Domain Integration and Cost Reduction in Electronic Product Design: a case study

Wessel Wits[1], Tom Vaneker[1], Jan Mannak[2] and Fred van Houten[1]
[1] Design, Production and Management Group, University of Twente, Netherlands
[2] Thales Nederland B.V., Netherlands

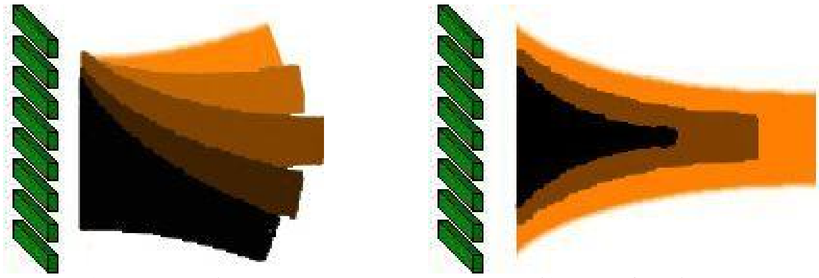
Abstract

This publication discusses domain integration of various engineering disciplines as an effective methodology to design new, innovative products or to upgrade existing ones. A case study illustrates how this approach is applied to the design process of a high performance electronic product. Thanks to newly developed cooling technologies, fewer constraints are put on the location of heat dissipating components with respect to their heat exchanger. This allows for more overall design flexibility, which can result in a more integrated product design with advantages in terms of performance, volume, weight and production efficiency.

1 INTRODUCTION

In today's society there is a continuous demand for more and more technologically advanced products. Industrial suppliers try to maintain their competitive edge through a continuous product improvement cycle. However, for complex products this is easier said than done, as even small changes in one domain can have profound effects in other domains. Therefore (re-)design, in many cases, should not focus on modifying products in a unidisciplinary manner; instead a multidisciplinary approach must be utilized. This especially applies to products that inherently relate to various domains, such as electronic products.

In this case study, the design considerations in the development of an Active Electronically Scanned Array (AESA) radar antenna are assessed. The combined elements of the antenna array collectively steer the radar beam, without the need to physically move (i.e. rotate) the radar antenna. This results in a highly flexible and fast responding antenna system. Figure 1 illustrates such an antenna array. Until now, these antenna systems have been mainly used for 'high end' applications (e.g. defense, astronomical science), particularly due to their high manufacturing cost. The research project, in which this study took place, focuses on making these systems much more affordable by combining the latest advances in semiconductor technology with efficient packaging technologies, thus achieving a level of integration previously unimaginable in radar engineering.



a) Beam steering b) Beam focusing

Figure 1. Active electronically scanned array radar antenna.

In the electronic products industry, multilayer printed circuit board technology is an established mass-market production method, appreciated for its high degree of integration of mechanical and electronic functions. Polymeric layers, on which a conductive pattern is produced, are laminated together to form a Printed Circuit Board (PCB). On top and bottom of the PCB, electronic components (e.g. IC's, resistors, connectors) can be assembled, thus forming a Circuit Card Assembly (CCA).

In Radio Frequency (RF-) design, PCB technology is also applied for the realization of EM transmission lines. On these multifunctional carriers, active components, such as RF amplifiers can be mounted on the surface. To design such a complex system, in-depth and coherent knowledge of every engineering field involved is required to pursue the best system performance at the lowest cost.

2 ANTENNA DESIGN

Traditionally the design process of most electronic products has been dominated by electrical and mechanical requirements. In the case of an AESA antenna system this is augmented by EM requirements. Figure 2(a) illustrates the design process from a thermal point-of-view. As cooling is not a primary function in electronic products, thermal analyses were usually addressed towards the end of the design process or not at all, as until recently, thermal management aspects scarcely impeded an optimal product design.

As semiconductor technology advances and smaller, higher performance electronic components become available, internal heat fluxes increase dramatically. This is one of the negative side effects of Moore's law. In case of the subject antenna system this continuous miniaturization has reached a thermal limit, and the design fails to converge. This is illustrated in figure 2(b-e), where no acceptable designs are found. As the antenna design focuses primarily on the disciplines of figure 2(a) and no integrated action towards the thermal issues is taken, design changes can only be moderate and thus the core product remains virtually unchanged.

This justifies a more substantial thermal engineering contribution earlier in the design phase. An upcoming technology in the field of electronic cooling is two-phase cooling embodied by heat pipes, as depicted in figure 2(e).

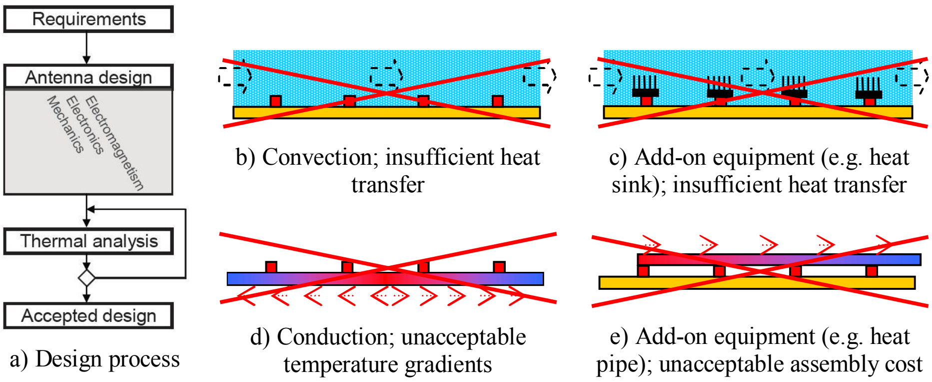


Figure 2. Traditional antenna design and cooling methods.

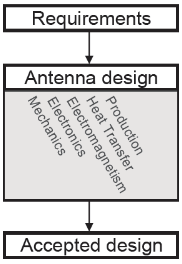
These devices are able to transport relatively large amounts of heat at low temperature gradients in a small form factor. Heat pipes have already become common practice in high performance electronic products, such as notebook PC's and video game consoles. However, the current state of the art in heat pipe technology, albeit a significant improvement in cooling performance, still lacks the level of integration required for low cost AESA applications.

3 DOMAIN INTEGRATION

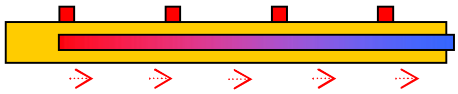
As indicated in the previous section, due to thermal management issues, the design fails to converge. This is not just an isolated case. In fact, recent research publications indicate that a limit has been reached for cooling electronics in general [1]. As a result, the continuous product improvement cycle threatens to stall, if no appropriate action is taken towards thermal innovation in the design and manufacturing process. Acceptable solutions can be found by focusing on systems architecting and engineering [2]. The design challenges, in the case of subject antenna system, are conquered through domain integration, resulting in further integration of primary and support functions [3]. Knowledge of heat transfer and production principles are integrated into the overall design process, as illustrated in figure 3(a).

Although the design process looks more compact it actually tends to become more complex due to the addition of thermal and production aspects. A greater number of conflicting relationships needs to be researched, to establish cause-and-effect coherence. In the case of subject antenna system the adapted design process has lead to a new cooling concept, which is shown in figure 3(b).

This concept depends on the incorporation of heat pipes into the PCB to effectively transport heat away from the dissipating elements. It uses the unique quality of heat pipes that heat from multiple sources can be transported without introducing unacceptable temperature gradients. In terms of design freedom, the independence of heat source and heat rejection location shows many advantages. Heat exchangers can now be located further away from their respective heat sources (the electronic components), thus allowing less constraint design solutions. For PCB technology in general, this concept leads to new manufacturing strategies where thermal management functions and electronic circuitry are fully integrated, resulting in more compact electronic systems at a lower cost.



a) Design process

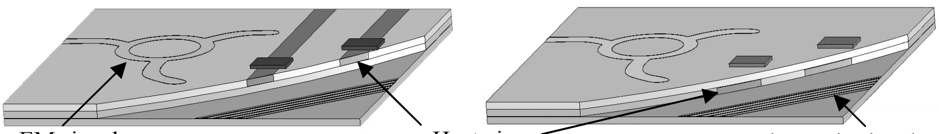


b) Cooling method by incorporating heat pipes into the PCB

Figure 3. Antenna design and cooling concept through domain integration.

4 MANUFACTURING TECHNOLOGY

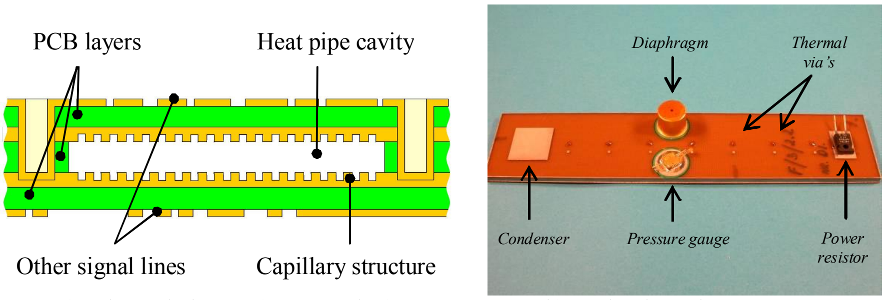
As PCB technology is the preferred manufacturing technology for volume production, a thermally optimized design should still fit within these production process windows. During the detailed layout phase of the board design, electronic and EM signal lines, as well as thermal paths are optimized in an integrated manner. There are two options. By machining a cavity in the applicable top layer, procured, conventionally produced heat pipes can be embedded in the assembly stage, as illustrated in figure 4(a).



a) Embedded b) Integrated

Figure 4. Cross section (partial) of PCB incorporated heat pipes.

The second option is to manufacture the heat pipe based on PCB technology itself, as depicted in figure 4(b). In general, a heat pipe consists of a hermetically sealed enclosure, wherein a capillary structure is incorporated to facilitate the required liquid return. As PCB technology permits metallic patterns to be produced on each polymeric layer, this feature can be utilized to fabricate microgrooves, acting as capillary channels. By machining a cavity in an intermediate layer of the PCB, with microgrooves on the adjoining layers, a fully integrated heat pipe is realized. For this concept a technology demonstrator, depicted in figure 5, has been successfully produced and tested. Detailed information on this prototype can be found in a previous publication of this study [4].



a) Schematic layout (cross section) b) Technology demonstrator

Figure 5. Prototype integrated heat pipe.

Of particular interest from a competitive point-of-view is the cost relationship between both concepts. By integrating the heat pipe into the PCB the total number of production steps can be reduced, resulting in a cost advantage. This is illustrated for both cases and for low as well as high production volumes, in figure 6.

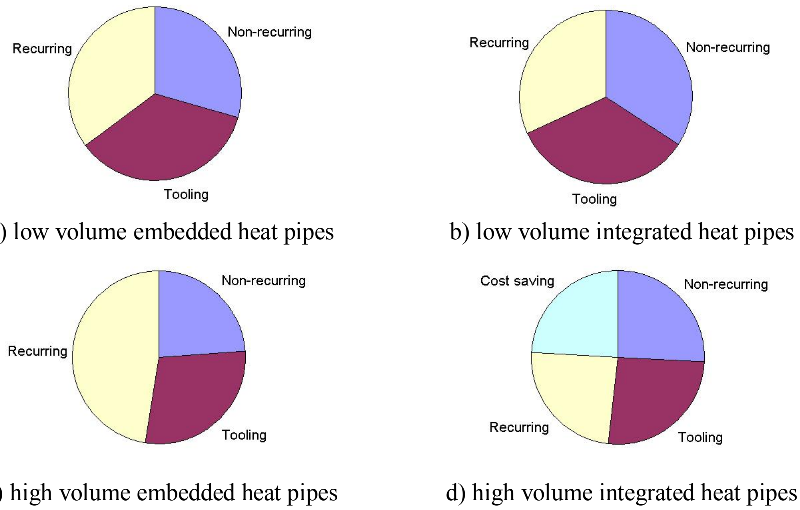


Figure 6. Cost component comparison.

When utilizing PCB technology, there are three major cost components: 1) non-recurring engineering cost (i.e. PCB design, layout), 2) tooling set-up cost (applies to each individual production batch) and 3) recurring production cost (i.e. materials, machine time per production batch). Integration of multiple heat pipes into one PCB requires additional engineering effort, but no substantial additional production cost is introduced, as most PCB production steps are batch processes. On the other hand, embedded heat pipe assembly is assumed to be non-automated, hence assembly of more heat pipes will cost more.

In terms of procurement, every additional embedded heat pipe has to be paid for, whereas integrated heat pipes can be produced on the same layer at virtually no additional cost. The estimated cost saving for high volume integrated heat pipes is depicted in figure 6(d). In all cases, electronic component assembly is based on standard automated Surface Mount Technology (SMT) processes, hence there are no extra cost drivers in this area.

5 CONCLUSIONS

Through a case study new thermal management and manufacturing strategies for electronic products have been presented. By incorporating thermal and production engineering aspects at an early stage in the design process, more integrated solutions can be realized. Decoupling of hot components and their respective heat dissipating areas is possible, thus increasing design freedom and enabling a more multifunctional product design.

Full integration of thermal management functions and electronic circuitry in electronic products pushes the boundary further towards more functionality and performance in a smaller form factor. In addition, by employing mass production facilities, products can be realized at a lower cost. Altogether this can lead to smaller, lighter and more affordable products. Thanks to this approach, 'high end' products may soon turn into commodities.

ACKNOWLEDGMENTS

This work is part of the PACMAN project which is supported by the Netherlands Ministry of Economic Affairs, SenterNovem project number TSIT3049. The authors especially want to thank Rob Legtenberg for his spirited motivation to tackle any problem, as well as Eric Lutters and Juan Jauregui Becker for their part in theoretical design discussions on domain integration. The authors also thank the PCB production and electronics assembly department of Thales Nederland for their assistance during proof-of-principle research efforts.

REFERENCES

[1] Lasance, C.J.M. and Simons, R.E., 2005, Advances in high-performance cooling for electronics, ElectronicsCooling, Volume 11, Number 4.

[2] Maier, M.W. and Rechtin, E., 2002, The art of systems architecting, 2nd edition, CRC Press.

[3] Suh, N.P., 1990, The principles of design, Oxford University Press.

[4] Wits, W., Legtenberg, R., Mannak, J. and Zalk, B. van, 2006, Thermal management through in-board heat pipes manufactured using printed circuit board multilayer technology, Proc. International Electronic Manufacturing Technology, pp. 55-61.