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PRE-STUDY OF PRINTED WIRED BOARD IDENTIFICATION

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ABSTRACT

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This thesis was made for Nokia Networks, which is a multinational telecommunications equipment and data networking company headquartered in Espoo, Finland. Nokia Networks is a subsidiary, owned by Nokia Corporation.

The scope of this thesis work was to study the identification methods for the existing and future products e.g. printed wired boards (PWB) and mechanics. The main content was to concentrate on product identification requirements during manufacturing process. This included content, specification and IT-restrictions.

The information that was required to complete this thesis work was predominantly gathered by keeping weekly meetings with the experts from Nokia. The information obtained from these meetings was used to assist in the making of short and long term proposals as well as future marking method for the PWBs.

The output of this thesis work was a comprehensive summary of a different identification technologies, process specifications and alternative solution proposals. Laser technology was studied more deeply, as it seems to be the most potential identification method for the PWBs.

Keywords: PWB, laser, identification, RFID, marking, Nokia

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I would like to give my special thanks to the members on behalf of the Nokia Networks for their invaluable help throughout this project. I would also like to thank Heikki Kurki, Principal Lecturer, for his assistance for bringing the documentation of the project into a closure.

February 15th, 2015

Timo Lipponen

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VOCABULARY

AOI = Automatic Optical Inspection

ESD = Electrostatic Discharge

ICT = In-Circuit Test – Electrical probe tests PWB for shorts, opens, resistance, capacitance and other basic quantities which will show if the PWB was faulty assembled

ID = Identifier

Nd:YAG = Neodymium-Doped Yttrium Aluminum Garnet

Product = Module type (FSPM for example)

PWB = Printed Wired Board, also called as the module

RFID = Radio Frequency Identification

SFC = Serial Number

Shipment = Contains one or multiple units

STI = Sort Temporary Instructions

Unit = Assembled from different modules

1D Barcode = One Dimensional Barcode

2D Barcode = Two Dimensional Barcode

1 INTRODUCTION

The commissioner of this thesis work was Nokia Networks. Nokia Networks is a subsidiary of Nokia Corporation. Networks is one of the largest companies that is specialized for the developing and designing new telecommunications equipment. Networks has offices and operations in around 150 countries.

Nokia Networks is studying different kind of PWB marking methods and the existing marking method for PWBs is the use of labeling. In use, there are three different labeling methods: manual labeling, label feeder installed in placement machine and in-line labeling robot.

Drivers for the identification development are traceability requirement, identification reliability and cost effectiveness.

The output of this thesis work is a summary of the identification technologies, process specifications and the making of the alternative solution proposal. Laser marking was studied more deeply as a solution proposal, because it was the most potential identification method for PWBs.

2 IDENTIFICATION TECHNOLOGIES

This chapter focuses on the barcode- and the RFID identification technologies. The 1D- and the 2D barcode technologies are the primary marking methods used at the moment in the factories of Nokia.

2.1 Barcodes

The barcodes are divided into two different groups, 1D and 2D barcodes. The use of barcode technology requires relatively small investments if it is done by using the labeling technology (only ink and label costs). (1.)

2.1.1 One dimensional barcode

One-dimensional (1D) barcodes represent the data by varying the widths and spacing of parallel lines (Figure 1). Having much smaller data density and data capacity. The information type of the 1D barcodes only consists of numbers and English, which produces high restrictions for the content of the marking. While using the barcode technology as marking method for the PWB's, the data density comes in essential aspect, since the available area for marking is very limited on the PWB. (1.)

0 36000 29145 2

FIGURE 1. Example of a one dimensional barcode

2.1.2 Two dimensional barcode

Two dimensional (2D) barcodes usually represent the data in rectangular form, but other geometric patterns are also possible. (6.) There are dozens of different two dimensional barcode types. Different types have their own advantages, such as maximum data capacity, error correction levels, possible shapes etc. (TABLE 1.)

TABLE 1. Technical data comparison of the QR-, PDF417-, CM and Data Matrix barcode types

2D barcode	QR	PDF417	CM	Data Matrix
Max capacity	3 KB	1 KB	32 KB	3 KB
Error correction level	Levels 1 - 4	Levels 0 - 8	Levels 1 - 8	0 - 8
Barcode shape	Square only	Any rectangle	Any rectangle	Any rectangle
Chinese encoding effiency	Normal	Low	High	Normal
Savable information	Text, symbols and small images	Text, symbols and simple images	Text, symbols, colorful pictures and voice	256 byte ASCII character set
Intellectual property rights	Japan	US	China	Public

For example the difference of space requirements for PDF417 and CM types can be seen in Figure 2.

FIGURE 2. Space requirements for the PDF417 (left) and CM (right) when saving 200 numbers

As can be seen from Figure 2, there are major differences between the two dimensional barcode types, the space requirement differences with the PDF417 and CM technologies have the scale of 5.2 : 1. (1.)

The Data Matrix technology is used at the moment in the factories of Nokia. The Data Matrix is used for its capability to encode large amounts of data with high data density. Usually one black dot is used as one bit, but the Data Matrix can be also printed with white color on black surface. (2.)

The Data Matrix code can be in either square or rectangular form, which can include both text and numeric data. The data content can be from few bytes up to 1556 bytes. It is also possible to add error correction codes to increase reliability. Error correction codes will make the Data Matrix unreadable, if one or more cells are damaged. (3.) The Data Matrix code can be read from any direction and it is one of the formats along with PDF417 that can be used to print postage accepted by the United States Postal Service (4).

Additional technical data can be found in Nokia Networks Product Marking Specification document (only accessible from the networks of Nokia).

2.2 Radio-Frequency (RF) Identification

Radio-frequency identification (RFID) is common identification method, which can be used to identify different articles. Requirements for the tracking of PWB manufacturing process are increasing and becoming more important in the future. (5.)

2.2.1 Radio-Frequency ID Technology

The RFID technology uses electromagnetic fields to transfer data for the purposes of automatically identifying tags attached to objects. The main difference of the RFID and barcode technologies is that the RFID technology does not require direct eye contact to the tag, while barcode does. The RFID tags can be separated into three groups: passive, active and battery-assisted passive. (6.)

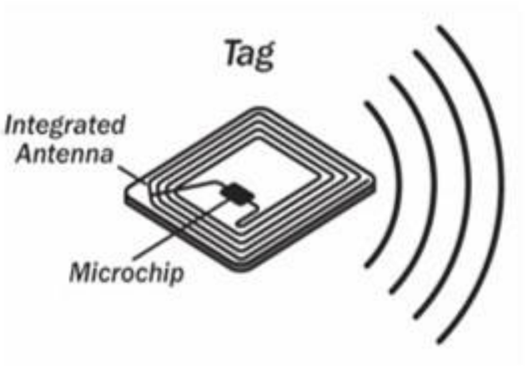

FIGURE 3. Passive RFID tag

Active tags have power source included within them, and they periodically transmit their ID signal. A passive tag is smaller and cheaper since it does not have battery included in it (Figure 3), instead the passive tag uses the radio energy transmitted by the RFID reader. Battery-assisted passive has a small battery on board, and it is activated then an RFID reader is nearby. (7.)

2.2.2 RFID Frequencies

The RFID technology uses three different worldwide established frequency areas, which are:

- Low frequency (LF): < 135 kHz
- High frequency (HF): 13.56 MHz
- Ultra high frequency (UHF): 850 – 960 MHz (8.)

The application type determines which frequency area should be used. The low frequency (LF) area is more commonly used in industrial use. The main benefit of the low frequency area is the readability through different materials, which allows the reading of the RFID tag from PWB through the unit's metallic shell. (8.)

The disadvantages of the low frequency tags are the expensive tags and having a short reading range, which is between 0.5 – 1.0 m. (8.)

Higher frequencies allow higher reading speeds, higher reading ranges and better data storage possibilities. The high frequency signal does not penetrate material, but allows the reading of the multiple tags simultaneously. (8.)

2.2.3 Restrictions

There are several restrictions not supporting the use of RFID technology for PWB marking and it is difficult to find a potential RFID tag for PWB identification.

The smallest RFID active label tags have their sizes starting from 35 * 10 mm, which is over four times bigger than existing labels, tags with such size would be too big to be used in the smallest products. (9.) The size of the smallest passive RFID tags start from 2 * 1 mm. Because of the small size of the passive tags, they are considered more potential choice for PWB identification.

Most of the tags cannot withstand the high temperatures of the re-flow oven. Some ceramic tags can tolerate such temperatures, but the glue from the tags bottom side would not. (9.)

To get enough reading range for the tag, it would require even more space for the antenna. There are tags like Magicstrap from Murata, which does not have antenna, but the PWB would need to be planted with copper antenna in the manufacturing process. Copper antenna with the size of 37 * 54 mm would only give the reading range of 15mm. (10.)

The lifespan of the RFID tags depends from which tag type is used. Most of the vendors can promise the lifespan of 10 years for their passive tags. Humidity and other environmental factors may decrease this lifespan. The lifespan of the active tags depend from the battery type and how often the tag is asked to transmit a signal. (11.)

2.2.4 Features to be examined for RFID technology

This chapter contains list of features that require more studying if RFID technology is taken into use as PWB identification method.

- Content; if RFID technology is taken into use, it requires total knowledge for the required information content of the RFID tag. Higher content requirements will increase the size of the RFID tag. If more information is required in the future, it is better to store the data into the database of the Nokia.

- Use of RFID tag; it is required to know the method of the use for RFID tag. Is the tag used only for identifying the serial code, or does it require the capability to be re-programmed in certain process steps? Re-programming requires own separate equipment to be purchased.

- RFID tag placement; it is possible to place the RFID tag on either side of the PWB as a component, on the edge of the PWB or it is possible to embed the tag into the layers of the PWB. Certain PWBs can have separate restrictions for the placement of the RFID tag. If embedded technology is used, it is needed to ensure capability of PWB suppliers to implement RFID. Also check minimum thickness needed vs. Nokia PWB specification.

- Optimal reading range; by increasing the reading range of the RFID tags, it is possible to read multiple tags simultaneously. But by increasing the reading range, it is possible to read wrong PWB tag, if it is located near the tag reader.

- Temperature; if the RFID tags are placed into the PWB at the beginning of the production line, the RFID tags must withstand the temperatures of the reflow oven (~240 °C).

- Lifespan; some RFID tags have shorter lifespan promise from the manufacturer than others. Typical lifespan range is 2 – 10 years. It is required to know how long the tags can be used in the field.

- Repair; if the data of the PWB is stored behind the serial number in the database of the Nokia, does the tag reader in the field require the access to the database to get the required information? It is also possible to encrypt or password protect the data in the tag.

- Readability; existing label in the PWBs are required to be readable by human eyes. Is the readability still required in the future, if RFID technology is taken into use?

- Reader type; it is not possible to read low frequency tags with high frequency readers. If different types of RFID tags are used in the process (for PWBs and units), it requires the purchasing of the separate reader.

- Reader cost; the price of the RFID reader depends from the required frequency area. Simple USB connected RFID tag readers can be used in the process and are cheaper (~50 € or cheaper in mass ordering). Wireless standalone readers are better if reading is required in the field, but the cost of the high quality readers can be up to ~400 €.

- Protection; RFID tags can cause problems with the used radio frequency area. Sensitive machines at the factory may require protective shielding from the radio frequencies of the tags.

3 BARCODE MARKING TECHNOLOGIES

Different marking technologies are used to mark various materials around the world. Choosing the most potential marking technology is done on a case by case basis. Different technologies have their own restrictions on their use, which will prevent the use of same technology on every case. The laser and the inkjet technologies are studied in this chapter.

3.1 Laser

The laser technology is used to mark virtually all metals, plastics and various list of other materials. The laser technology does not have restrictions for the shape or content. A laser can be used to mark both one dimensional (1D) and two dimensional (2D) barcodes as well as different serial numbers, consisting of letters and numbers. (12.)

The major advantages of using the laser technology for marking are:

- small cycle times (Average marking time for a single PWB of Nokia is 0.9 – 1.0 s.)
- marking is permanent and it is not possible to remove it
- no label material costs
- electrostatic discharge (ESD) proof
- better quality for positioning.

Disadvantage note: As the identification mark from laser is permanent, this may cause problems when re-marking is needed. It would require reserve area from the PWB to make second marking, or other way is to use the existing label in these special cases.

A solder mask is a solder resistant area that is applied to copper traces of a printed wired board (PWB) and commonly used with laser marking technology. Solder mask is used to protect the PWB from the oxidation and to prevent solder bridges from forming between closely spaced solder pads. (13.)

When using CO_2-laser marked area must be covered with solder mask to protect the copper wiring. The laser marking will burn only on the solder mask and it will not penetrate the mask to cause problems with the oxidation. (14.)

3.1.1 Carbon dioxide laser

The Carbon dioxide (CO_2) lasers are one of the most powerful continuous wave lasers currently available. CO2-lasers belong to the gas laser group. The reason for the powerful output of CO_2-laser is caused by the lasers used wavelength. The CO_2-laser emits laser light in the infrared region of the spectrum and the infrared radiation is basically heat radiation. The CO_2-lasers are mainly used for cutting, welding and marking in industry. (15.) The CO_2-lasers are not suited for metallic surfaces, but can be used on wood, acrylic, glass, paper, textiles, plastics, foils, films, leather and stone (16).

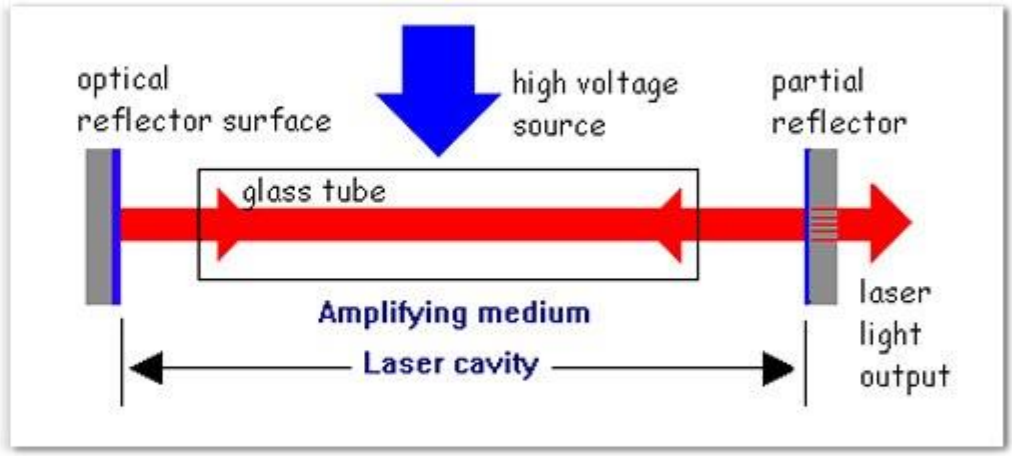

FIGURE 4. Structure of the laser light source

The major restriction for using CO_2-laser on PWB marking is the required solder mask, the CO_2-laser cannot mark on any metal surfaces on the PWB (17). This may cause problems when marking very small items with limited solder mask area. The advantage of the CO_2-laser is that it will not burn down to base material, and it will not cause problems with the oxidation. CO_2-laser is fulfilling main criteria for Nokia Networks PWB identification targets.

3.1.2 Fiber-laser

The fiber-lasers belong to the solid state laser group and use specially designed glass fibers to amplify the source laser to create more powerful laser beam. Optimal uses for fiber-lasers are metal marking applications because it is capable for metal engraving and high-contrast plastic marking. The fiber-lasers are not suited to mark on solder mask, which causes big restrictions for the use. (16.) The fiber-laser could be used to mark metallic surfaces of the units, too.

3.1.3 Crystal-laser

The crystal-lasers also belong to the solid state lasers. The most commonly used crystal-laser type is the neodymium-doped yttrium aluminum garnet (Nd:YAG), it is named after the doping element neodymium and the carrier crystal. The crystal-lasers have the same wavelength as fiber lasers, this is why they are also suited for marking metals and plastics. (16.)

The main disadvantages of the YAG-lasers are the expensive pump diodes, that are wearing parts. The pump diodes must be replaced after 8 000 – 15 000 hours. The crystal itself also has shorter service life than fiber laser. (16.)

3.1.4 Green laser

It is possible to use q-switched diode-pumped solid-state laser in green wavelength (532 nm) to mark both metallic surfaces and solder masks on the PWBs. The green laser can also be used to de-panel thin PWBs. (18.) The green laser will require re-programming to switch from metallic surface to solder mask. (19.)

TABLE 2. Comparison of laser technologies

	Fiber-laser	CO2-laser	YAG-laser
Acceptable materials	Metal / High contrast plastic	Organic (wood, glass, PWB..)	Metal and Organic
Cooling method	Air	Air	Air or Water
Equipment cost	60-120 k€	~80 k€	~90 k€
Amplifier type	Glass fiber	Gas	Diode
Lifespan of Amplifier	~15 000 hours	~10 000 hours	~8000 hours

3.1.5 Test trials

Experimental PWBs were sent to factories of OSAI and ASYS and applied with 1D and 2D barcode labels. Equipment manufacturers marked the exactly same information to PWB by using the laser technology. The test samples were verified with supplier's barcode scanner and human eye. The test results were received from the ASYS and OSAI and results were acceptable.

Representative members from ASYS corp. used INSIGNUM 4000 machine and the used laser source was Synrad 48-series 10W.

Size	5x5 mm
Matrix	22 Modules (resolution0,227mm)
Content	[)>061P083909A.X12SL91447000491TA4U06V7R

FIGURE 5. Test results from 2D-barcode (17.)

The test results with the 2D-barcodes were successful (Figure 5.). The size of the 2D-barcodes were 5 * 5 mm, but this does not include the readable content next to the barcode. All the codes were successfully read with Microscan "Mini

Hawk HR” scanner and with the Honeywell “Xenon 1900” handheld scanner. (17.)

FIGURE 6. Test results from 1D-barcode (17.)

The 1D-barcodes marking quality was also good (Figure 6.), but they had to increase the size to 30 mm from 27.5 mm. The 1D-barcodes tend to leave burning residues, but all the codes were readable with the barcode scanners. (17.)

It was not possible to make a marking on the gold coating on the other side of the PWB with the CO_2-laser. It is possible to mark the gold coated surface with the fiber laser, but test trials with fiber laser were not done. Another possible equipment is green laser, and it is capable to mark both solder mask and the metallic surfaces. The recommendation from ASYS was to find a place from the solder mask and to use CO_2-laser. The complete test results can be seen from the attachments. (APPENDICES 1/1 – 1/6)

The test results were made by OSAIs 30 Watt CO_2-laser, with the wavelength of 10.6 µm. 2D barcode was done with cycle-time of 0.9 s and 1.1 s for 1D barcode. Results for both barcodes were good with high contrast (no pictures from results). Due to the small size of the 2D barcode, it was difficult to use low quality barcode readers. Reader requirements need to be clarified when implementing laser marking process. (20.)

3.1.6 Maintenance and wearing parts

Two vendors made a proposal of possible laser marking systems (ASYS and OSAI). The representatives from OSAI and ASYS were asked for proposed laser technology, estimated costs and the required maintenance and spare parts.

The representatives from ASYS corp. sent data sheets for two potential laser equipment, these machines were INSIGNUM 2000 and INSIGNUM 4000. Both machines are CO_2-lasers. The main difference between these machines is that the INSIGNUM 2000 has fixed marking head with moving mirrors and the INSIGNUM 4000 has moving marking head. The 2000-version has higher speed and the 4000-version has better flexibility in x-y-axis. (21.)

The proposed marking system from ASYS corp. was 10 W CO_2-laser, with less than 1kW power consumption and the air consumption of 12 Nl / min. The evaluated costs for this equipment were 60 – 120 k€ for each machine. The required maintenance was daily cleaning of dust and mirrors and the changing of filters and waste bags. Needed spare parts are mainly for the conveyor belts and motors with low spare part consumption. (21.)

The proposed laser types from OSAIs representatives were CO_2-laser for the PWBs, YAG-laser if it is required to burn the marking to base material (metallic surfaces) and the green laser to be programmed for both surfaces. Estimated costs for CO_2 or YAG-lasers were 85 k€, for both lasers 110 k€ in total and for the green laser 95 k€. (19.)

Laser smoke requires special filter with the cost of 2 k€, the data management costs were 5 k€, installation 5 k€ and the freight cost was ~ 1 k€. Required power was 230 V / 10 A. OSAI suggested 1 maintenance / year. The life time of laser crystal is approximately 10 000 hours, with the working time of 33 % of the day, the crystals estimated life cycle is 4 years. The cost of the new crystal is around 10 k€. (19.)

TABLE 3. Summary of invests for different laser types

Cost / k€	CO_2-laser	YAG-laser	Both CO_2 and YAG	Green-laser
Material type	PWB	Metal	PWB and Metal	PWB and Metal
Machine cost	85	85	110	95
Smoke filter	2	2	4	2
Installation	5	5	10	5
Freight	~1	~1	~1	~1
Total	93 k€	93 k€	125 k€	103 k€

3.2 Inkjet

Inkjet markers are able to make the similar markings as existing printers and lasers. Laser markers and inkjet markers do not require excess white area around the 1D / 2D marking like labels do. Inkjet marker sprays tiny ink droplets to produce a direct marking into the item without physical contact. Inkjet can be used to mark a wide range of materials, therefore it is widely used in typical household and industrial volume products. Inkjet can be used to mark both one dimensional (1D) and two dimensional (2D) barcodes as well as different serial numbers, consisting of letters and numbers. (22.)

It is possible to remove an inkjet marking with chemicals. This is a major advantage as there is no need for extra space in the PWB if the first marking was incorrectly marked.

3.2.1 Summary of inkjet technology

Advantages of the inkjet technology:

- Inkjet technology can be used to mark existing barcodes. Investments for the new barcode readers are not required.
- Similar size requirements than laser
- It is possible to remove inkjet markings with certain chemicals.
- ESD proof marking method
- Similar cycle times than laser

Disadvantages of the inkjet technology:

- Easier to ruin the marking compared to permanent laser marking.
- Print head can clog, causing ruined markings.
- Expensive ink ribbons, compared to long lasting crystals of the laser technology.
- Very sensitive to water, causes blurring

If an inkjet is chosen to serve as a marking method, more study for the ink type is required, for example;

- Ink drying time
- Durability vs temperature conditions (high and low temperatures for long period of time)
- Removal of ruined marking
- Possible chemical hazards

4 USE OF THE IDENTIFICATION

This chapter explains the various needs and uses of a different markings and identifications in the process. The explained markings are PWB, unit and package markings, PWB marking is explained in more detail, as it is the main target of this thesis work.

4.1 Printed wired board markings

The item label (1D/2D) in the PWB contains serial number and process lot data fields. (23.)

4.1.1 Serial number

The serial number contains eleven characters, for example: *L1234567890*

The serial number contains production information of the PWB. This production information includes production date, the place of production and the type of the module, which can be either prototype or volume module.

The serial number (SFC) is used for traceability. By scanning the SFC barcode, it is possible to restore the module level process and component information for the IT-system of Nokia (SCE). The component data includes all component details needed for traceability. (24.)

By scanning the SFC, it is possible to track down data like which components are used in each module, which components are hand soldered and by whom, or to check if that module has passed ICT or module testing. In a summary, every process step with any results will be added under the SFC-code. (24.)

4.1.2 Process lot code

The process lot code contains eight characters, for example: *1AB23456.* The process lot code contains the process lot identifier (ID). This ID is unique for different products, when new products are made, they have their own process lot ID, generated by the Nokia's IT-system. (23.)

The AOI process step reads this process lot ID in order to identify which product will be tested, the AOI machine can automatically choose the right testing program by using this ID. (23.)

In the multi-panel, which can have several modules in same module frames, this process lot ID is read just from one module, because all the other modules in that frame will have the same process lot ID. (23.)

For example, a frame with four modules:

- The serial numbers in the product configuration are linked to the same process lot ID.
- The SFC's coordinates are predetermined in the module panel.
- Module sequence in the AOI's testing programs is synchronized with the PLCM's configuration.
- If one of the modules in processed panel fails, AOI's repair spot can automatically show which module did fail in that panel.
- The failure data is automatically added under the SFC of the failed module. (23.)

All this is based on the synchronized sequence of the SFC's on that panel, since without the correct sequence of the SFC's on that panel, the AOI cannot register the failure date for the right SFC. (23.)

4.2 Unit marking

The unit marking is also using labeling as marking method, primary 2D barcodes. The unit label contains BOM (bill of material) information, which tells the content of the each unit (modules, material of the hull etc.). It is possible to read the data of the each module in that unit, by reading the unit label with barcode scanner. (24.)

4.3 Shipment information

Products that are ready for shipping are packaged into shipment packages. These shipment packages are attached with shipping information, which is used to determine the content of the package with customer and sender information.

Shipping information uses Package Marking Specification to define Nokia Networks marking requirements. Package Marking Specification can be found in the attachments.

Shipping information contains:

- Site ID
- Delivery number
- Total number of packages
- Delivery and package ID
- Delivery text (optional)
- Customer data
- Sales order
- Weight and dimensions (25, s. 28.)

5 LABELING OPERATION MODELS

This chapter discusses the different possible labeling methods. At the moment, the labeling robot cannot insert 2D- or STI-labels. These labels are inserted by hand.

5.1 Manual labeling

At the moment around half of the labels are inserted manually. This method can cause major differences in the label placements, which can cause the misplacing of the label to a wrong module in the multi-panels. Placing the wrong label in wrong module will preclude the traceability.

When the module labeling is done manually in the beginning of the process, it is possible to get good a traceability from the beginning of the assembling. This allows the traceability of all the components placed in the module. This can be seen in *Figure 7.*

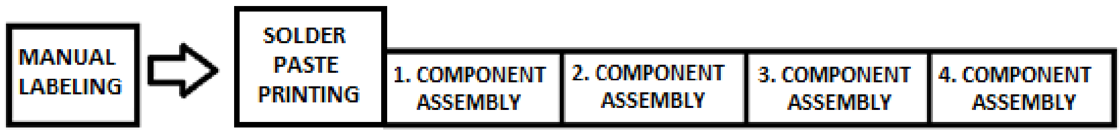

FIGURE 7. Manual labeling before the production line

5.2 Inline feeder robot

The in-line feeder robot cell is positioned at the beginning of the production line (See Figure 8). At first the cell prints the labels. After the printing this cell feeds the printed label roll for the pneumatic suction head, which picks the labels and inserts them to the PWB. The negative side of this cell is that the feeder robot can only insert 1D-labels, this prevents the inserting of the 2D- and STI-labels. Use of this Inline feeder robot cell allows good traceability for the process.

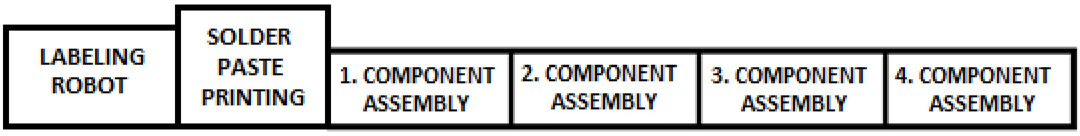

FIGURE 8. Use of the label robot in the beginning of a production line

5.3 Label feeder

The label feeder is installed in the assembly machine, process phases assembled before the first assembly machines are not traced. Label is assembled similar way as normal components in assembly line.

Since the label feeder is not at the beginning of the production line, it will cause the lack of traceability. The components assembled to the module before the label feeder will not get their data saved to the modules serial number. To get these components traced, it would require a software update, which would save the component data and add them under the correct serial numbers when that label is added for the module. Software used at the moment is not supporting this kind of option and this is the reason why label feeder is not recommended before the traceability problems are solved.

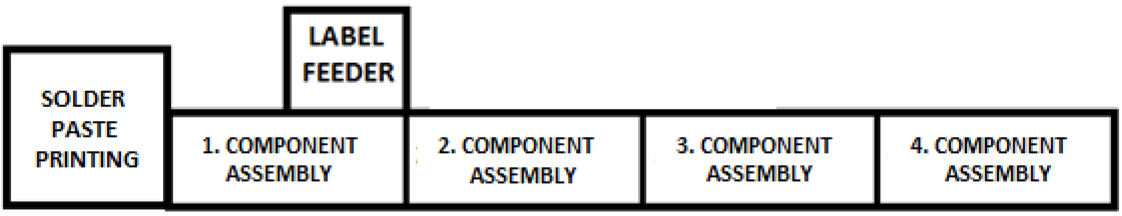

FIGURE 9. Label feeder in production line

5.4 Off-line cell

By using the off-line cell as marking system, one cell is able to serve multiple production lines. Traceability requirements are fulfilled by using an off-line cell.

Off-line cell is marking PWBs in separate cell before batches are going to production line. This means careful scheduling is needed. When using offline cell, total traceability is in use including stencil, solder paste and components. Off-line cell requires less work compared to manual labeling process.

The off-line cell uses existing labeling robot and printer, or technologies like laser, inkjet or RFID.

The off-line cell includes loader marking cell and unloader and it is operating automatically by loading and unloading the cell with the PWBs from racks. It is also possible to use de-stacker for loading PWBs to marking cell.

Because the off-line cell is a critical machine in the process, it needs to be ensured by manual printing capability as a backup plan.

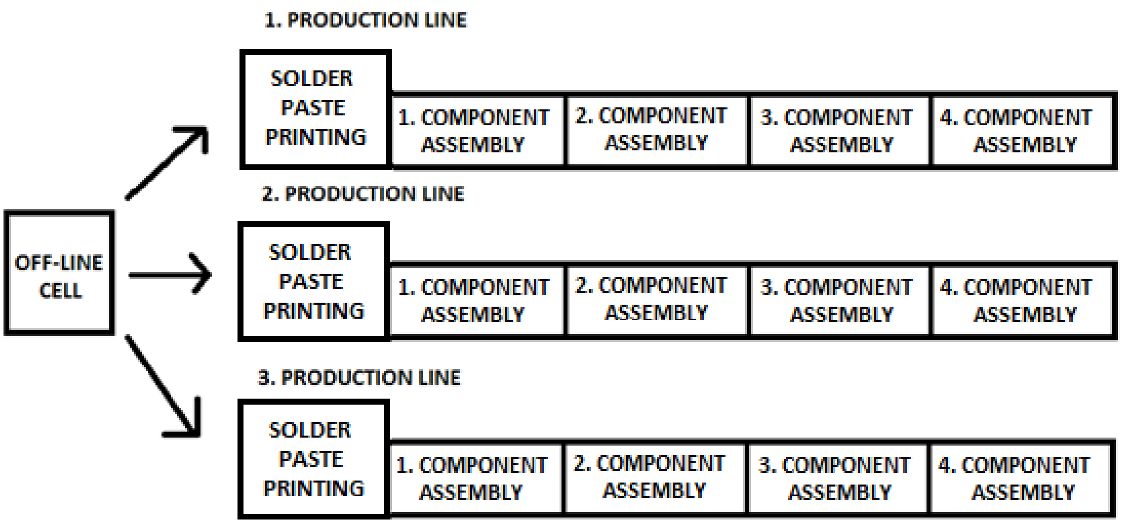

FIGURE 10. Off-line cell for multiple production lines

6 OBSERVATIONS FOR MARKING METHODS

This chapter contains the different problems and restrictions which were encountered while studying the different product marking methods. These restrictions will impact on case by case basis.

6.1 Printed wired board size requirements

When choosing the equipment for the marking process in the future, the minimum and maximum size requirements for the PWB's should be taken into account. These requirements can be seen from the *TABLE 4*.

TABLE 4. PWB size requirements (26.)

	Min	**Max**
Width	120 mm	405 mm
Lenght	140 mm	450 mm
Thickness	0,6 mm	4,5 mm

6.2 Re-marking

When the serial numbers barcode (1D or 2D) is defectively printed, damaged in any process step or is unreadable for some reason, it is possible to print new label for that module. Serial number in the new label will be the same as it was in the damaged label. (27.)

Re-marking with the laser technology requires a reserve area because the laser marking cannot be removed.

6.3 Label space requirements

The label space requirements for the existing 2D labels require free surface area of 10 mm x 8 mm. Marking the same data with 1D barcode label requires the free space of 20 mm x 8 mm. (28, s. 29.) This is a problem with small and very populated PWBs. Labels have unnecessary white space surrounding the text marking. The benefit of the laser and inkjet technology is that they do not require this safety area.

7 COST ANALYSIS OF DIFFERENT MARKING METHODS

When choosing the most potential PWB marking method solution, the estimated investments for each method has to be taken into account. The estimated invests and costs in this chapter are calculated for the factory of Oulu, Finland. Other countries will require their own calculations to be made. Calculations for the cost analyze are based on evaluations.

TABLE 5. Cost analysis for total factory (5 lines per Oulu)

Cost / k€	**Off-line manual labeling**	**In-line robot labeling**	**In-line label feeder**	**Off-line laser cell**	**In-line laser cell**
Operator cost	87.6	3.6	7.3	29	0
Invest (3 year)	1	100	16.7	40	133.33
Power cost	0	0.35	0	0.2	1
Label + ink cost	27	27	27	0	0
Total	**115.6**	**130.95**	**51**	**69.2**	**134.33**

The operator costs have been calculated by using the hourly wages of 20 € / h for the operator. Operator costs are based on estimated time that each method would require from the operator.

The in-line marking methods require their own marking equipment to be purchased for each of the production lines, while single marking equipment for off-line solutions can serve all of the five production lines.

The power costs have been calculated with the cost of 8 cents / kWh. The total power cost may vary widely, depending on the actual use of the equipment.

The label and the ink costs are the same for each labeling method. The roll of 10 000 labels have the price of 339 €, and the each roll lasts for 5 days, this makes around 73 rolls a year, with the cost of 24.7 k€ / year.

The price of a single ink ribbon is 60 € / ribbon. The factory requires approximately 40 ink ribbons per year, this makes the cost a 2.4 k€.

7.1 Off-line manual labeling

When using manual labeling, estimated one operator / 50 % is needed to support five assembly lines (calculated 12h / 365 yearly working days). This makes around 4380 hours a year. By using the hourly wages of 20 € / h, the estimated cost for the manual labeling is 87 600 k€ per year.

The only equipment investment for the manual labeling comes from the printer. The estimated cost for the Zebra / CAP printer is 3 k€, if the investment is divided for three years, the cost for each year is around 1 k€.

The power consumption costs for the manual labeling have not been taken into account.

7.2 In-line robot labeling

The in-line robot labeling requires approximately 0.5 hours of work from the operator to serve all the five production lines for whole day. This makes around 182 hours a year. By using the hourly wages of 20 € / h, the estimated cost for the manual labeling is 3.6 k€ per year.

The estimated cost of each labeling robot is 60 k€, when each of the five production lines requires their own robot, the total cost for five labeling robots is around 300 k€. When this investment is divided for three years, it makes the investment of 100 k€ for each year.

The power consumption of the labeling robot is approximately of 2.4 kWh / day, which makes around 876 kWh / year. For the five labeling robots it makes 4380 kWh / year, causing the power cost of 0.35 k€ per year.

7.3 In-line label feeder

The in-line label feeder requires approximately 1 hour of work from the operator to serve all the five production lines for whole day. This makes 365 hours a year. By using the hourly wages of 20 € / h, the estimated cost for the manual labeling is 7.3 k€ per year.

The cost of the one label feeder is 10 k€, while each of the five production lines requires their own label feeder, the total cost is 50 k€. This cost is divided between three years, which makes the investment of a 16.7 k€ for each year.

7.4 Off-line laser cell

The off-line laser cell requires approximately 4 hours of work from the operator to serve all the five production lines for whole day. This makes around 1460 hours a year. By using the hourly wages of 20 € / h, the estimated cost for the manual labeling is 29 k€ per year.

The equipment cost is approximately 120 k€ which makes the estimated investment of 40 k€ if it is divided between three years.

The power consumption is around 5.0 kWh / day, this value is based on the evaluation that the laser cell is not in the use for 24 hours a day. The power consumption is calculated by using the power consumption of the Insignium 4000 laser cell from ASYS. The total consumption for a one year is around 1825 kWh. This causes the power cost of 0.2 k€ for one year.

7.5 In-line laser cell

In-line laser cell will not need any time from operator, if it is part of the production line. Maintenance times are not taken into account.

If the equipment cost for one laser cell is around 80 k€, and each of the five production lines require their own laser cell, the total cost for five laser cells is around 400 k€. If the total cost is divided for three separate years, the investment for each year is around 133.33 k€.

By using the same Insignum 4000 laser cell equipment, the power consumption is five times greater than in the off-line laser cell, since each of the production lines would require their own laser cell. The estimated total power consumption is 1 k€ / year.

8 CONCLUSION AND RECOMMENDATIONS

This chapter contains the equipment and technology proposal and conclusion of the different marking technologies and methods.

8.1 Conclusion

At the moment, a labeling process with robots provides the possibility to continue marking and identifying the existing items e.g. PWBs. Alternative method is manual labeling, but it requires extra operator working time and costs. This causes costs every year and affect a risk of label misplacing. It is also possible to continue marking PWBs with labels if new labeling robots are bought.

The laser technology can be used to replace labels and it could be also used to mark casting of the units. These units are also labeled manually at the moment. Laser technology would also provide the possibility to make other markings to the PWBs and units (e.g. country of origin), this gives good flexibility for the future needs. Label and laser technology has similar identification information, but remarking is not possible with laser technology.

The RFID technology differs from the barcode markings, as it will not require visually readable contact from the scanner to read the tag information from the PWB. Implementing the RFID technology in Nokia requires specific study of requirements and piloting with sample products. Main observations for the RFID tags are size, lifespan and temperature limits if they are placed to PWB before the reflow oven.

There are two alternative layout models, in-line and off-line. In-line solution includes own identification equipment in all assembly lines. In-line model requires less operator work, but higher investments. The off-line model consist of one off-line cell, which is used to mark all the PWBs from every production line. This requires extra operator time like operating marking cell and transporting of the

PWBs from the off-line cell to the production lines. Advantage of the off-line cell is minimized investment cost.

8.2 Proposal for future marking model and technology

As a permanent proposal would be CO_2-laser (e.g. INSIGNUM 4000 laser marker from ASYS). It would be better to use in-line method for marking, as it would greatly reduce the required time from the operator and less buffering of PWB's. Payback time for in-line cell is approximately 3 years. If the marking is failed for some reason, it might require excess space for new laser marking, or it would be possible to use labeling in these cases. As short term period solution off-line cell could be most cost efficient because investments are minimized.

An alternative method for a long term solution could be RFID technology, but it requires more detailed study of alternative tags and technology how to integrate tags to PWB. First step is to make comparison of features between different RFID tag components. Next step is to analyze different tag integration methods on PWB. Choosing of RFID tag includes comparison of restrictions, information content, size, reading range, cost and temperatures. RFID tags should be integrated to PWB by PWB supplier or place in the beginning of the production line, this allows good traceability for every process steps. RFID technology is an alternative technology for identifying unit castings, too. RFID technology identification requires totally own process with placing, programming and reading.

8.3 Summary of key findings during this study

- Process requirements
    - A visual readability is required at the moment. Is it possible to remove this requirement in the future?
- Traceability
    - Use of an inline labeling robot, manual labeling and off-line cell allows good traceability.

   - Weakness of the label feeder; Because the feeder is installed in the first assembly machine, process phases assembled before the first assembly machines are not traced.

- Laser technology
  - The laser cell requires more studying for cost effectiveness vs low cost countries (in-line and off-line methods).
  - The laser equipment requires own evaluation (CO_2-laser most potential for PWB marking)
  - Is the metal casting of the units required to mark with laser in the future? If needed, the technology solution is a fiber laser.
  - Disadvantage note: As the identification mark from the laser is permanent, this may cause problems when a re-marking is needed. It would require a reserve area from the PWB to make the second marking, or the other way is to use the existing labels in these special cases.
  - Use of the laser technology may require an own process phase to clean / remove the burning residues from the PWB.
- RFID
  - The RFID solution requires totally own study to be made, features that require studying for example are;
    - Content requirement, type of tag, type of use for tag, reading range, tag placement, temperature withstand, required lifespan, data access in field, readability requirement, reader requirement and costs.

Use of RFID technology may still require label or laser cell to make other markings to the PWB or unit e.g. country of origin or material information.

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APPENDICES

- Appendix 1: Applications Report

Applications Report

Dornstadt, 07.01.15

Application: Testmarking on sample PCBs

Machine: **INSIGNUM 4000**

Laser source: **Synrad 48-Series 10W**

Galvo INSIGNUM: **MS-II-14**

PCB1

We did test markings on this PCB.
In general it is not possible to mark on any metal surface with a CO_2. If a marking on this position is needed, it would be necessary to do additional tests with a fiber laser.

As an alternative we have placed a label on solder resist to show the marking result.

Size	5x5 mm
Matrix	22 Modules (resolution0,227mm)
Content	[)>061P083909A.X12SL91447000491TA4U06V7R

PCB 2

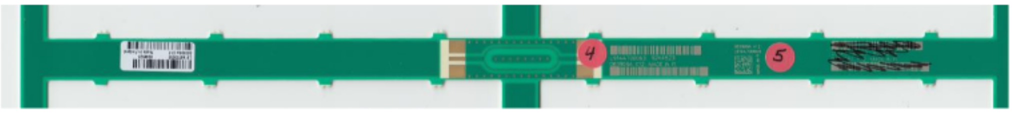
Size	5x5 mm
Matrix	22 Modules (resolution0,227mm)
Content	[)>061P083909A.X12SL91447000491TA4U06V7R

Size	25x2,5 mm
Codetyp	Code 128
Content	A4U06V85

Size	27x2,5 mm
Matrix	Code 39
Content	L9144700063

The marking quality on this sample is very good. All Codes are readably by the used Microscan "Mini Hawk HR" Scanner.

PCB 3



Size	25x2,5 mm
Codetyp	Code 128
Content	A4U06V85

Size	27x2,5 mm
Matrix	Code 39
Content	L9144700063

Size	5x5 mm
Matrix	22 Modules (resolution0,227mm)
Content	[)>061P083909A.X12SL91447000491TA4U06V7R

The laser marking quality on this PCB is good but the 1D code tends to slight smoke residues. However, all codes are readable by the used Microscan "Mini Hawk HR" Scanner.

A marking on the gold coating on the second side is not possible with a CO_2 Laser. As mentioned above, additional tests with a fiber laser would be necessary if a marking on this side is needed.

PCB 4

Size	5x5 mm
Matrix	22 Modules (resolution0,227mm)
Content	[)>061P083909A.X12SL91447000491TA4U06V7R

Size	25x2,5 mm
Codetyp	Code 128
Content	A4U06V85
Size	27x2,5 mm
Matrix	Code 39
Content	L9144700063

The marking quality on this sample is very good. All Codes are readably by the used Microscan “Mini Hawk HR” Scanner.

Marking

Conclusion:

All PCBs are markable with the INSIGNUM 4000 CO_2 system. The result on the solder resist is quite good and all codes are readable by the Microscan "Mini Hawk HR" scanner and the Honeywell "Xenon 1900" handheld scanner.

We had to increase the size of the 1D Code, because the resolution was too small for the CO_2 laser system. The beam diameter in the focal point is about 180µm. For a code with the given contend a length of ~30mm would be very good for a process stability.

For any metal surface on the PCBs there is no possibility to get a marking result with the CO_2 laser. In this case further trials with a fiber laser are necessary.
Another possibility would be a green light laser; this kind of laser could be able to mark both solder resist and metal coating. However here are also further tests necessary.

Our recommendation is to find a place on solder resist to mark the label with the used CO_2 laser system.

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