ADVANCED ANTENNAS FOR MOBILE PHONES

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I. INTRODUCTION

Diversification, styling, miniaturization and cost reduction are trends in the field of portable electronics. Nowadays the design is the one of the key features for any consumer product. End-users are expecting increasing amount of novel functions available inside trend-looking covers. An antenna makes no exception. In addition, new technologies directed into volume market products have to be flexibly modified into several products and cost competitively manufactured in global manufacturing networks. New innovative technologies are needed to develop in order to meet the market's demands.[1]

This paper introduces the LPKF-LDS (Laser Direct Structuring) technology for the manufacturing of 3D-MIDs (Moulded Interconnect Devices) that is predicted to have a successful future in electronics and mechatronics. The principle of the LPKF-LDS technology is the production of injection molded thermoplastic circuit carriers with laser treatment that is new means to incorporate electronic circuitry, connections, patterns, antennae, and many other features directly onto the 3D molded thermoplastic surface. The focus of this paper is in internal antenna applications for mobile phones and other portable devices made with Laser Direct Structuring method. A stamped metal sheet antenna technology is well known low cost technology. However, due to the stamping process there are limitations in the pattern geometry. Furthermore, tooling is expensive and an altering of a RF pattern causes high-priced and time-consuming modifications into tooling. The LPKF-LDS technology increases flexibility for design of a device, ease of modification of antenna patterns and production lines from product to product and allows multiple antennas integrated into the device's mechanical structure.

II. ANTENNA MARKET

The wireless device market has exploded over the last decade. Worldwide there are almost a billion cellular/PCS subscriber. New product capabilities and applications such as short-range wireless connectivity (Bluetooth and WLAN), wideband data connectivity (2.5–3G services), DMB (Digital Multimedia Broadcasting services) and global connectivity (multi-band operation) are drivers for antenna technology development. Significant design challenges are needed to solve by product designers and manufacturers, since new feature set requirements do not map adequately into existing antenna solutions.

Portable handheld devices are diversifying in future. New functions are required to add, but at the same time a size of a device should become smaller and a design should have a novelty appear. Even nowadays a mobile phone could have three or four radio units working in different frequency band and an increase of new functions means increasing number of antennas and multi-band solutions. These antennas must be placed inside continually shrinking device. As portable devices become smaller and have a need for multiple antennas, the footprint allowed for antennas is reducing. [1,2] Furthermore, a design is one of the key features of a portable device and end-users perceive external antennas old-fashioned. The integration of electronics and mechanics, like the 3D-

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MID technology, is an innovative way to meet market's demands by producing cost and space utilization efficient embedded antennas and offering increased design freedom for industrial designers.[2] Electronics is going towards modular or single-chip solutions. Many companies and research institutes have published System-in-Package (SiP) or System-on-Chip (SoC) solutions and the 3D-MID technology offers versatile and cost effective interconnection platforms for them. [3]

III. Manufacturing Technology

In the past, mechatronic products, also known as 3D-MIDs with real three-dimensional structures have primarily been produced using two-component injection molding (2-shot-molding) with subsequent chemical surface activation and selective metal coating – a method involving high initial costs and which is only economically viable for large production numbers. The 3D-MID production method using laser structuring throws out the 2-shot-molding and enables MID blanks to be produced by single component injection molding.
And compared to subtractive laser structuring, the additive LPKF-LDS technology also benefits from a very short process chain. The main process steps are shown in figure 1.

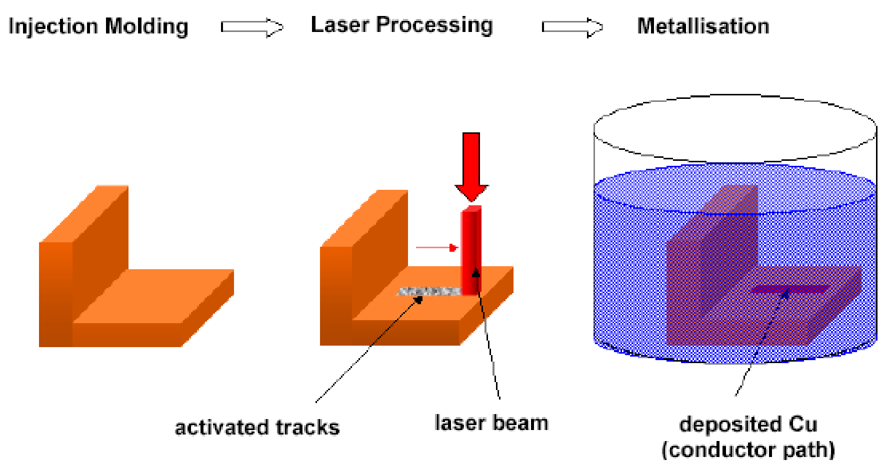

Figure 1: LPKF-LDS-process steps

Compared to conventional methods, Laser Direct Structuring has additional advantages in the production of ultra-fine tracks. Moreover, this method also gives high degrees of flexibility for the conductor layout because modifications can be easily incorporated by changing the structuring data. This enables subsequent changes to be made to the circuit layout without having to modify any tools. This degree of flexibility in particular enables users to harness the benefits of Laser Direct Structuring for their product development processes in the firm knowledge that this can simultaneously provide them with a series production process and therefore makes the cost and time-intensive transfer of prototype production to series production unnecessary.
The application-oriented selection and industrial availability of the standard laser-activatable plastics used by the electronics industry is an important prerequisite for the use of the LDS method for series production. This availability is guaranteed by the intensive material development and corresponding licence contracts with the relevant plastic-makers: in this context, LPKF has already signed agreements with BASF AG, Bayer Material Science AG (since 01.07.04 LANXESS), Degussa AG and Ticona GmbH.

IV. Experiments

A. Background

The electrical and mechanical specifications are target values for typical mobile phones. Structures in which electronics functions are integrated directly onto the 3D surface of a thermoplastic part have no ready-made testing procedure. For integrated technologies a testing procedure is always application specific and drivers for testing come from several sources; development phase testing, obligatory, customer driven or product related, mass production related and problem solving. The evaluation procedure for an antenna performance of an internal antenna made with LPKF-LDS technology is based on usage environment conditions of targeted end product i.e. a mobile phone.

The main target was to evaluate the LPKF-LDS technology's capability for an internal antenna application directed into the mass volume market and this paper introduces the summary of these evaluation methods and results. In addition to RF properties also manufacturability, electrical, mechanical and environmental performances, cost efficiency of the LPKF-LDS technology were under the evaluation.

B. Mechanical performance of internal antenna

Peel strength is one of the most important characteristics of the 3D-MID technology. Peel strength is measured stress through peeling of a bonded surface resulting in a plating failure. The initial adhesive strength in PCB engineering is defined as between 0.6 – 1.1 N/mm in accordance with DIN IEC 326. As a supportive method a tape test and a cross hatch were included into the testing procedure. The tape test method uses pressure sensitive tape (3M Brand 600 ½ inch wide) to determine adhesion quality of plating, marking inks or paints, and other materials used in conjunction with printed boards. Cross Hatch adhesion test is used to test bonding strength of plating to plastic substrate. Using a sharp utility knife, score 4 parallel lines 3/16" apart. Score 4 additional lines in the same manner perpendicular to the first, creating a tic-tac-toe. Scoring should go through all layers of plating. Using a piece of clear cellophane tape, test the adhesion by removing the tape quickly. If no pieces of plating are removed, the adhesion of the plating is sufficient. [11] According to this research the peel strength of metallization on LPKF-LDS substrates exceeds the defined peel strength value of a PCB.

Every portable device will be exposed to vibration through its projected life. It will be shipped by truck, rail, ship or aircraft, all which involve varying vibration profiles. Customer will set it down on vibrating equipment such as vehicle seats. Mechanical stress testing was simulating real usage environmental mechanical stresses that a mobile phone is exposed to during its life cycle or stresses that an antenna module will be exposed to during a manufacturing process of a device. In the case on an antenna mechanical stresses can cause harmful defect into antenna pattern and disturb the antenna's performance. Mechanical vibration testing was performed according to Random vibration, MIL-STD-202E, test method for electronic and electric components and parts. Test is carried out according to Method 214, test condition A (frequency range and shape of spectrum changed, but spectral acceleration about same).

Mechanical shock serves to simulate the forces involved in situations like when a car strikes a pothole or a device falls from a desktop. The applications are numerous. Drop test for small portable electronic device is typically done from height of 0,5 to 3m to surfaces such as concrete, wood and steel. Some specifications call out precision drops to a combination of planes, edges and corners and others random drop by hand suffice. For the drop test a total design is needed to know. In this work device design is not defined, so only mechanical shock test has been performed. According to MIL-STD-202E, Test method for electronic and electrical parts, Method 213, Condition A. Tests were carried out in both directions of perpendicular axis of the conductive pattern. The pulse sine was half sine and the number of pulses was 10 in each direction. [12]

Structural characterizations and electrical measurements were performed before and after the mechanical vibration and shock testing. No signs of deterioration of the adhesion were observed on the test models and the electrical properties were similar before and after the mechanical vibration and shock testing.

C. Electrical performance of integral antenna

The electrical specifications were target values for typical mobile phones. The electrical performance of internal MID antennas was evaluated by the comparison between a commercial antenna model and similar MID antenna. The measurement included the full 3D radiation patterns in free space and return loss measurements. The pattern and dimensions were similar between the commercial antennas and the MID antennas.

In Figure 9 is presented a part of the return loss measurement results for test antennas. The antenna test pattern was designed to simulate a not optimized antenna in order to find out the technology's capability to produce an internal antenna.

The return loss measurement results show that with the LPKF-LDS technology it is possible to fabricate functional internal antennas. The 3D free space radiation patterns were very similar between commercial stamped metal antennas and the MID antennas manufactured by Laser Direct Structuring

Moisture and Insulation resistance measurements were performed according to IPC-6018, Paragraph 3.9.3 and IPC-TM-650, Method 2.6.3. Test samples are conditioned for 24 hours at 50°C after specimens are cooled initial insulation resistance measurements are measured. Five hundred VDC is applied to the test samples for one minute prior to taking each insulation resistance measurement. Test specimens are placed in a vertical position in a temperature humidity chamber. A polarizing voltage of 100±10 VDC is applied during the entire test. Samples are exposed to 20 cycles of temperature and humidity. The humidity chamber is cycled from temperature of 25°C and relative humidity 90% to +65°C and relative humidity 90%. Insulation resistance measurements were made after one hour and before two hours stabilization at ambient.[13] The results didn't show any unwanted phenomena.

D. Environmental characteristics

Technologies that integrate electrical and mechanical functions into one coherent unit have to be able to resist environmental stresses critical for both mechanical and electrical performances. The approach for environmental testing was based on the usage environment condition of a mobile phone. Climatic exposures are used to simulate the conditions to which the electrical devices are exposed during transportation, operation or while in warehouse. The objective is to check whether such conditions can harm the device - does the device after the exposure still meet the requirements of the safety standards or still operate normally. The testing procedure was consists of thermal cycling, damp heat and salt mist tests.[14]

Humidity testing is typically done at extremes e.g. high temperature/high humidity and low temperature/low humidity. The upper extreme tests to see if moisture can be forced into tested structure resulting in undesirable parameter variances or corrosion. The lower extreme tests factors like the vulnerability of materials that might dry out and crack. [15]

The Damp Heat test was carried out according to IEC 60068-2-30, Test Db. Conditions were:

High Temperature	+55°C ± 2°C (9 hours)
Low Temperature	+25°C ± 2°C (9 hours)
Temperature change	2 * 3hours
Humidity	90% ± 5%
Cycle	6

Salt mist tests were performed according to ASTM B117 (5% NaCl at 35°C) with an exposure time of 48 hours. The objects are positioned in the salt spray chamber in such a way that the inside is directed towards the spray nozzle. After completed exposures testing the objects are rinsed with deionised water, to remove traces of sodium chloride, and thereafter dried and wrapped in sealed polyethylene bags. ASTM B117 Salt Mist test is aggressive test method and literature has reported several salt mist test method with smaller per sentage of NaCl.[16]

Temperature cycling is the process of cycling through two temperature extremes, sometimes at relatively high rates of change. It is used to age products through fatigue. As components heat up and cool down, they expand and contract. This causes failure over time. In addition to evaluating designs, it is also used in manufacturing to screen products to catch early-term, latent defects. In this work the temperature cycling test temperatures are taken from the handheld device specification that is commonly used in the telecom market. The lower temperature is -30° ± 2°C, the upper temperature is +60° ± 2°C and the rate of change of temperature is -7°C/min. The test duration is 50 test cycles, which is approximately six days. [17]

Thermal shock is an extreme application of rapid temperature change. It compares to moving from the desert to the arctic in few seconds. Improperly formulated or manufactured materials can have undesirable internal stresses that can lead to failures. Thermal shock provides a stimulus to relieve these stresses in the form of cracks, warping, etc. The scope of this test method is to determine the physical endurance of conformal coating/printed boards to sudden changes of high and low temperature excursions that cause physical fatigue. Samples are subjected to one hundred cycles of thermal shock between temperatures of –40°C and +85°C. Dwell times at each temperature extreme is 15 minutes and transition time between extremes is less than two minutes. [18, 19]

After the climatic tests electrical properties and the adhesion quality of the conductive pattern was verified. As a summary can be concluded that the MIDs manufactured in LPKF-LDS technology passed all operational environment testing. There was no evidence of cracking, separation, blistering, delamination, deterioration or change in resistance and no conductors lost continuity.

E. Mass production capability

The capability evaluation of a technology's manufacturability is always application and technology specific. In this work the manufacturability evaluation is focused on a mobile phone's internal antenna applications made with the LPKF-LDS technology and targeted at the volume production. In the case on an internal antenna the position accuracy and repeatability during mass production were the most important characteristics under evaluation. The manufacturability evaluation is needed to perform through the entire manufacturing network.
Features like wirings, antenna patterns and connections integrated directly into a plastic part's surface require high pattern's shape repeatability and positioning accuracy due to automated assembly processes in a mass production. According to the manufacturability evaluation results Laser Direct structured MIDs have very good pattern's shape repeatability and positioning accuracy. The LPKF-LDS process is highly flexible, cost effective and viable technology for internal antenna applications.

V. SUMMARY OF RESULTS

This paper introduces a sweeping summary of the evaluation results due to the confidentiality of measurement data related to the commercial product or companies' strategic know-how. The evaluation of a technology that integrates electrical and mechanical functions into one coherent unit has no ready-made testing procedures. The evaluation of LPKF-LDS was based on the operational environment conditions of portable electronic devices i.e. mobile phones directed into the volume market. Although, the focus of this paper is in LPKF-LDS's capability for internal antenna applications the goal of the evaluation was more extensive. The goal was the overall feasibility evaluation of the LPKF-LDS technology. Results proved that LPKF-LDS technology could be used in antennas electronic circuitries, connections and many other features in portable devices.

VI. CONCLUSIONS

It can be concluded that the LPKF-LDS technology is reliable and flexible 3D MID technology for internal antennas of mobile phone applications. Furthermore, the LPKF-LDS technology offers a low cost manufacturing process and offers increased design freedom for product designers.

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