The Development of A Low Cost Non-destructive Inspection System for Plating Quality Assessment of Plated-through Holes in Printed Circuit Boards

A Thesis Presented in Partial Fulfilment of the Requirements for the Degree of Master of Technology
in the
Department of Production Technology
at
Massey University

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1995

ABSTRACT

The status of printed circuit board inspection is reviewed with special focus placed on the existing techniques of assessing plated-through hole quality. The need for developing a non-destructive method for plated-through hole inspection has been identified and is the major objective of this research.

The results of the investigation into various methods that could lead to this objective are presented. This investigation has been concerned with the application of image processing techniques and the leakage light detection method. The hardware and software requirements for automatic visual inspection of stuffed board components are established initially using available equipment from the Department of Production Technology.

Image processing techniques are found to be capable of discriminating copper-plated and unplated surfaces using the difference in reflectance between the surfaces. This suggests the possibility of applying such techniques to assess the quality of through-hole plating.

The leakage light detection method can be implemented to assess the plating coverage of plated-through holes. A low cost inspection system demonstrating the principle of leakage light detection has been constructed. This system is particularly relevant to the small batch manufacturers in the printed circuit board industry.

The performance of the demonstration system has illustrated the simplicity and reliability of the design. It is concluded that the leakage light detection technology offers a practical low cost solution for non-destructive plated-through hole inspection.

ACKNOWLEDGEMENTS

I wish to thank my supervisors, Professor Bob Hodgson and Dr Roger Browne, for all the guidance, the support, and the time they generously provided during the course of the work. I am also indebted to Dr Ross Nilson for his valuable comments and suggestions at various stages of this research.

Messrs Dexter Muir, Ken Mercer, Farshad Nourozi, Gary Allen and Peter Haw are thanked for their helpful technical support.

I also wish to thank my sister-in-law, Marlene, and her husband, Shaoquan (Dr Liu), for proof-reading this text. Finally, I shall always be grateful to my wife, Yvonne, for her understanding and tolerance to my frequent staying up late during the preparation of this thesis.

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LIST OF ABBREVIATIONS

ANSI	American National Standard Institute
CAD	Computer aided design
CCD	Charge coupled device
DIP	Dual in line packaging
DPI	Dots per inch
IPC	Institute for Interconnecting and Packaging Electronic Circuits
IC	Integrated circuit
IR	Infrared
LLD	Leakage light detection
PCB	Printed circuit board
PWB	Printed wiring board
PTH	Plated-through hole
ROI	Region of interest
SNR	Signal-to-noise ratio
UV	Ultra violet

CHAPTER ONE

INTRODUCTION

Printed circuit boards (PCBs) are the building blocks of almost all modern electronic systems. They provide a convenient way of mounting and interconnecting electronic components to form circuits and systems. The primary functions of the PCB are component support and circuit interconnection.

1.1 BACKGROUND

According to [THE62] the concept of the printed circuits has earlier origins than it is commonly supposed. A US patent dated 1903 describes ribbon cables formed *in situ* by electro-deposition. Between 1923-1929, a number of US patents were granted covering some of the techniques now still in use for printed circuit manufacture [THE62]. In 1936, P. Eisler was granted a British patent under the title "Printed Circuits" [EIS85]. Although Eisler's idea of etched foil circuits eventually became the most widely used method of producing circuits, the idea was not immediately successful [POL84]. Some of the early printed circuit patents granted to Eisler can be found in appendix 1-1.

During the Second World War the heavy demand for electronic devices stimulated the investigation into methods of producing circuits quickly and cheaply [POL84]. The first major application of the printed circuit concept occurred in 1945 when mass production of a United States military proximity fuse began at 5000 units a day. The circuit pattern was screen printed on a ceramic wafer using a conducting ink. The ink consisted of a binding agent, a solvent and fine silver powder. The printed ceramic plate was then heated to 500-800 °C, driving off the solvent and leaving the silver fused to the ceramic surface. The silver thus formed an excellent solid conductor and was well adhered to the ceramic base plate [THE62].

The success of the proximity fuse stimulated the launch of the printed circuit industry after the war. By the middle of the 1950s, printed circuits were being used in consumer products as well as military and industrial equipment [POL84]. Since then, the basic elements making up a PCB have remained unchanged. These are the base and the conductors. The base is a thin insulating material supporting all the conductors and electronic components. The conductors are customised patterns of thin metal strips, usually copper, firmly bonded to the base to form a laminate.

A PCB provides the necessary interconnections for the mounted components, it is also referred to as a printed wiring board (PWB) [LEO81]. By shaping the conductor patterns appropriately, it is possible to incorporate passive components such as small inductors, small capacitors and resistors directly on the board. In this case it is always called a printed circuit board because the functional circuitry is also printed [HAI91]. To avoid confusion, this thesis uses only the term Printed Circuit Board (PCB) and PWB is treated as a synonym of PCB.

1.2 PRINTED CIRCUIT BOARD MANUFACTURERS

According to [TYL94], up to 60 percent of the PCB manufacturers world wide are in the prototype and small batch sector. They provide services "where price is less of an issue and customers are prepared to pay for things in a hurry" and that these small companies generally "enjoy much higher profit margins than their large competitors". It has been estimated that the small batch sector represents 10 percent of the entire PCB market. On the contrary, 50 percent of the total PCB output is produced by only 7 percent of the manufacturers [TYL94].

In a case study report prepared for the Ministry of Research, Science and Technology, McNaughton [MNA92] suggests that the main problem faced by the New Zealand electronics industry is a matter of scale when adapting overseas technology to New Zealand needs. In coping with New Zealand's small production runs, specialised technology has to be developed to counter the scale problems.

1.2.1 Example of a Small Batch Production Facility

The Department of Production Technology at Massey University has established a manufacturing pilot plant (MPP) for electronic products. The plant is capable of PCB design, bare board production and component assembly. As stated in [NIL91], one of the many aims of the MPP is "to focus on the technology and management of a strategic New Zealand industry". To be of New Zealand relevance, the MPP "is a low cost process capable of short runs and rapid response".

The level of technology involved is a double-sided PTH capability. Output volume has been designed at up to fifty panels (each 305 x 406 mm or 12 x 16 inches) a day. Various features of the MPP are described in [NIL91].

1.2.2 Competition Strategy of Small Batch Manufacturers

Tyler [TYL94] identifies four key investment targets that are becoming essential for contemporary PCB manufacturers to survive in competition. These are:

- Yield improvement
- Reduction of labour cost
- Fine line and small hole technology
- Guaranteeing product quality in the field.

It has been estimated that typical investment in response to such demands would require US $0.3-0.5 million. Drilling and visual inspection systems are the two top areas of spending [TYL94].

Unlike major PCB manufacturers that can afford to stay ahead in technology and equipment, the small batch manufacturers' competitive strategy is to remain profitable on a low capital base. For example, commercial machine vision systems are designed for high volume inspections and require heavy capital investments (minimum US $ 0.3 million) [TYL94]. The small batch manufacturers will find this level of spending prohibitive. Most importantly, such systems fail to match the needs of small scale production. This is a "matter of scale" problem no different to that as described in the McNaughton report (section 1.2). This helps to explain why in small scale production human visual inspection dominates.

1.2.3 Meeting the Needs of the Small Batch Manufacturers

Installation of suitable low cost PCB inspection systems could help the small batch competitors to achieve three goals:

- improved yield
- reduced labour cost
- better quality of the product.

A higher customer confidence and higher yield will combine to create a potential of increased profits. Here, low cost inspection systems constitute a significant investment advantage for the small manufacturers. This is due to:

- A low level of injected capital generates relatively high return
- Minimal increase in sales is required to adequately cover the injected capital
- Overall capital level remains low to retain profitability.

Such an investment strategy therefore falls in line with the low capital base strategy of the small batch manufacturers. It can be anticipated that low cost inspection systems, though less sophisticated than their expensive counterparts, would meet the needs of most small batch PCB competitors.

1.3 OBJECTIVE, SCOPE AND RELEVANCE OF THIS RESEARCH

1.3.1 Main Objective

The main objective of this research was to explore and develop non-destructive methods for PTH inspection. These methods are relevant to small batch PCB production such as the facility in the Department of Production Technology at Massey University.

1.3.2 Scope

This research covers only double-sided PCBs with PTHs. Work has been focused on low cost solutions only. The PCB manufacturing process described in this thesis is based on the pilot plant facilities in the Department of Production Technology at Massey University. Although some of the work involved may be extended to cover certain categories of multilayer boards, such tests have not been conducted.

1.3.3 Relevance

The low cost approach towards non-destructive PTH inspection is targeted at providing technology support to the prototype and small batch sector of PCB manufacturers. Such a strong orientation towards serving the small business sector is relevant to the New Zealand industry.

1.4 LIST OF CONFERENCE PAPERS PUBLISHED

The following conference papers have been published in connection with the work described in this thesis:

1. K.C.Mak, R.M.Hodgson, R.F.Browne, R.R.Nilson, 'Image processing techniques for non-destructive testing of printed circuit boards'. *Proc. 2nd New Zealand Conference on Image Vision & Computing*, Palmerston North, August 1994, pp.2.5.1-2.5.5.

2. K.C.Mak, R.M.Hodgson, R.F.Browne, R.R.Nilson, 'Image analysis of copper plated surface - towards non-destructive inspection of plated through holes in printed circuit boards'. *Proc. Inaugural New Zealand Postgraduate Conference for Engineering & Technology Students*, Palmerston North, August 1994, pp.277-281.

3. K.C.Mak, 'Identifying defective through-hole plating in printed circuit boards using the leakage light detection method'. *Proc. 2nd New Zealand Postgraduate Conference for Engineering & Technology Students*, Auckland, August & September 1995, pp.195-200.

1.5 ORGANISATION OF THIS THESIS

A literature review on PCB manufacture and inspection is presented in chapters 2 and 3. Chapter 2 starts with a description of double-sided bare board manufacturing. The key processes of PTH production are then examined. Chapter 3 describes the status of PCB inspection, focussing on the conventional method of testing PTHs. The need to develop non-destructive inspection methods for PTHs is identified.

The use of image processing techniques to discriminate between copper-plated and unplated surfaces is reported in chapter 4. The potential requirements and implications of applying these techniques to assess the through-hole plating quality are then discussed.

Chapter 5 examines alternative schemes for non-destructive inspection of PTHs and highlights the potential use of visible light as a penetrant for surface flaw detection.

Following the development in the previous chapter, chapter 6 focuses on the leakage light detection method and describes the development and performance of a low cost leakage light detection system for PTH inspection.

Chapter 7 presents the preliminary results on establishing the hardware and software requirements for a stuffed board component inspection system.

The important issues identified during this research are summarised in chapter 8. This chapter also discusses the inspection strategy and then examines the possible impact of a low cost inspection system on PCB manufacturers in the prototype and small batch sector. Chapter 9 concludes this thesis and recommends some directions for future work.