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 Appleton Inc., Computervision Corp., and Racal-Redac Inc. have produced automatic computer-aided design systems. These systems have a variety of capabilities including circuit analysis, component placement, wire routing, and generation of artwork. Of these, determining the routing or track paths is the most demanding CAD operation in PWB design. For complicated multi-layered boards, this PWB process is costly and the routing computations can take as long as 80 hours to complete.

Thermal analysis of the PWB is usually performed after the layout and routing routines are finished, to check the PWB thermal reliability limits. 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.

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 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 com-
ponents. Typically, rails lie under adjacent com-
ponents to form a series of 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 meth-
dology HSINK uses to automatically design rails
is modeled after a human designer by using heuris-
tics 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
detected 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 conduc-
tance 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 com-
ponents.

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 ana-
lysis 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 formulated3
for each node (center of the component),

\[
q_i + \sum_j \frac{T_i - T_j}{R_{ij}} = 0
\]

(1)

where \( R_{ij} \) is the thermal resistance between
adjacent components and/or edges, \( q_i \) is the heat
dissipation of the component and $T_j$ 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:

$$T_{junction} = \frac{q_i}{k_i} + T_{case}$$ (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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REFERENCES


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.