

**DEVELOPMENT OF THE NAVAL POSTGRADUATE SCHOOL
SOLID STATE DATA RECORDER PROJECT**

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ABSTRACT

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THE NAVAL POSTGRADUATE SCHOOL'S SOLID STATE DATA RECORDER PROJECT

INTRODUCTION

The Solid State Data Recorder (SSDR) project was intended as a proof of concept for a solid state memory device with space applications. The goal of the project was to develop a data recorder which utilizes the inherent advantages of a magnetic bubble memory and was inexpensive enough to serve as a data recorder in a 'lightsat' application. The data recorder was conceived in 1984 and has been through an extensive developmental process, managed and executed by successive graduate students at the Naval Postgraduate School (NPS). For an explanation of the SSDR hardware and bubble technology see "Nonvolatile Solid State Data Recorder for Space Applications", by Russell E. Averill[Ref. 1].

The advantages of a solid state device in a space environment make it an attractive alternative to the commonly used tape and disk systems. However, there are tradeoffs which make the bubble memory concept inappropriate for applications where a high data rate is required. Table 1 shows the advantages and disadvantages of the NPS data recorder compared to tape or disk systems.

ADVANTAGES	DISADVANTAGES
Operates in a vacuum No moving parts Longer expected MTBF (Mean time between failure) No undesirable torques generated Radiation hardness of the main memory component	Slower Data Rate (currently 100K BPS) Limited data capacity

TABLE 1: BUBBLE MEMORY ADVANTAGES AND DISADVANTAGES AS
COMPARED TO TAPE OR DISK SYSTEMS

This paper provides an overview of the current NPS device, with a discussion of the status of its testing, and suggestions for improving the current recorder are presented.

STATUS OF THE SSDR DEVELOPMENT

Software

The software development effort has most recently been aimed at developing programs by which the host, currently an IBM clone, can access all the commands provided by Hitachi for testing and control of the bubble memory recorder. Further effort has been devoted to developing a set of programs which will facilitate environmental testing, notably a program which will perform continuous reads and writes to allow electromagnetic interference (EMI) testing and thermal testing with minimal operator intervention. Additionally, a user interface has been written which allows the operator easy access to all capabilities of the device with minimal effort.

The next software project is to write the routines which will allow the device to interface with another NPS experiment to allow the recorder to replace an earlier effort at solid state memory. This process will determine the procedure which will be necessary to create project specific interface schemes, depending on the proposed application.

DESIGN OF THE SSDR CONTAINMENT BOX

The first SSDR containment box suffered from several problems which necessitated a design change. The Naval Research Lab (NRL) has designed a box with the necessary qualities that will help to space qualify the SSDR if the containment box design is based on the NRL box.

The new design which will soon to be tested will provide a quality support structure for the SSDR during launch, a path to dissipate waste heat, and have the ability to contain the EMI generated by the recorder. The first container lacked all of these qualities in part or in whole.

Figure 1[Ref 2] below shows the typical NRL box design. It is machined from aluminum and has standard spacing between slots. Since the SSDR circuit boards had already been designed the NRL design was modified to fit the SSDR boards. The sides of the SSDR box were milled from one inch thick 6061-T651 aluminum, and the side walls were designed to be 1/4 inch thick to provide a higher degree of radiation shielding than the NRL box.

Vibration and Shock

Figure 2[Ref 2] depicts the levels of vibration and noise that a device must endure for qualification as a shuttle experiment. The test results of the NRL box design are shown in Figure 3 taken from the paper "Design And Development of a

THIRD-OCTAVE BAND SOUND PRESSURE LEVEL
(DB REF. 2×10^{-5} N/m²)

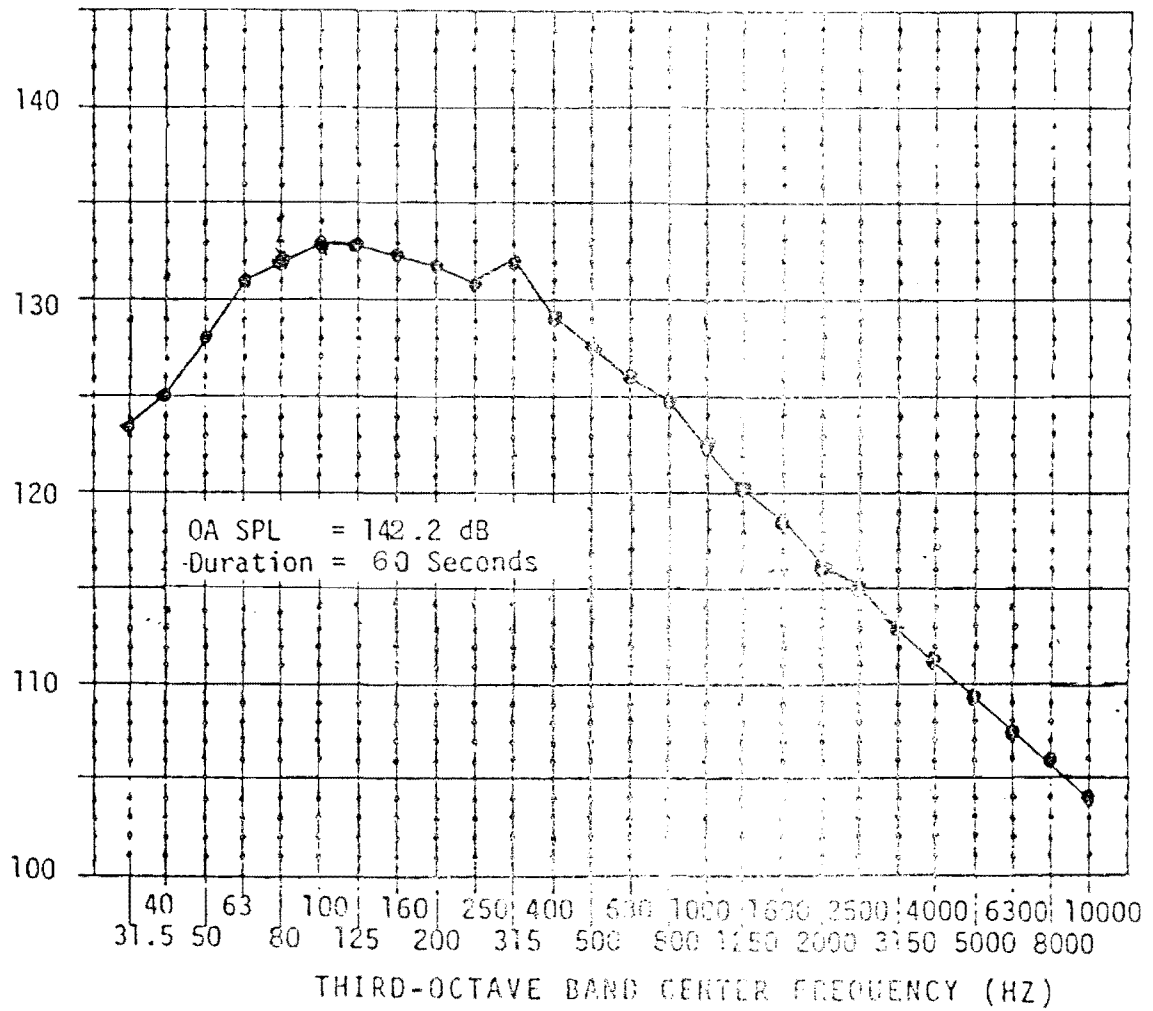
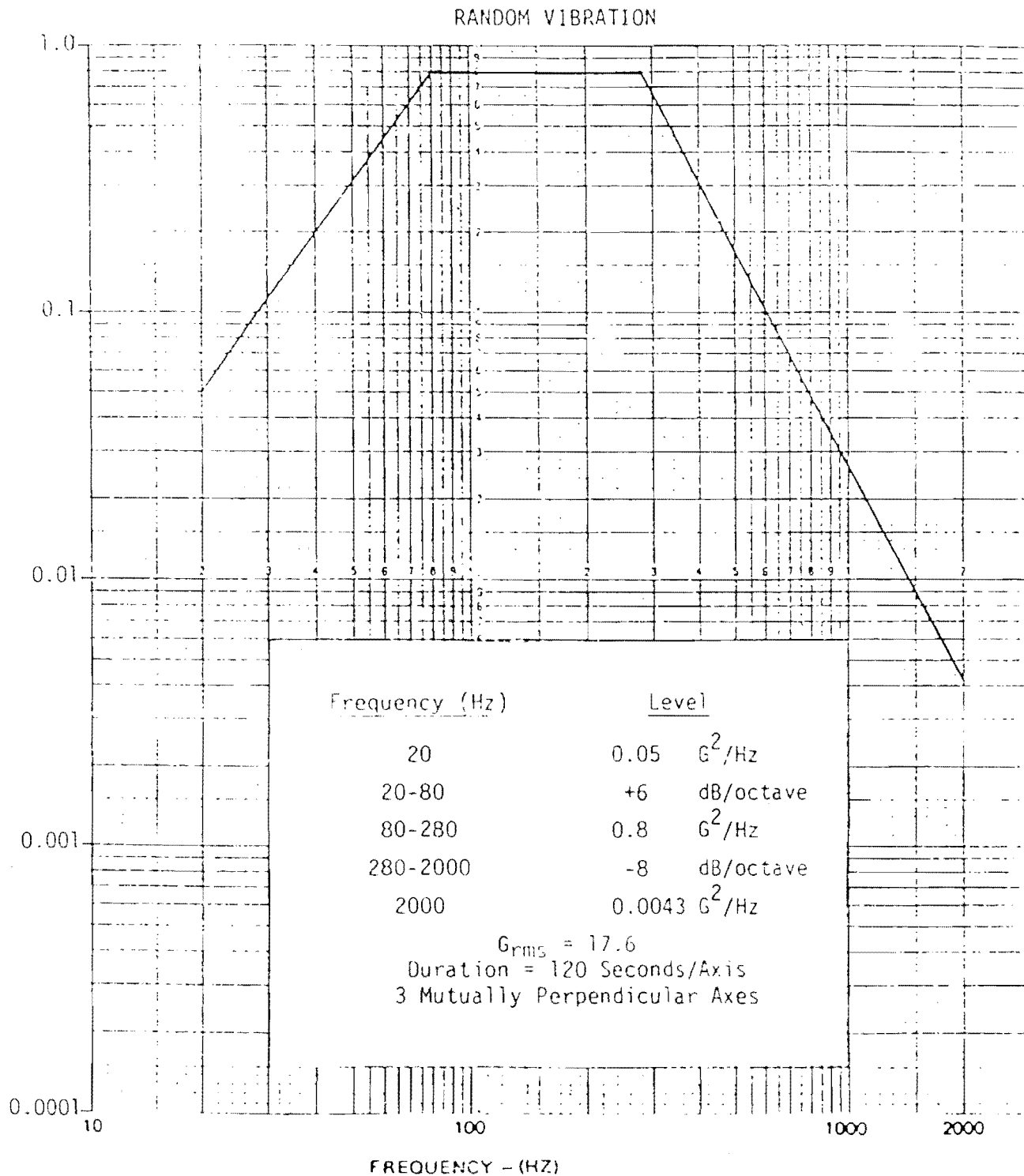


FIGURE 2

ACCEPTANCE ACOUSTIC ENVIRONMENT

FIGURE 3
DESIGN AND QUALIFICATION TEST LEVEL



Standardized Electronics Box", by David D. Spencer, Naval Research Laboratory. The author of the paper states, however that the test results were not repeatable and attributes the discrepancies to the edge supports of the circuit cards [Ref. 2]. Because NRL is using this design as a standard box, it can be assumed that the results of the design tests are close to published data. But, for our purposes a test procedure for determining the response of the NPS design must be developed before it is flown and the box tested.

Thermal Requirements

A requirement for the new box design is to efficiently conduct heat away from the SSDR. As this paper is being written the thermal analysis of the SSDR (containment box and circuit boards) is being carried out to determine its steady state thermal properties. The results of this analysis will determine if thermal problems exist with the current design. This topic is discussed in greater detail later in this paper.

Electromagnetic Interference and Compatibility Requirements (EMI/EMC)

Military Standard 461C, "Electromagnetic Emission and Standards for the Control of Electromagnetic Interference" [Ref. 3] defines the electromagnetic interference and compatibility requirements for Department of Defense hardware. Emission requirements limit the energy a device generates into the surrounding environment, and susceptibility requirements determine the amount of external electromagnetic energy the device must be able to withstand without a degradation in its performance. Thus the containment box has as another important function the duty of shielding the environment not only from noise generated by the SSDR but also to shield the SSDR from noise induced in the power supply lines and data communication lines and other electronic noise generated in the environment.

To effectively shield the environment from the SSDR requires the box to be built with the wall thickness of at least 1/4 inch. To understand how this was determined refer to the equation below.

The shielding effectiveness of a material is defined as

$$SE = A + R \quad (1)$$

where:

R = reflection loss for both sides in dB.

A = absorption loss in the wall material in dB.

Absorption loss is determined by:

$$A = 3.338T\sqrt{f\mu} \quad (2)$$

where:

T = wall thickness in inches

f = frequency in Hertz

σ = material conductivity

μ = material magnetic permeability

Therefore, the determined absorption loss for the box would be in a range from 206 dB at 100kHz to 6000 dB at 50 MHz. Thus, even ignoring the reflection loss the 1/4 inch thick walls will provide a very effective shield.

The container walls cannot be built as homogeneous parts due to the need for an air vent for the evacuation of air during launch, and due to the need for connector openings to route power and data communication lines. The vent hole(s) will cause signal noise from the SS DR to leak out or outside electrical noise to get in, therefore, some form of shielding has been designed to prevent this.

Although it would be possible to cut a large hole for this vent and then filter out the noise with a wire mesh screen it has been determined that a more structurally sound way to approach this problem is to drill tiny holes. These vent holes, 0.069 in. in diameter will act as waveguides for any frequencies below their cutoff frequency which is determined by the following equation.

$$f_0 = 6920 \text{ in/D in Hertz} \quad (3)$$

with the attenuation provided above this frequency as determined by,

$$A = 32L/D \text{ dB.} \quad (4)$$

It was determined that small waveguides of 0.069 inches in diameter with a length of greater than 0.2 inches will provide 96 dB of attenuation with a cutoff frequency of 100 kHz. Therefore, if a hole were drilled into the box, it would act as a wave guide due to the thickness of the wall.

Corrosion at the junctions of the box will lower the effectiveness of the containment box shielding properties by increasing the resistance between the sides of the container. This occurs when aluminum oxide forms between these junctions causing nonlinear tunnelling and spurious interference when radiated by RF frequencies [Ref 4, p. 36]. Therefore a conductive gasket or other means must be provided to maintain good electrical contact between the walls of the containment box.

Filtering

To complete the EMI/EMC analysis of the SSDR, the power and signal lines which enter the box need to be considered for their possible contributions to unwanted electrical interference. The solution to limiting the unwanted interference was not found by any analytical process but rather in an extensive body of empirical knowledge which when applied will give the desired results of reducing interference from the power and data lines of the SSDR.

It has been determined that to reduce noise introduced into the SSDR from the outside environment via the power and signal wires that in-line filtering of the wires with special Bendix connectors will reduce EMI to acceptable levels.

For the DC power line the filter should have a cut-off frequency as low as possible with a steep attenuation curve and for the data lines, the cutoff frequency of the filter must be high enough for the waveform to pass and restrict higher unwanted frequencies. To maintain a steep rise time for the data bit waveforms, the cutoff frequency for the data lines should be no less than 1 MHz.

The attenuation of the filter is the weak point of the shielding provided by the container. However, with properly installed connector filters and EMI gaskets, the achievable attenuation level of the container should be sufficient to meet or exceed the requirements of MIL-STD 461C.

Procedures for testing the environmental qualifications of the SSDR are now under development. A device designed to be used on a launch vehicle must meet standards in several areas. The EMI/EMC requirements are delineated in several publications, most notably MIL-STD-461C and MIL-STD-462. These publications combine to form the basis for determining emissions requirements of and susceptibility to the electromagnetic environment likely to be encountered in space. Given the current design of the recorder, we feel the emission requirements can be met. Further effort may be needed to meet susceptibility requirements, especially the reliability required when the device is subjected to induced anomalies on the power supply lines.

THERMAL ANALYSIS

With the help of Dr. Alan Kraus of the ECE department at the Naval Postgraduate School a thermal analysis of the SSDR is currently underway. The analysis is being carried out with the following assumptions.

All parts dissipate heat at their maximum power ratings.

The ambient analysis temperature is 25 degrees C.

The atmosphere is a vacuum.

Capacitors dissipate no heat.
The duty cycles are 100%.

When the SSDR is in a vacuum there are only two paths for thermal flow. Since a vacuum does not permit heat flow by convection, only heat flow by conduction and radiation are possible. Also, by making the first assumption in the above list the results of this first analysis determined the upper limit (worst case) of the steady state temperatures of the SSDR in a simple and quick manner.

Analysis Procedures

The analysis began by dividing the SSDR into sub-volumes called nodes where each sub-volume is considered to have an isothermal, representative geometric center, or node point.

Next the thermal resistance to conductance of each of these subnodes was determined to be used later in the thermal model. Determining this resistance (K) of the 5 circuit board's sub-volumes requires the following steps.

Each circuit board must be divided into a 6 by 6 matrix.
The thickness of all layers must be determined.
The resistances of each layer must be calculated both horizontally and vertically using equation 5 below.
An equivalent thermal flow model must be developed for each board.

The layers of the SSDR circuit boards consist of alternating layers of copper traces, fiberglass and prepreg. Thermal resistance is calculated for each layer in two directions, vertical (thermal flow between layers) and horizontal (thermal flow in the layers), see Figure 4. For this analysis the thermal effects of the prepreg were ignored.

$$R = L/kA \quad (5)$$

where:

L is the length of the flow path
k is the thermal conductivity of the material.
A is the area perpendicular the heat flow.

The resistance to thermal conductance for the SSDR containment box was also calculated using equation 5 above and the dimensions of the sub-volume, with the thermal conductivity of aluminum (0.8 watts/meter-degree C).

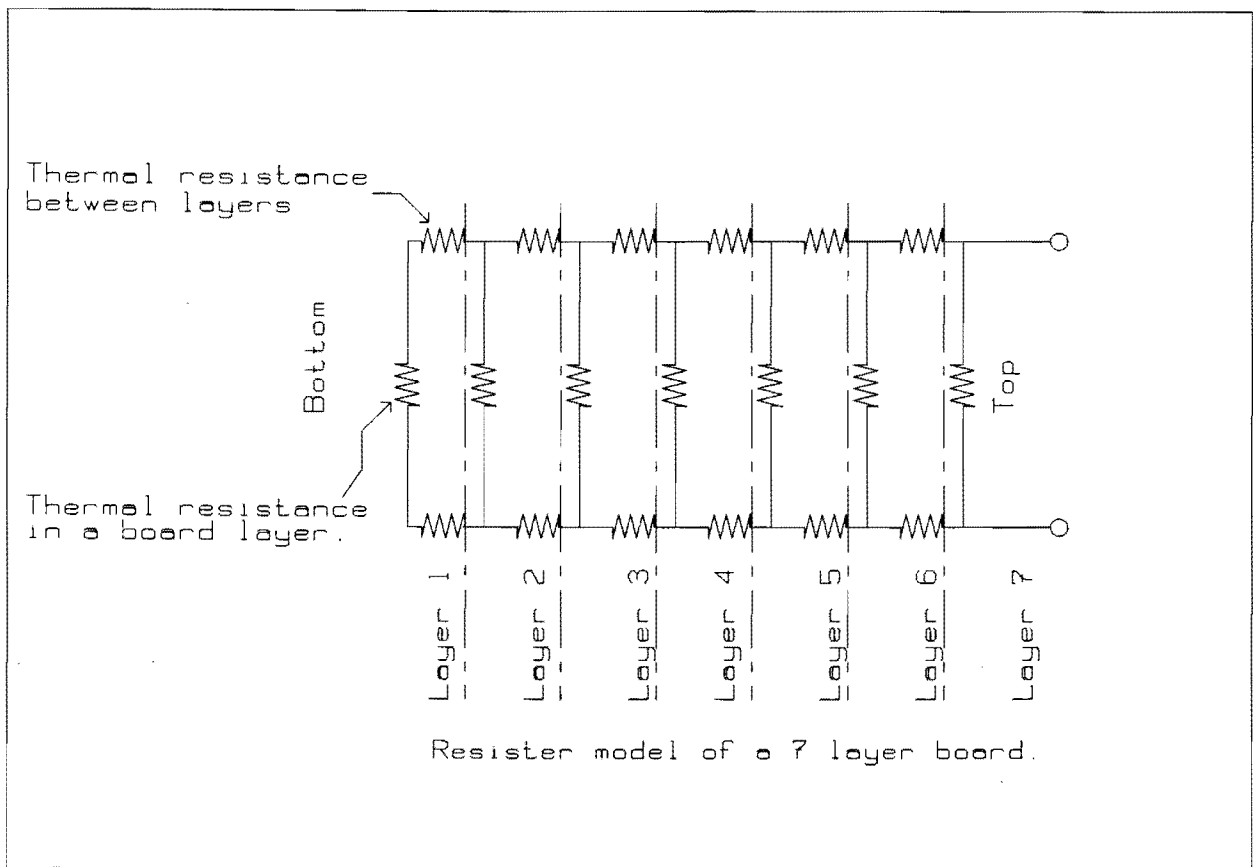


Figure 4

The property of thermal radiation can not be described with a linear equation, therefore, the method of determining the values of the resistances as shown in Figure 5 is an iterative process as carried out by the software program used for this analysis.

To understand this process consider Equation 6 below which describes the thermal flow due to radiation.

$$q_r = \sigma S (T_s^4 - T_r^4) \quad (6)$$

S is surface area, ft²

$$\sigma = 1.713 \times 10^{-9} \text{ BTU/Hr-Ft}^2\text{-}^\circ\text{R}^4$$

This equation can be factored into the following,

$$q_r = h_r S (T_s - T_r) \quad K = h_r S \quad (7)$$

where:

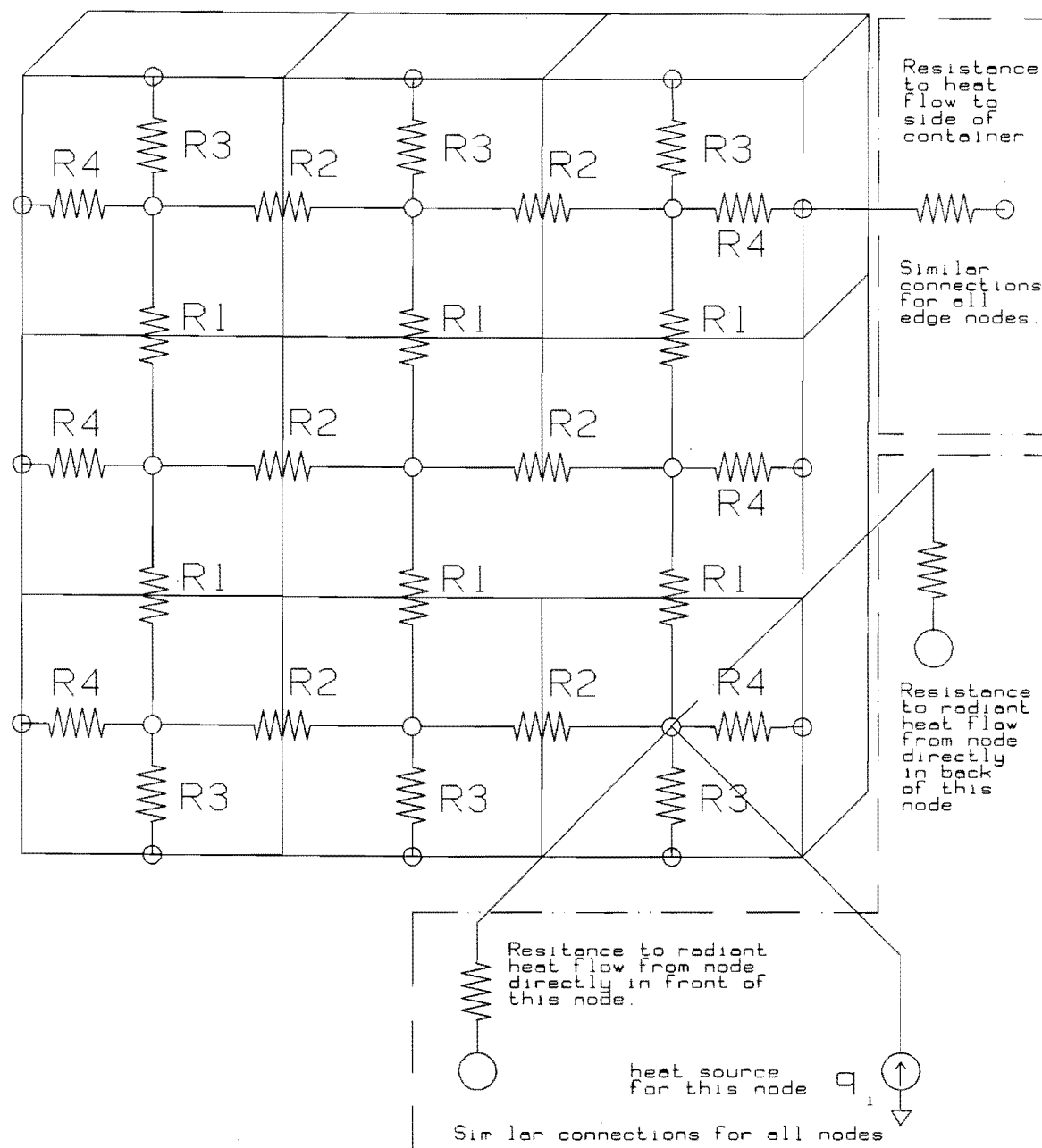
F_e is the emissivity factor T_s is source temperature, $^\circ\text{R}$

F_A is arrangement factor T_r is receiver temperature, $^\circ\text{R}$

Using the preceeding relation and the starting ambient temperature for the value of receiver temperature (T_r) and source temperature (T_s) the software will iteratively solve for K and use inverse K in the resistor matrix shown in Figure 5 and calculate new temperatures.

Heat source values were determined by adding the power dissipations of all components that fell completely within the boundary of a given sub-volume, or by determining the percentage of the component that resides inside the sub-volume's boundary and then using that percentage of the component's power dissipation rating.

Using a software program Thanss (thermal analysis steady state) and a data input program specifically written to format the data, all the values of these resistances along with the heat sources and connections between nodes were input into a data file. Thanss then analyzed the data in an iterative process using a starting ambient temperature of 25 degrees C. With each pass the last temperature determined at a node is used to find the new temperature. This process is repeated until the difference in the node temperatures between iterations falls below a predetermined value.



Example of node connections in
A circuit board

Figure 5

RESULTS

Based on preliminary computations it was determined that there were two hot spots on the power supply board. A simulation of the power supply board circuit will determine more accurately the power dissipation of the suspect components. While the steady state temperatures were high, they were still within the operating temperatures of all the components with the exception of the two hot spots on the power supply board. Even then, the most temperature sensitive components (which are the bubble modules with an operating temperature range of 0-70 degrees C) were within their operating range. Further analysis should verify that there is no thermal problem at an ambient temperature of 25 degrees C.

Further thermal analysis of the SSDR will require an analysis of the power supply and bubble boards. A thermal plane needs to be constructed for the bubble board. and the present thermal plane on the power supply board needs to be more accurately modeled. Once total the thermal model of the SSDR is completed the steady state temperatures can be calculated for a range of ambient temperatures. This will permit finding the operating temperature range of the SSDR.

CONCLUSIONS

The software has been completed for testing of the SSDR operation. Testing will verify the models generated by thermal and EMC/EMI analysis. In addition to developing detailed test plans, NPS is currently obtaining the necessary facilities to accomodate space qualification testing of electronic modules.