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Computer-Aided Heat Sink Design for Printed Wiring Boards

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COMPUTER-AIDED HEAT SINK DESIGN FOR PRINTED WIRING BOARDS

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ABSTRACT

A computer-aided design (CAD) program has been developed which generates a graphical layout of a printed wiring board (PWB) showing its fundamental characteristics, automatically performs a heat sink design for conductively cooled in-line PWBs, and sets up a working data base containing generated thermal characteristics for subsequent thermal and reliability analysis. The program was designed to interface with an existing computer-aided component layout and routing routine and to be user interactive.

INTRODUCTION

With the increased demand for high density electrical packages, the design of printed wiring boards has become more complex and time consuming. To meet the design requirements, manufacturers such as Applicon Inc., Computervision Corp. and Racal-Redac Inc. have produced automatic computer-aided design systems. These systems have a variety of capabilites including circuit analysis, component placement, wire routing, and generation of artworks[4,5]. Of these, determinating the routing or track paths is the most demanding CAD operation in PWB design. For complicated multi-layered boards, this CAD process is costly and the routing computations can take as long as 80 hours to complete[7].

Thermal analysis of the PWB is usually performed after the layout and routing routines are finished, to check the PWB thermal reliability limits[1,6]. If the resulting PWB layout does not meet thermal reliability specifications, the design process must be restarted causing a considerable loss of design and implementation time[9].

To solve this problem, a computer program called HSINK has been developed in cooperation with the Westinghouse Defense and Electronics Systems Center. HSINK serves to improve the design process by interfacing heat sink design, thermal analysis, and reliability analysis with the computer-aided PWB layout routine providing a tool for quick and accurate analysis. Thus, as soon as a description of the geometric component layout of a PWB is known. HSINK can be executed in parallel with the routing routine or can be used as a preprocessor to determine if the routing routine should even be implemented.

Thermal and reliability PWB considerations are effectively handled by utilizing HSINK to automatically design heat sinks using rules to emulate the decision making process of the human designer. An interactive, manual heat sink design using the keyboard and monitor is an option if the automatic heat sink design proves to be unacceptable. Various heat sink designs or changes in the thermal parameters of the PWB can be easily simulated, a thermal analysis executed and reliability determined so that results can be compared.

PROGRAM OPERATION

In general, routines for the various functional tasks in PWB design make use of independent and incompatible data bases and thus require the intermediate steps of data conversion, data transfer and decision making when transferring between tasks. For this reason, a working data base has been implemented within the HSINK program which is independent of the functional tasks and governed by decision rules incorporated into the program. Information is added and updated during the program execution. The user also has the ability to alter data. The working data base contains information pertaining to the specific design configuration. Data includes the geometry, thermal and reliability characteristics of the cooling mechanism, components and the PWB.

The use of an internal working data base allows HSINK to interface to layout-routing CAD systems by including an appropriate module to convert the host data into HSINK's internal format. HSINK currently interfaces with the RACAL-REDAC[2] CAD system which contains the PWB outline coordinates, a library of the component's shapes and sizes, and the locations of the components on the PWB. This information is transformed into a working data base within HSINK.

A graphical color representation provides the design foundation which presents the engineer with the ability to easily check results and make modifications depending on the design requirements. Each PWB component is identified, the lower left-hand pad determined for correct orientation, and the component appropriately rotated.

Once an initial component layout is established, thermal conductance strips, also called rails, which form the heat sink can be automatically placed on the PWB. Conductance strips are thin metallic strips which lay beneath the packages to dissipate heat away from the components. Typically, rails lie under adjacent components to form a series a horizontal strips connected to vertical strips at the board edges where external heat sinks are located. However, because component layouts are not limited to simple, orderly patterns due to the variety of complexity of component arrangements, the rail placement process can be complex.

The objective of the rail placement program is to have the minimum number of rails pass under the centers of a maximum number of heat dissipating components. In addition, heat sinks should be designed to maximize the heat transfer from the components to the external heat sinks. The methodology HSINK uses to automatically design rails is modeled after a human designer by using heuristics to size, direct and place the rails.

HSINK uses the working data base and a rule base to automatically place rails. Rules determine which components are to be connected by the same rail, the path of the rail including bends, turns, junctures and splits, and which components can be ignored in the rail placement. Components with little or no heat dissipation are identified and can be ignored. Certain components such as some capacitors and resistors are predefined in the rules and noted in the data base to be excluded from the thermal analysis.

The rules are for the most part based on geometrical information concerning the size of the components, the pin arrangement of the component, whether the component is a DIP, flat pack, or lead less carrier, and the adjacency of the components. A list of some of the rules follows:

: rule : IF Component is defined within the working data base.
THEN Map out the component location and proximity boundary on the PWB. Assign a label to each mapping. Append an adjacency qualifier to the label which specifies component neighbors.

: rule : IF Component is heat dissipating.
THEN Append qualifier "HD" to its label.

: rule : IF Component can utilize a heat conduction rail: i.e. component does not have leads on four sides.
THEN Append qualifier "RP" to its label.

: rule : IF Component is HD.
AND Component is RP.
THEN Add rail. Define component as "railed component."

: rule : IF Railed component is adjacent to another component.
AND Both components have centers which are located within a predetermined band width
THEN Connect rail between components

: rule : IF Railed component is adjacent to more than one railed component within bandwidth.
THEN Split rail and pass under both components.

: rule : IF Railed component is located at the edge of the board.
THEN Connect the rail to the board edge.

Rails are graphically displayed on the screen and superimposed over the PWB outline (Figure 1). A thermal conductance network is then computed based upon the rail locations. In instances where rails bend or join under components, the conductance terms in the data base are altered to reflect the rail change. If the automatic design of the heat sink is not desired, the user can choose manual design. Manual design of the heat sinks using HSINK is accomplished interactively by allowing the operation/designer to graphically overlay the rails on a view of the PWB and components.

Once the heat sink rails have been designed and corresponding thermal conductance values determined a thermal analysis routine is employed to solve the steady-state conductance problem. The thermal analysis routine uses thermal information obtained from the heat sink placement routine to calculate and display the PWB temperatures along with rails and component identifiers.

The thermal analysis routine uses a finite difference scheme to solve the steady-state conductance problem. An equation is formulated[3] for each node (center of the component),

$$q_i + \sum_j \frac{(T_j - T_i)}{R_{ij}} = 0 \qquad (1)$$

where R_{ij} is the thermal resistance between adjacent components and/or edges, q_i is the heat dissipation of the component and T_i is the temperature at a node. Each node corresponds to a component on the board or to an edge element. The temperatures solved for in equation (1) are case temperatures. These are converted to junction temperatures using the following equation:

$$T_{junction} = q_i/k_i + T_{case} \qquad (2)$$

where q_i is the dissipation of the component and k_i is the thermal conductance of the package case.

The thermal analysis routine displays the PWB temperatures on the screen along with the rails and component identifiers. Indicators are used to flag thermal hot spots. The user has the option of changing any of the input parameters, such as the thickness of the heatsink, and re-calculating the temperatures of the components on the board.

The introduction of HSINK as a tool in the overall PWB design process has provided lower overall design times. HSINK can be used as a preprocessor and/or in parallel with routing routines. It can also easily be interfaced with existing commercial systems, through an intermediate database conversion table.

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Figure 1. Rail Placement

Heat conduction rails run underneath the component packages and transfer heat to external heat sinks located at the board edges. A leadless chip carrier (LCC) in the lower center of the board requires that the rails end at the LCC proximity boundary. Railed components adjacent to more than one railed component with a prescribed bandwidth generate a split rail.