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The Vector Current Viewer For Electric Current Visualization

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Abstract: Previously we have proposed the current viewer in order to visualize the current distribution on planar electric circuits. Further, we have proposed the vector current viewer by combining two current viewers in orthogonal way, and verified its usefulness in order to visualize the magnitude as well as direction of the currents along with the Lissajous diagram methodology. To realize the current distribution visualizing system in a most efficient manner, the present paper proposes a vector current viewer array system assembling with the computer, AD (Analogue to Digital) converter and vector current viewer array. A simple prototype of the vector current viewer array system demonstrates its usefulness to visualize the current distribution on planar electric circuits.

Keywords: Current Viewer, Current Distribution, Printed Circuit Boards

1. Introduction

In recent years, PCBs (Print Circuits Boards) are widely employed to work out the compact as well as lightweight electrical appliances. Further, the integrated circuit technology of the semiconductors realizes Micro Processing Units (MPU), which are ones of the essential elements for the modern electrical apparatus. That makes them possible to stimulate their downsizing. Another factor of this downsizing is that assembling the semiconductor elements is accomplished by employing PCBs. 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 all of the faults and destroyed parts. In most cases, changing the PCBs without any inspection is general to repair due to cost performance. However, if such fault parts can be identified, the device could be repaired efficiently, and also, PCBs obtain further reliability. One of the nondestructive tests to do that is to measure the electromagnetic fields in the vicinity essentially during their operation. Estimating the field sources from the measured fields becomes useful and important information not only for checking up their regularity but also for the EMC/EMI problems (Doi et al, 1998). To breakthrough such a situation, we have proposed the current viewer, which makes it possible to visualize the current distributions in PCBs, directly (Aoki et al, 1999). Operation principle of this current viewer is based on those of modified Rogowski coil method. The mechanical structure of this viewer is that a semicircle of the target current carrying conductor is covered with the sensor solenoidal coils to scan on the PCBs. Because of Ampere's law, the current viewer whose shape is a finite length semicircular solenoid coil has focusing function to the particular current generating magnetic fields. This makes it possible to search for the current position as well as magnitude with high sensibility compared with those of conventional solenoidal search coil. Furthermore, we have proposed a vector current viewer, which is composed of two current viewers combined in orthogonal ways each other. In this case, existence as well as flowing path of the current can be imaged by means of Lissajous diagram of which horizontal- and vertical- axes respectively correspond to the current viewer output voltages of *x*- and *y*- axes. Thereby, this vector current viewer has successfully visualized the real time current flowing path with oscilloscope (Tsunoda et all, 2002).

To carry out nondestructive inspection to highly integrated PCBs in much more highly efficient manner, we are spurred to developing a vector current viewer array system by assembling the computer, AD converter and vector current viewer array. A simple prototype of the vector current viewer array system demonstrates its usefulness.

2. Vector Current Viewer System

2.1 Outline of a Vector Current Viewer System

Figure 1 shows a schematic diagram of a vector current viewer system. The vector current viewer system consists of the three major parts. One is the vector current viewer array board composed of multiple vector current viewers arranged like a matrix; the second one is the interface system assembled by the AD converter and preamplifiers; and the last one is a computer system with keyboard, mouse and display.

The vector current viewer array board is one of the most important parts, because it catches the magnetic field distribution classified into two orthogonal components. Since it is difficult to work out the vector current viewers having the just same configuration, then the difference among them should be adjusted by gain control of the preamplifiers. Although the AD converter equipped with multi-channels does not have the same characteristics, the discrepancies among them should be also pre-compensated by the operation of computer. The computer processes multiple input signals in parallel so that it is reasonable to use a massively parallel computer. To classify the frequency components of target current distribution, Fourier transform is applied to each of the input signals to the computer via interface system. After that, the Lissajous diagrams arranged in the same layout to that of the vector current viewer board is drawn on the computer display. Thus, the current distribution classified into each of the frequencies is visualized on the computer display.

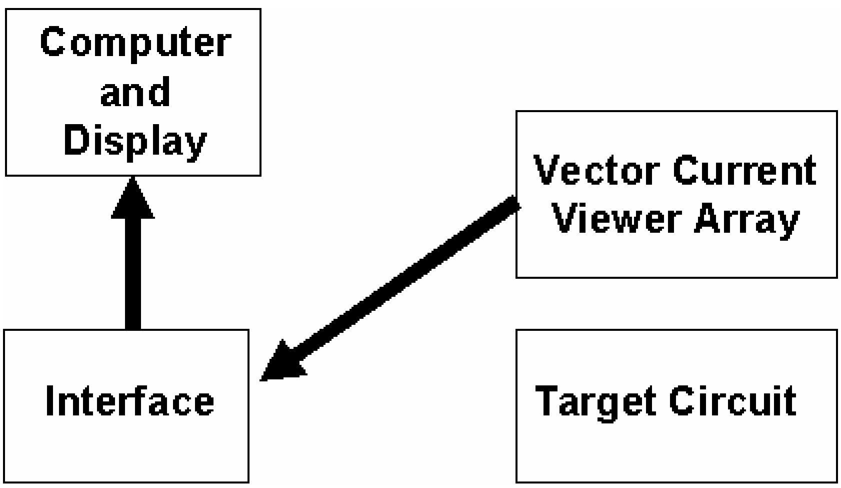


Fig.1 Schematic Diagram of the Vector Current Viewer System

2.2 Structure of Vector Current Viewer

To carry out current visualization on PCBs without any decomposition, employing the magnetic field sensor is one of the methods. Previously, Aoki et al. have proposed the current viewer shown in Figure 2(a). 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 is composed of two current viewers as shown in Figure 2(b).

(a) Current Viewer (b) Vector Current Viewer

Fig 2 Practical Current Viewers

2.3 Operating Principle of Vector Current Viewer

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 line current I illustrated in Figure 3. This realizes a focusing function to the line current I. The current viewer shown in Figure 2(a) is a single coil sensor. On the other hand, the vector current viewer shown in Figure 2(b) is composed of two current viewers in order to carry out visualizing of the two dimensional current distribution. The two current viewers are crossed them orthogonal ways each other. The Lissajous diagram obtained from the horizontal- and vertical- axes of respective sensor output voltages enables us to visualize the current flowing path as well as existence in oscilloscope screen.

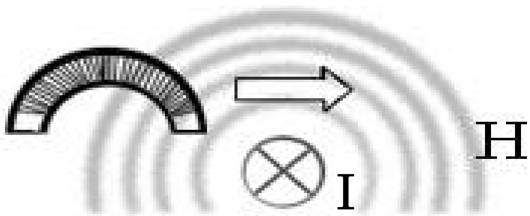


Fig.3 Current Searching by Current Viewer

2.4 Basic Equations of Current Viewer

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

$$d\phi = \mu_0 HdS \tag{1}$$

where μ_0 is permeability of the air. Ampere's law gives the magnetic field H in (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 (1) is rewritten by small distance dr from the straight-line conductor as $ds = l \cdot dr$. This reduces (1) into (3).

$$d\phi = \frac{\mu_0 Il}{2\pi r} dr \tag{3}$$

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

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

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

$$v = -N \frac{d\Phi}{dt} \tag{5}$$

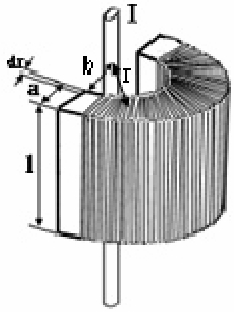


Fig.4 Constants of Current Viewer for Sensor Output Calculation

3. Prototype of Vector Current Viewer System

3.1 Tested Vector Current Viewer Array

As an initial test example, we have worked out a simple 2 by 2 square matrix array vector current viewer system. Table 1 lists the specification of a tested vector current viewer array. The vector current viewer array is composed of the same four vector current viewers. The interface system has been constructed by 64 channels AD converter board without any preamplifiers, which is installed to a popular personal computer.

Table 1 Specification of One of the Tested Current Viewer Array

Radius b [mm]	Thickness a [mm]	Length l [mm]	Number of Turns N [turn]	Center to Center of the Vector Current Viewers Distance [mm]
15	3.5	10	240	30

3.2 Spatial Resolution

At first, we have examined spatial resolution characteristics of our vector current viewer. Figure 5 illustrates a schematic diagram of the experiment. The sensor has been shifted in a direction of orthogonal to the line current with 1cm intervals measuring each of sensor output voltages. The line current in Figure 5 is 10kHz, 0.5A. Figure 6 shows characteristics of the sensor position vs. output voltages. The x- and y-curves in Figure.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 vector current viewer 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 of that 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 peek as shown in Figure 7. In case of our tested vector current viewer, this figure of sharpness is about 2.0cm.

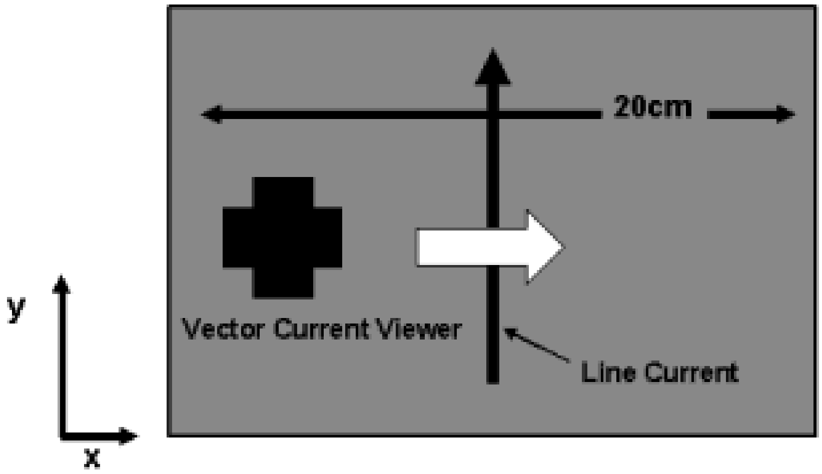


Fig.5 Experimental Verification for Spatial Resolution of Vector Current Viewer

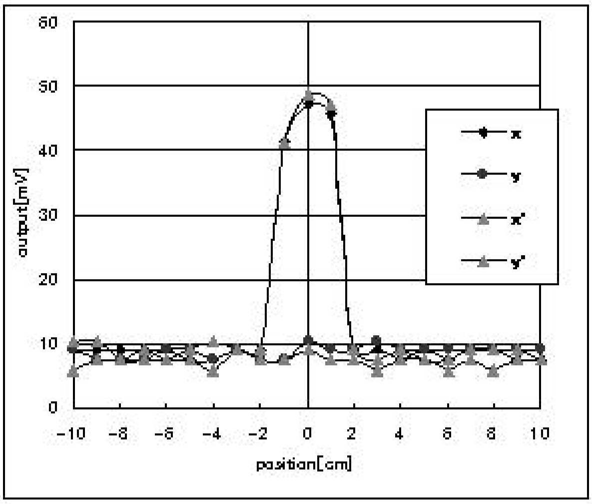


Fig.6 Spatial Characteristics (10kHz, 5A)

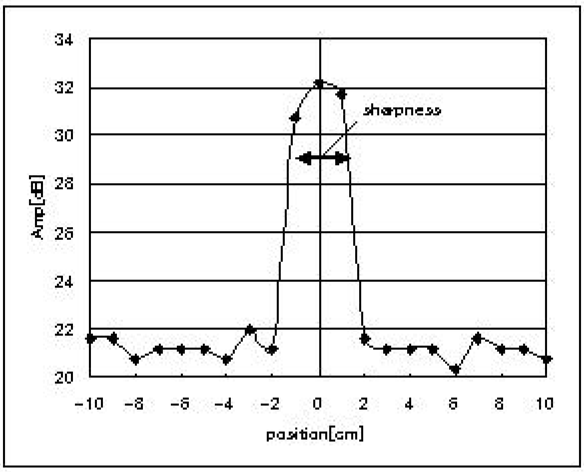


Fig.7 Definition of Figure of Sharpness

3.3 Current Direction Visualization

Since the vector current viewer is constructed by combining two current viewers in orthogonal way, Lissajous diagram is capable of visualizing a current flowing direction. Namely, projecting the output voltages of *x*- and *y*- current viewers, respectively, onto the horizontal- and vertical- axes yields a Lissajous diagram whose direction corresponds to the current flowing path. Figure 8 shows the Lissajous diagrams at each of the sensor angles. It is obvious that the Lissajous representation identifies the direction as well as existence of current conduction. Moreover, our vector current viewer enables us to carry out real time nondestructive evaluation by oscilloscope measurement.

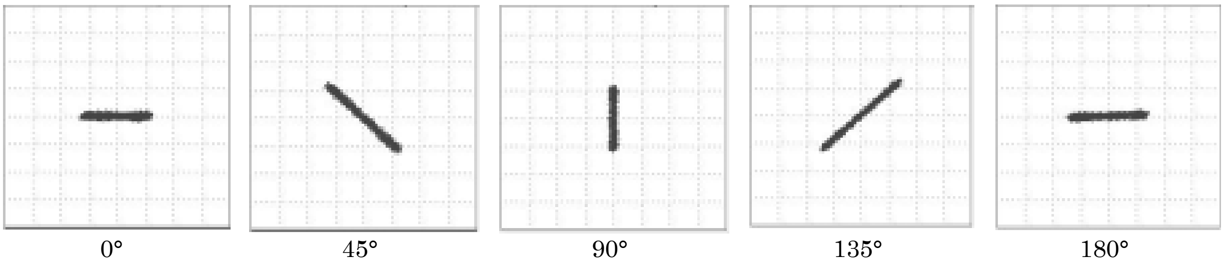


Fig.8 Lissajous Diagrams at each of Vector Current Viewer Angles (10kHz, 5A)

3.4 Initial Test Example

As an initial test of current visualization on PCBs, let us consider a simple current flowing path model shown in Figure 9. Scanning our vector current viewer array on this model surface visualizes current flowing path by means of Lissajous diagrams. The number of measured points is 100 and its interval is 3.0cm

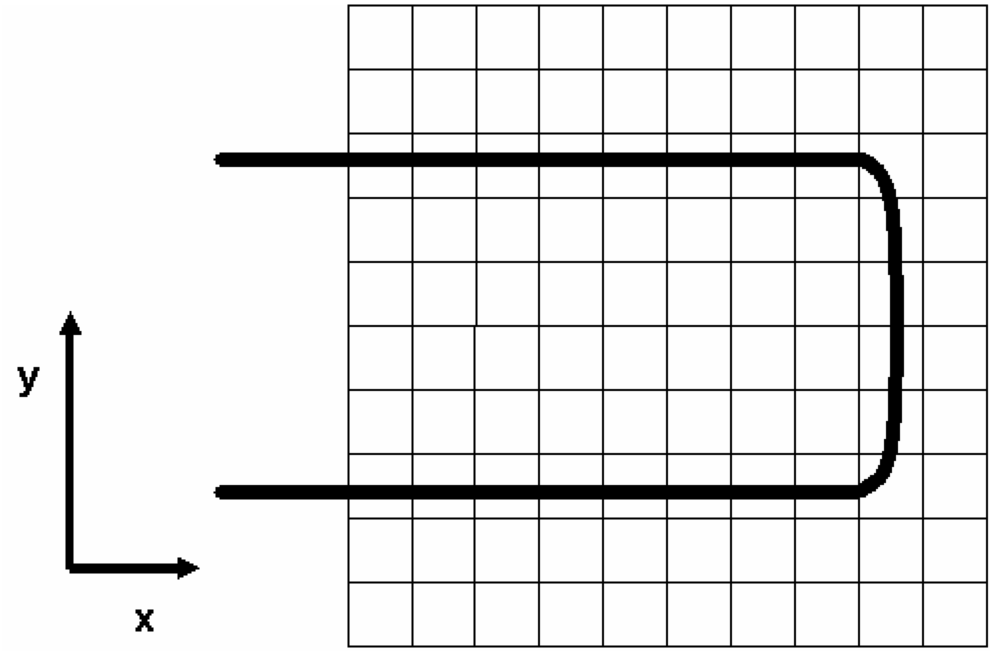
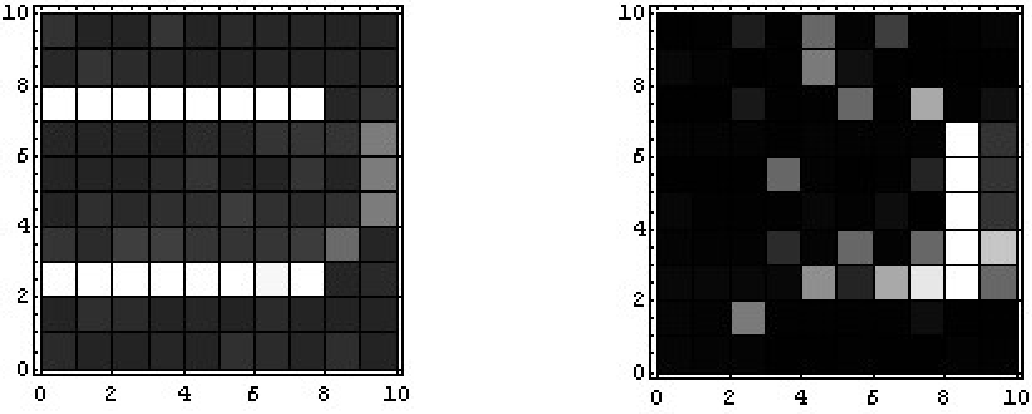


Fig.9 Electric Current Model for Current Distribution Tracing

Figure 10 illustrates *x*- and *y*- components of our vector current viewer output voltages. Figure 11 shows the result of current flowing path tracing obtained as Lissajous diagrams at each measured point of output voltages in Figure 10. At the current existing point, we obtain a line in the Lissajous diagram reflecting on the direction of current flowing. In case of no current existing point, Lissajous diagram becomes like a point.

Thus, our vector current viewer system makes it possible to trace the current flowing path only one scanning in a most efficient manner.



(a) x-component (b) y-component

Fig.10 Output Voltage Distributions of the Vector Current Viewer (10kHz, 5A). White: High, Black: Low

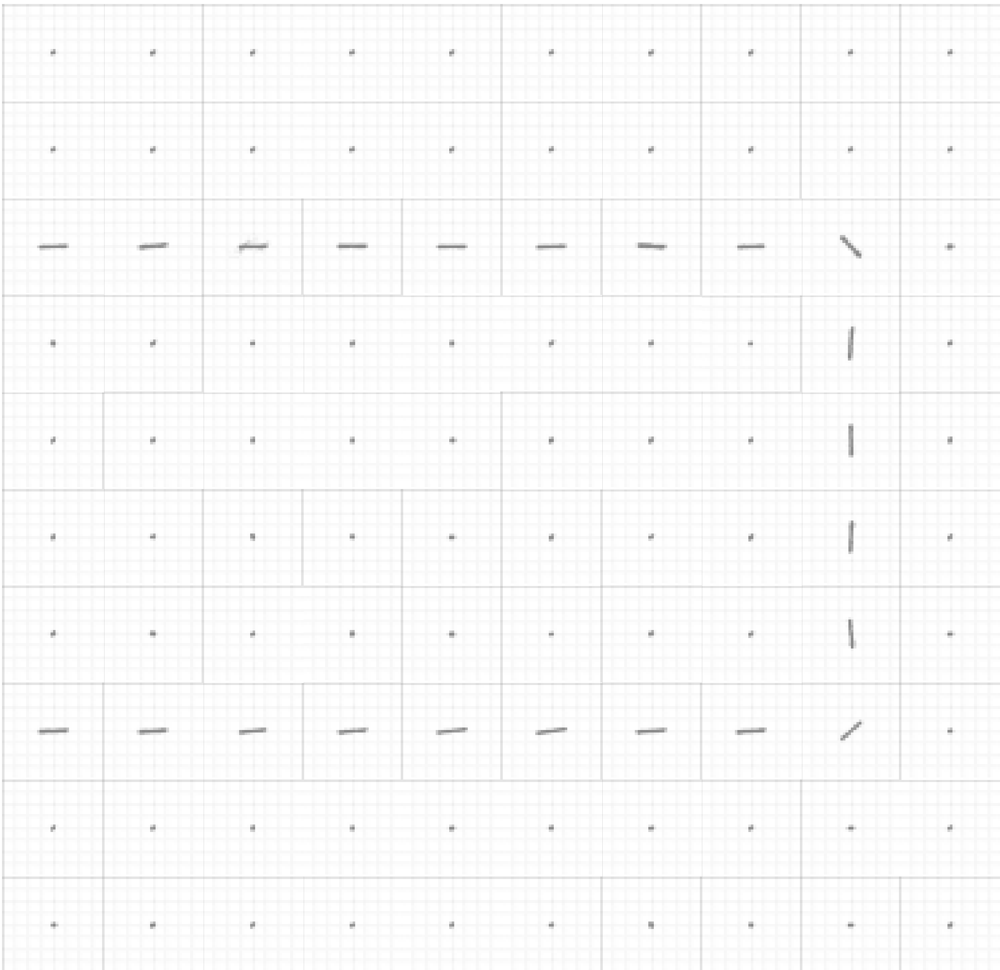


Fig.11 Lissajous Diagrams Along with the Scanned Positions

4. Conclusion

We have proposed the vector current viewer system as a current visualization tool on PCBs. The device has been composed of three major parts. One of the most important parts is the vector current viewer array board. Each of the vector current viewers on the current array board is composed of the two current viewers, which have high spatial resolution capability, are combined in orthogonal ways each other. Projection 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.

We have developed a simple prototype of the vector current viewer array system and demonstrated its validity and usefulness.

References

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