Magnetic field distribution caused by a notebook computer and its source searching

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Previously, we have proposed a method of solution for the inverse problems, and successfully applied it to the biomagnetic fields. In the present article, we apply our inverse approach to the leakage magnetic field source searching for the notebook computers. As a result, it is found that our inverse approach is quite effective in searching for the leakage magnetic field source. The validity of our solutions is carefully examined by comparing the measured and calculated magnetic field distributions. © *1996 American Institute of Physics.* [S0021-8979(96)53108-4]

In order to prevent the misoperation and mutual action among the electronic devices, a magnetic shielding is one of the key techniques in the electromagnetic compatibility (EMC) field. Searching for the magnetic field source from locally measured magnetic fields is reduced into the solution of an inverse problem. Inverse problems are classified into two major categories, i.e., one is the inverse parameter problem[1] and the other is the inverse source problem.[2-4] In order to shield the leakage electromagnetic field from the electronic devices effectively, it is essential to solve the inverse field source problem.

Previously, we have proposed the sampled pattern matching method as a method of solution for the inverse problems, and we have applied it to the biomagnetic fields as well as conventional nondestructive testing problems.[1-4]

In the present article, we measure the magnetic field above the keyboard of a notebook computer as well as a typical example of electronic devices. And we apply our inverse approach to the leakage magnetic field source searching of the notebook computers.

Most of the inverse problem in the electromagnetic fields reduces to solving for a following governing equation

$$\mathbf{X}_p = \int_v G\mathbf{Y}_s dV, \tag{1}$$

where $\mathbf{X}_p$, $\mathbf{Y}_s$, G, and V are the known field vector, unknown source vector, Green's function or its space derivative, and volume containing the unknown source vector, respectively.

In the sampled pattern matching (SPM) method, we assume that the magnitude of a field source at each position can be represented by the space occupying rate of unit source. This means that the governing Eq. (1) is assumed to be modified into

$$\mathbf{X}_p^{[N]} = \int_p G^{[N]} \delta dP, \tag{2}$$

where superscript $[N]$ refers to the normalized quantities. Also, δ and P are the vector delta function representing the source vector $\mathbf{Y}_s$ and $(|G|/|\mathbf{X}_p|)V$, respectively.

Physically, this transformation corresponds to the pulse width modulation (PWM) technique in power electronic engineering. Representation of the space occupying rate of unit source is one of the key ideas of the sampled pattern matching method.

Discretizing Eq. (2), we have

$$\mathbf{X}_p^{[N]} = \sum_{i=1}^{m} \Delta P_i \mathbf{G}_i^{[N]} = D\mathbf{P} \tag{3a}$$

$$\begin{bmatrix} \Delta X_{p1} \\ \Delta X_{p2} \\ \vdots \\ \Delta X_{pn} \end{bmatrix} = \begin{bmatrix} G_{11} & G_{12} & \cdots & \cdots & G_{m1} \\ G_{21} & G_{22} & \cdots & \cdots & G_{m2} \\ \vdots & \vdots & \ddots & & \vdots \\ G_{n1} & G_{n2} & \cdots & \cdots & G_{nm} \end{bmatrix} \begin{bmatrix} \Delta P_1 \\ \Delta P_2 \\ \vdots \\ \vdots \\ \Delta P_m \end{bmatrix}. \tag{3b}$$

where m denotes a number of subdivisions of the field source existing space. Denoting n as a number of field measured points (i.e., the order of vector $\Delta\mathbf{X}_p$), D becomes an n by m rectangular system matrix composed by the column vectors $\mathbf{G}_i^{[N]}(i=1,2,\cdot,m)$, and $\mathbf{P}$ is a mth order PWM field source vector whose element is $\Delta P_i(i=1,2,\cdot,m)$.

In order to evaluate the vector $\mathbf{P}$ in a least-squares sense, multiplication of D^T to both sides of Eq. (3a) yields

$$D^T \Delta\mathbf{X}_p^{[N]} = D^T D\mathbf{P} \tag{4}$$

or

$$\mathbf{P} = |D^T D|^{-1} D^T \Delta\mathbf{X}_p^{[N]}. \tag{5}$$

From Eq. (5), it seems able to evaluate the solution vector $\mathbf{P}$. But, this is practically difficult, because the column vectors $\mathbf{G}_i^{[N]}(i=1,2,\cdot,m)$ constituting the system matrix D are not linear independent. In other words, the elements of matrix D have been obtained by discretizing the same continuous function G, so that the matrix $D^T D$ becomes a singular matrix. Thus, it is difficult to evaluate the vector $\mathbf{P}$ by means of the conventional least-squares fit.

Consideration of the matrix $D^T D$ in (4) reveals that the diagonal elements take 1 but the other elements are always less than 1 because each of the column vectors $\mathbf{G}_i^{[N]}(i=1,2,\cdot,m)$ in D is normalized. Thereby, the matrix $D^T D$ may be regarded a unit matrix with order m. This assumption means that Eq. (4) yields an approximate solution of $\mathbf{P}$, which coincides with those of a factor analysis. Further consideration of Eq. (4) suggests that the elements in (4) take values between -1 and 1. Namely, the elements $\Delta P_i, (i=1,2,\cdot,m)$ in the vector $\mathbf{P}$ are

$$\Delta P_i = \mathbf{X}_p^T \cdot \mathbf{G}_i / [\|\mathbf{X}_p\| \, \|\mathbf{G}_i\|], \quad i=1,2,\cdots,m, \tag{6}$$

where the elements $\Delta P_i(i=1,2,\cdot,m)$ of $\mathbf{P}$ are called the *pattern matching figures*.

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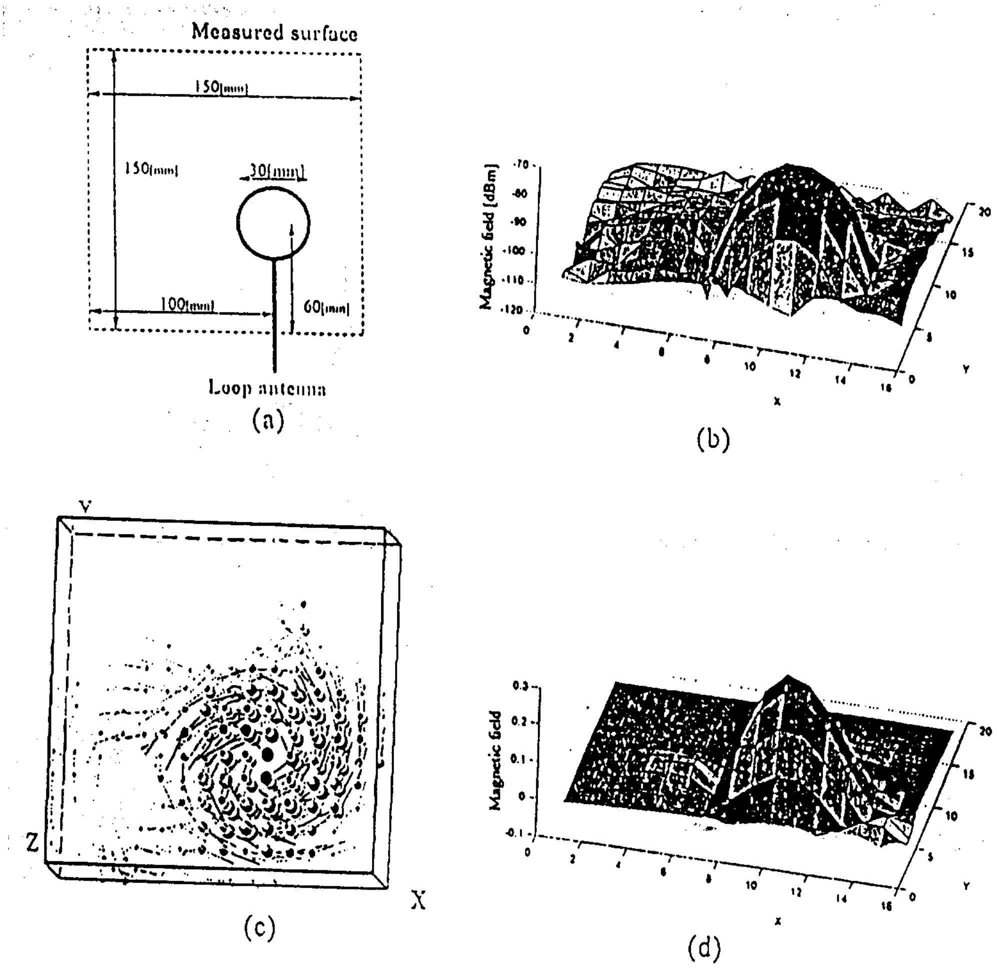

FIG. 1. An experimental result of the field source searching. (a) Schematic diagram of a loop antenna, (b) measured magnetic field distribution above the loop antenna, (c) estimated current distribution, and (d) reproduced magnetic field distribution by the currents in (c).

Since we have to decide the existence of vector delta function δ in (2) by the least-squares sense, the SPM method assumes that only one element taking the maximum pattern matching figure in Eq. (6) has a unit vector delta function. If the ΔP_h takes the maximum, then this point h is the *first pilot point* and its associated pattern vector $\mathbf{G}_h$ is called the *first pilot pattern*.

The second pilot point is decided as the maximum element of

$$\Delta P_{h,i} = \mathbf{X}_p^T \cdot (\mathbf{G}_h + \mathbf{G}_i)/[\|\mathbf{X}_p\| \, \|\mathbf{G}_h + \mathbf{G}_i\|], \quad i = 1,2,\cdots,m; i \neq h. \tag{7}$$

The similar processes of Eqs. (6) and (7) are continued until the peak value of the pattern matching figure is obtained. Finally, the field source $\mathbf{Y}_s$ is transformed into the PWM field source pattern $\mathbf{P}$.

As shown above, one of the merits of the SPM method is that the SPM method gives a most dominant solution against a locally measured field pattern. For further details of the SPM method, see Refs. 1–4.

One of the problems of the field source searching is the validity of the solutions. In order to check the validity of solutions, a simple experimental example demonstrates the validity of the SPM method.

First, we measured the magnetic field having 75 MHz frequency above the loop antenna. Figures 1(a) and 1(b) show the schematic field distribution, respectively. The magnetic field above the loop antenna was measured with the spectrum analyzer. The 75 MHz current flows in the loop antenna. The magnetic fields at 256 (16×16) equispaced locations above the loop antenna were measured. Second, we applied the SPM method to this magnetic field. Figures 1(c) and 1(d) show the obtained current distribution from the locally measured magnetic field in Fig. 1(b) and the reproduced magnetic field distribution calculated from the currents in Fig. 1(c), respectively.

Obviously, the results in Fig. 1 suggest that the SPM method is capable of estimating the global magnetic field source distribution. Thus, the SPM method is a useful solution strategy for the leakage magnetic field source searching from the electronic devices.

We measure the leakage magnetic fields for the two types of notebook computers. One is operating at 75 MHz, and the other is operating at 100 MHz CPU frequency. Both the computers equipped the INTEL DX4 CPU.

The magnetic fields above the keyboards were measured with a spectrum analyzer under the full CPU condition.

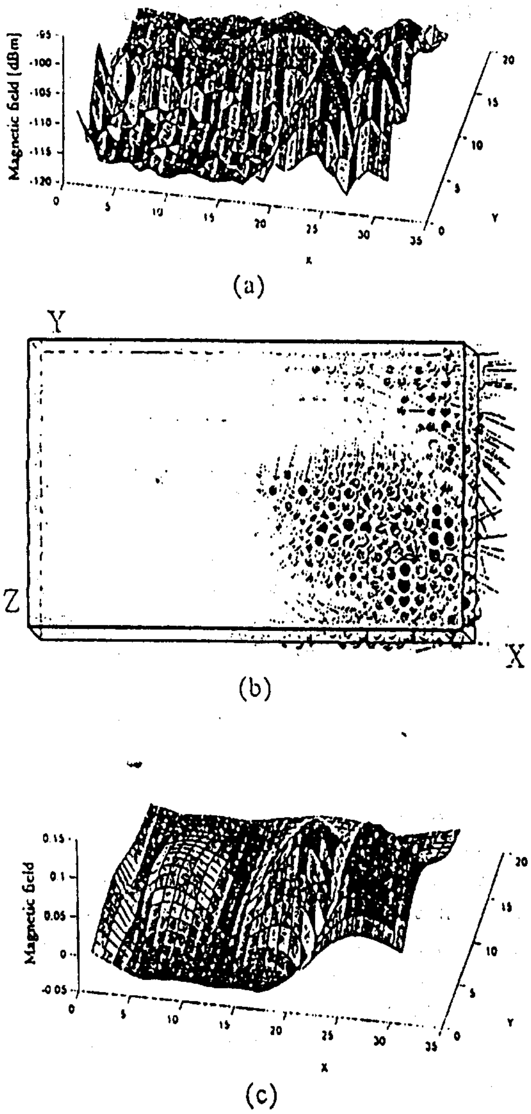

FIG. 2. The leakage magnetic field source distribution searching of the notebook computer operating at 75 MHz CPU frequency. (a) The measured magnetic field distribution, (b) the estimated current distribution, and (c) the reproduced magnetic field distribution calculated by the currents in (b).

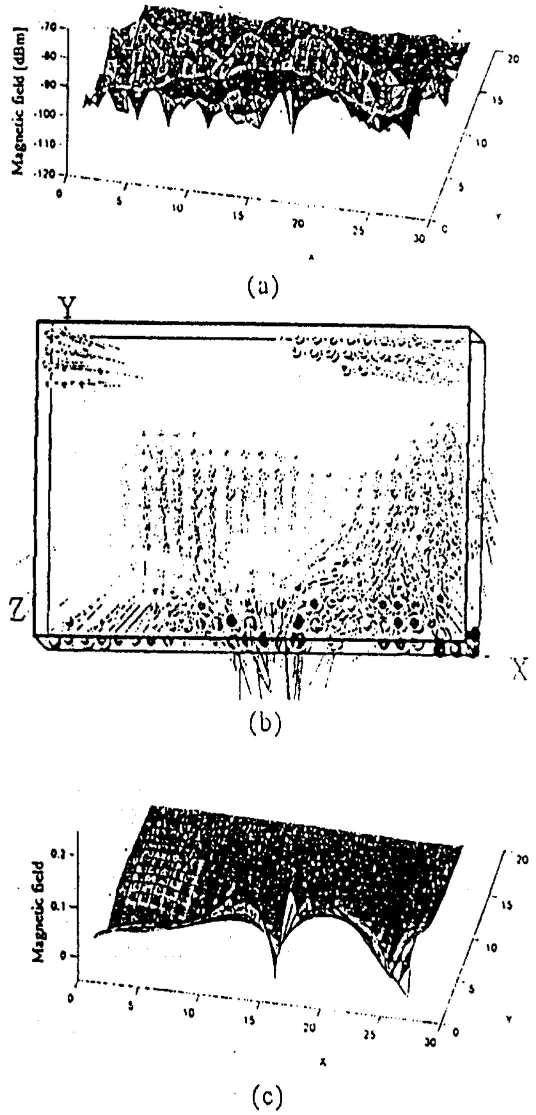

FIG. 3. The leakage magnetic field source distribution searching of the notebook computer operating at 100 MHz CPU frequency. (a) The measured magnetic field distribution, (b) the estimated current distribution, and (c) the reproduced magnetic field distribution calculated by the currents in (b).

Figure 2(a) shows the measured magnetic field distribution having 75 MHz. Figures 2(b) and 2(c) show the estimated current distribution and the reproduced magnetic field distribution calculated by the currents in Fig. 2(b), respectively. The results in Fig. 2 suggest that the magnetic field source measured above the keyboard is roughly classified into two parts; one is the CPU and the other is the power supplier. Thus, the magnetic shielding should be carried out mainly to these two parts.

Figure 3(a) shows the measured magnetic field distribution having 100 MHz. Figures 3(b) and 3(c) show the estimated current distribution and the reproduced magnetic field distribution calculated by the currents in Fig. 3(b), respectively.

The results in Fig. 3 suggest that the magnetic field source measured above the keyboard is mainly caused by two parts: one is the power supplier and the other is the signal flowing line to the display. Thus, the magnetic shielding of this computer should be carried out mainly to the power supplier and the line connecting from the CPU to the display.

In the present article, the validity of our inverse solution method has been carefully checked by means of the simple loop antenna. Further, it has shown that the different parts become the leakage magnetic field source depending on the circuit structure, and the common leakage magnetic field source of the two types of computers is the power supplier. This means that the magnetic shielding of any notebook computers should be carried out to the power supplier.

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