Rapid and Accurate System-Level Design for Electronics Packaging and Production using Flow Network Modeling (FNM) – A Case Study for the Design of a Burn-In Oven

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Introduction

Fluid flow and heat transfer processes play a vital role in the processing and thermal design of electronics packages. The design of electronics packages and processing equipment proceeds through three design stages - *Conceptual System Design*, *Detailed Design*, and *Design Verification*. A good layout of the system needs to be developed at the end of the Conceptual Design stage in order to avoid the costly design changes later in the design cycle and to meet increasingly stringent time-to-market demands.

In the conventional design process, hand calculations/spreadsheets and Computational Fluid Dynamics (CFD) are commonly used for evaluation of various system designs. Hand calculations and spreadsheets are tedious, time-consuming, and inflexible. Similarly, use of CFD analysis is impractical for examination of a large number of design alternatives because it is time-intensive in model setup, computation, and interpretation of results.

The technique of Flow Network Modeling (FNM) fulfills the need for a quick and accurate analysis procedure for performance evaluation of various design options in a scientific manner during the Conceptual System Design. This technique has been used by Ellison [1] for the prediction of flow and temperature distributions in electronics systems. This paper describes a generalization of this technique to complex systems and illustrates its application for the design of a burn-in oven used for testing electronic components.

The Technique of Flow Network Modeling (FNM)

Network Representation

FNM is a generalized methodology involving representation of a flow system as a network of components and flow paths for predicting the system-wide distribution of flow rates and temperatures. Practical flow systems are represented as networks of components such as ducts/passages, bends, orifices, screens, area changes, tee junctions, card arrays, filters, plenums, and fans. Each component in the network is represented by empirical correlations that relate pressure drop and heat transfer rate to the corresponding flow rate.

Component Characteristics and Network Solution

The flow characteristics of a component involve specification of the pressure loss in that component as a function of flow rate. Typically, the following equation describes this variation:

$$\Delta p = K \frac{1}{2} \rho (Q / A)^2 \tag{1}$$

Other functional forms can also be used. The loss coefficients for standard components (screens, ducts, bends, etc.) are available from handbooks such as Idelchik [2] and Blevins [3]. The geometry of complex flow passages such as a card arrays can be constructed using standard components for determining the pressure loss through them. For nonstandard components, supplier data, CFD analysis, or test data can be used to get the flow characteristics. The performance characteristics of fans and pumps are specified in terms of pressure rise as a function of the flow rate. The bulk temperatures in the different cooling streams are determined from the energy equation with appropriate heat transfer coefficients for the flow within a component.

The overall flow and thermal performance of a flow system is predicted by imposition of the conservation of mass, momentum, and energy over the flow network. More details on the FNM methodology are provided by Belady et al. [4] and Kelkar et al. [5].

Benefits of Flow Network Modeling (FNM)

Because of the use of overall component characteristics, FNM-based analysis is very quick in terms of model definition (~ 1 hour) and computational time (~20 seconds on a PC). Further, use of accurate empirical characteristics that are valid over laminar, transitional, and turbulent flow regimes assures that system performance predictions are accurate over a wide range of operating conditions.

Due to the simplicity, accuracy, and speed of FNM, it offers the following advantages in the design of cooling systems and process equipment used in advanced electronic packaging:

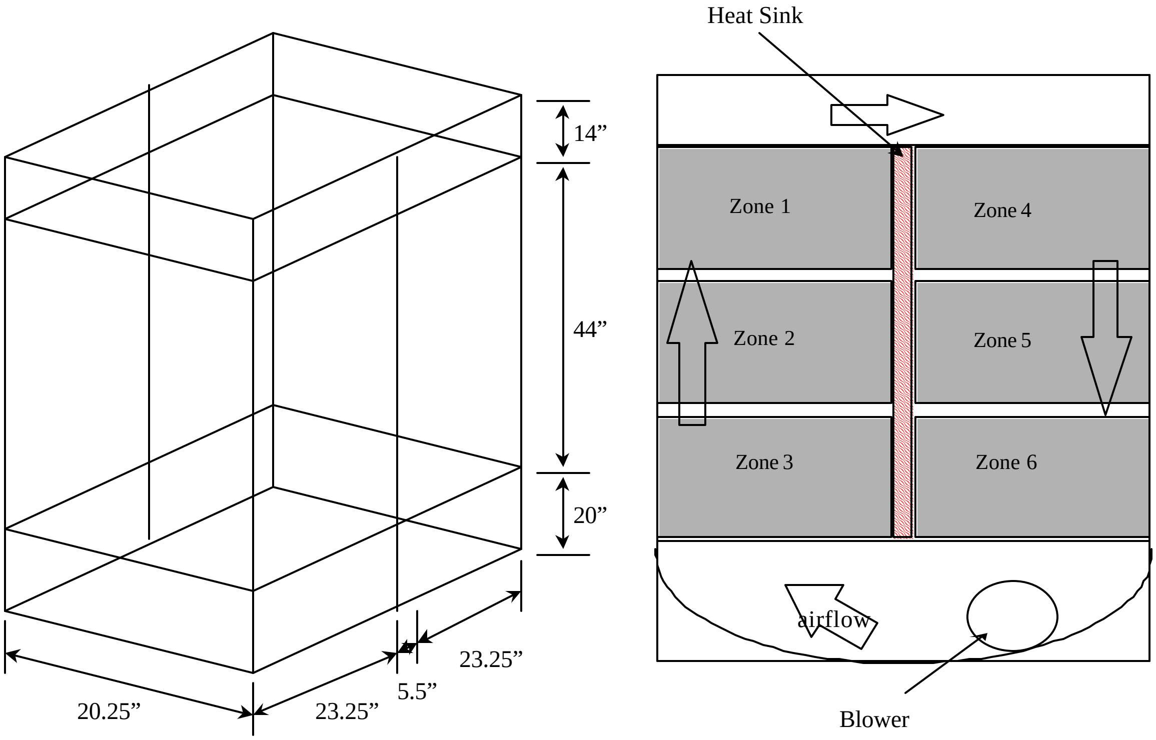
- Evaluation of competing designs
- Development and evaluation of new concepts for design improvements
- “What If” and contingency studies
- Complementary use with CFD

Application of FNM to the Design of a Burn-in Oven

The use of FNM for system-level design involves the same basic steps for both system-level design of electronic packages and process equipment. Application of this technique for system-level thermal design of electronic systems such as servers and telecommunication cabinets has been illustrated by Belady et al. [2] and Kelkar et al. [3]. In this study, its use has been illustrated for the system-level design of a burn-in oven. A commercially available software package, MacroFlow™ [6] was used for this purpose.

The Physical System

Electronic components undergo burn-in inside a forced convection oven as a part of the production cycle. The purpose of the burn-in oven is to accelerate mechanisms of quality failures and screen for infant mortality over a specified production lot of electronic components. As shown in Fig. 1, the oven is comprised of two sections, each of which contain three zones. The two sections are separated by a heat sink.



(a) Overall Dimensions

(b) Zone arrangement and Flow structure

Figure 1 – Schematic diagram of the burn-in oven

A schematic of the board configuration for one zone is shown in Fig. 2. Each zone contains an array of burn-in boards (BIB) with electronic devices under test (DUT’s). Components such as passives were not considered, as it was assumed the thermal contribution from these components is minimal. The air flow is driven by a blower.

The Design Goal and the Purpose of FNM Analysis

To ensure quality output, the oven is designed to ensure that the temperature distribution across all the boards is uniform and adequate to achieve burn-in. Thus, the goal of the design process is to maximize the production yield while satisfying the thermal processing constraint.

The level and the uniformity of the temperature across the BIB’s is controlled by the total flow induced in the oven and the uniformity of the flow distribution between the boards. The flow distribution is, in turn, dependent on the interaction of the impedences of the flow passages and the characteristics of the blower. The FNM technique is ideally suited to analyze this interaction for different physical configurations of the six zones and the BIB's.

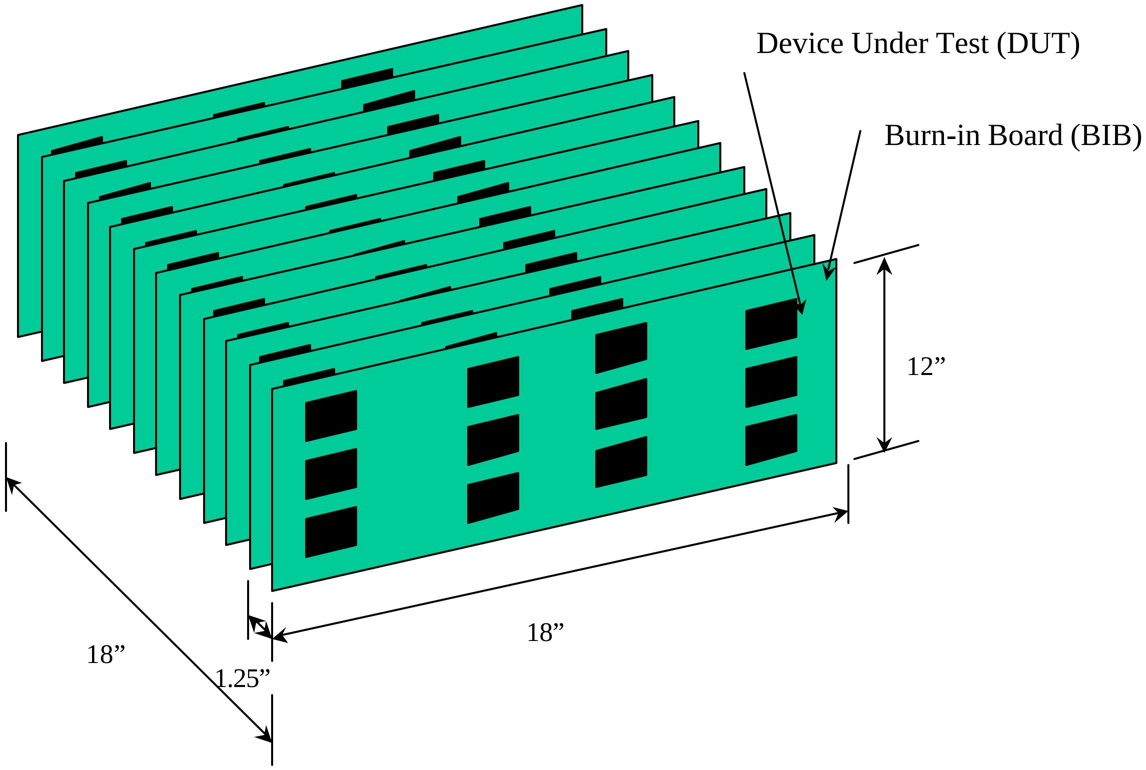


Figure 2 - Schematic diagram of the burn-in boards in one zone of the burn-in oven

Network Representation of the Burn-in Oven

Due to space constrains, the network diagram for one zone is shown in Fig. 3. The network of the entire physical system contains six networks of this type arranged in a closed loop that also contains a blower. In the flow network of Fig. 3, the flow moves from the bottom to the top of the segment shown.

The network consists of ducts, area expansions and contractions, screens, plenums, and blowers. Unless otherwise stated, correlations from handbooks (Idelchik [3], Blevins [4]) are utilized for characterizing the components. The flow impedence of the passage between the two adjacent BIBs is experimentally characterized and used in the analysis. The blower provides a maximum head of 3 inches of water and its maximum flow capacity is 6000 CFM.

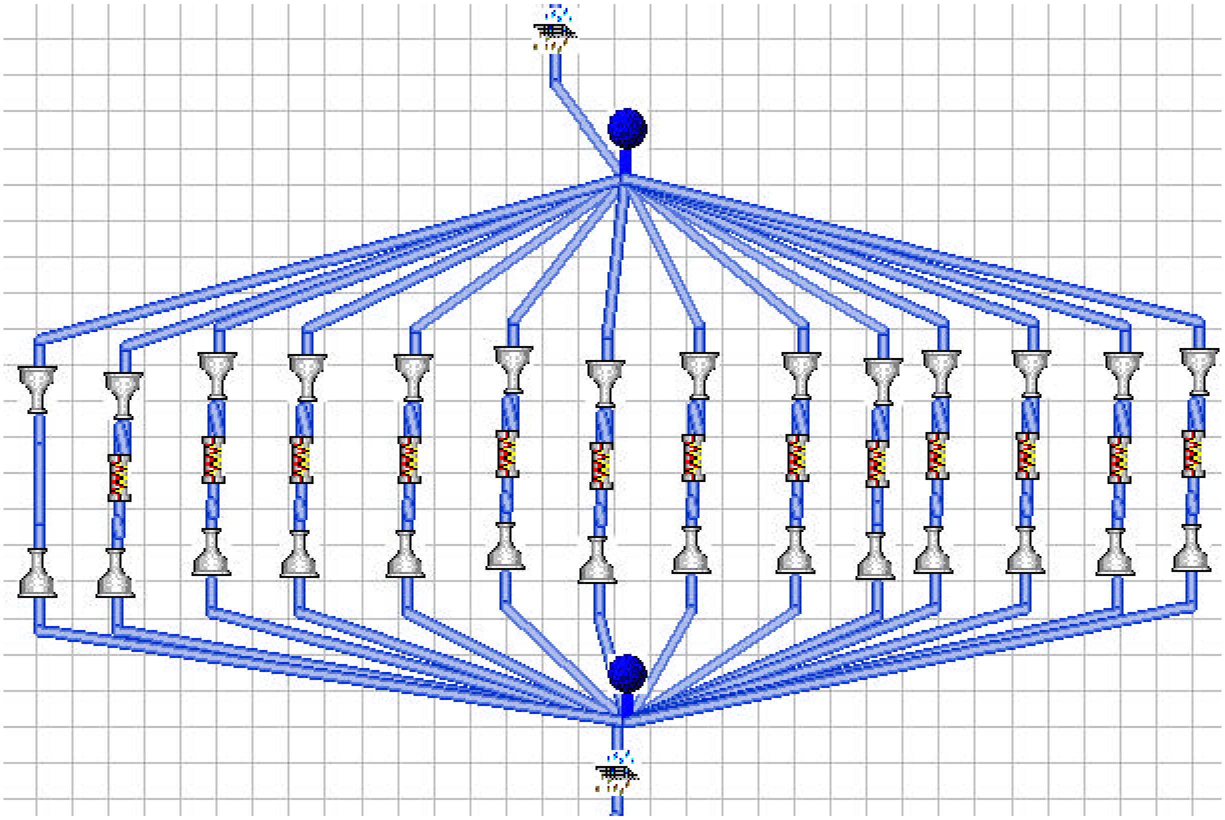


Figure 3 - A FNM of one zone of the convection flow burn-in oven.

Results

Comparison with Measurements for Model Validation

Validation of the FNM model was made by comparing the FNM predictions of the average temperature across the BIB and the flow rate at the downstream side of a passage with the experimental measurements. The cards were numbered 1 through 12 in a zone relative to the direction of flow from bottom to top for tracking flow data. Tables 1 and 2 show that the FNM model accurately predicts the flow and temperature distribution in the burn-in oven.

Table 1 – Comparison of the measured and calculated flow rates (CFM) in the chamber

Zone		**Card 1**	**Card 6**	**Card 12**
1	Measured	1000	1200	1650
	Calculated	981	1198	1585
3	Measured	1650	1700	1550
	Calculated	1689	1689	1534
4	Measured	1100	1850	1750
	Calculated	1268	1880	1811
6	Measured	1050	1400	1600
	Calculated	983	1411	1578

Table 2 – Comparison of the measured and predicted temperatures (in °C) in the chamber

Zone		Card 1	Card 6	Card 12
1	Measured	83	82	79
	Calculated	81	81	80
3	Measured	78	79	75
	Calculated	79	79	77
4	Measured	84	84	83
	Calculated	88	89	81
6	Measured	84	83	80
	Calculated	88	88	82

Design Iterations

The validated network model was used to investigate the following design parameters to optimize the design of the burn-in oven.

- Number of BIBs - Effect of different number of BIBs in each zone was studied to determine the maximum number of BIBs that guarantee sufficient amount of flow for burn-in.
- Variable spacing – Since BIBs are not identical, variable spacing was explored to achieve uniformity of flow within each zone.
- Component Placement – Different component placements on individual BIBs were investigated to minimize flow impedences and to achieve flow balancing.

Productivity Gains due to FNM in the Design of the Burn-in Oven

Although the network model of the entire oven uses over 500 flow components, the FNM analysis was very easy and rapid. The network construction for the original design required 2.5 man hours; solution for each case required less than 15 minutes on a Pentium 133 MHz laptop; and the examination of results took fifteen minutes. Further, due to the component-oriented nature of the network representation, incorporation of changes in the system configuration and evaluation of their effects was very efficient.

The benefit of using FNM early in the design cycle can be summarized as follows:

- Analysis time for each design was reduced dramatically relative to conventional CFD-based approach, thereby allowing comparative evaluation of many design changes. Over fourteen designs were evaluated within a five day period day to arrive at a good design of the oven. The optimum design was validated using a prototype.
- The good oven design was obtained early in the design cycle through incorporation of beneficial system changes determined from FNM analysis. This prevented the possibility an undesirable design proceeding to a stage where implementation of any changes would have been prohibitively costly.

The Enhanced Design Cycle

Extensive experience with the use of FNM in the design of flow systems suggests an enhanced design cycle shown in Fig. 4. Use of FNM for Conceptual System Design allows quick evaluation of several design options. CFD and laboratory testing can then be used in a focused manner for a few selected systems. The resulting design cycle is substantially shorter than the conventional design process that does not employ FNM.

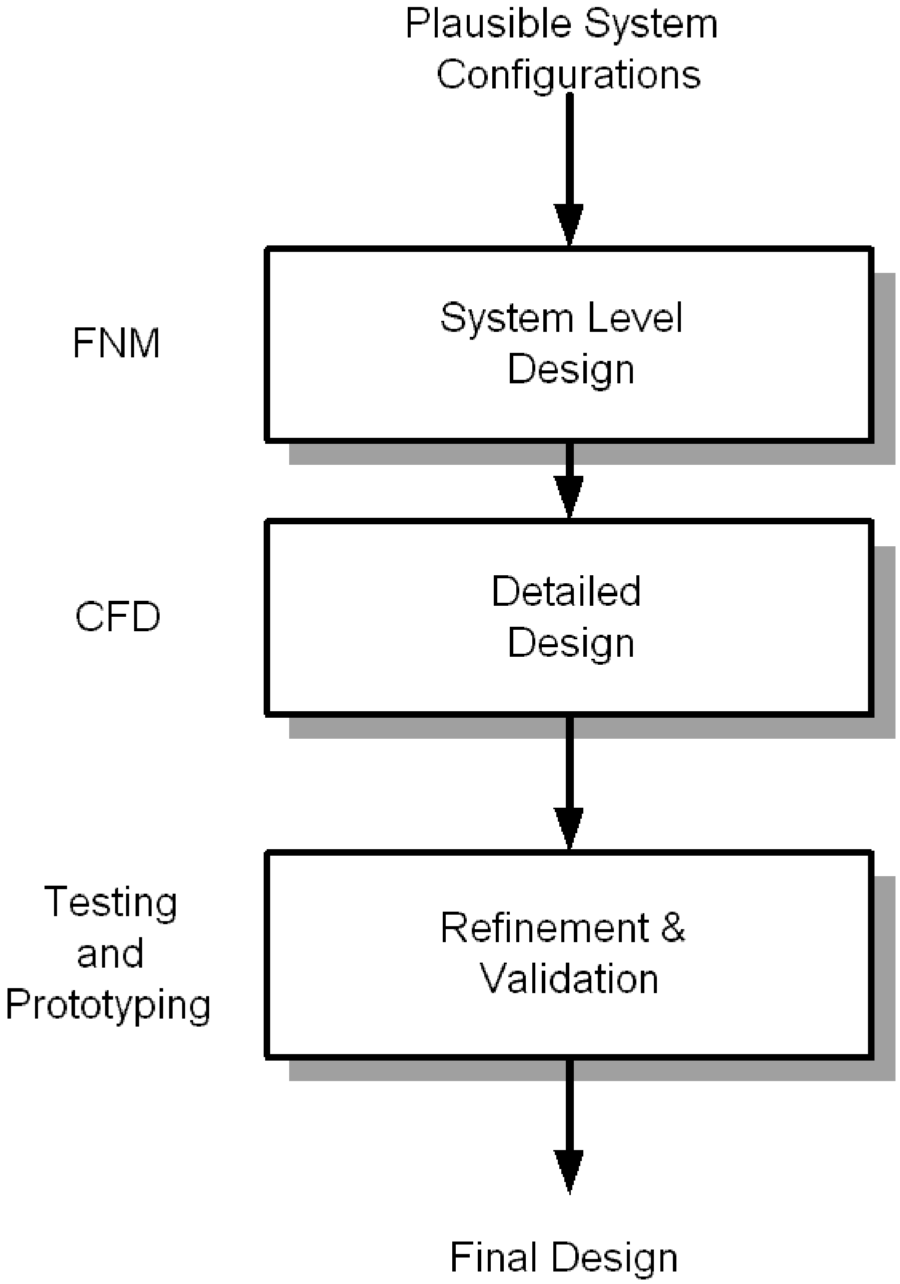


Figure 5 – The enhanced design cycle

Conclusions

The present study describes the technique of Flow Network Modeling (FNM) and its application for the system-level design of electronic cooling systems and process equipment used for manufacturing and quality control of electronic packages. For system-level design of a burn-in oven, this technique allowed rapid and accurate investigation of the flow distribution for different arrangements of the burn-in boards within the zones and alternate placements of the components on the boards. This case study illustrates how FNM is useful in significantly shortening the overall design process, reducing the risk of design changes later in the design cycle, and improving the productivity of the thermal and process design engineers.

References

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