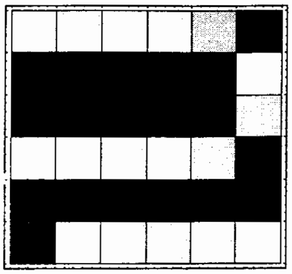
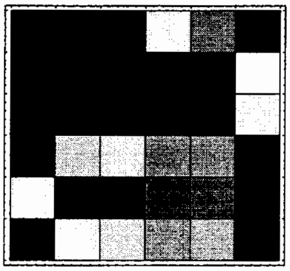


Fig.7. Definition of figure of sharpness



(a) x component



(b) y component

Fig.10. Output voltage distributions of the vector current viewer, where the current in the model shown in Fig.9 is 10 kHz, 0.5A. White: High, Black: Low

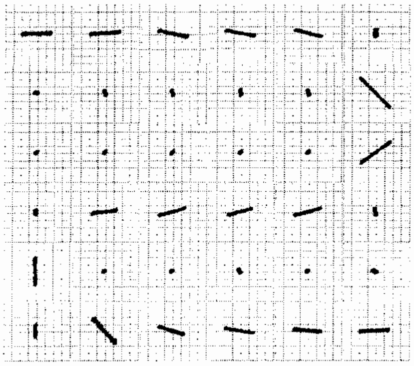


Fig.11. Lissajous diagrams along with the scanned position

4 CONCLUSIONS

We have proposed the vector current viewer as a current visualization tool on PCB. Two current viewers, which have high spatial resolution capability, are combined in orthogonal ways to each other. Projection of each of the x- and y-output voltages respectively onto the horizontal- and vertical- axes of an oscilloscope screen has made a Lissajous diagram, whose direction corresponds to a current flowing path. Thus, we have succeeded in visualizing the current flowing path by arranging the Lissajous diagrams along with physically scanned position.

5 REFERENCES

[1] M. Aoki, S. Hayano, and Y. Saito, "Measurement of 2D Current Distribution", *Magnetic Society of IEE of Japan, MAG-99-150*, 1999, pp.19-23 (in Japanese).

[2] M. Aoki, S. Hayano, and Y. Saito, "A Study of Current Viewer – Part 2. Deconvolution of the Current Distributions –", *Magnetic Society of IEE of Japan, MAG-98-265*, 1998, pp.63-68 (in Japanese).