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Wavelet-Based Processing of ECT Images for Inspection of Printed Circuit Board

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Abstract—**This paper presents a wavelet-based image processing technique, which analyzes eddy-current testing (ECT) images derived by scanning printed circuit boards (PCB's) with an ECT probe and automatically detects the existence and location of the defect. First, the undesired components contained in probe output are removed through two types of wavelet filtering. Then the comparison of two images obtained from reference and tested PCB's are carried out to extract the signal due to the defect. In this paper, one-dimensional (1-D) wavelet is used only in the horizontal direction considering that the scanning of the probe is along that direction. In addition, the square norm of difference between original and processed signal is proposed as a criterion to keep the waveform of the defect peak as possible. The application examples of sample PCB's reveal the effectiveness and problems of the given approach.**

Index Terms—**Eddy-Current testing (ECT), printed circuit board (PCB), wavelet transform.**

I. Introduction

THE INSPECTION of printed circuit board (PCB) by using eddy-current testing (ECT) probe [1], [2], a novel application of ECT technique, has been verified to be useful for the fast inspection of PCB's without mechanical stress. The examination of the imperfection of thickness and/or multilayer PCB, not achieved by visual-based approach, is also enabled by this method. But since the ECT image derived from PCB contains many signals concerning other reasons than defect, the inspection is not completed without a post-data (= image) processing technique which automatically detect the existence and location of defect from the ECT images not depending on human power. To satisfy this requirement, authors have proposed an image processing method based on comparison of images [3].

But here the problem is the existence of undesired components involved in ECT images which disturb correct defect-judgment. And the method in [3], utilizing low pass filter (LPF) and histogram, does not have enough ability to remove them. In this paper, to overcome this problem, a wavelet-based image processing method is given paying attention to the aspect of wavelet as a set of band pass filters (BPF's) with high capability to reduce the noise.

While conventional studies on wavelet ECT image processing utilize two-dimensional (2-D) wavelet (ex. [4]), this paper adopts one-dimensional (1-D) processing only in the horizontal direction considering that the scanning of the probe is along that direction, and each horizontal line can be dealt independently. In addition, one criterion for the determination of removed element, which is vital to appropriate wavelet filtering, is also proposed.

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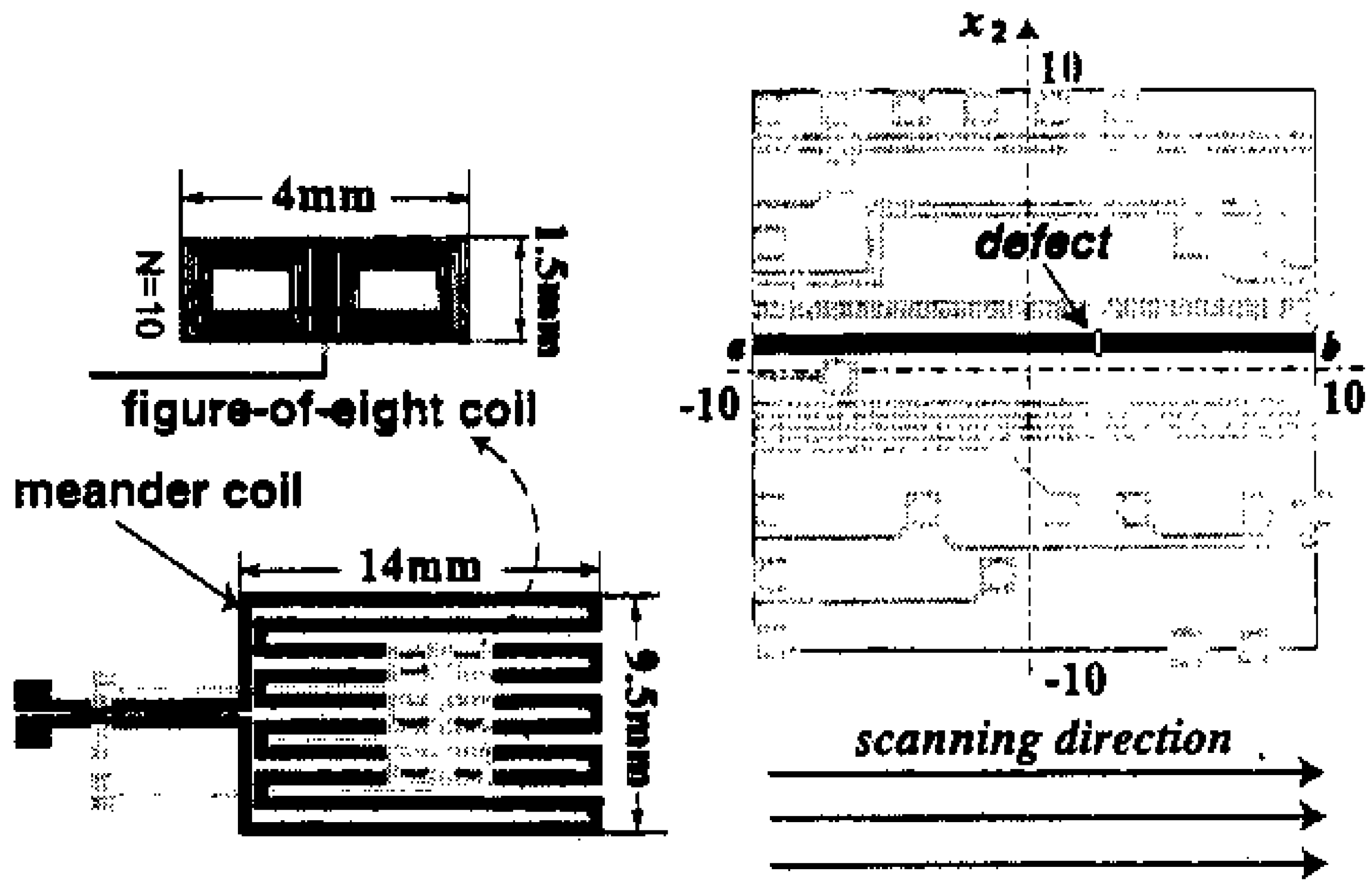
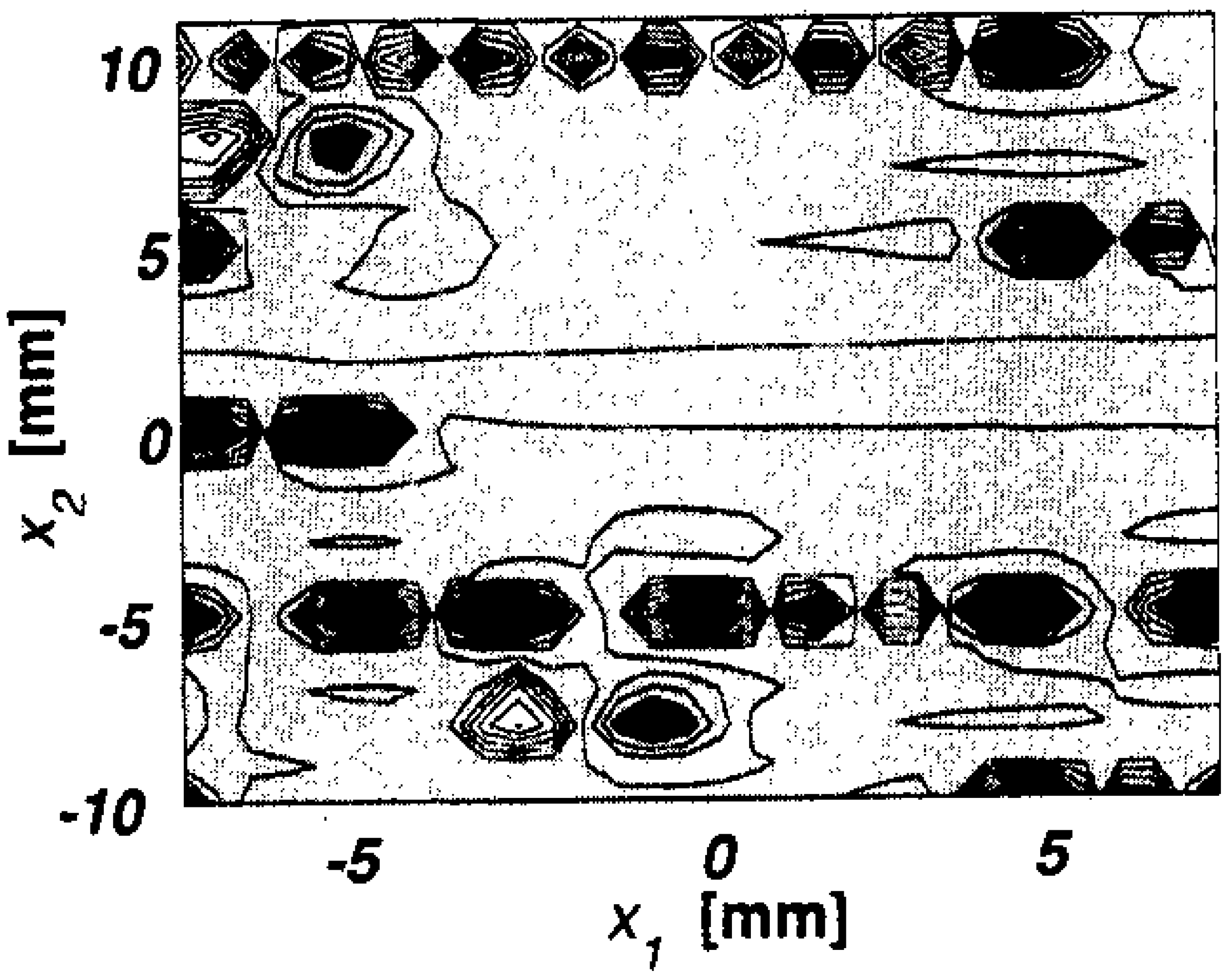


Fig. 1. ECT probe and measurement of PCB.

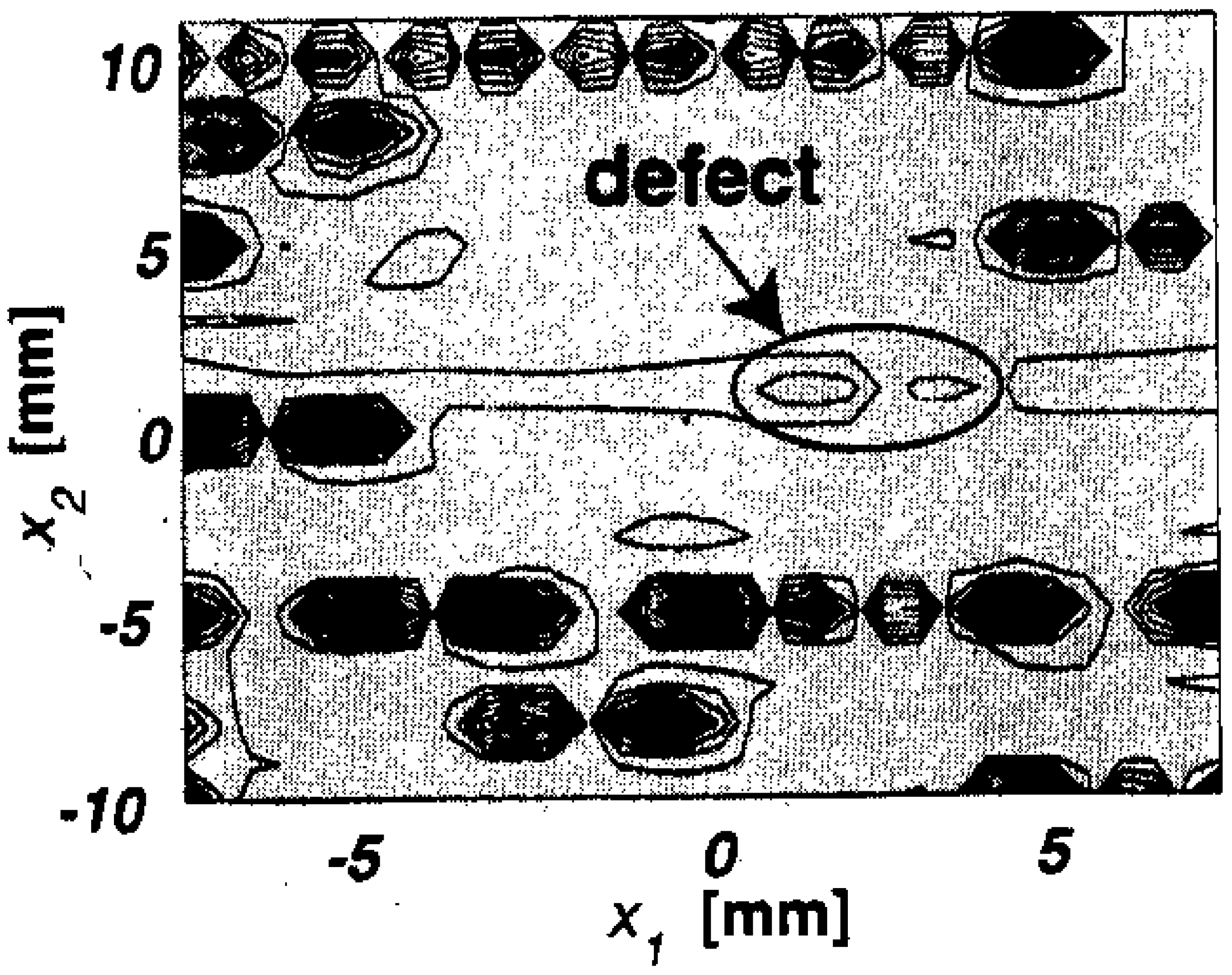
II. PCB Measurement and Image Processing

The ECT probe used here consists of a meander type coil for the excitation of eddy-currents and figure-of-eight pick-up coils (Fig. 1). The output of the probe is constant when it is passing over uniform part of the conductor on PCB, since the magnetic flux penetrating both rings of a pick-up coil is equal. However, if nonuniform distribution of conductor exists, the unbalance of the magnetic flux produces a peak signal which consists of positive and negative pulses. Consequently, by scanning PCB with ECT probe, the ECT images as depicted in Fig. 2 are derived. The peaks in Fig. 2 are classified into two groups, the ones due to printed pattern (ex. soldering point) which are present commonly in all PCB's and defect peak found only in where defect exists. Therefore, comparison of images derived from PCB without defect (reference image) and the one from tested PCB (tested image), enables us to extract the defect by finding a peak that exists only in the tested image.

But the ECT image contains undesired components occupying wide range of frequency, for example, measurement noise, offset, its variation, etc., which sometimes cause wrong recognition of defect. And conventional image processing method in [3] does not have enough ability to remove them. Hence, we adopt the wavelet transform (WT) [5] which has the characteristics of efficient implementation of BPF's [6]. Given here is an image processing method based on WT. In the PCB application, the shape of peaks should be maintained for the image comparison which follows to the wavelet processing.

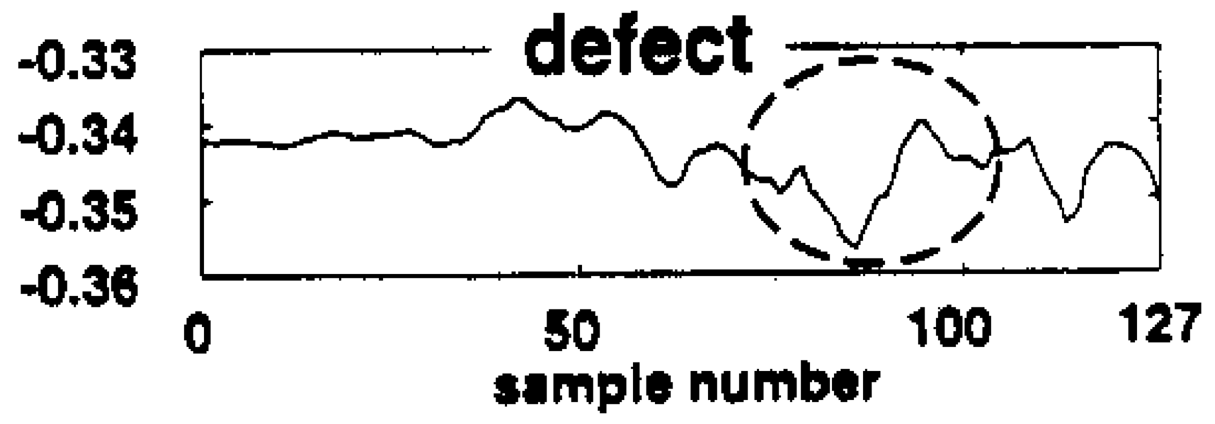


(a) ECT image of a nondefect PCB.

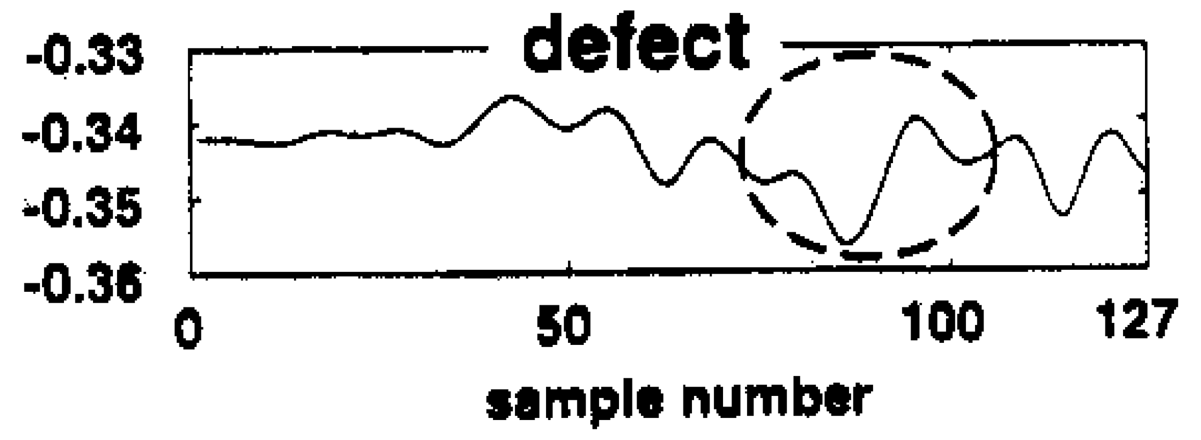


(b) ECT image of a PCB with disconnection.

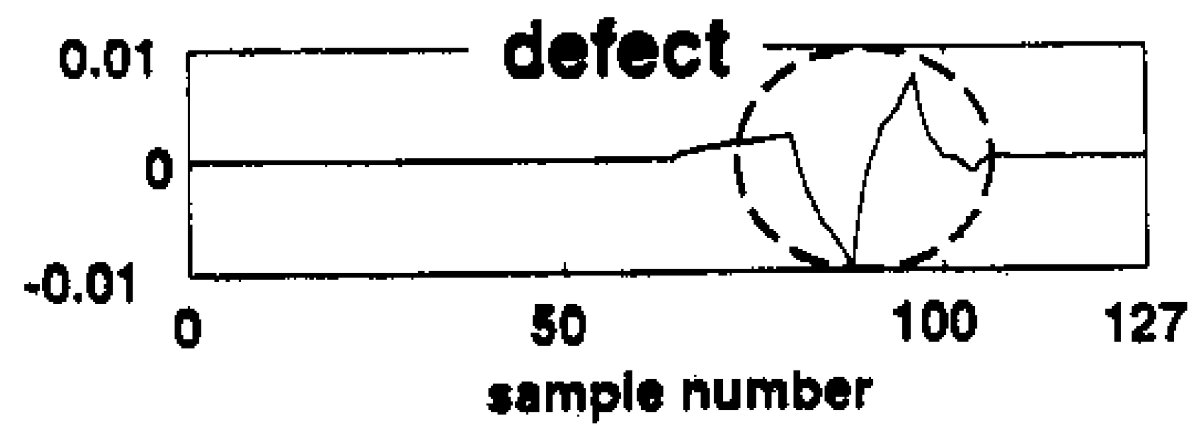
Fig. 2. ECT images derived by scanning PCB with an ECT probe.



(a) Original ECT signal corrupted by undesired components.



(b) ECT signal after conventional processing in [3].



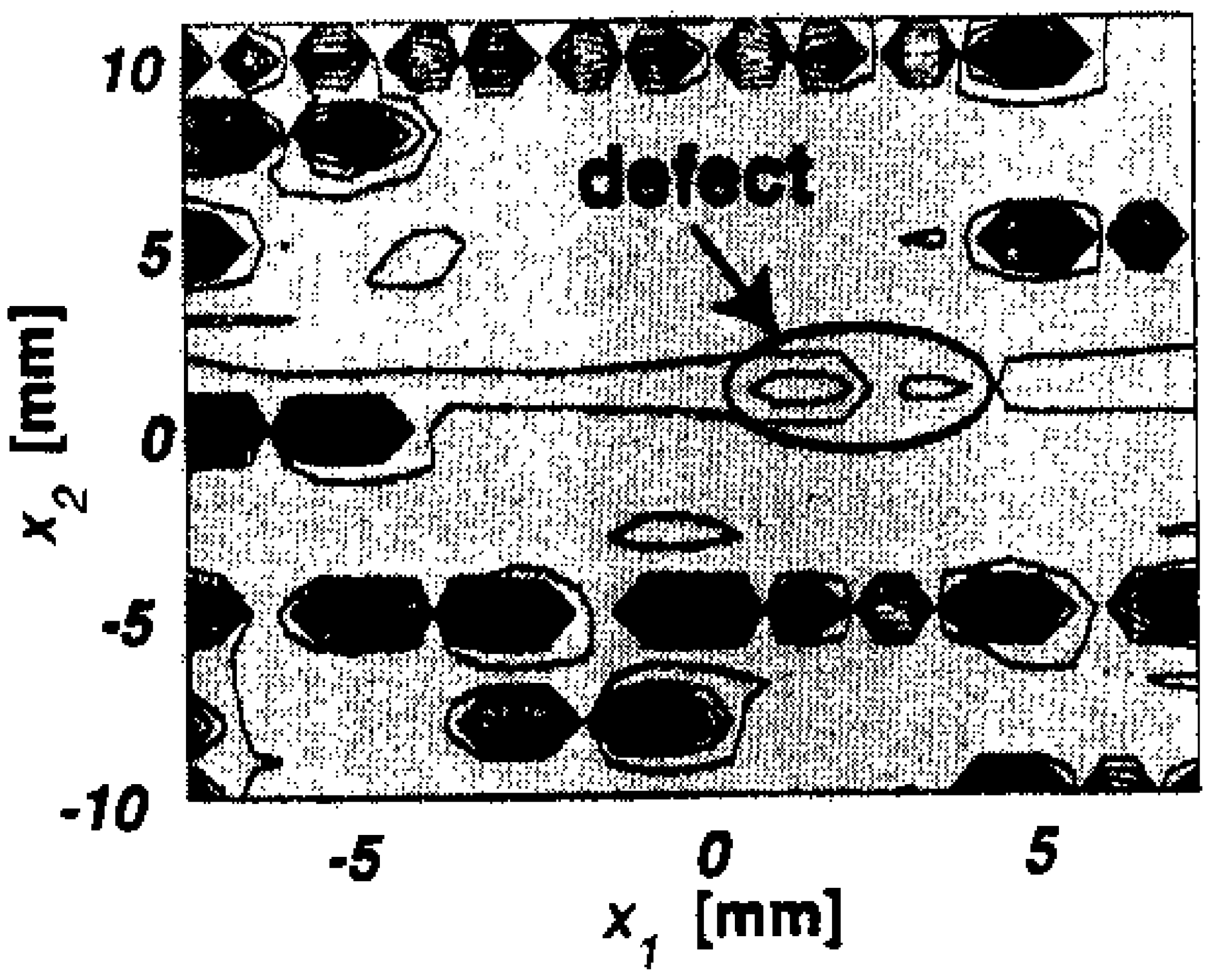
(c) ECT signal after wavelet processing.

Fig. 3. Results of 1-D signal processing.

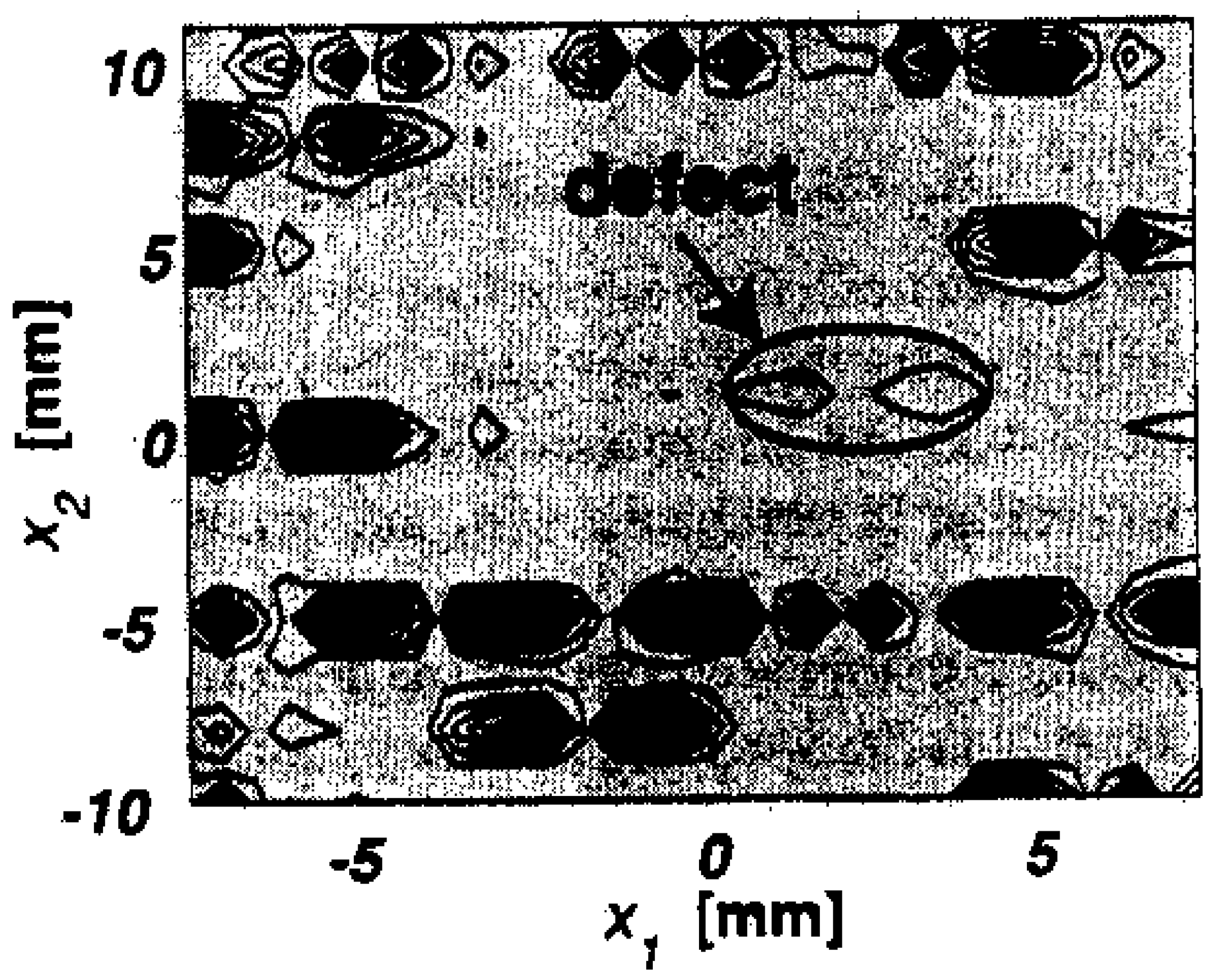
In this paper, for this aim and for the reduction of the computational cost, the 1-D wavelet is used only along horizontal direction instead of usual 2-D operation, also considering that the scanning of the probe is along that direction.

The procedure is given below. The steps i) ~ vi) are applied to both reference and tested images.

i) The 1-D WT is applied to each horizontal line of ECT image to calculate the wavelet coefficients (WC's).
ii) The WC's which belong to the frequency bands not containing defect components are removed.
iii) The WC's with smaller amplitude than a given threshold level A are eliminated, since they are considered to contribute mainly to undesired components [7]. The way to choose the removed components keeping peak-waveform is discussed in the next section.
iv) The ECT image is reconstructed through the inverse WT.
v) For the emphasis of signals similar to defect, the correlation is calculated between ECT image and theoretical waveform of defect signal.
vi) To extract peak regions, binarization of the ECT image is made. Namely, the pixel with larger amplitude than threshold ε is given value of 1, while others are set to zero.

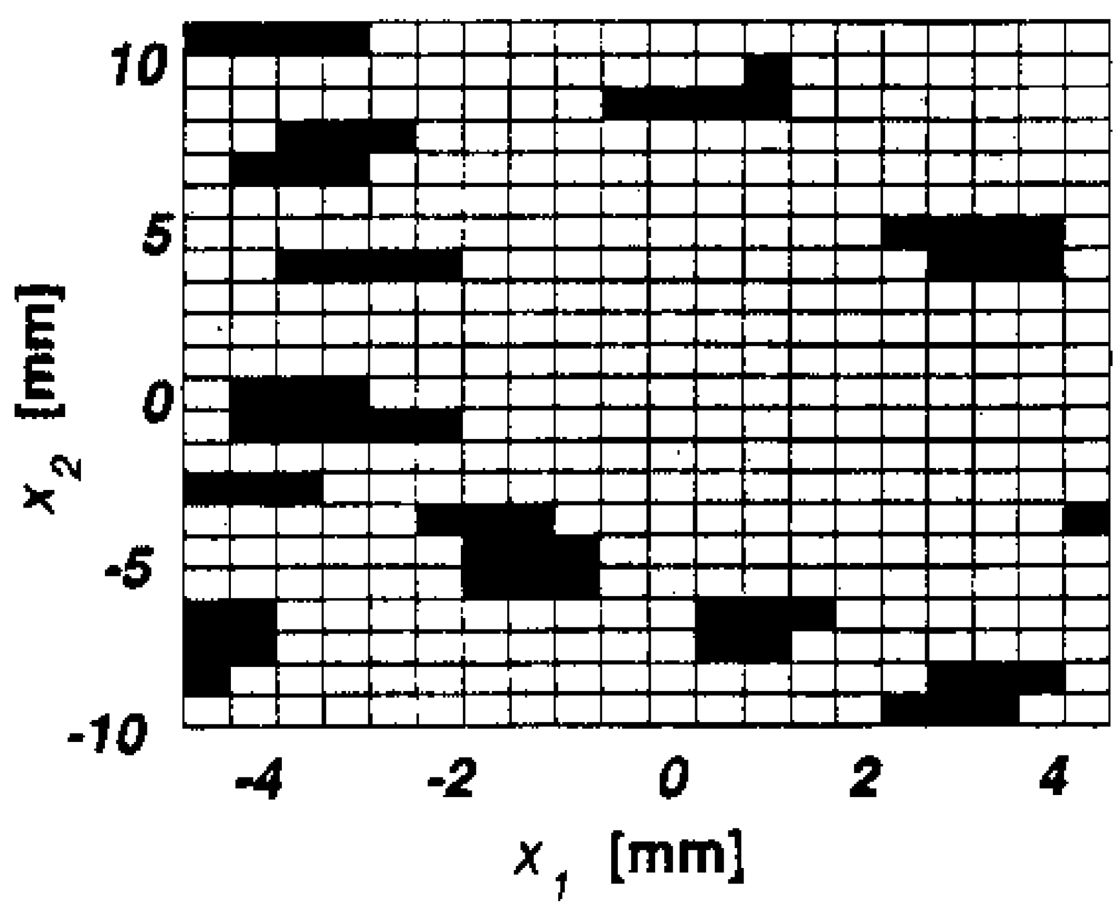


(a) Nondefect PCB.

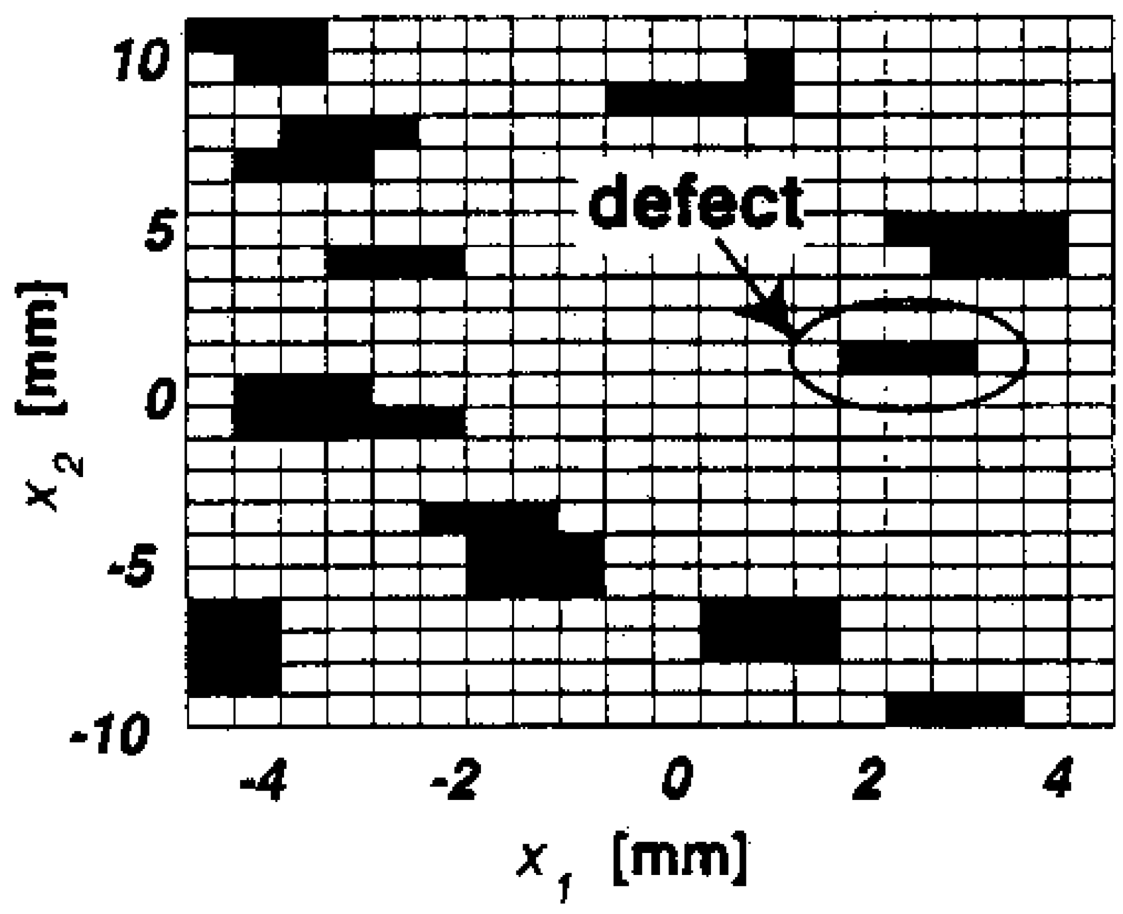


(b) PCB with disconnection.

Fig. 4. Images after applying wavelet filtering to Fig. 2. The lowest and highest bands are removed and threshold for amplitude filtering is $A = 0.3$.



(a) Nondefect PCB.



(b) PCB with disconnection.

Fig. 5. Images after taking correlation and binarization (threshold 70% of maximum value). The peak region in (b) which has no correspondent in (a) is due to the defect.

vii) The correspondence of defect regions in reference and tested images are investigated. If a region in tested image has no correspondent in reference image, go to viii). If all the regions have correspondents, the tested PCB is considered to have no defect.

viii) The threshold level for reference image in vi) is diminished on certain standard (ex. 10% lower) and go to step vii) again. If the peak in the tested image still has no pair, it is considered to be coming from a defect.

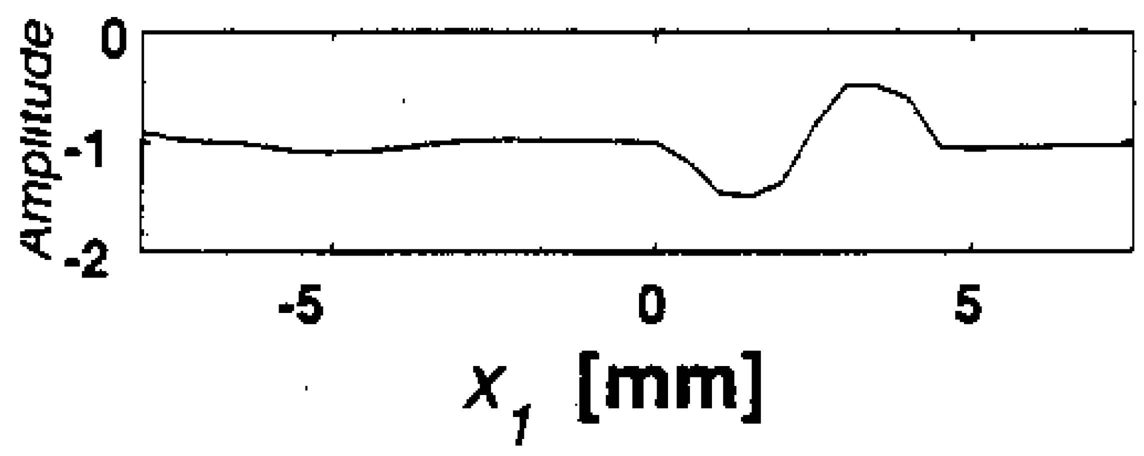
III. Examples and Discussions

The procedure described in previous section is applied to actual PCB's to verify its effectiveness. The results derived using Daubechies' wavelets [8] are shown in Fig. 3. First, the wavelet-based processing is compared with the conventional method through 1-D examples. The defect peak in (a) is not extracted even by using conventional approach as depicted in (b), but it is clearly observed after wavelet processing as shown in (c), which shows the better performance of the given method. Based on these results, the wavelet operation is applied to 2-D images. Fig. 4 shows the ability of the given approach to reduce undesired components in ECT images. Namely, use of 1-D wavelet is enough for our purpose. After calculation of correlation and binarization, a region in Fig. 5(b) which has no correspondent in (a) is recognized as the one due to defect.

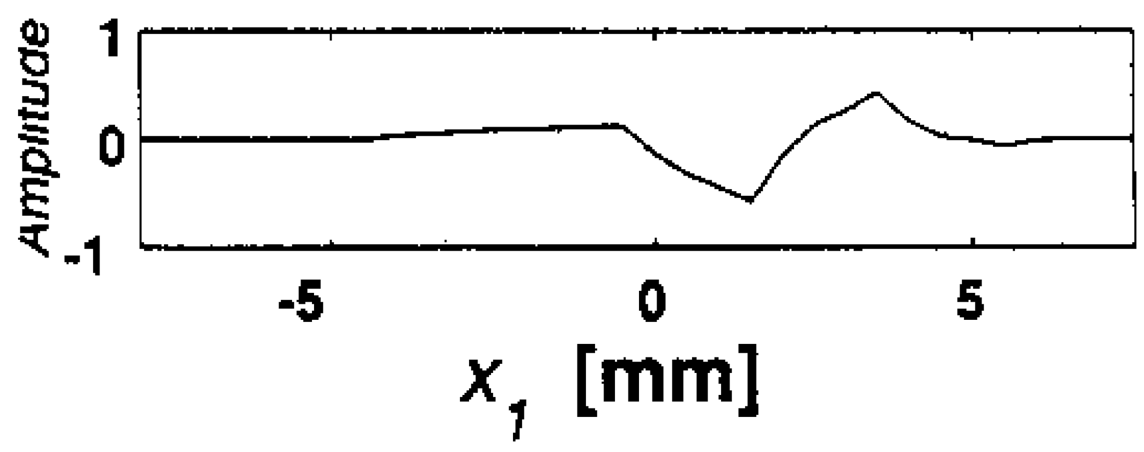
Here we have another problem, i.e., if the WC's removed in the wavelet filtering are chosen inadequately, the shape of the defect peak is severely distorted and not detected correctly. One criterion to avoid such an excessive deformation is square norm of the difference between sample defect waveform before ($f(x)$) and after ($\hat{f}(x)$) wavelet processing, shown in the following equation:

$$E = \frac{\left\| f(x) - \hat{f}(x) \right\|^2}{\left\| f(x) \right\|^2}. \tag{1}$$

By choosing E to be smaller than certain value (here $E < 0.25$ is adopted. The change of the waveform is shown in Fig. 6), the removed WC's are selected suppressing excessive deformation of peaks. Either measured or theoretically calculated defect peak scaled into smallest detection level can be used as sample defect.



(a) The defect signal observed on the line a-b in Fig. 2(b).



(b) The defect signal after wavelet processing.

Fig. 6. Waveform deformation of defect peak by wavelet operation.

IV. Conclusions

An image processing method based on wavelet analysis for the inspection of PCB by using ECT technique, which automatically detect the defect from the output of ECT probe, has been presented. In this approach, two types of wavelet filtering, about frequency and amplitude are carried out to remove undesired components contained in ECT images. It was verified through some examples that the application of 1-D WT only along the horizontal direction is enough for our purpose and the given method has a better defect-detection ability than conventional one by adequately choosing the WC's to be removed. As a criterion for this selection, we have proposed a square norm of difference of the defect signals before and after wavelet processing.

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