To the Graduate Council:

We are submitting herewith a thesis written by Michael S. Yuki entitled "The Development of an Experimental Simulator for Optimizing the Thermal Design of a Generic Table Model Television Receiver." We have examined the final copy of this thesis for form and content and recommend that it be accepted in partial fulfillment of the requirements for the degree of Master of Science, with a major in Mechanical Engineering.

J. Roger Parsons, Major Professor

Robert J. Krane, Major Professor

I have read this thesis
and recommend its acceptance:

Accepted for the Council:

Vice Provost
and Dean of The Graduate School

# THE DEVELOPMENT OF AN EXPERIMENTAL SIMULATOR FOR OPTIMIZING THE THERMAL DESIGN OF A GENERIC TABLE MODEL TELEVISION RECEIVER

A Thesis

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## ABSTRACT

Although much work has been directed toward the packaging of electronics with large numbers of integrated circuits, little work has been done to optimize the cooling of electronic components in consumer electronics. In the process of designing a television receiver, engineers have depended upon their experience and product testing to package the electronic components. This research project begins the process of placing the thermal design of a television receiver on a more fundamental basis.

Using a baseline 20 inch diagonal table model television receiver made by North American Philips Consumer Electronics Corporation, experiments were performed to determine the temperature distribution and flow field. Also, experiments were performed to examine how different vent patterns affected the heat removal. Various vents were blocked to see how temperatures within the receiver changed in comparison to the baseline all vents open case. Also, flow visualization tests were performed to examine the cases of all vents open and all vents closed.

The results of the tests show that the worst case of blocking all the vents only increased temperatures on the order of 10°C. The best case is blocking the lower

extension vents which reduced the receiver temperatures by about 2°C. Based on the temperature and flow visualization tests, six rules for locating vents were also developed.

To provide engineers with a method of predicting the thermal performance of a particular packaging design, a simulator of a television receiver was constructed and its performance was compared to that of a production television receiver. This simulator was designed so that changes in cabinet shape, vent patterns, and circuit board location could be modeled quickly and inexpensively. Flow visualization and temperature measurement tests were performed and verify that the simulator accurately modeled the temperatures and flow patterns of a television receiver.

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# LIST OF SYMBOLS

## SYMBOLS AND ABBREVIATIONS

| | |
|---|---|
| A | Surface Area |
| C | Celsius |
| cal | Calories |
| cm | Centimeters |
| $h_c$ | Convection Heat Transfer Coefficient |
| $h_r$ | Radiation Heat Transfer Coefficient |
| I | Current |
| K | Kelvin |
| mm | Millimeters |
| mV | Millivolts |
| NAPCEC | North American Philips Consumer Electronics Corporation |
| P | Power |
| Q | Rate of heat transfer |
| $Q_1$ | Rate of convection heat transfer from the circuit board to the inside cabinet air, cal/sec. |
| $Q_2$ | Rate of energy convected out the cabinet vents, cal/sec. |
| $Q_3$ | Rate of radiation heat transfer from the circuit board to the cabinet wall, cal/sec. |

SYMBOLS AND ABBREVIATIONS (continued)

| | |
|---|---|
| $Q_5$ | Rate of conduction heat transfer through the cabinet wall, cal/sec. |
| $Q_6$ | Rate of convection heat transfer from cabinet wall to ambient, cal/sec. |
| $Q_7$ | Rate of radiation heat transfer from cabinet wall to ambient, cal/sec. |
| R | Thermal resistance |
| $R_1$ | Convection thermal resistance between the circuit board and the inside cabinet air, sec °C/cal. |
| $R_2$ | Convection thermal resistance between the internal cabinet air and the cabinet wall, sec °C/cal. |
| $R_3$ | Radiation thermal resistance between the circuit board and the cabinet wall, sec °C/cal. |
| $R_5$ | Conduction thermal resistance of the cabinet wall, sec °C/cal. |
| $R_6$ | Convection thermal resistance between the cabinet wall and the ambient, sec °C/cal. |
| $R_7$ | Radiation thermal resistance between the cabinet wall and the ambient, sec °C/cal. |
| s | Stress factor |
| sec | Seconds |
| T | Temperature, °C |

SYMBOLS AND ABBREVIATIONS (continued)

| | |
|---|---|
| $T_{act}$ | Measured temperature of component, °C. |
| $T_C$ | Corrected room temperature, °C. |
| $T_r$ | Measured room temperature, °C. |
| V | Thermocouple Voltage, absolute millivolts. |
| | Thermofoil Heater Voltage. |
| W | Watts |
| $w_T$ | Temperature uncertainty, °C. |
| $w_{Tc}$ | Uncertainty of corrected temperature, °C. |
| $w_{Tr}$ | Uncertainty of measured room temperature, °C. |
| $w_V$ | Voltage uncertainty, mV. |
| $\varepsilon$ | Combined Emissivity |
| $\pi_t$ | Temperature Acceleration Factor |

# CHAPTER I

## INTRODUCTION

Over the past 10 years, television receivers have become lighter and more compact. Digital electronics have replaced most analog or electro-mechanical devices. The thermal design and packaging of receivers is still, however, primarily based on experience factors and product testing. The average television receiver uses about 90 to 150 watts of power. Most of this power is converted to heat in operating the electrical components. This heat must be transferred to the surroundings. Thus, the thermal goal of the electronics packaging designer is to remove this heat from the receiver using a compact and aesthetic cabinet around the picture tube while maintaining acceptable component temperatures. Typically, this is done by venting the cabinet in various areas to provide for airflow through the cabinet by natural convection. It is, however, preferable to keep the number of vents to a minimum to reduce the manufacturing cost and enhance receiver aesthetics. Minimizing the number of vents also reduces the probability of electrical accidents by liquid spillage or penetration of vent openings by electrical conductors and enhances the structural rigidity of the cabinet.

Although vacuum tube components have all been replaced by integrated circuits and transistors which produce less heat, the thermal environment has nonetheless become more important in modern receivers. Integrated circuits are especially sensitive to temperature. The North American Philips Design Manual states that a 10°C increase in temperature causes a 50% decrease in operating lifetime for many integrated circuits (1986). Thus, the possibility of dramatic improvements in reliability provide a strong incentive for improving the component cooling in typical table model television receivers.

# CHAPTER II

# LITERATURE REVIEW

## 1. General References on Electronic Cooling

Much work has been done in the area of electronic cooling. The primary focus of this work is directed toward microelectronics in computers, avionics, or other "high tech" products which have high chip densities and, therefore, relatively high cooling needs. Yet, over the years, increasing amounts of microelectronics have found there way into common consumer electronic products. Surprisingly, little attention has been directed towards cooling consumer electronics products like television receivers despite the trend to very compact packaging arrangements and the temperature dependence of component reliability. Currently, there appear to be no references in the open literature which specifically discuss the thermal environment within a television receiver. Some applicable related literature does exist, however, including general electronic cooling and packaging models and discussions of natural convection in partial enclosures.

Ellison (1984), Kraus (1965), Kraus and Bar-Cohen (1983), Scott (1974), Sloan (1985), and Steinberg (1980)

have all written books discussing electronic cooling and packaging. Most of this literature contains highly simplified models that are useful for obtaining first estimates of the thermal environment in an electronic package. For example, Steinberg examines combined natural convection and radiation heat transfer for circuit boards in full enclosures. He also considers using an impedance analogy to determine the pressure drop in a vented enclosure and, thus, is able to estimate the heat removal for a given flow rate. There is little discussion of optimizing the packaging design with respect to maximizing cooling or minimizing production cost.

## 2. Natural Convection in Enclosures and Partial Enclosures

There is much research in the area of natural convection in enclosures. This work covers both 2 and 3 dimensional geometries. In a complete enclosure, thermal energy is transferred from the heat sources to the enclosure wall by natural convection and thermal radiation. This energy is then transferred through the enclosure walls by conduction and, finally, to the surroundings by natural convection and radiation. The natural convection flow in a complete enclosure is always a recirculating flow, since no flow can pass through the

walls of the enclosure. Unfortunately, a partial or vented enclosure such as the cabinet of a television receiver is a considerably more complex problem. Typically, in a vented enclosure some of the thermal energy is transferred from the heat sources to the surroundings in the same manner as in a complete enclosure; that is, by natural convection and radiation to the walls, through the walls by conduction, and from the outer surfaces of the walls to the surroundings by natural convection and radiation. In a vented enclosure, however, most of the thermal energy is transferred from the sources in the enclosure to the surroundings by the natural convection flows that enter the enclosure through some vents and exit through others. In addition to these main flows that pass through the enclosure by way of the vent openings, there may be localized regions of recirculating flows. Such regions of recirculating flow should be avoided, however, since they are not replenished with cooler outside air and, thus, usually lead to higher heat source temperatures. Therefore, vent geometry and the location of the vents and heat sources relative to one another are significant factors which will determine not only how much flow will pass through the enclosure, but also the path followed by this flow. This type of problem has not yet been extensively explored. However, there are several relevant studies of electronics housed in vented

enclosures that should be mentioned here. Torok (1984) used a 2-dimensional finite element model to numerically investigate the heat transfer from a component board in a low-aspect-ratio enclosure, such as might be found in computer or avionics applications. This study shows the effect of different vent sizes and locations on the heat transfer from a horizontally mounted component board, which is modeled as an isothermal surface. The effect of tilting the board with respect to the horizontal on the heat transfer from the board was also studied. Krane and Phillips (1986) performed an extensive experimental study of the effects of enclosure geometry, including vent sizes and locations, on the maximum temperature on a simulated horizontal component board mounted in a low-aspect-ratio enclosure.

Aung, Beitin, and Kessler (1972) presented numerical and experimental results for natural convective cooling of vertical circuit card arrays in a vented enclosure. The primary goal of this work was to determine card spacings for different card arrays. Ishizuka, Miyazaki, Sasaki, and Yokono (1987) also studied the problem of cooling vertical circuit board arrays, but they examined the impact of vent size on air temperature rise in a rectangular cabinet. The end result was that they were able to predict the outlet air temperature using a relatively simple formula.

Vertical card array models, such as those of Aung et al. and Ishizuka et al. portray circuit board configurations similar to parallel arrays of vertical channels. In contrast, a television receiver typically has only one or two circuit boards and at least one is mounted horizontally. A television receiver also has a cathode ray tube with a set of electron guns that generate a considerable amount of heat. Because of the shapes of the picture tube, the cabinet, and the component boards, the internal geometry of the receiver cannot be modeled as a simple enclosure.

## 3. Applicable References From Fire Research Literature

Another category of research work with possible application to the current problem is fire research, since this field involves natural convection flows in partial enclosures with internal heat sources. This literature is concerned with turbulent natural convection in rooms with ventilation (doors, windows, and ceiling and floor vents). Although the primary focus of these studies is the spread of fire and the smoke concentrations in a room, they form the only significant body of literature that addresses the problem of natural convection in vented enclosures. Typically, a "ventilation parameter" is used for determining the amount of ventilation in a compartment.

Also, the fire is modeled as a volumetric heat source with a volumetric smoke source. Both numerical and experimental studies are extensive. A general survey of this literature is given by Kakac, et al. (1985). The major limitation of this work is that geometries are restricted to simple large rectangular shapes. Also, severe thermal stratification of the air occurs in the enclosures, which is not typical of the relatively well vented enclosures occurring in electronics applications.

From the review of the literature it is concluded that there is very little applicable literature. Moreover, none of the applicable literature performs a detailed examination of the temperature or flow fields within a partial enclosure with the unique geometry of a television receiver. Thus, this research is focussed on the effects of vent and component board locations on the component temperatures in a table model television receiver.

# CHAPTER III

## ADOPTION OF A "TYPICAL" TABLE MODEL TELEVISION RECEIVER

### 1. Introduction

Television receivers vary from manufacturer to manufacturer. In general, they are classified by the diagonal length of their screen and by the type of cabinet. There are floor models, which are mounted in more elaborately styled large cabinets, and there are table models which are more compact. Nevertheless, all receivers have some characteristics in common. For the purposes of this study, only table model receivers, which do not have cabinetry unrelated to the function of the set, will be considered. A Magnavox 20 inch diagonal screen color television receiver made by North American Philips Consumer Electronics Corporation was adopted as an example of a "typical" table model receiver. Specifically, two production model number RG4332-WA05 television receivers, were used. Sketches of the receiver are shown in Figures 3.1 and 3.2. The descriptions of a 20 inch diagonal television receiver below are based on measurements of these sets.

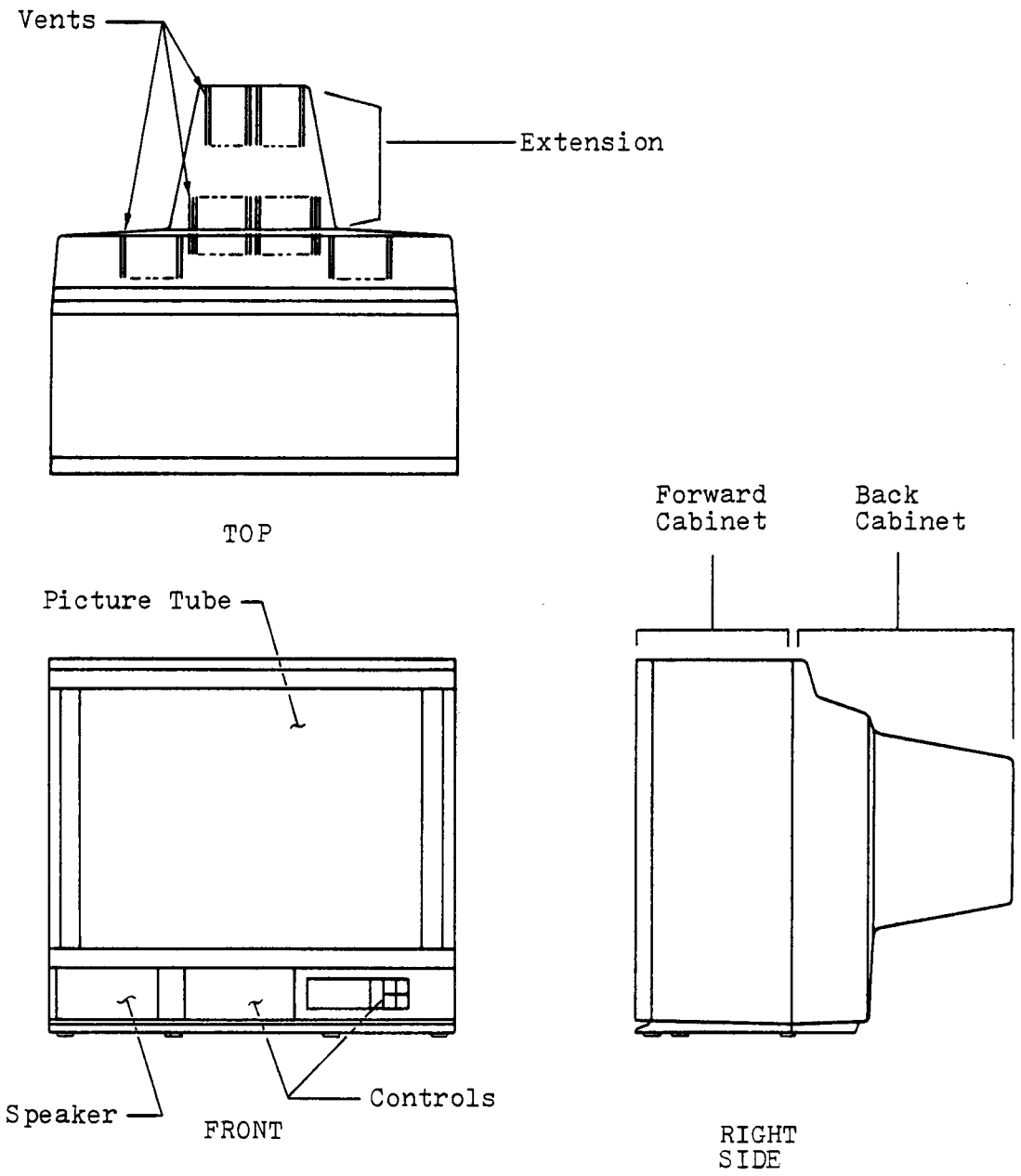



**FIGURE 3.1. Magnavox 20 Inch Television Receiver - Top, Front, and Right Side Views**

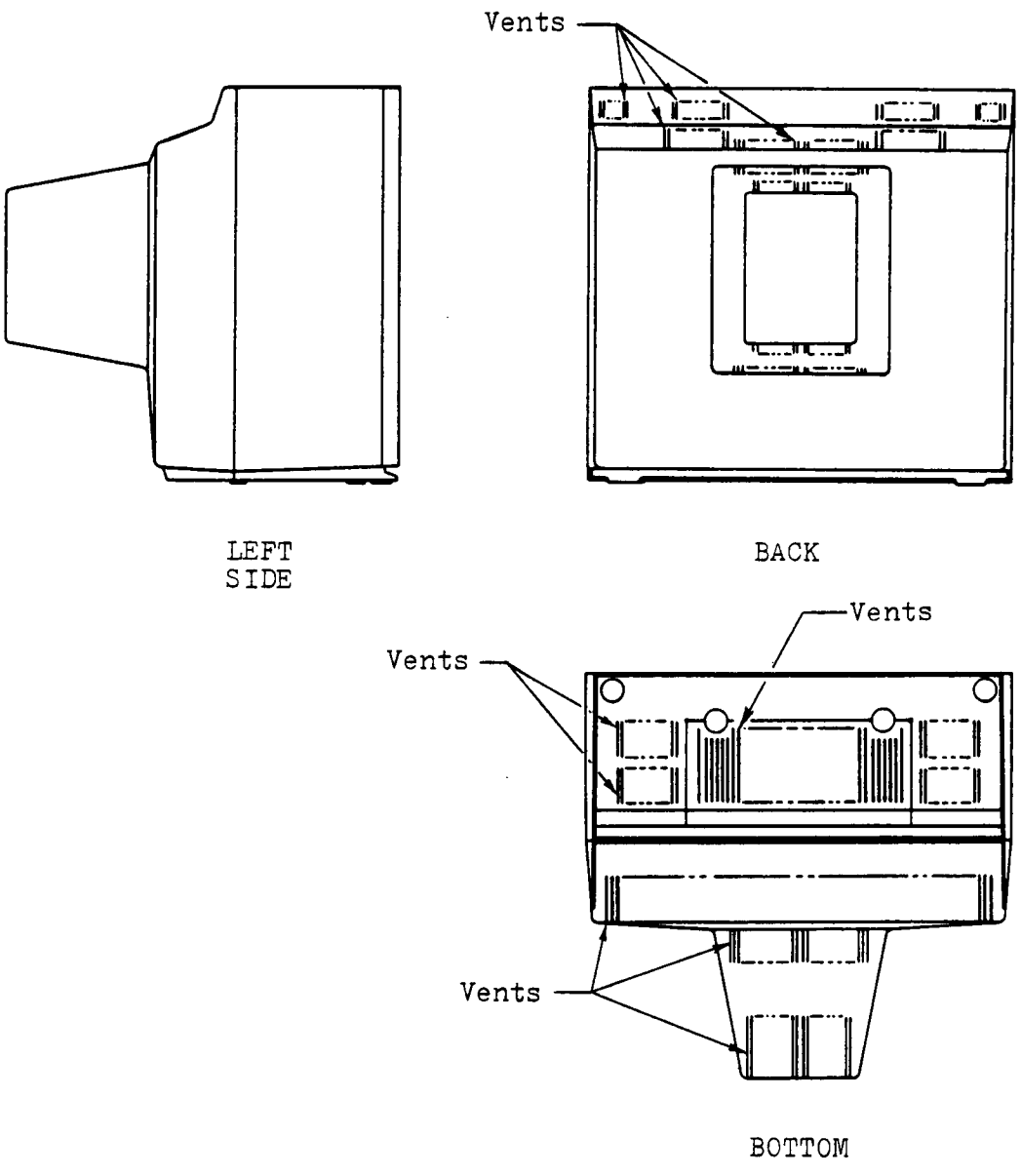



**FIGURE 3.2. Magnavox 20 Inch Television Receiver - Bottom, Back, and Left Side Views**

## 2. The Cabinet

A television receiver consists of a picture tube and the electronics to power and control the electron guns in the tube. Also, there are audio circuits and circuits for processing the signal from a television transmitter. All of these components are housed in a cabinet. The cabinet is a two-piece, injection molded, thermoplastic enclosure. This enclosure is usually shaped as a rectangular box with a width, height, and depth on the order of 50 cm, 45 cm, and 25 cm, respectively. It is made in two parts that are usually bolted together. A typical cabinet wall thickness is on the order of 0.3 - 0.4 cm. The front half contains the picture tube and circuit board mounting brackets. The back half is a protective cover. Both sections of the cabinet have vents molded into them.

The total vent area varies significantly between manufacturers, but for this baseline receiver, the vent area of the main cabinet is approximately 195 $cm^2$. The back of the box-like structure of the main section of the cabinet contains a horizontal, rectangular extension (called a "cup") which houses the neck of the picture tube. This extension also has vents. The vent area of the extension is approximately 104 $cm^2$.

The size and shape of an individual vent hole are limited by structural and safety requirements for the

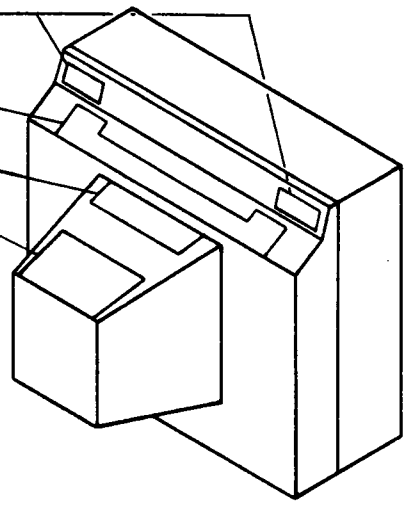
cabinet. The receiver must undergo Underwriters Laboratory (UL) examination for their approval. UL has a battery of standardized tests specified in Television Receivers and High-Voltage Video Products (1986) to gage the electrical shock and fire hazards of a receiver. These tests are oriented toward the structural integrity of the cabinet. For example, one test involves trying to insert a coin-like probe through a top vent. The probe must not come in electrical contact with any high voltage receiver component. The lower vents must be able to support the weight of the receiver on a 2 inch diameter sphere. Similarly, the side walls of the cabinet must be able to withstand an impact from a 2 inch diameter sphere. Also, the receiver is operated continuously for 7 hours in a room with an ambient air temperature of 60°C. In this time period, the cabinet must not distort.

For the baseline Magnavox receiver, the vent areas are distributed as shown in Figure 3.3. For clarity, vents are grouped into sets and in the text are referred to by the set number.

## 3. The Picture Tube

The largest and heaviest component of the receiver is the picture tube. The general shape of the tube is shown in Figure 3.4. The tube is constructed from 0.3 - 1.3 cm

| VENT SET DESIGNATION | AREA |
|---|---|
| I | 14.7 $cm^2$ |
| II | 40.1 $cm^2$ |
| III | 23.2 $cm^2$ |
| IV | 28.7 $cm^2$ |
| Total Top | 106.7 $cm^2$ |



| VENT SET DESIGNATION | AREA |
|---|---|
| V | 23.2 $cm^2$ |
| VI | 28.7 $cm^2$ |
| VII | 62.5 $cm^2$ |
| VIII | 78.2 $cm^2$ |
| Total Bottom | 192.6 $cm^2$ |

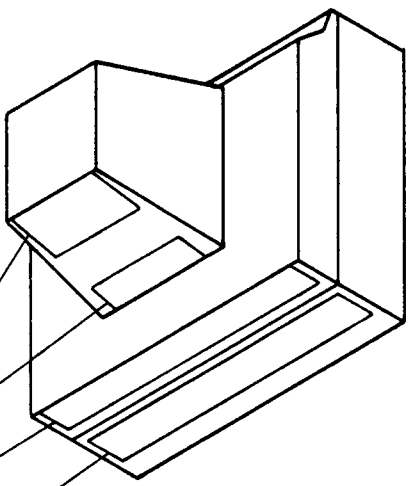


**FIGURE 3.3. Vent Locations and Areas on Baseline Television Receiver Cabinet**

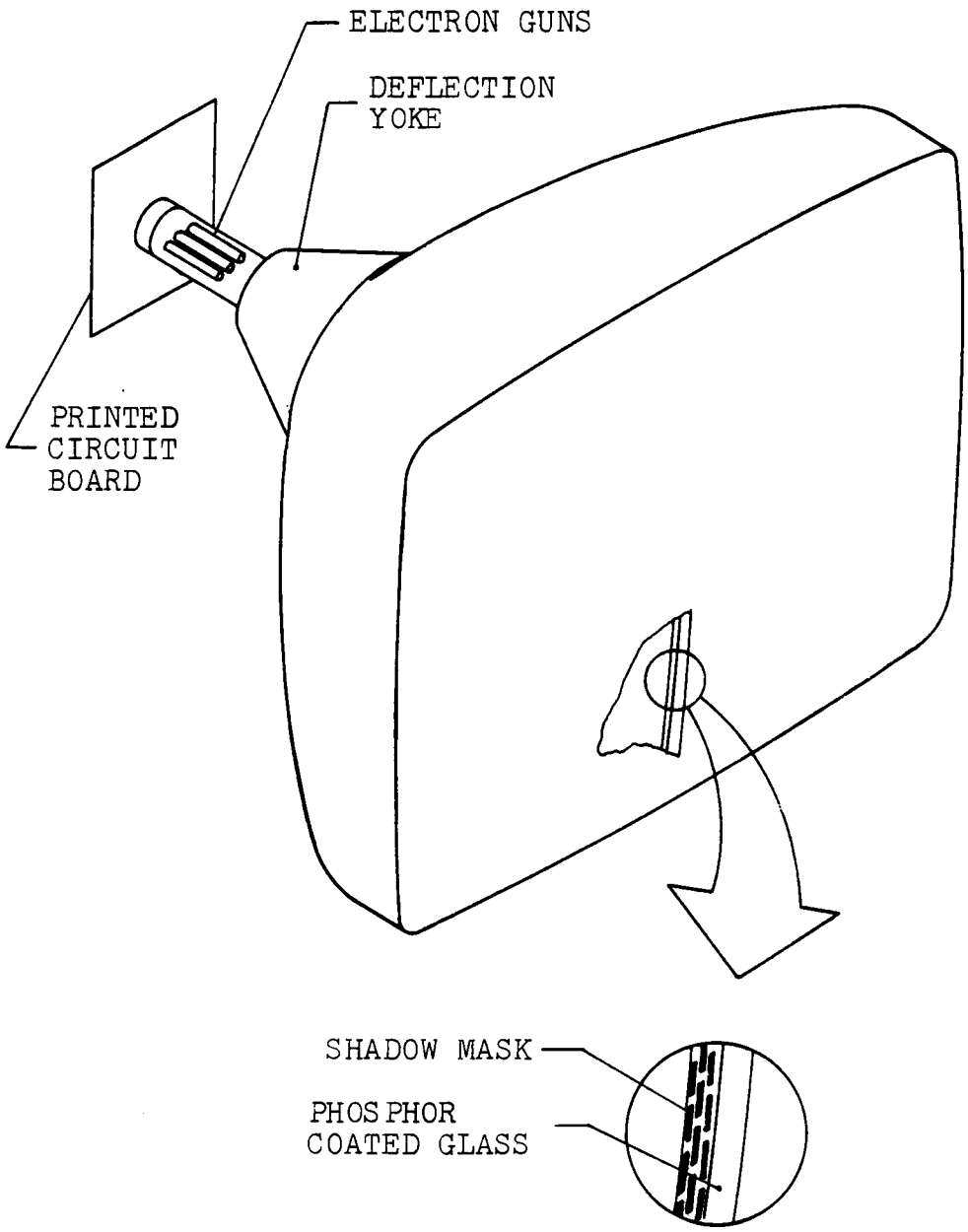



**FIGURE 3.4. Picture Tube Components**

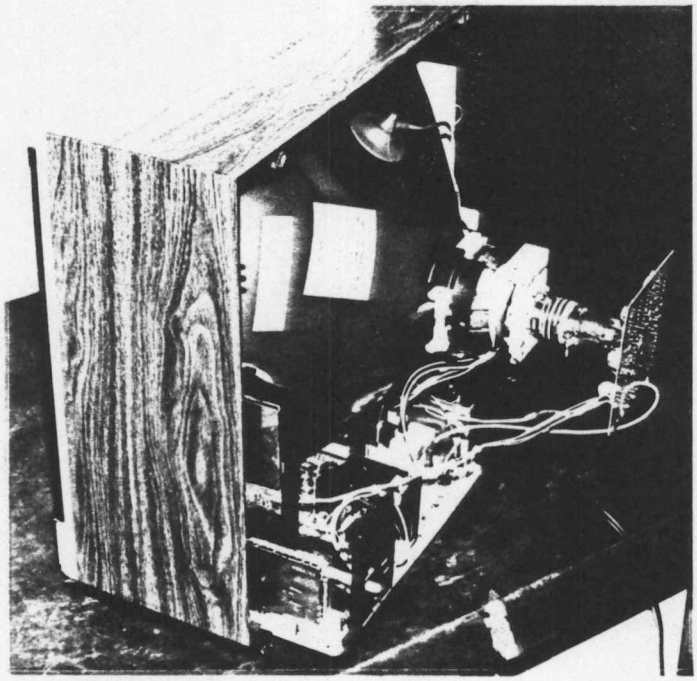
thick glass, weighs on the order of 30 pounds, and is bolted to the forward cabinet face. It is the cathode ray tube that contains three electron gun/heater assemblies. These assemblies, one each for the colors, blue, green, and red, scan a phosphor screen and cause it to fluoresce to create a picture. Indirectly heated cathodes serve as the electron source, while the guns accelerate the electrons and produce a beam. The cathode heaters are the main heat sources in the tube and are mounted in the neck. The heaters, which are connected in series and rated at 6.3 volts and 0.7 amps (maximum current), dissipate a total of about 13 watts of power. Also, a small, vertically oriented component board is commonly mounted at the rear end of the picture tube. The nominal anode power dissipation of the picture tube is on the order of 28 watts, but this will vary with the picture generated on the screen. The maximum anode power dissipation is 40 watts. These numbers do not include the power dissipated by the cathode heaters. The most power is dissipated by an all white screen because brighter pictures require higher voltages to accelerate electrons to greater velocities. For the white picture, all guns are operating.

Much of the power input to the picture tube is dissipated as heat from the neck. The phosphor coatings on the inside face of the picture tube are typically not

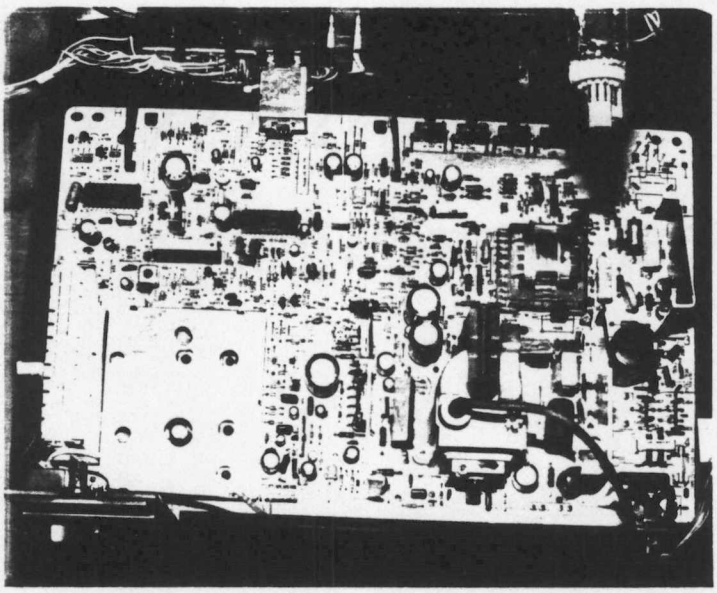
more than about 20% efficient (Bolz and Tuve, 1983). Thus, of the 40 watts reaching the phosphor, at the most, only 8 watts are converted to visible light. Also, several watts are converted to heat at the shadow mask at the picture tube face. The shadow mask is a thin piece of perforated sheet metal used to sharpen the picture by intercepting unwanted electrons before they reach the phorphor screen. It is mounted at the back face of the tube between the electron source and the phosphor screen and, thus, intercepts much of the electron beam.

### 4. The Main Circuit Board

The main circuit board is an epoxy-fiberglass material. In the baseline receiver, the board is approximately 23 cm by 36 cm and is 0.16 cm thick. It is mounted horizontally at the bottom of the receiver and is offset about 12.7 cm to the right of the centerline (looking at the picture screen). Figure 3.5 shows where the circuit board is located in the cabinet and how it appears unmounted without the connecting wires. The majority of heat sources in the receiver are mounted on the main circuit board. The integrated circuits and transistors for the horizontal and vertical output and audio are located on this board as well as the power transformers and the majority of the resistors,



(A) Circuit Board Mounted in Receiver (Back Cabinet Removed)



Forward

(B) Top View of Unmounted Circuit Board

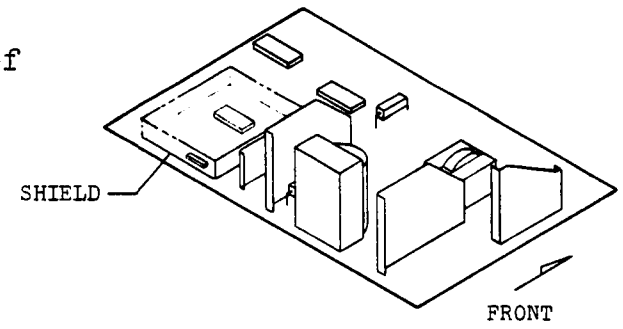
FIGURE 3.5. Views of Main Circuit Board Mounted in Receiver and Unmounted

capacitors, and diodes. Of all of these components, the resistors, integrated circuits, and transistors typically operate at the highest temperatures.

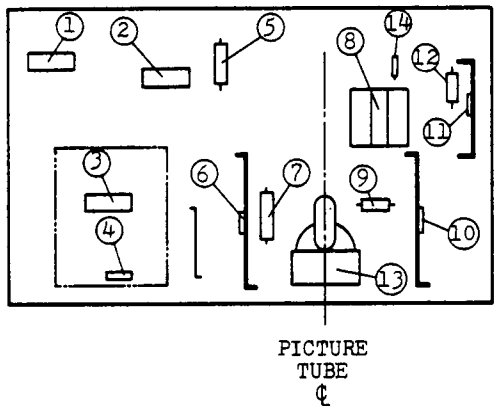
In this receiver there are three main heat sinks, one for each the switch mode regulator, vertical output integrated circuit, and horizontal output transistor. These heat sinks are constructed from 0.2 cm thick sheet aluminum, two of which are black anodized. NAPCEC estimates that this anodization increases the heat transfer by about 10%. There are about 10 integrated circuit chips used in the receiver, along with about a dozen transistors with small metal tabs for cooling. Figure 3.6 shows the general locations of the components that dissipate the largest amounts of input power to the main circuit board. Note that part of the audio circuitry, including two integrated circuits (Audio IF's designated IC201 and IC202), is enclosed by a shield made from 0.1 cm thick sheet aluminum. This shield protects the circuitry from receiving unwanted signals that might cause sound distortion. The shield has several holes at the top to provide some clearance between the top and several capacitors; thus, it appears that these audio components are isolated from the cooling air flow.

With the adopted "typical" television receiver as a baseline it is now possible to make alterations to the cabinet and circuit board and examine the impact of these

(A) Isometric View of Main Circuit Board




(B) Top View of Main Circuit Board




| COMPONENT NUMBER | NAPCEC DESIGNATION | COMPONENT |
|---|---|---|
| 1 | IC310 | Integrated Circuit |
| 2 | IC640 | Integrated Circuit |
| 3 | IC201 | Audio IF |
| 4 | IC202 | Audio IF |
| 5 | R456 | 5 Watt Resistor |
| 6 | IC580 | Vertical Output Integrated Circuit |
| 7 | R513 | 7 Watt Resistor |
| 8 | T401 | Transformer |
| 9 | R505 | 5 Watt Resistor |
| 10 | Q501 | Switch Mode Regulator |
| 11 | Q400 | Horizontal Output Transistor |
| 12 | R408 | 5 Watt Resistor |
| 13 | T504 | Flyback Transformer |
| 14 | R421 | Resistor |

**FIGURE 3.6. Location of Major Components on the Main Circuit Board**

changes on component and air temperatures and the flow field. It is also possible to try to model the thermal environment of the receiver either numerically or experimentally and have a basis for comparison.

# CHAPTER IV

# DEFINITION OF THE RESEARCH PROJECT

## 1. Statement of Objectives

The primary objectives of this research are: (1) to determine the internal thermal environment of a typical television receiver, (2) identify those design and operating factors that affect the temperatures of major heat sources in the receiver, and (3) use the knowledge gained from (1) and (2) to build a thermal model of the receiver.

## 2. The Thermal Environment

For the first objective, some things can be deduced from a basic understanding of heat transfer. The modes of heat transfer in a receiver are natural convection, conduction, and radiation. Figure 4.1 shows the possible energy flow between a component and the surroundings. Heat from the components may be conducted to the circuit board, radiated to the circuit board or to the cabinet walls, or convected away to the surrounding air. For a cabinet with vents, natural convection will be the primary mode of heat removal from the receiver.

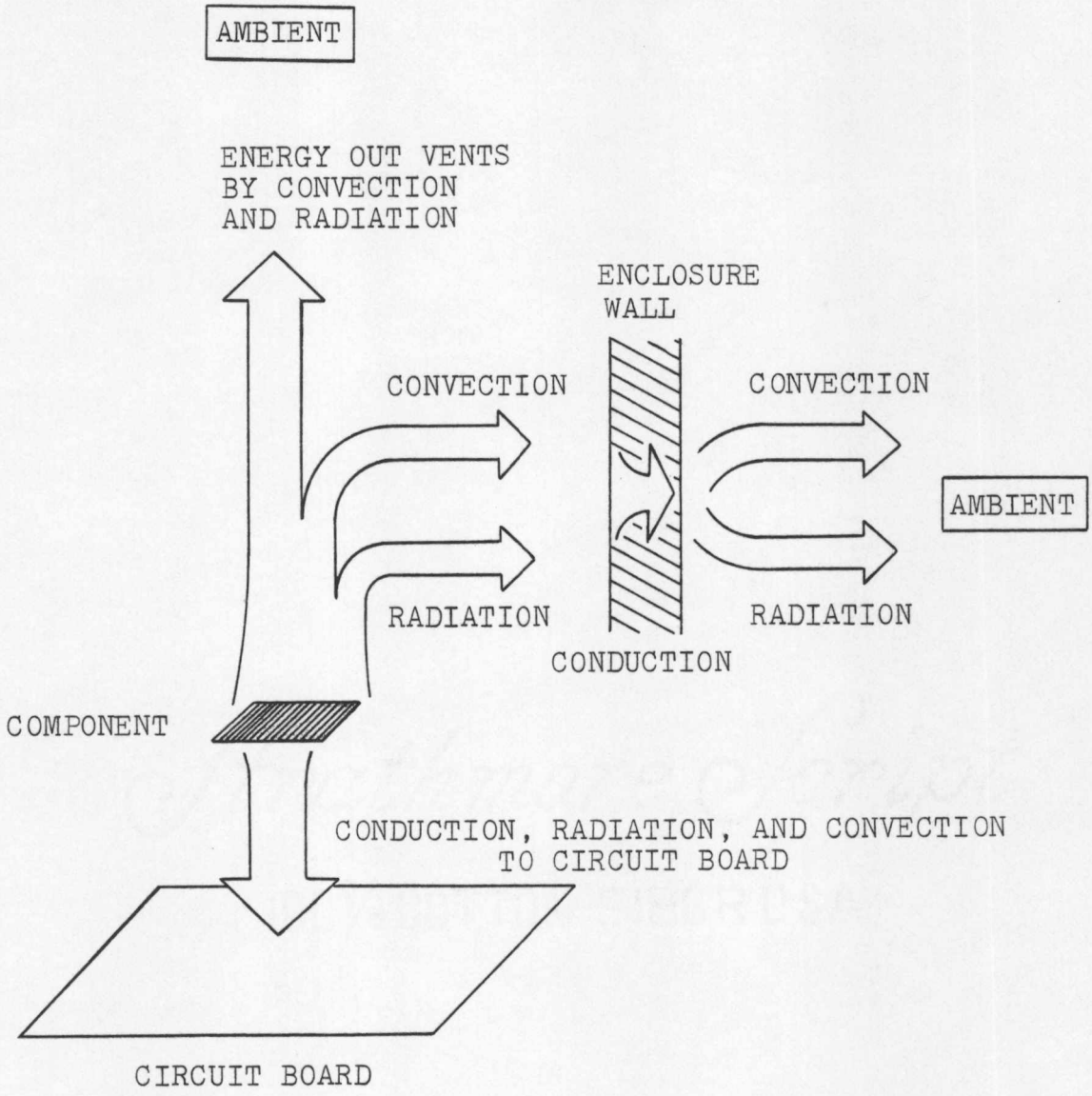



**FIGURE 4.1. Heat Flow Paths From Component to Ambient**

Buoyancy-induced flow will cause significant vertical fluid movement. As heated air rises and exits through some cabinet vents, cool air will be drawn into the enclosure through other vents. Between the inlet and outlet vents, components along a (relatively) high velocity flow path should be efficiently cooled as high velocity flow is the most effective manner of enhancing the local heat transfer coefficient and lowering component temperatures. In contrast, recirculation, or other regions of low velocity flow, may exist. These must be eliminated if possible or at least kept away from temperature sensitive components.

To study the thermal environment of the receiver, two things must be done. First, temperature measurements of the components and inside cabinet air must be performed. This will provide a temperature field within the receiver that can be used as a baseline for comparison with equivalent temperatures from modified receiver cabinets. Secondly, the flow field must be studied. It is essential in this study of the convective heat transfer to determine the flow paths. Cooling air inlets and outlets must be identified, and air flow paths between the two must be identified. Yet, knowledge of the air flow paths is not enough. If the air flow velocity is low, its cooling effect on a component is less than that of a higher velocity flow. Thus, knowledge of air flow velocities is

also required. The best method available to determine air flow paths is with flow visualization. This method will also yield some information of the flow velocity. With the temperature data, the air flow experiments will be used to gain insight into how the components are being cooled.

### 3. Design and Operating Factors That Affect the Temperature of Components

Once the thermal environment for the baseline receiver is defined and understood, the second objective can be addressed. Design factors such as heat source location, circuit board orientation, cabinet material, vent shapes, and vent location may all affect the component temperatures. Likewise, operating factors such as ambient temperature, picture settings, and volume setting also affect the component temperatures. Again, a basic understanding of heat transfer provides some direction on determining which factors to examine in detail.

To increase the convective cooling of a component, it is necessary to increase the air flow past the component and/or decrease the air temperature adjacent to the component. The use of forced convection is not acceptable because the addition of a fan would increase manufacturing and material costs, increase undesirable noise and

decrease reliability. Also, radiant energy to a component can be reduced if the hot components are located away from the temperature sensitive component or by shielding that component. Although heat removal from a component by conduction is typically small because of high thermal resistance due to small contact areas, conduction paths (between the heated air and the ambient) through the enclosure wall may be significant. Increasing the thermal conductivity of the wall could allow more heat to be carried away. Therefore, potential modifications include, but are not limited to, changing the cabinet shape, the vent shapes and locations, and location of those components that dissipate the most power.

Since the easiest modification to make to a receiver is the addition or removal of vents, this alternative will be the main focus of the research project. Changes in component and internal air temperature changes are the best indicators of the effectiveness of the vent modifications. Temperature tests will be performed and compared to the baseline case for a fixed set of operating factors.

The operating factors must be considered primarily when attempting to make comparisons between modified and baseline receivers. One gage of the impact of the operating factors on receiver operation is the power drawn by the receiver, and the distribution of this power within

the receiver. Since most of the electric power is converted to thermal energy, the power distribution within the receiver will also aid in understanding the receiver component temperatures. Ideally, it would be valuable to know the exact power dissipation for each component for any operating condition. This type of information, however, is not readily available. Moreover, for components like transistors and integrated circuits, direct measurement of the power input is difficult and time consuming. For the purposes of this research, the total power drawn by the receiver is calculated from the measured current and voltage for several operating conditions. The detailed distribution of this power among the components will be estimated based on some rudimentary knowledge of component power requirements.

Once a standard operating condition is selected, the receiver modifications, such as blocking vents or changing cabinet geometry, can be made and tests to determine the effects of these modifications on component temperatures can be performed. Unfortunately, there are limitations to the types of modifications that can be performed. Changes in heat source distribution, circuit board location, and cabinet geometry could not be performed in the present investigation using production model receivers; thus, a thermal simulator that can be easily modified was designed and constructed.

# 4. The Thermal Simulation of a Receiver

Once the internal temperatures and flow patterns have been determined for the baseline receiver, it is possible to construct a model to simulate the thermal environment of a television receiver. Two types of thermal simulators can be constructed. The current state of computer technology allows the construction of a numerical simulator. Numerical simulators may range from a simple thermal model based on the electrical resistance analogy to a sophisticated thermal model using finite difference or finite element techniques.

The second type of simulator is an experimental model. This model may also range from the simple to the complex. For example, it may consist of be a rectangular box with one constant flux heat source to represent the components, or it may be a fairly detailed representation of the receiver with each individual component modeled in detail, or its level of complexity may be something in between.

There are several advantages to a numerical simulator. They typically save time because of the ease of making modifications to them. Secondly, they can deal with modifications that are difficult to implement in an experiment. Also, the numerical simulator may provide more information per run than an experiment. In contrast,

the experimental simulator has the possibility of providing more realistic information.

In this research project, the focus will be on the experimental approach, but a very simple numerical model of a receiver will be constructed. The experimental simulator will be built in as simple a manner as possible and still provide accurate flow and temperature patterns. The design of the experimental simulator will be based on the experimental results of the previous tests using the baseline receiver. Knowledge of the flow patterns will be used to determine how components affect the flow. Temperature data will be used to try to reasonably approximate the largest number of components with the smallest number of model heat sources. Hopefully, this knowledge can be used to determine reasonable simplifications for designing an experimental simulator of a receiver. This simulator will allow a designer to quickly examine the temperature and flow field changes due to different vent patterns, cabinet geometries, heat source distributions, or circuit board locations. As a first step toward attaining this capability, the research project will demonstrate that a experimental thermal simulator can be built and, this simulator will accurately model changes to an actual receiver.

# CHAPTER V

# THE EXPERIMENTAL RESEARCH

## 1. Introduction

A goal of the experimental tasks of this research project is to collect data from the baseline receiver that can be used to design and verify an experimental simulator of a generic table model television receiver. The experiments were designed to determine: (1) the internal temperature distribution, (2) the flow field in the baseline receiver, and (3) the vent locations and geometries that provide the desired component cooling.

## 2. Temperature Measurements

Using the baseline Magnavox television receivers (designated "Receivers I and II"), five sets of temperature experiments were performed in which component, cabinet, and internal air temperatures were measured. The five sets of experiments were to perform (1) a general temperature survey of the receiver components to identify high temperature components, (2) a general temperature survey of components for a receiver with a cabinet with plexiglas panels, (3) a series of component and air temperature surveys with different vent sets blocked, (4)

a survey of the internal air temperatures in the receiver, and (5) a component and air temperature survey in a receiver with a partitioned cabinet.

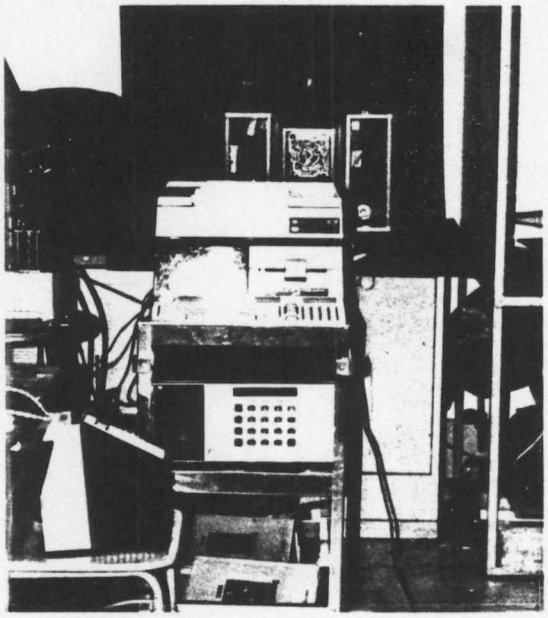
### 3. Temperature Survey of Baseline Receiver To Identify High Temperature Components

The first set of tests were performed to determine which components were operating at the highest temperatures. First, Receiver I was operated for about two hours without the cabinet back. Although the receiver typically requires 3 to 4 hours to reach steady state condition, only the relative magnitudes of the temperatures were needed. In two hours, the component temperatures achieve about 90% of their steady state values. At the end of the warmup time, a chromel-alumel thermocouple and hand held potentiometer were used to survey the temperatures of the various components. The back had to be removed for this test because it was too difficult to reach many of the components by inserting the thermocouple through the vents. Based on these measurements, 38 (36 gage) copper constantan thermocouples were strung through the cabinet vents and installed in the receiver. The thermocouples were attached to various components or were radiation shielded with tape and positioned to measure air temperatures in the receiver.

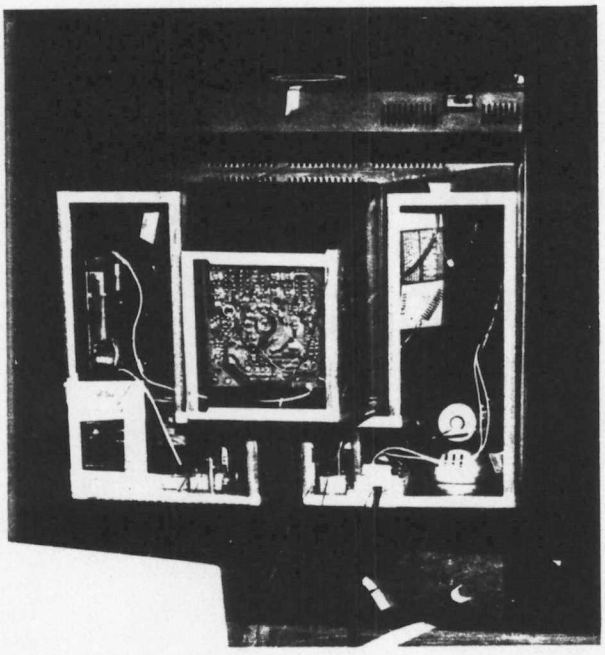
The back of the cabinet was replaced and the receiver was operated for several hours until the receiver temperatures stopped increasing. The thermocouple outputs were then measured and recorded with a Hewlett Packard 9826 microcomputer equipped with a 3497-A Data Acquisition / Control Center. An ice water bath was used as a reference junction. The output from each thermocouple was sampled, in sequence, three times and averaged. These average values were printed and taken as the component temperature. Room air temperature was also measured. In order to have a consistent temperature comparison between various tests and because of the difficulty of keeping the laboratory at a constant temperature, all component temperatures are corrected to a standard room temperature of 20°C. This was done by subtracting the difference in room temperature from the measured component temperature. This was done based on advice from NAPCEC, and for small (4°C) variations in room temperature this correction is deemed adequate. Figure 5.1 shows the test setup used.

4. Temperature Survey With Modified Cabinet Back

A cabinet back of a baseline receiver was modified by replacing most of the flat panels with plexiglas. This was done so that the flow patterns in the receiver could be visualized using injected smoke illuminated by the



(A) Receiver and Hewlett-Packard 9826 Microcomputer With a 3497-A Data Acquisition/Control Center

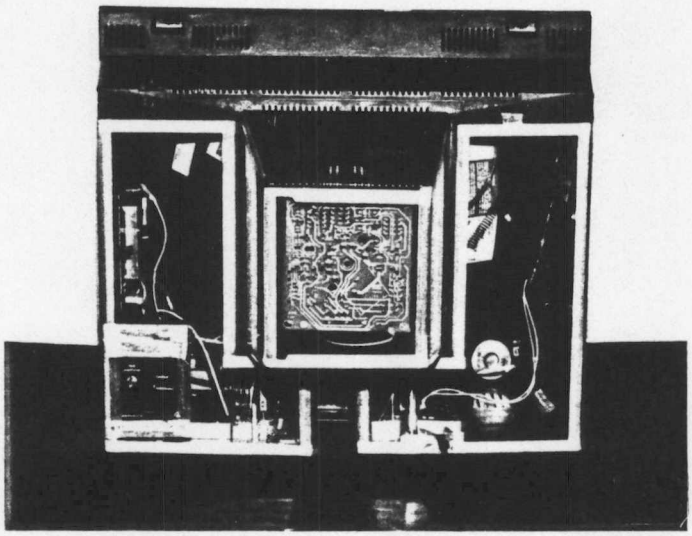


(B) Close-up of Receiver With Thermocouples

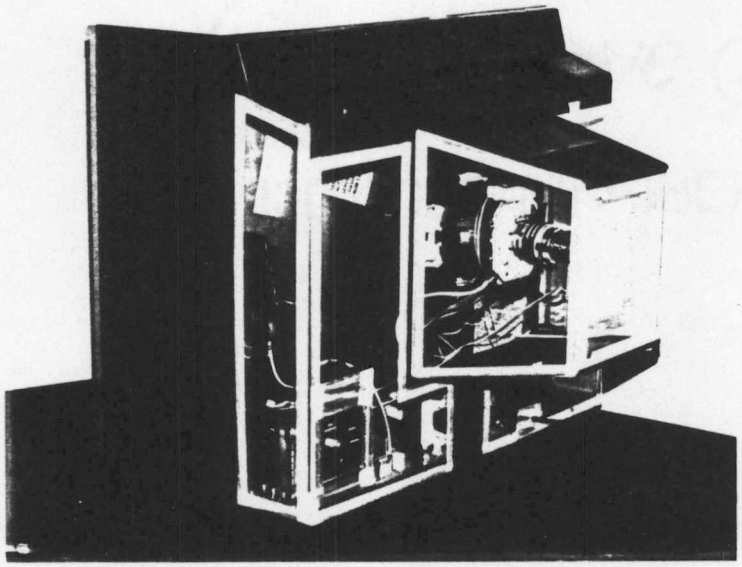
FIGURE 5.1. Photograph of Test Setup For Receiver Component Temperature Measurements

(red) light from a Helium-Neon laser. The modified back is shown in Figure 5.2. With this configuration, a second set of temperature tests was performed to verify that there is no significant temperature difference between the receiver with the standard opaque cabinet back and a receiver with a plexiglas cabinet back due to thermal radiation through the plexiglas panels. The reflectance and transmittance of acrylic (plexiglas is cast acrylic) and white polystyrene are about the same in the wavelengths of 2 to 15 microns. Table 5.1, given by Bolz and Tuve (1983), lists transmittance and reflectance data for these two materials. For a blackbody radiating at 100°C, the fraction of radiation with a wavelength in the 3 to 15 micron range is 0.696. Also, the fraction of radiation with wavelengths above 3 microns is 0.999. Since most of the components operate at or below 100°C, the radiation wavelength is expected to be primarily above 3 microns. Thus, the theory of heat transfer by thermal radiation predicts that the plexiglas panels should absorb or reflect about the same amount of radiation as the plastic baseline back. We may conclude that the receiver temperatures will not change significantly when the modified back is used.

Nineteen temperature measurements were made in each receiver to study the impact of the plexiglas panels on the component and inside air temperatures of the receiver.



(A) Back View



(B) View Looking Forward From Right Side

FIGURE 5.2. Television Receiver With Cabinet Back Modified For Flow Visualization Experiment

TABLE 5.1. Reflectivity and Transmissibility of Acrylic and Polystyrene Plastic

| Wavelength (microns) | Reflectance (%) | Transmittance (%) |
|---|---|---|
| Clear Acrylic (0.12 in. thick) | | |
| 0.4 - 1.0 | 6.0 | 92.0 |
| 2.0 | 8.0 | 53.0 |
| 4.0 - 15.0 | 3.0 | 0.0 |
| White Polystyrene (0.12 in. thick) | | |
| 0.4 - 0.6 | 29.0 | 26.0 |
| 1.0 - 2.0 | 16.0 | 42.0 |
| 4.0 - 15.0 | 3.0 | 0.0 |

(Bolz, R. E. and Tuve, G. L.,1983)

Temperatures of all of the components listed in Figure 3.6 (see page 20), except the flyback transformer were measured. Figure 5.3 shows the thermocouple locations for the air temperature measurements. The results of the tests, which are discussed in Chapter VIII, demonstrate that the receiver operates cooler with the plexiglas panels, but the temperature differences appear to be small (less than 3°C) relative to the operating temperatures. Thus, it is concluded that the temperature field inside the receiver with the modified back and baseline back are essentially equivalent.

### 5. Temperature Survey With Blocked Vents

The purpose of the third set of temperature tests was to quantify the effectiveness of the vents and to examine how flow changed with different vent configurations. Using Receiver I, blocked vent tests were performed to try to determine the impact of vent patterns on the receiver components. The vents were systematically blocked with masking tape and the receiver was operated until steady state was reached. Steady state was determined by examination of the measured temperature histories. These tests were run with the plexiglas cabinet back. The receiver picture control knobs labeled Color, Tint, Picture, Bright, and Sharp were set to their clockwise

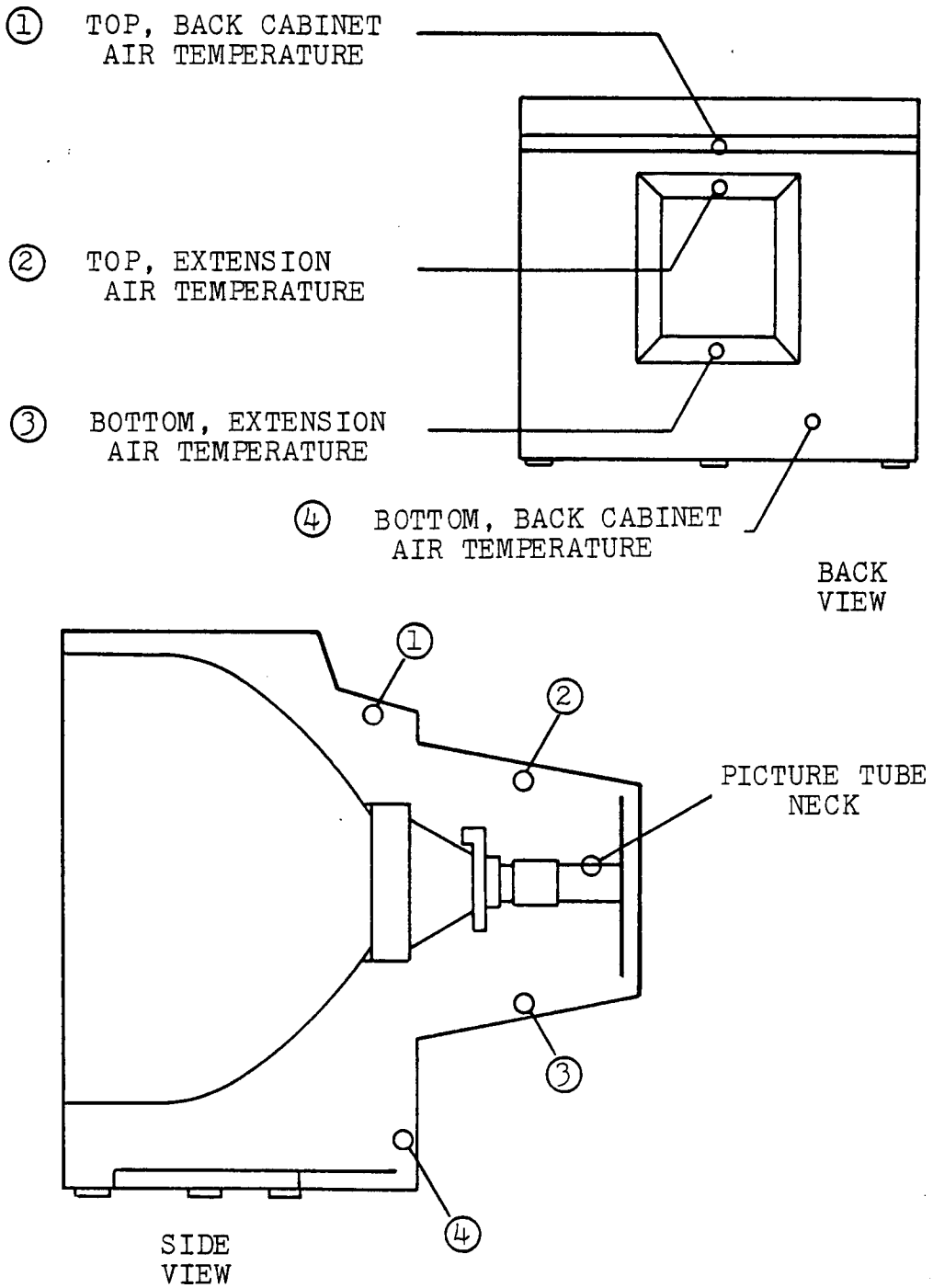



**FIGURE 5.3. Thermocouple Locations in the Cabinet and Picture Tube**

most positions. These settings bias the color to red and maximize the picture brightness. The receiver volume was off and the channel was fixed at 3 which gives a blank screen with white, blue, green, red, and black dots. Voltage and current drawn by the receiver were measured at the wall plug with a multimeter. They were found to be 113 volts and 0.86 amps. Thus, the power drawn in this configuration was calculated to be 97.2 watts.

### 6. Air Temperature Measurements Inside the Receiver

The fourth set of temperature experiments was made to measure air temperatures in the cabinet. Nineteen thermocouples were used to measure the vertical air temperature gradient in Receiver I and air temperatures in the lower and upper sections of the cabinet. The picture settings were identical those used in the previous set of tests. In the present set of tests, the ice bath reference was replaced with an Omega model TRC Electronic Ice Point Cell. This device has an accuracy of 0°C to 0.1°C and is stable to ±0.02°C for the typical room conditions. To measure the vertical temperature gradient in the air in the receiver, 9 thermocouples were mounted 5.1 cm apart on a 0.3 cm diameter wooden rod. The rod was placed adjacent to the picture tube on the left or right sides as shown in Figure 5.4. Figure 5.5 shows the

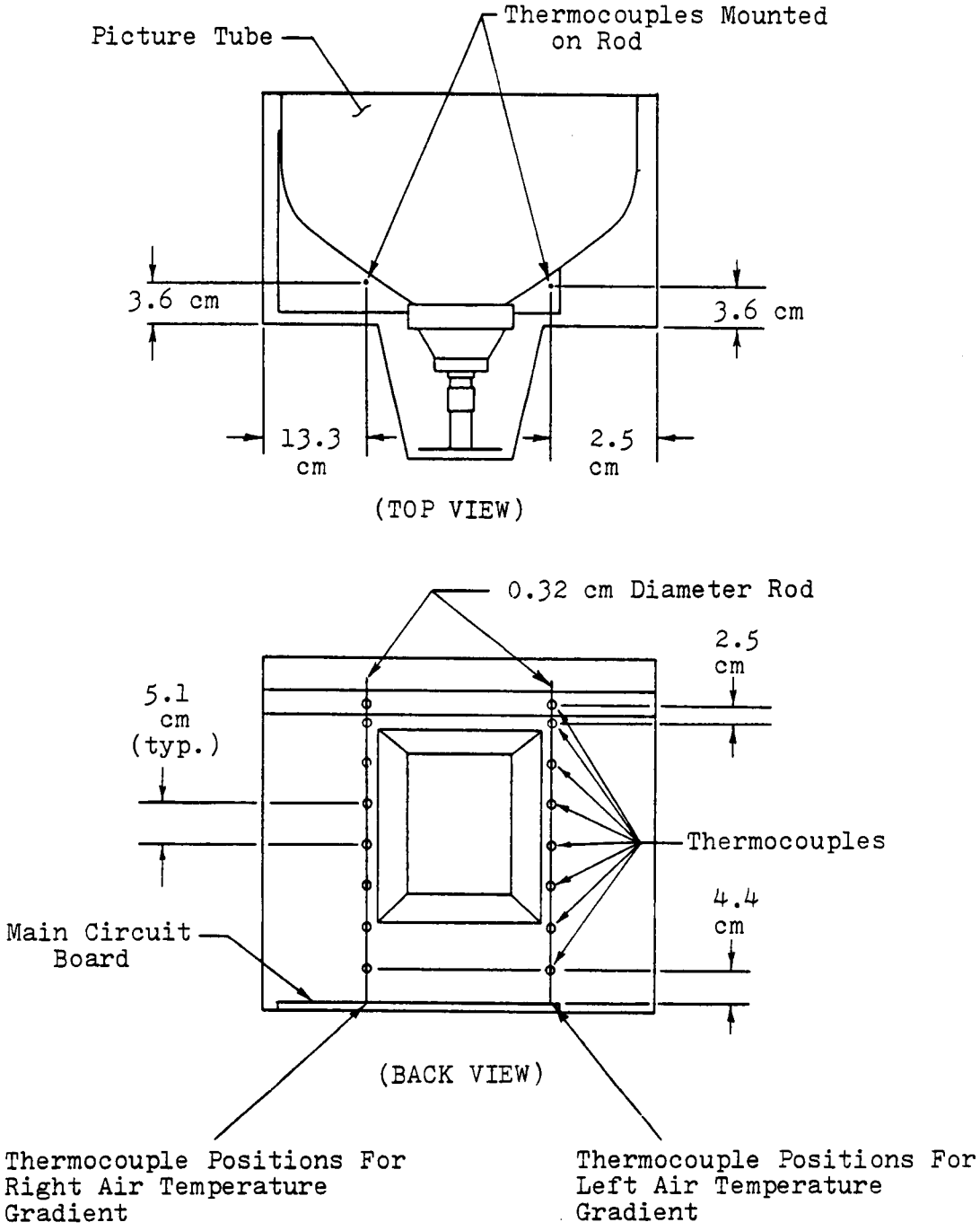



**FIGURE 5.4. Thermocouple Locations For Air Temperature Gradient Measurements**

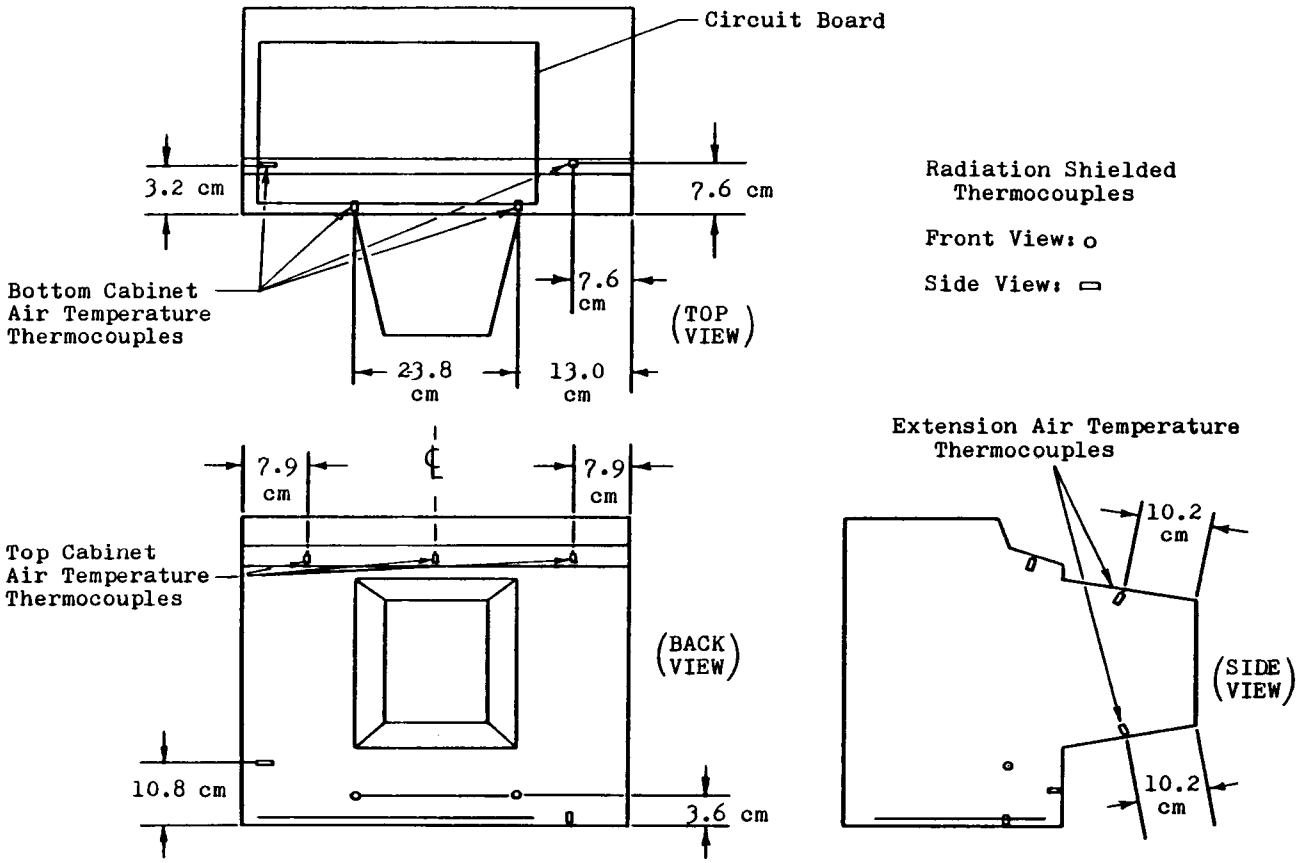



FIGURE 5.5. Thermocouple Locations on Cabinet Back

location of the thermocouples not mounted on the rod. In order to make 26 temperature measurements with only 19 thermocouples, it is necessary to run two tests, one test for the right temperature gradient and one test for the left. The other thermocouples were left in the same position as a check on repeatability. The results of this show that the air temperatures are within 2.4°C.

### 7. Temperature Survey With A Partitioned Cabinet

One final test was performed to examine the impact of separating the air flow in the extension, or "cup", from the main cabinet. It was believed that this modification would improve the air flow through the receiver by keeping the extension vents from "short circuiting" the pressure drop between the cabinet inlet and outlet vents, and thereby maximizing the chimney effect. The separation of air flows would also keep any hot plumes from the main circuit board away from components in the extension. This was accomplished by adding a 22.9 cm by 27.3 cm cardboard sheet at the picture tube yoke as shown in Figure 5.6. The thermocouple locations are identical to those used in the blocked vent experiments, but the temperature of the picture tube on the horizontal centerline (approximately 15 cm to the right of the vertical centerline) was also measured.

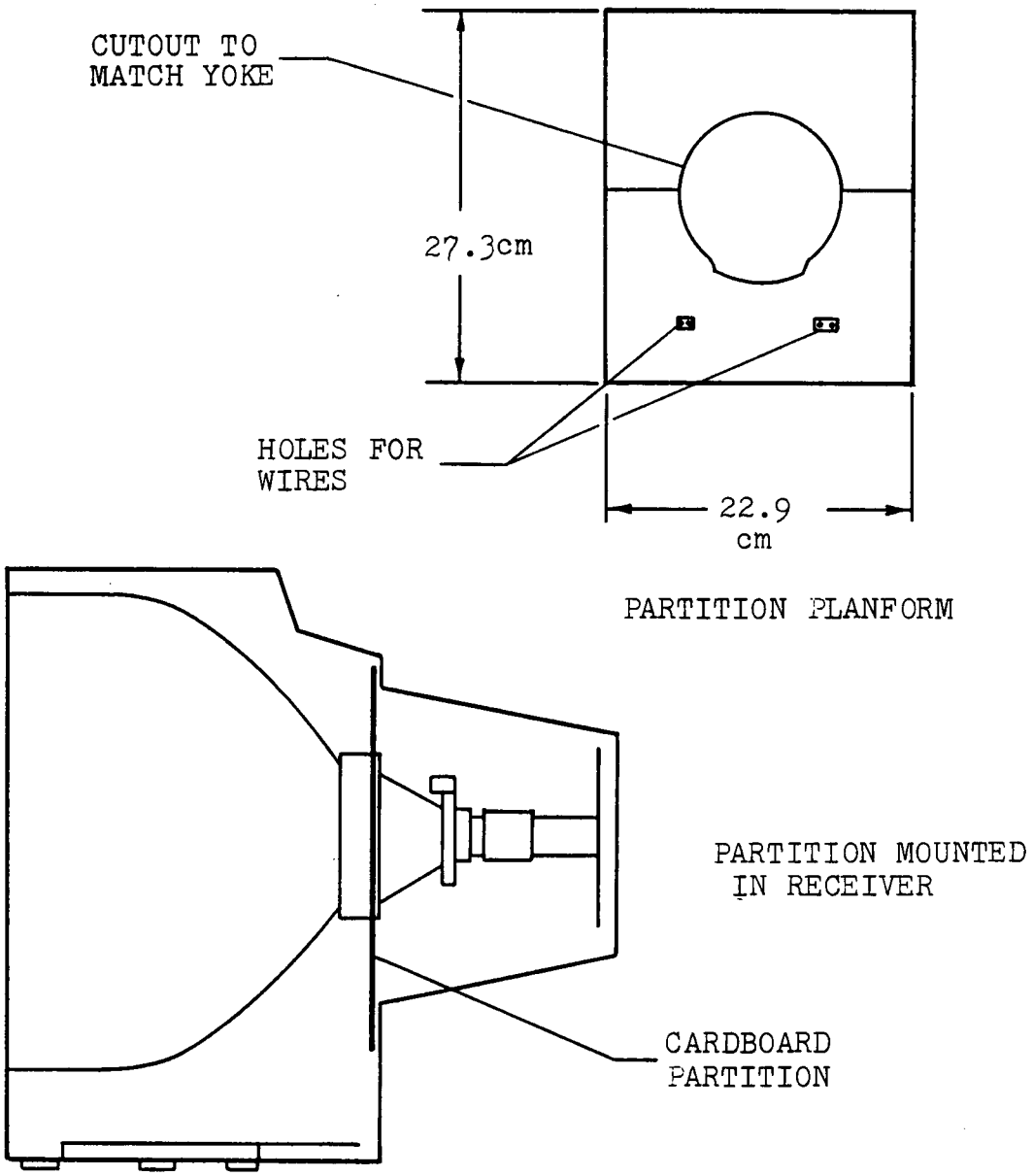



FIGURE 5.6. Receiver With Blocked Extension (Cup)

To examine the importance of a gap between the partition and the cabinet, two such tests were performed. First, a test was run with a 1.3 cm gap between the lower section of the partition and the cabinet. In this test the gap at the top was about 0.2 cm. Then, a test was run with a gap between the partition and the cabinet of 0.2 cm around the entire edge of the partition.

## 8. Safety Considerations

Because of the high voltages present in the receivers, certain components could not be safely examined in a direct manner. Transistor temperatures could only be approximated by measuring the case temperatures. In many instances, the tab or heat sink temperature, which is more representative of the actual operating temperature, could not be measured. Also, the transformer core temperature could not be measured. Although electrically insulated epoxy would allow these measurements, it was not used because of the need to be able to quickly relocate thermocouples and reuse them for different temperature tests. For consistency, Receiver I was used for all temperature tests and flow visualization tests while Receiver II was held as a backup if Receiver I failed. This required that the thermocouples not be permanently

attached to components. Thus, tape was used to hold the thermocouples on the components.

## 9. Experimental Uncertainty

An uncertainty analysis is presented in Appendix A. Only the results of that analysis are quoted here. For the first 3 sets of experiments, the temperature uncertainty varies with the magnitude of the measured temperature. It is approximately ±1.4°C at 20°C, ±1.4°C at 60°C, and ±2.0°C at 120°C. The error increases significantly at temperatures above 120°C. The increase in the error is due to the curve fit used to convert millivolt readings from thermocouples to temperatures. This curve fit is given in Appendix A. At temperatures under 110°C, much of the error is due to the fixed error of the thermocouple, which is given by the manufacturer as ±1.0°C. This fixed error refers to the characteristic of a given thermocouple to measure temperatures either consistently high or low. All thermocouples from the same spool should all behave in the same manner. Moreover, error occurs because rapid variations in air temperature may not necessarily cause instantaneous changes in component temperatures. Although the averaging of the thermocouple outputs does compensate for this effect, the averaging is performed over a short, 10 second interval.

For the examination of the effects of a cabinet modification on component temperatures, the uncertainty of the temperature change is much lower than the uncertainty of the actual temperature. The fixed error of the thermocouple cancels out when component temperatures are subtracted from one another to determine the temperature change. The uncertainty of the temperature change is about 0.7°C.

For the fourth and fifth sets of temperature tests, some of the shortcomings of previous tests were reduced. With the TRC Electronic Ice Point Cell and a new curve fit, the uncertainty is about ±1.4°C up to 130°C.

For all temperature tests, another concern is the repeatability of the measurements. Reinstalling thermocouples, variations in the line voltage, variations in the random signals at the channel setting, etc. all affect the measured temperatures of the components. For the blocked vent tests, all experiments were performed with as little disturbance to the thermocouples as possible. While for a particular test set up changes in a component or air temperatures of 0.7°C can be considered physically significant, later attempting to duplicate "identical" test conditions (reinstall the thermocouples, etc.) resulted in an overall repeatability of about ±2.0°C. The repeatability should not effect the blocked

vent test data unless all the thermocouples are removed and reinstalled in the receiver.

## 10. Flow Visualization Experiments

Using the baseline television receiver and a cabinet back with plexiglas panels, flow visualization tests were performed. Three 7.5 milliwatt and one 15 milliwatt, helium-neon lasers were the light sources. Although one laser is adequate to see the flow with the naked eye, the light output was too low to make video recordings. Thus, up to four lasers were used to illuminate certain parts of the flow. Figure 5.7 shows the test setup with two lasers. Cylindrical lenses (Glass rods) mounted outside the receiver were used to spread the laser light beams into a plane. All the lasers were aligned to insure that they were all illuminating the same plane. Thus, with the aid of smoke, it was possible to get 2-dimensional pictures of the flow inside the receiver. The smoke was generated by burning tobacco in a container connected to a compressed air supply. The smoke was cooled by running the outlet hose through a room temperature water bath to insure neutral buoyancy. The smoke was allowed to drift around the lower cabinet vents and was drawn into the receiver. The receiver was run to steady state (about 3 to 4 hours) before any flow testing was performed. The

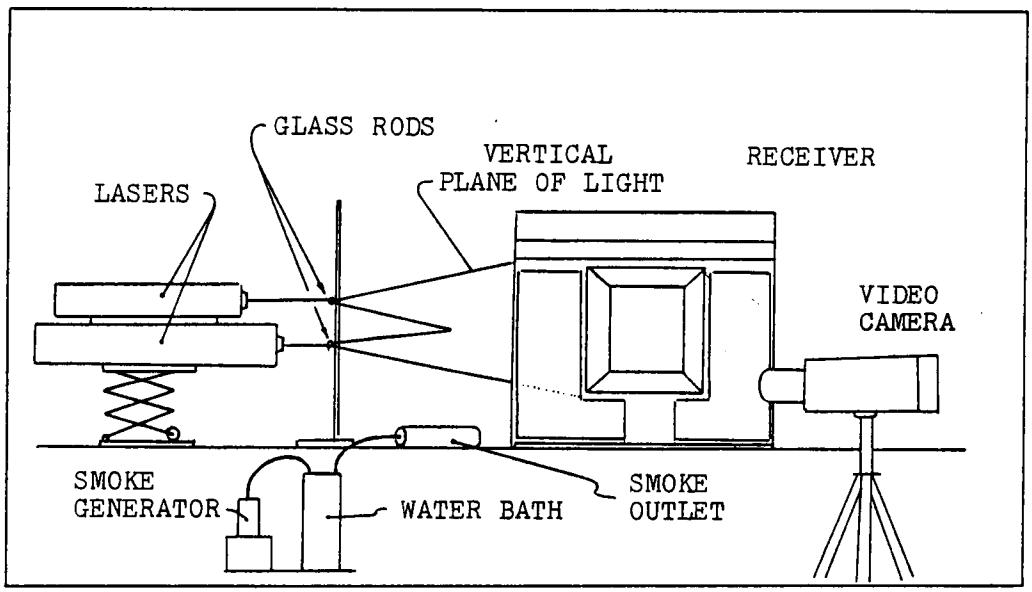



FIGURE 5.7. Flow Visualization Experimental Setup

results of the tests were video taped with a Sony video recording system. After reviewing the video tape, sketches of the flow field and estimates of the flow velocity could be made. The flow velocity estimates are made by placing a strip of graph paper on the picture tube and extension wall. By measuring the amount of time it takes a feature of the smoke pattern to move some length along the grid, it is possible to estimate the velocity. Obviously this is very crude, and the uncertainty associated with this method is on the order of 50%. Since the relative velocities in different sections of the cabinet were the important result, this technique was deemed adequate.

There are a number of limitations to using an actual receiver for flow visualization testing. Several blind spots could not be examined because large components and wires created shadows or blocked the view. Also, since no transparent panels were put into the forward half of the cabinet that supports the picture tube. Therefore, there is a paucity of flow visualization information for the extreme forward part of the cabinet.

# CHAPTER VI

# THE ELECTRICAL RESISTANCE MODEL

## 1. Introduction

As a means of obtaining some physical insight into the relative importance of system parameters, like cabinet wall thermal conductivity, circuit board heat transfer coefficient, and radiation emissivity, that could not be easily changed on the experimental simulator, a numerical model of a receiver is a valuable tool. Although a sophisticated numerical model is preferred for accuracy and detail, one designed for analyzing a problem as complex as a television receiver was not available and its construction is beyond the scope of this research. Thus, a simple numerical model was constructed. The model is based on the heat flow paths briefly described in Chapter IV and shown in Figure 4.1 (on page 23).

## 2. The Physical Model

The physical model accounts for a steady state natural convection, thermal radiation, and conduction heat transfer in a partial enclosure. Heat transfer by natural convection is the primary mode of heat removal from components. Air drawn in through the vents circulates

underneath and over the main circuit board and convects heat away. A significant amount of heat is also removed from the components by thermal radiation. The components, the circuit board, the cabinet walls, the air, the picture tube back, and the ambient all exchange thermal radiation between themselves and each other. The third mode of component heat dissipation is conduction. Heat is conducted from the component to the circuit board through the electrical leads and solder joints, but some components are mounted such that their cases come in contact with the circuit board; thus, the conduction heat path may be larger. Also, there is some conduction from the circuit board to the cabinet through the circuit board mounting brackets.

A large portion of the heat is convected to the ambient by air entering and leaving the receiver enclosure through the vents. The remainder of the energy is transferred to the cabinet walls or the picture tube back. Heat convected or radiated to the cabinet walls is conducted through or along the walls and is then radiated or convected to the ambient. Heat is transferred through the picture tube to the ambient. Heat radiated or convected to the glass picture tube back side is either conducted along the picture tube back side to the picture tube screen or conducted through the glass, radiated to

the screen, then conducted through the screen. At the screen face, heat is convected or radiated to the ambient.

## 3. The Numerical Model

From a physical understanding of the heat transfer mechanisms in a receiver, a thermal model was developed. For simplicity, a one-dimensional steady state heat transfer model based on the electrical resistance analogy was used. The components are lumped into one constant heat flux circuit board. The cabinet and picture tube are modeled as a rectangular box with vents. Conduction heat transfer from the circuit board is assumed to be negligible because of poor thermal contact due to small contact area between the circuit board and the mounting brackets. Thus, only convection and radiation heat transfer to or from the circuit board is considered. This energy either is transferred to the enclosure walls or leaves through the vents. The energy transferred to the walls is conducted through the walls and then radiated or convected to the surroundings. Conservation of energy, Fourier's law, Newton's law of cooling and the Stefan-Boltzmann law are used to describe and determine the rates of heat transfer by conduction, natural convection, and radiation.

Using the electrical resistance analogy, the heat transfer rate is analogous to electrical current, the thermal resistance is analogous the electrical resistance, and the temperature change is analogous to voltage. Thus, a thermal version of Ohm's law can be written as :

$$Q\ R = \Delta T$$

where Q is the heat rate (W), R is the thermal resistance (°C sec/cal), and $\Delta T$ is the change in temperature across the thermal resistance (°C). The thermal resistance is defined by the type of heat transfer mechanism involved. For some plate or wall area, A ($cm^2$), the convective thermal resistance is defined as:

$$R = 1 / (h_c\ A)$$

where $h_c$ is the average heat transfer coefficient (cal/sec $cm^2$ °C). The conductive thermal resistance is defined as:

$$R = \Delta x / (k\ A)$$

where k is the thermal conductivity (cal/sec cm °C) and $\Delta x$ is the wall thickness (cm). The radiative thermal resistance is defined as:

$$R = 1 / (h_r\ A)$$

where $h_r$ is the radiative heat transfer coefficient (cal/sec $cm^2$ °C). This coefficient is defined as :

$$h_r = 1.362 \times 10^{-12}\ \varepsilon\ (T_1^4 - T_2^4) / \Delta T$$

where $\varepsilon$ is the average combined emissivity of the plate and the enclosure wall, $\Delta T$ is the temperature difference between surfaces (°C), $T_1$ and $T_2$ are the absolute

temperatures (K) of the surfaces. The average combined emissivity is defined by :

$$\varepsilon = \frac{1}{1/\varepsilon_1 + 1/\varepsilon_2 - 1}$$

where $\varepsilon_1$ is the plate total hemispherical emissivity and $\varepsilon_2$ is the wall total hemispherical emissivity. A sketch of the model is shown in Figure 6.1.

Determining the energy leaving through the vents is a major problem. Electrical resistance models are typically applied to enclosures, not partial enclosures. One method of dealing with partial enclosures is to estimate the pressure drop between inlet and outlet; then, calculate the mass flow through the partial enclosure and use the product of mass flow, the specific heat of air, and the temperature difference between the air and heated surface to calculate the heat removed. A simpler alternative is to use conservation of energy. The amount of energy dissipated by the circuit board is fixed, and at steady state, the energy removed from the receiver is equal to the power dissipated by the board. The amount of power transferred to the enclosure wall can be calculated. The energy that does not pass through the walls must leave through the vents. This alternative was selected because of its simplicity and because of the uncertainty in determining the mass flow through the receiver. A "vent energy fraction", n is defined as the ratio of the energy

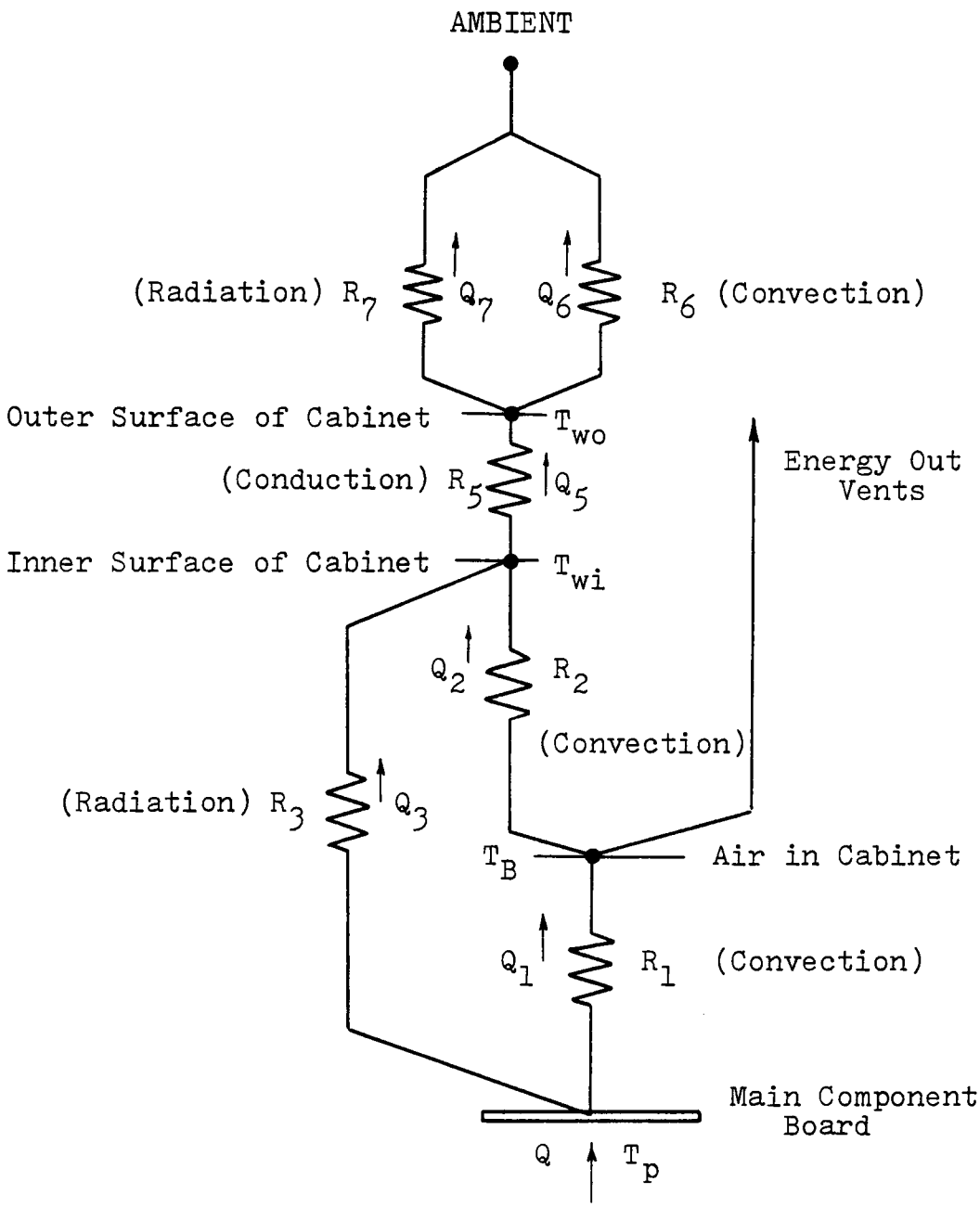



**Figure 6.1. Numerical Thermal Model of Partial Enclosure**

that leaves through the vents to the total energy that is convected to the air from the circuit board. Using conservation of energy, 4 governing equations can be written for 5 unknowns: circuit board temperature, average air temperature in the enclosure, inside wall temperature, outside wall temperature, and the vent energy fraction. For the baseline case of all vents open, the temperatures are estimated from the experimental data. Thus, the values of thermal resistance and vent energy fraction can be determined. For all vent open sensitivity trade studies, and the nonradiative thermal resistances and n are held constant and the temperatures are calculated. For the all vents blocked case, n is 0.0.

The model was calibrated using the experimental data from the receiver temperature tests. The model was checked by approximating an all vent closed configuration.

Assumptions built into this model include:

(1) Air is a non-participating medium for the radiation heat transfer.

(2) The enclosure walls do not see each other, and thus do not exchange radiation with one another.

(3) Conduction paths away from the circuit board are negligible.

(4) the circuit board only "sees" the enclosure walls; thus, the shape factor for the circuit board is 1.

The model was programed into a personal computer using the BASIC computer language. A program listing and documentation is provided in Appendix B. The user is in the iteration loop and must input estimates for outside wall and plate temperatures. The primary output from the program includes the outside wall temperature, inside wall temperature, average enclosure air temperature, and heated plate temperature. This program allows general trade studies to be conducted. It is possible to study how changes in vent area, wall thermal conductivity, wall and circuit board heat transfer coefficient, or wall and circuit board emissivity alter the temperatures and amount of heat flow along a path.

# CHAPTER VII

# THE THERMAL SIMULATOR

## 1. Design and Construction

There are several problems with using production model television receivers for development testing. First, the high voltages present in such receivers are a safety hazard for test personnel. Also, the data acquisition system is susceptible to damage from unintentional electrical contact between a thermocouple and a receiver component. Wires and components that do not appreciably affect the flow or temperature field create shadows and obstruct the experimenter's views of certain areas in the receiver. Moreover, to study the effects of vent geometry and location and heat source distribution on component temperatures may require expensive fabrication of new circuit boards and large amounts of fabrication time. Thus, because of these inherent difficulties a thermal simulator of a generic table model television receiver was built. Figure 7.1 shows the general layout of the simulator.

The simulator design was based on the baseline receiver. Production drawings were obtained for the cabinet and picture tube. Any dimensions not given on

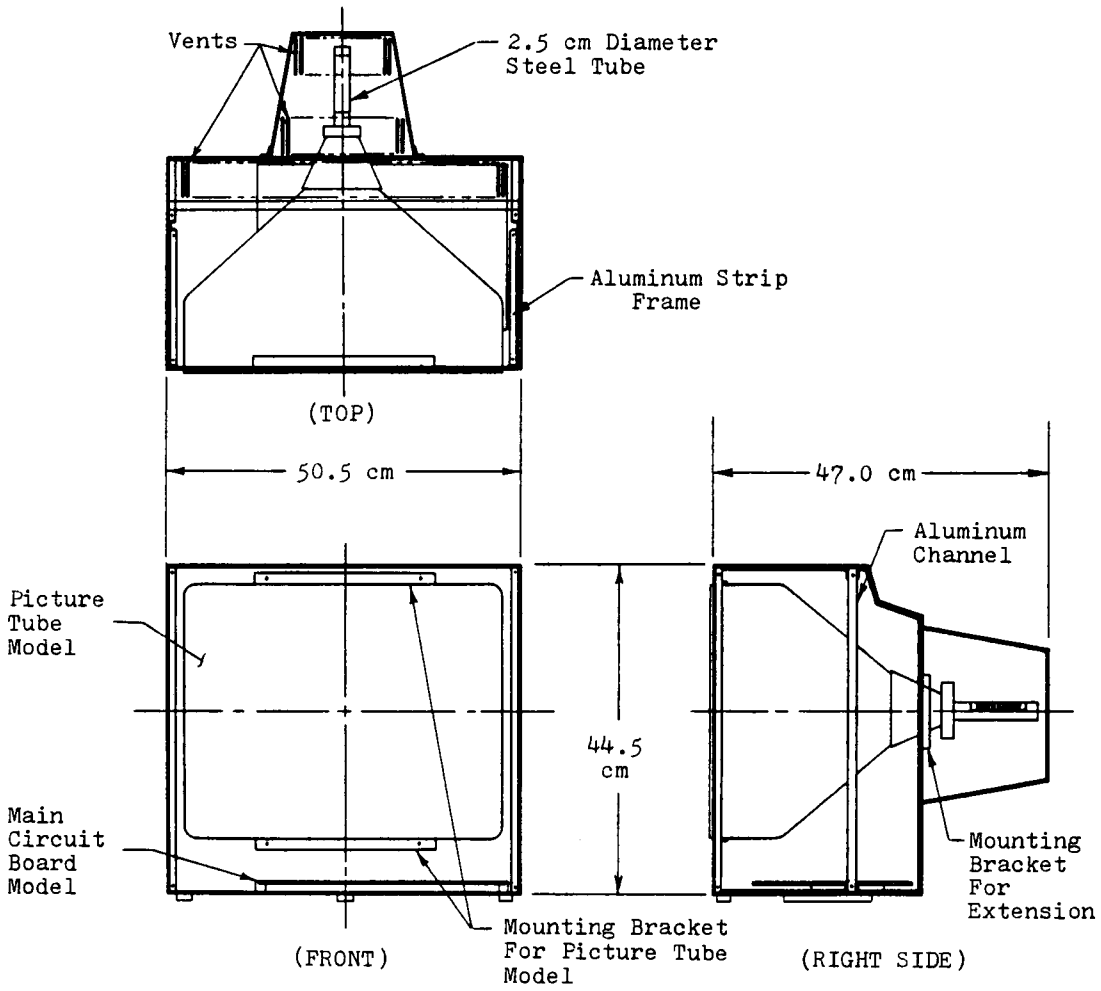



**Figure 7.1. The Experimental Simulator**

these drawings were measured directly from the receiver. The critical dimensions were deemed to be the ones defining the major internal features of the receiver. The objective was to model the internal geometry as closely possible without unnecessary obstruction of view or complications that would require large amounts of fabrication time. If the simplifications were too extreme, then additional features could be added as required.

## 2. The Cabinet

The simulator is constructed to provide better flow and temperature testing than can be obtained using a production model receiver. It also is easier to modify and, therefore, it is possible to quickly and economically alter the geometry in order to study how changes affect component cooling. The cabinet was designed with this in mind.

The critical dimensions of the cabinet were the average internal distance between the top and bottom (43.8 cm), between the sides (49.8 cm), and between the front and back of the cabinet (46.4 cm). These are all approximate values because the walls have a small tilt. The extension (cup) internal dimensions and angles were taken from the production drawings. The step-like

geometry of the upper back cabinet was also taken from the drawings.

The simulator cabinet consists of an aluminum frame with plexiglas panels bolted on. The panel joints are sealed with masking tape. Because of the desire to maximize the transparent wall area, the frame was made as small as possible. Also, the frame had to allow cabinet geometry changes. Thus, most of the frame is simply constructed of 1/16 inch thick, 1/2 inch wide strips of aluminum which are bolted together. On each side, these strips are bolted to an aluminum channel. The channel provides vertical support for the model. The plexiglas panels were cut from 1/8 inch thick sheets into which vents were cut using an end mill. The vents were all standardized at 2.0 inches long by 3/32 inches wide which are typical of the vent size in the baseline receiver. There are 72 vents on the upper section of the main cabinet with a total area of 89.8 $cm^2$. Also, there are 50 vents on the upper surface of the extension with a total area of 59.9 $cm^2$. Another 50 vents, identical to those on the upper surface of the extension, are located on the lower surface of the cabinet extension. Finally, there are 140 vents with a total area of 167.7 $cm^2$ located on the bottom of the main cabinet. In all cases the number of vents cut was the maximum number that would fit between the frames plus about 1.3 cm for structural integrity

because the desire to keep stress fractures from developing between the bolt holes at the panel corners and the vents. These vent areas are greater than those for the baseline receiver. The purpose for this was to allow some flexibility in the vent pattern used to match the receiver. Also, it allows additional tests to study the impact of additional vents on the simulator temperature and flow distributions. For the initial part of the verification tests, the vent patterns and areas matched the receiver as closely as possible. Note that unlike the baseline receiver, all the simulator vents are identical. Thus, total vent areas of the simulator and receiver will match, but their distribution on the cabinet will not be identical. Also, vent set I (shown in Figure 3.3 on page 14) on the receiver has been eliminated from the simulator because 2 inch long vents would not fit on the panel. Essentially, vent sets I and II of the receiver have been combined for the simulator. It is believed that making these changes will not seriously affect the temperatures at and around the model circuit board or change the general flow patterns.

For simplicity of construction, the simulator cabinet is not identical to the baseline receiver. The walls of the actual cabinet have a small tilt to ease the removal of the part from the mold. The wall angles are on the order of 1° to 5° from the vertical, while the simulator

walls are vertical. Only the extension walls and the upper back cabinet are set at the correct angles. The wall angles are so small that neglecting them should not measurably alter the flow or temperature fields. Also, the fillets and rounds at the intersections of the cabinet walls are not modeled in the simulator. Likewise, the wall stiffeners and guides that are molded into the cabinet were not included. Again, it should not significantly affect the results. Also, because all vents in the simulator are identical to one another, there are some differences in the distribution of the vent areas between the baseline and the simulators. Vent sets I and II are combined into one set whose area matches that of the baseline receiver cabinet. This will alter the flow field in the upper section of the cabinet, but there are no components mounted there. The cabinet rests on two 12.7 cm long balsa wood supports which keep the bottom of the cabinet 1.3 cm from the table.

### 3. The Picture Tube

Because the aluminum frame is structurally weak, the picture tube was made from balsa wood to minimize weight. The geometry of the tube was approximated as a trapezoid as shown in Figure 7.2. The actual picture tube has a maximum height of 36.1 cm, a maximum width of 45.7 cm, and

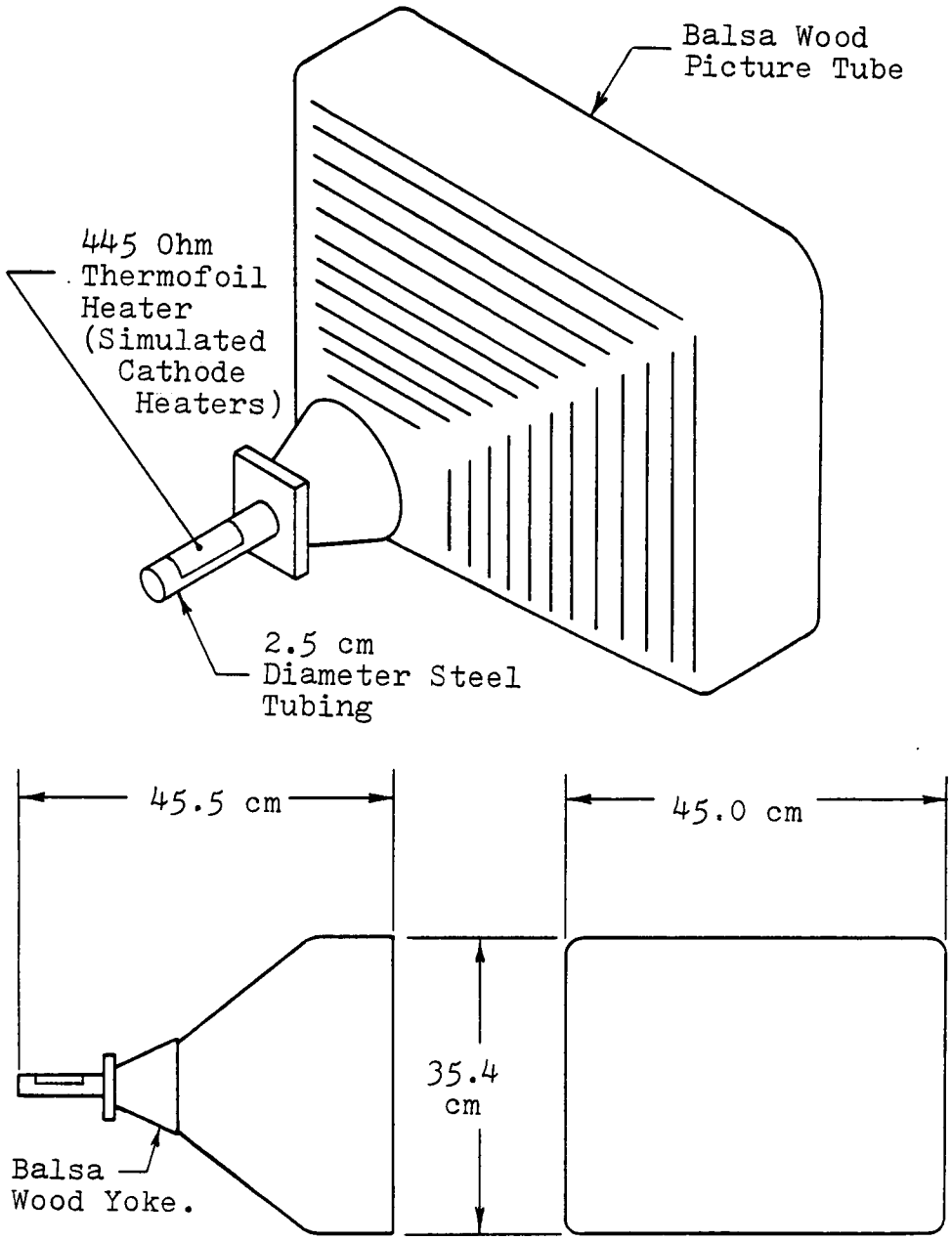



**Figure 7.2. The Picture Tube Model**

a depth (from the face to the end of the neck) of 43.8 cm. The overall dimensions of the mock picture tube are based on these dimensions. The trapezoidal section of the mock picture tube was defined by the measured distance of a 10.2 cm diameter circular section of the picture tube to the back of the tube (18.4 cm) ,and the approximate depth of the square section of the picture tube screen (9.9 cm) plus about 0.3 cm. The tube neck and plug (for the small vertically mounted circuit board) length was measured to be 11.0 cm.

The picture tube model was constructed from 1/2 inch thick balsa sheet and is painted flat black to reduce the reflection of laser light during flow visualization testing. The major heat sources on the picture tube are the cathode heaters which are mounted on the neck. These were modeled with a Thermofoil heater, which is an electrical resistance heater made by Minco Products, Inc. It consists of an etched foil grid encased in Kapton insulation. The heater thickness is approximately 0.64 mm over the heating elements. The heater can operate in an ambient temperature range from -200°C to 200°C. The picture tube neck model consists of a 2.5 cm diameter, 0.16 cm thick, 12.7 cm long piece of steel tubing. The heater is wrapped around the outside of the tube. Because there was no adhesive on the heater, copper electrical tape and silicon rubber tape were used to hold the heater

in place. The heater dimensions are 5.1 cm by 7.6 cm, and the heater has a resistance of 445 ohms. This heater is connected to a variac to control the power. Note, that the steel tube has the ends covered. The forward end has a wooden stopper while the aft end, exposed to the air flow, has a copper foil cover. Also, the hollow section of the trapezoid is filled with styrofoam sheets covered with a rectangular piece of cardboard which is sealed with tape to prevent air leakage to the surroundings.

The small printed circuit board on the end of the picture tube is not modeled in the simulator. From the flow visualization tests, it was concluded that the board is so close to the extension wall, that deleting it from the simulator would have no noticeable impact on the flow field. This also allows a better view of the flow field around the center section of the receiver.

### 4. The Main Circuit Board

The simulated main circuit board is made from a 35.6 cm by 22.9 cm by 0.32 cm thick glass-epoxy board with copper foil glued on the bottom. Although this is twice as thick as the main circuit board in the baseline receiver, the material is similar to that of the original, also, the main concern is to accurately model the heat source distributions along the length and width of the

board, not the board thickness. The components mounted on the board are modeled with wooden cylinders and blocks. Only the larger components were modeled. The numerous plugs, resistors, diodes, etc. were ignored. This was done because the primary direction of the flow is vertical and because natural convection flows are typically not sensitive to "small" obstructions unless these obstructions are larger than the local boundary layer thickness. If the flow is significantly different than that in the baseline receiver, then additional components can easily be added as required.

The heat sources on the heat sinks are modeled with 5.1 cm square Thermofoil heaters. Each heater has a rated resistance of 661 ohms (±10%) and is attached with pressure sensitive adhesive to one of the three main heat sink models. For power control, the three heaters are connected in parallel to one variac. The heat sinks are made from aluminum sheet stock. Each heat sink has the same planform as the actual heat sink, but does not have the bent corners or the anodized coatings as in the baseline receiver. Many of the smaller individual heat sources on the circuit board are lumped into two uniformly heated rectangular areas. The two heaters on these areas are connected in parallel to a second variac. The largest area is 11.4 cm by 11.4 cm by 0.32 cm thick and is made from steel. The attached heater has a measured resistance

of 159 ohms (165 ohm rated resistance) and measures 10.2 cm by 10.2 cm. The second area is made from aluminum and measures 5.7 cm by 12.7 cm by 0.16 cm thick. The attached heater is 10.2 cm by 5.1 cm and has a measured resistance of 356 ohms (331 ohm rated resistance). This plate is located on the left side of the simulator and is mounted on a 10.2 cm by 12.7 cm by 0.16 cm aluminum plate. The purpose of this was to try to bias the heat flow toward the back of the simulator in the area where the baseline receiver's audio IF's are located. This was done to bring the simulator air flow pattern closer to that observed in the receiver. Figure 7.3 shows the general layout of the circuit board model. The initial locations for the heaters were based on the experimentally determined component temperatures and the locations of these components in the baseline receiver.

## 5. Simulator Performance Verification

To insure an accurate simulation of a generic table model receiver, thermal model, the power dissipation distribution is approximately the same as in an actual receiver. The main circuit board heaters dissipate approximately 75 watts, while the picture tube neck heater dissipates 10 watts. The breakdown of power dissipated per heater is shown in Figure 7.3. Also, a range of

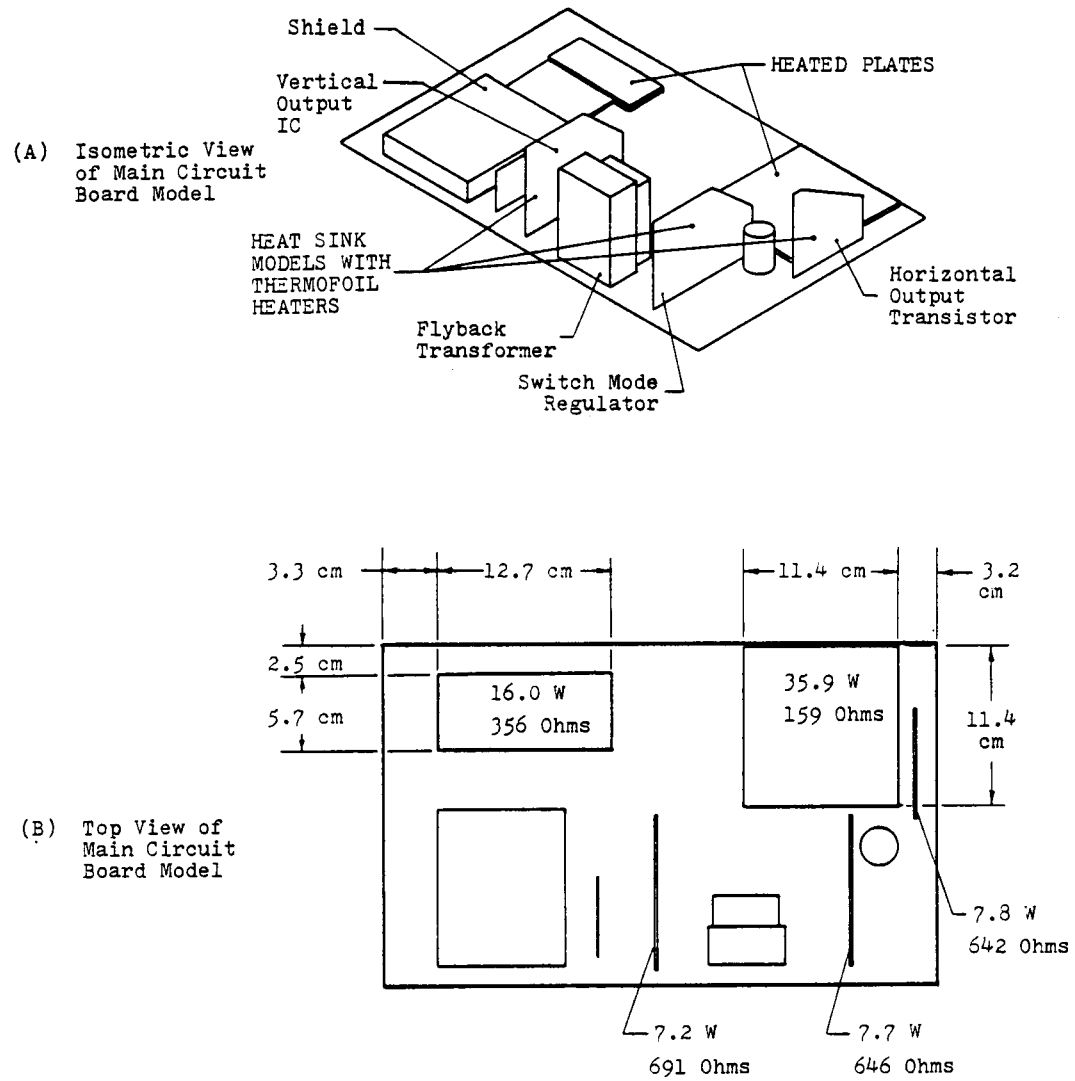



**Figure 7.3. The Circuit Board Model With Thermofoil Heaters**

heater power settings were explored which covered the uncertainty in the power distribution and the range of power dissipation for different control settings (brightness, tint, sharpness, and volume). The voltage settings were determined by applying the relation

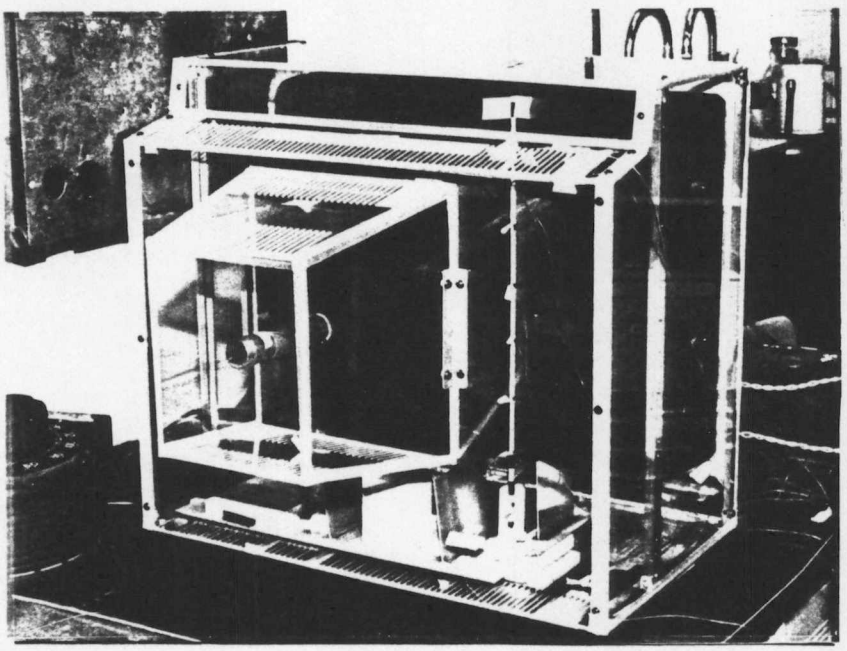
$$P = V^2/R$$

where P is the power (watts), V is the voltage (volts), and R is the heater resistance (ohms). The resistances were measured for each circuit using an Ohmmeter. Likewise, the voltage settings on the variacs were initially made using a voltmeter. Uncertainty in voltage is approximately ±1.0 volt, while the resistance uncertainty is ±1.0 ohms.

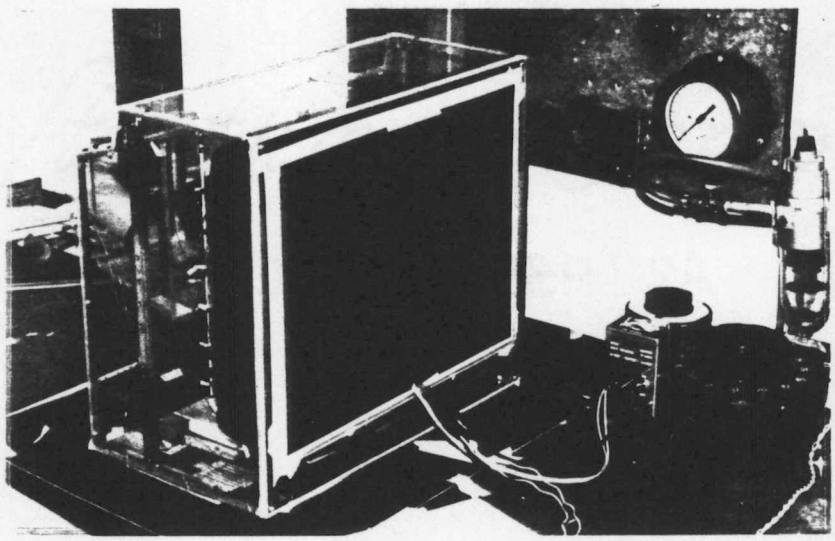
Temperature measurements and flow visualization tests were performed in the simulator. The temperature testing was performed in a manner similar to that done with the actual receiver. The same instrumentation was also used, except that the ice bath was replaced with the Omega electronic ice point. This device will hold the reference temperature of 0°C to within ± 0.1°C. It is not possible to match component temperatures of the simulator and the receiver, since the heat sources in the receiver were lumped into a smaller number of sources. Thus, component temperatures will be higher in the simulator for a given power dissipation. Yet, it is reasonable to anticipate that the inlet and outlet air temperatures to be close

because power dissipation per unit volume of air should be close to that in the baseline receiver. Also, changes in local air temperatures are to be examined to show that new vent patterns and heat source distribution changes will mimic the changes observed experimentally in the baseline receiver. The thermocouple locations are identical to that used for the actual receiver shown in Figure 5.4 on page 40 and Figure 5.5 on page 41. Figure 7.4 shows two views of the simulator with the thermocouples installed. Also, the all blocked vent configuration was examined to see how closely the simulator could predict the new temperatures.

Likewise, flow visualization tests were performed in a manner similar to the tests done with the baseline receiver. Because many small details were eliminated from the simulator, it is not expected that every detail of the flow fields would match. Instead, the goal is to model the general flow patterns; that is, the flow recirculation and main flow paths are to be matched. Moreover, flow velocities should be relatively close to those observed in the baseline receiver. Video tapes were also made to allow comparisons with those in the receiver. Sketches of these results are given in Chapter VIII.



(A) Back View of Simulator Instrumented With Thermocouples.



(B) Front View of Simulator.

**Figure 7.4. Views of the Experimental Simulator**

# CHAPTER VIII

# RESULTS

## 1. The Experimental Results For the Baseline Magnavox Television Receiver

### Temperature Survey of Receiver Components

As an initial test, the component temperatures were examined as previously discussed. The receiver was set to a station and the picture was adjusted for quality. The goal was to determine the magnitudes of the temperatures and locate the high temperature components. The small components mounted on the main circuit board and the vertical printed circuit boards are of relatively low temperatures - on the order of 40°C to 50°C. The hottest components are resistors. Of the resistors, the hottest ones are mounted using long leads to place the resistor case several millimeters away from the board. The transistor temperatures are on the order of 40°C to 70°C, while the integrated circuits operate in the 40°C to 60°C range. Based on this information, the number of components to be examined in detail for the blocked vent tests were determined.

Comparison of Receiver Component Temperatures When Using the Original Cabinet Back and the Cabinet Back With Plexiglas Panels

To determine the effect of using a cabinet back with plexiglas panels, two temperature tests were performed to compare the two configurations. For the two tests, the receivers were set to a channel with a transmitter signal. The volume was set to a minimum level. The five picture control knobs labeled Color, Tint, Picture, Bright, and Sharp were set at their most clockwise positions. Receiver I was used for both temperature tests. Because the thermocouples were strung through the vents in the cabinet, the thermocouples had to be removed and reinstalled when the cabinet back was switched. The conclusion of these tests was that the components in the receiver with the plexiglas cabinet back operated 1°C to 3°C cooler than those in the receiver with the original cabinet back. For the blocked vent and blocked extension tests, the primary interest is in the component temperature change due to the receiver modification. For the flow visualization tests, the concern was with temperatures in that a large temperature discrepancy caused by differences between the two cabinet backs could result in an unrealistic air flow field which would make the tests meaningless. Since the component temperature differences are on the order of 1 - 3°C, they were

considered negligible for the blocked vent and blocked extension temperature tests and the flow visualization tests to follow.

The Test Conditions

As a result of experience gained from receiver temperature testing, a standard television test condition was defined. From the initial temperature survey tests, it became apparent that several operating factors affect the receiver component temperatures to such an extent that, if they were not consistent, their effect on receiver temperatures might overwhelm any changes caused by a vent modification. The volume will change the audio IF operating temperature. The type of picture on the screen will effect the horizontal and vertical output IC's and switch mode transistor. Changes in the ambient temperature will also cause temperature changes in the receiver. Thus, the following standard set of operating conditions were defined.

(1) There was no antenna connected to the receiver.

(2) There was no transmitter signal. This means that the picture was "snow" - a combination of white, red, blue, green, black dots. This uses less power than a normal picture, but it is consistently reproducible. The component temperatures will, thus, be operating at lower temperatures. The component temperature differences for

most components will be on the order of 1 - 5°C.

(3) The volume was set to a minimum. The power measurements indicate that volume has a little impact on the power consumption. Also, it is easily reproducible and less disruptive than maximum volume.

(4) There are 5 picture control knobs. They are marked: Color, Tint, Picture, Bright, and Sharp. They were all set to their most clockwise positions. The primary reason for this was that it will cause a greater than average amount power to be drawn (when compared to a normal picture setting) and it is easy to reproduce and remember. This corresponds to a maximum brightness, red biased picture.

(6) The ambient room temperature was approximately 20°C. The actual room temperature varied between 19.1°C and 23.5°C. The room temperature was coarsely adjusted using the room air conditioner in the summer and the room heater in the fall. Temperature variations for a given test were on the order of 0.5°C between the beginning and the end. This was typically a 4 to 5 hour time period.

Power Consumption of the Baseline Receiver

The picture control knobs were not adjusted. The voltage and current were measured using a digital multimeter. The measurement was taken at the connection between the receiver plug and the isolation transformer.

The power is calculated by multiplying the voltage (volts) by the current drawn (amps). Table 8.1 shows the results.

Table 8.1. Measured Voltage and Current and Calculated Power Drawn By Baseline Receiver

| Test Condition | Voltage (Volts) | Current (Amps) | Power (Watts) |
|---|---|---|---|
| No Transmitter Signal, No Volume (Baseline) | 113 | 0.86 | 97 |
| Transmitter Signal, No Volume | 113 | 1.00 - 1.10 | 113 - 124 |
| Transmitter Signal, Max Volume | 113 | 1.05 - 1.10 | 119 - 124 |
| Blank Screen | 113 | 0.79 | 89 |
| Receiver Turned Off | 113 | 0.17 | 19 |

The test conditions given show the effect of picture and volume. The baseline condition power consumption is 97 watts. By adding an antenna and changing the station to a channel with a transmitter signal, the power increases by about 20 watts. By increasing the volume to its maximum setting, the power increases only a few watts. Most of this small difference is dissipated at the speaker. By adjusting the controls knobs marked "Picture" and "Bright" to their counter-clockwise most positions, a blank picture is produced. Note that the cathode heaters in the picture tube neck are still operating in this

condition. The power drawn is 89 watts. The final set of measurements was with the receiver turned off. The power drawn goes to the "instant-on" circuit which must remain warm when the set is turned off.

The power drawn is significantly affected by the picture, while the volume has little impact. Thus, the measured current drawn varies from one condition to another. For a blank screen and the baseline condition, the variation is on the order of 0.05 amps. For the conditions with a transmitter signal, the variation in current drawn is much greater. Although the multimeter is capable of measuring current to within 0.01 amp and the voltage to within 0.1 volt, the variation in the current drawn with a normal picture is about 0.1 amp.

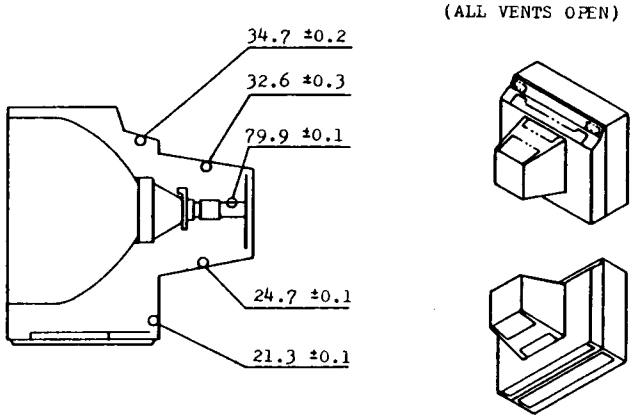
Of the power going to the picture tube, about 13 W (this is the rated power of the three heaters) goes to the cathode heaters and 8 W (this is the difference between the baseline case and the blank screen power measurements) goes to electron guns, which accelerate the electrons to create a brighter picture, or the deflection yoke, which directs the stream of electron to the proper location on the picture screen. Assuming that most of this power reaches the phosphor screen, about 2 W leaves as light (assuming that the phosphor coating has an approximate efficiency of 20%, See Bolz and Tuve, 1983). Thus, it is estimated that about 21 W are dissipated by the picture

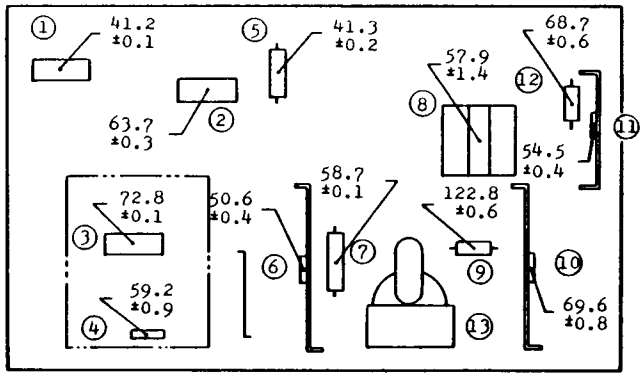
tube. The remainder of the input power is dissipated by the circuit board. Thus, it is estimated that 76 W is dissipated by the main circuit board.

The Baseline Temperature Results

The baseline case temperatures are given in Figure 8.1. For each component, two numbers are given. The first number is the temperature corrected for the difference between the actual ambient temperature and the standard ambient temperature of 20°C. The number after it is the standard deviation. All temperatures are given in degrees Celsius. The average temperatures and their standard deviations were calculated based on twenty data sets from 2 separate experiments. From the two tests, the hottest components were found to be ceramic resistors. Resistor R505 and R421 both register temperatures above 100°C. The thermocouple would not remain attached to R421; thus, for clarity, it is not shown on the component temperature figures. Before the failure of the adhesive, the temperature would register around 120°C. The temperatures of the three components attached to the large heat sinks - the vertical output integrated circuit, the switch mode regulator, and the horizontal output transistor - were 51°C, 69°C, and 70°C respectively. Figure 8.1 gives the temperatures of the same components for a picture setting as described previously.

| COMPONENT NUMBER | NAPCEC DESIGNATION | COMPONENT |
|---|---|---|
| 1 | IC310 | Integrated Circuit |
| 2 | IC640 | Integrated Circuit |
| 3 | IC201 | Audio IF |
| 4 | IC202 | Audio IF |
| 5 | R456 | 5 Watt Resistor |
| 6 | IC580 | Vertical Output Integrated Circuit |
| 7 | R513 | 7 Watt Resistor |
| 8 | T401 | Transformer |
| 9 | R505 | 5 Watt Resistor |
| 10 | Q501 | Switch Mode Regulator |
| 11 | Q400 | Horizontal Output Transistor |
| 12 | R408 | 5 Watt Resistor |
| 13 | T504 | Flyback Transformer |




NOTE:

The first number shown at each location is the measured temperature.

The second number is the standard deviation of the measured temperature.

All temperatures and their standard deviations are in degrees Celsius.

The results are for a picture and sound setting of no transmitter signal and no volume.

The picture control knobs labeled Color, Tint, Picture, Bright, and Sharp were set at their clockwise most position.

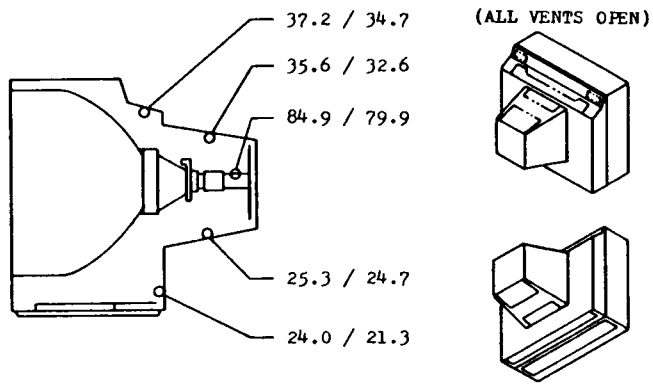
FIGURE 8.1. The Baseline Component and Air Temperatures in the Receiver With All Vents Open

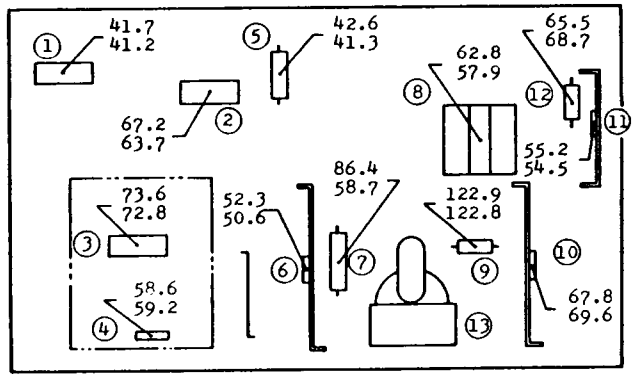
Comparison Between the Baseline Test Condition and "Normal" Operation

To determine the difference between a normal operation and the baseline condition a temperature test was performed. The "normal" operation condition is defined as the receiver with an antenna installed. There was a transmitter signal and a color picture on the screen. The controls were adjusted to give a reasonable picture. The volume was also set to a reasonable level. These settings are based on personal judgment, and are difficult to reproduce. The first number is the corrected temperature, the second number is the baseline temperature. Typically, there is a temperature increase for all components, which is expected based on the "power drawn" testing. The largest temperature change was for the 7 watt resistor, R513, which experienced a 28°C increase. Most of the other components experienced temperature increases on the order of 1 - 3°C. Figure 8.2 show the results of this test.

Temperature changes are more critical for the experiments performed. It is believed that the temperature changes seen will be consistent regardless of the picture settings, but the absolute magnitudes of the temperatures are the important factor when considering the acceptable operating range of a component.

| COMPONENT NUMBER | NAPCEC DESIGNATION | COMPONENT |
|---|---|---|
| 1 | IC310 | Integrated Circuit |
| 2 | IC640 | Integrated Circuit |
| 3 | IC201 | Audio IF |
| 4 | IC202 | Audio IF |
| 5 | R456 | 5 Watt Resistor |
| 6 | IC580 | Vertical Output Integrated Circuit |
| 7 | R513 | 7 Watt Resistor |
| 8 | T401 | Transformer |
| 9 | R505 | 5 Watt Resistor |
| 10 | Q501 | Switch Mode Regulator |
| 11 | Q400 | Horizontal Output Transistor |
| 12 | R408 | 5 Watt Resistor |
| 13 | T504 | Flyback Transformer |




NOTE:

The upper number shown at each location is the measured temperature for typical receiver operation.

The lower number is the measured temperature at the same location for the baseline, all vents open case.

All temperatures are in degrees Celsius.

The results are for a typical volume level and a typical transmitter signal.

FIGURE 8.2. Component and Air Temperatures in the Receiver With All Vents Open and "Normal" Receiver Operation

## 2. Blocked Vent Comparison to Baseline Temperatures

The Criteria for Blocked Vent Acceptability

From military specifications discussing the reliability of electronic components, and using engineering judgment, the following criteria of the acceptability of a given component temperature change are given:

(1) Any temperature decrease is acceptable.

(2) For resistors, any temperature increase up to 15°C is assumed to be acceptable. Resistor reliability is primarily a function of the ratio of the operational power dissipated to the rated power dissipation. The main concern lies with the temperatures at the solder joints and the local circuit board temperature, all of which should remain below 100°C. To counter a temperature increase of 5°C, it is assumed that the leads can be lengthened, or if the increase is too great, the resistor may be replaced with a resistor of equivalent resistance, but increased power dissipation rating.

(3) For the picture tube, the temperature is determined by the radiation heat transfer to the surroundings. Moreover, the heater temperature is on the order of 1500°C. Thus, a temperature increase of 5°C is considered acceptable. Note, that the change in the picture tube neck temperature is representative of the

changes in the temperatures of the components on the vertically mounted circuit board in the extension. Heat is conducted from the heaters through the electrical leads to the pin connections and to the circuit board mounted at the end of the tube neck. The maximum allowable temperature on this circuit board is 100°C.

(4) For the power transformer, the temperature limit is defined by the windings of the core. The maximum temperature is 90°C for an ambient temperature of 40°C and a nomal power condition. For a 40°C ambient and a normal picture (see Figure 8.1) then the operating temperature is about 83°C so, for this case it is believed that a temperature increase greater than 7°C is unacceptable.

(5) For the components mounted on the heat sinks, no temperature increase is allowed. The components mounted on the heat sinks are to be considered as special cases. If the components attached to the large heat sinks could tolerate higher operating temperatures then they would have been mounted on smaller or unanodized heat sinks. Two of these components are transistors, the reliability of which is defined by MIL-HDBK 217D. The reliability changes with junction temperature. A plot of this is shown in Appendix C.

(6) For integrated circuits mounted on the circuit board, there are correlations of a reliability factor (temperature acceleration factor, $\pi_t$) with component

junction temperature specified in MIL-HDBK 217D (this figure is given in the Appendix C). The reliability factor is proportional to the failure rate. Junction temperature is the temperature of the heat generating part inside the component case. For this study, the measured case temperature is assumed to be representative of the junction temperature. For the worst case, the measured temperature is about 70°C. The type of integrated circuit and its operating temperature will determine its sensitivity to a change in operating temperature. This requires a component by component analysis that is beyond the scope of this thesis. For this research, as a general rule, a 1.4°C is allowable for integrated circuits not attached to a heat sink. For a worst case this represents about a 15% increase in the failure rate. Note that from the information given in MIL-HDBK 217D, it is not possible to determine the change in the actual number of component failures. Thus, it is important to keep in mind that a large percentage increase in a low failure rate may be the same as the small percentage increase in a large failure rate as far as numbers of component failures per unit time are concerned.

Definition of Significant Temperature Change

Before examining the component and air temperature results, it is important to define what a significant

temperature change is. Based on the average of the standard deviation for the components, 0.5°C could be considered significant. Based on experimental uncertainty, the magnitude of a meaningful change could be in the 0.4 to 1.8°C range depending on the measured temperature. For the purpose of this work, a significant change in temperature will be defined as 0.7°C, which is the maximum experimental temperature uncertainty for measured temperatures under 100°C.

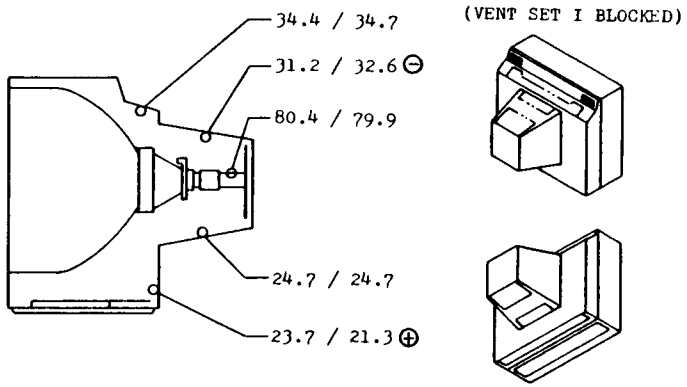
Blocking Individual Vent Sets

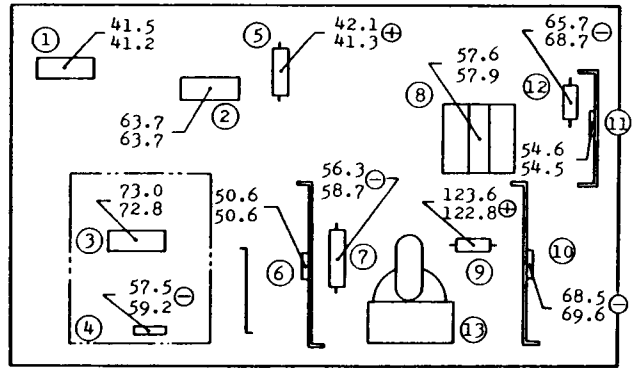
For the blocked vent results, the figures are arranged such that the configuration is shown at the top, right hand side of the page. The air and picture tube neck temperature are shown at the top, left hand side of the page, and the main component board temperatures are shown at the bottom. There are two temperature values given for each position. The top value is the measured temperature, corrected to 20°C and the lower value is the temperature recorded if all vents were open for an ambient room temperature of 20°C. The component temperatures must be corrected to 20°C because the room temperature is not exactly 20°C for all experiments. To account for this, the difference in room temperature from the "standard" ambient temperature of 20°C is also added to the component temperatures. Differences in the temperature data

exceeding 0.7°C at a given location are the result of the blocked vents. These differences are marked on the figure with a bubble containing either a "+" or a "-" to signify a temperature increase or decrease, respectively.

For the first set of tests, single vent sets were blocked. The first of these tests was to block the upper most vent set (vent set I) on the main cabinet. Figure 8.3 shows the results of closing vent set I. The only negative effect was on the temperature of resistor R456 which increased by 0.8°C. In contrast, the temperatures of R513, R408, Q501, and IC202 decreased by 2.4°C, 3.0°C, 1.1 °C, and 1.7°C, respectively. For components Q501 and IC202, the temperature changes translate to 3.5% and 4% decreases in component failure rate. The temperature changes of the resistors should be negligible. It appears that the components at the back and left edge of the main circuit board experience either a slight decrease or no change in operating temperature. It was expected that the blocking of vent set I would cause a slight increase in the temperatures because of an increase in the recirculation within the receiver, but this does not appear to happen. This modification whould result in a slight improvement in reliability and is considered an acceptable change based on the criteria specified in the previous section.

| COMPONENT NUMBER | NAPCEC DESIGNATION | COMPONENT |
|---|---|---|
| 1 | IC310 | Integrated Circuit |
| 2 | IC640 | Integrated Circuit |
| 3 | IC201 | Audio IF |
| 4 | IC202 | Audio IF |
| 5 | R456 | 5 Watt Resistor |
| 6 | IC580 | Vertical Output Integrated Circuit |
| 7 | R513 | 7 Watt Resistor |
| 8 | T401 | Transformer |
| 9 | R505 | 5 Watt Resistor |
| 10 | Q501 | Switch Mode Regulator |
| 11 | Q400 | Horizontal Output Transistor |
| 12 | R408 | 5 Watt Resistor |
| 13 | T504 | Flyback Transformer |




NOTE:

The upper number shown at each location is the measured temperature for the vents blocked as shown at the upper right of this figure.

The lower number is the measured temperature at the same location for the baseline, all vents open case.

All temperatures are in degrees Celsius.

The results are for a picture and sound setting of no transmitter signal and no volume.

The picture control knobs labeled Color, Tint, Picture, Bright, and Sharp were set at their clockwise most position.

⊕ indicates a temperature increase due to the blocked vent(s).

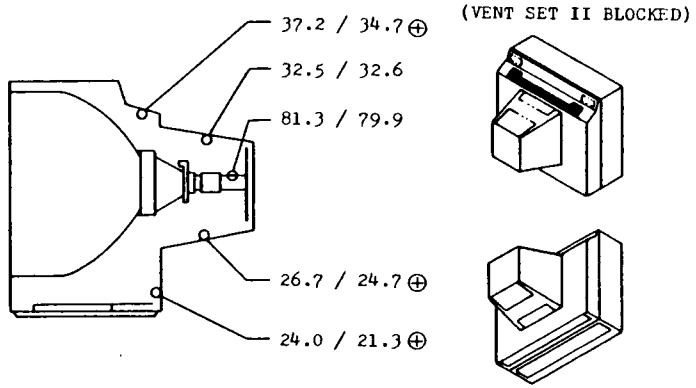
⊖ indicates a temperature decrease due to the blocked vent(s).

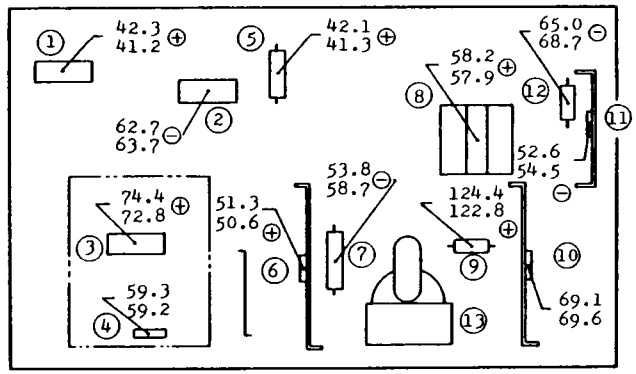
FIGURE 8.3. Component and Air Temperatures in the Receiver With Vent Set I Closed

Closing vent set II on the upper section of the cabinet back only increased component temperatures by 1 to 2°C. The most serious of these increases were for components IC310, IC201, and IC580 which experienced 1.1°C, 1.6°C, and 0.7°C changes for component failure rate increases of 10.4%, 12.6%, and 7.3% respectively. In some cases, as with components IC580 and IC640, there was a 1.9°C and a 1.0°C decrease for a 4% and a 3.5% drop in the component failure rate. Overall, there is no strong temperature change pattern for this case. The results are shown in Figure 8.4. It was expected that the blockage of these vents would increase the amount of recirculation within the receiver. Air that would have left the cabinet through vent set II must now leave through other vents (possibly vent sets I,III, or IV) or recirculate. Because the temperature of a heat sink component, the vertical output integrated circuit (IC580), has increased by 0.7°C and because the temperature increase of IC640 was greater than the limit of 1.4°C, this modification is unacceptable (see criterion 5).

Closing vent set III on the top of the extension has little impact on the component temperatures as shown in Figure 8.5. The largest increase is for IC201 where the temperature change was 1.6°C. Based on the worst case reliability curve, this is about a 12.7% increase in the component failure rate. Components R456, and the picture

| COMPONENT NUMBER | NAPCEC DESIGNATION | COMPONENT |
|---|---|---|
| 1 | IC310 | Integrated Circuit |
| 2 | IC640 | Integrated Circuit |
| 3 | IC201 | Audio IF |
| 4 | IC202 | Audio IF |
| 5 | R456 | 5 Watt Resistor |
| 6 | IC580 | Vertical Output Integrated Circuit |
| 7 | R513 | 7 Watt Resistor |
| 8 | T401 | Transformer |
| 9 | R505 | 5 Watt Resistor |
| 10 | Q501 | Switch Mode Regulator |
| 11 | Q400 | Horizontal Output Transistor |
| 12 | R408 | 5 Watt Resistor |
| 13 | T504 | Flyback Transformer |




NOTE:

The upper number shown at each location is the measured temperature for the vents blocked as shown at the upper right of this figure.

The lower number is the measured temperature at the same location for the baseline, all vents open case.

All temperatures are in degrees Celsius.

The results are for a picture and sound setting of no transmitter signal and no volume.

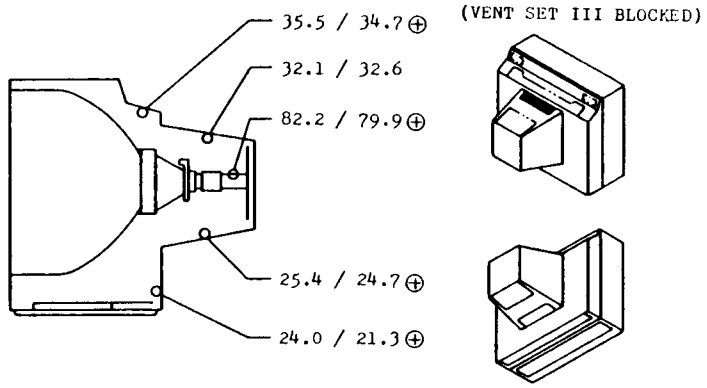
The picture control knobs labeled Color, Tint, Picture, Bright, and Sharp were set at their clockwise most position.

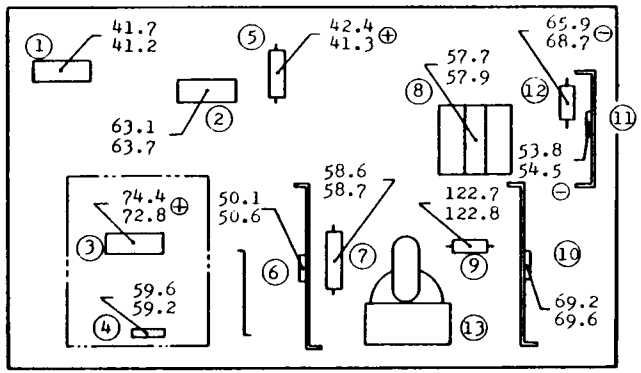
⊕ indicates a temperature increase due to the blocked vent(s).

⊖ indicates a temperature decrease due to the blocked vent(s).

FIGURE 8.4. Component and Air Temperatures in the Receiver With Vent Set II Closed

| COMPONENT NUMBER | NAPCEC DESIGNATION | COMPONENT |
|---|---|---|
| 1 | IC310 | Integrated Circuit |
| 2 | IC640 | Integrated Circuit |
| 3 | IC201 | Audio IF |
| 4 | IC202 | Audio IF |
| 5 | R456 | 5 Watt Resistor |
| 6 | IC580 | Vertical Output Integrated Circuit |
| 7 | R513 | 7 Watt Resistor |
| 8 | T401 | Transformer |
| 9 | R505 | 5 Watt Resistor |
| 10 | Q501 | Switch Mode Regulator |
| 11 | Q400 | Horizontal Output Transistor |
| 12 | R408 | 5 Watt Resistor |
| 13 | T504 | Flyback Transformer |




NOTE:

The upper number shown at each location is the measured temperature for the vents blocked as shown at the upper right of this figure.

The lower number is the measured temperature at the same location for the baseline, all vents open case.

All temperatures are in degrees Celsius.

The results are for a picture and sound setting of no transmitter signal and no volume.

The picture control knobs labeled Color, Tint, Picture, Bright, and Sharp were set at their clockwise most position.

⊕ indicates a temperature increase due to the blocked vent(s).

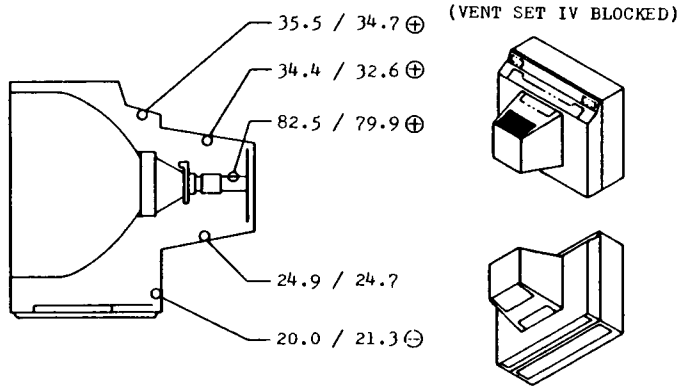
⊖ indicates a temperature decrease due to the blocked vent(s).

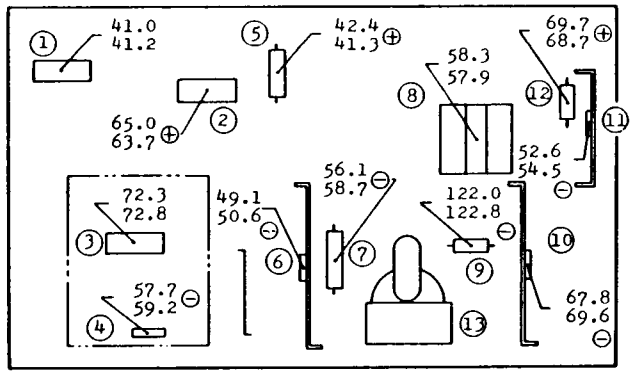
FIGURE 8.5. Component and Air Temperatures in the Receiver With Vent Set III Closed

tube neck also experience temperature increases of 1.1°C and 2.3°C, respectively. The only significant decrease is in the temperature of the horizontal output transistor which drops by 0.7°C for a component failure rate decrease of about 1.5%. Theoretically, this modification should have improved the chimney effect. If it does, the improvement is small. Because of the large increase in the failure rate of component IC201 (criterion 6), this is not an acceptable modification.

Figure 8.6 shows the results of closing vent set IV on the top, aft part of the extension. This causes the air temperature at the top of the extension and at the top of the cabinet to increase by 1.8°C and 0.8°C. Likewise, the picture tube neck temperature increases by 2.6°C. An increase in hot air recirculation is the probable cause for these increases. On the circuit board a temperature change pattern may be observed. The only temperature increases were components located on the forward half of the main circuit board. They were components IC640, R456, and R408 whose temperatures increased by 1.3°C, 1.1°C, and 1°C respectively. The temperature increase of IC640 will cause (worst case) about a 10.8% increase in failure rate. Yet, the temperature decreases in IC580, Q400, and Q501, which were 1.5°C, 1.9°C, and 1.8°C, respectively could lead to smaller heat sinks, or additional reliability of these components (for failure rate

| COMPONENT NUMBER | NAPCEC DESIGNATION | COMPONENT |
|---|---|---|
| 1 | IC310 | Integrated Circuit |
| 2 | IC640 | Integrated Circuit |
| 3 | IC201 | Audio IF |
| 4 | IC202 | Audio IF |
| 5 | R456 | 5 Watt Resistor |
| 6 | IC580 | Vertical Output Integrated Circuit |
| 7 | R513 | 7 Watt Resistor |
| 8 | T401 | Transformer |
| 9 | R505 | 5 Watt Resistor |
| 10 | Q501 | Switch Mode Regulator |
| 11 | Q400 | Horizontal Output Transistor |
| 12 | R408 | 5 Watt Resistor |
| 13 | T504 | Flyback Transformer |




NOTE:

The upper number shown at each location is the measured temperature for the vents blocked as shown at the upper right of this figure.

The lower number is the measured temperature at the same location for the baseline, all vents open case.

All temperatures are in degrees Celsius.

The results are for a picture and sound setting of no transmitter signal and no volume.

The picture control knobs labeled Color, Tint, Picture, Bright, and Sharp were set at their clockwise most position.

⊕ indicates a temperature increase due to the blocked vent(s).

⊖ indicates a temperature decrease due to the blocked vent(s).

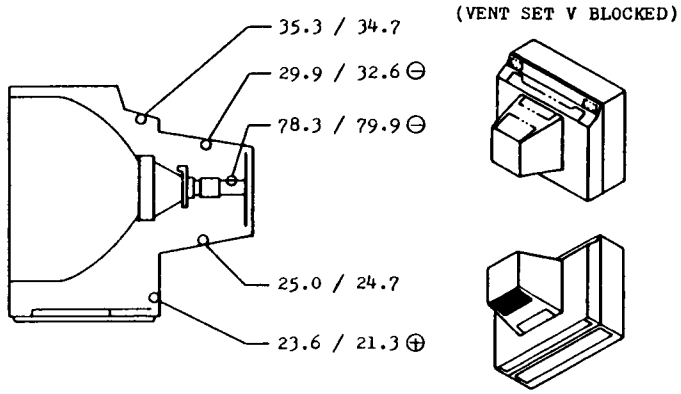
FIGURE 8.6. Component and Air Temperatures in the Receiver With Vent Set IV Closed

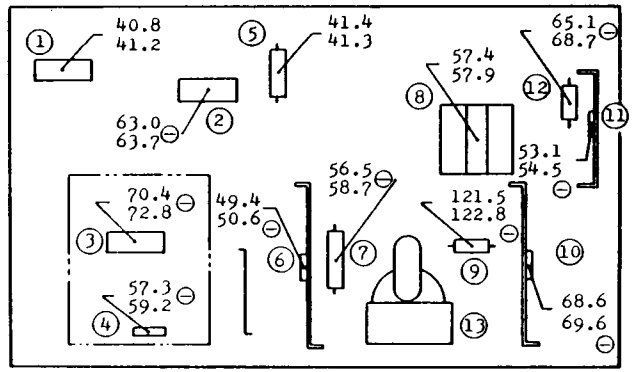
decreases of 13.2%, 4.1%, and 5.9%, respectively). As with the previous blocked vent test, the chimney effect should be improved. The drop in the bottom cabinet air temperature by 1.3°C may be an indication of this effect. Blocking vent set IV is an acceptable modification.

Figure 8.7 shows the result of closing vent set V on the bottom aft part of the extension. This is the best modification of the set. All main circuit board components and the picture tube neck temperatures decrease or remain constant, but the forward half of the main circuit board has a lower percentage of temperature drops than the back half (50% vs. 100%). The two hottest integrated circuits, IC201 and IC640, experience temperature drops of 2.4°C and 0.7°C, respectively. The temperature acceleration factor for IC201 drops by 15% while the factor drops by 2.7% for IC640. Only the air temperature at the bottom of the cabinet increases by 2.3°C and this has no effect on reliability. Table 8.2 is a summary of the reliability improvement. This is an acceptable modification.

Figure 8.8 shows the result of closing vent set VI on the forward bottom of the extension. The results of this modification are similar to, but less dramatic than the previous test since there are 2 fewer circuit board component temperature drops. The main circuit board component temperatures all drop or remain constant, but

| COMPONENT NUMBER | NAPCEC DESIGNATION | COMPONENT |
|---|---|---|
| 1 | IC310 | Integrated Circuit |
| 2 | IC640 | Integrated Circuit |
| 3 | IC201 | Audio IF |
| 4 | IC202 | Audio IF |
| 5 | R456 | 5 Watt Resistor |
| 6 | IC580 | Vertical Output Integrated Circuit |
| 7 | R513 | 7 Watt Resistor |
| 8 | T401 | Transformer |
| 9 | R505 | 5 Watt Resistor |
| 10 | Q501 | Switch Mode Regulator |
| 11 | Q400 | Horizontal Output Transistor |
| 12 | R408 | 5 Watt Resistor |
| 13 | T504 | Flyback Transformer |




NOTE:

The upper number shown at each location is the measured temperature for the vents blocked as shown at the upper right of this figure.

The lower number is the measured temperature at the same location for the baseline, all vents open case.

All temperatures are in degrees Celsius.

The results are for a picture and sound setting of no transmitter signal and no volume.

The picture control knobs labeled Color, Tint, Picture, Bright, and Sharp were set at their clockwise most position.

⊕ indicates a temperature increase due to the blocked vent(s).

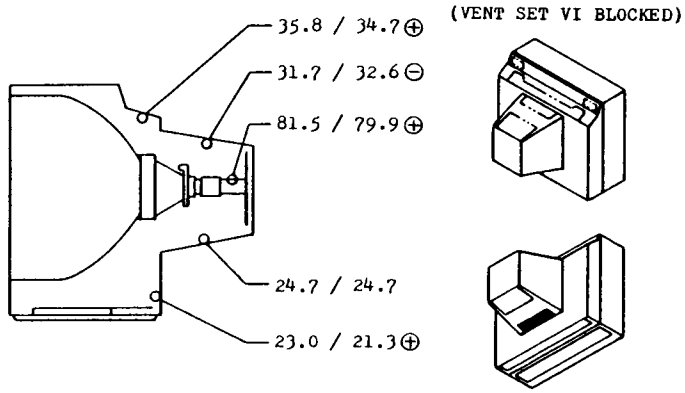
⊖ indicates a temperature decrease due to the blocked vent(s).

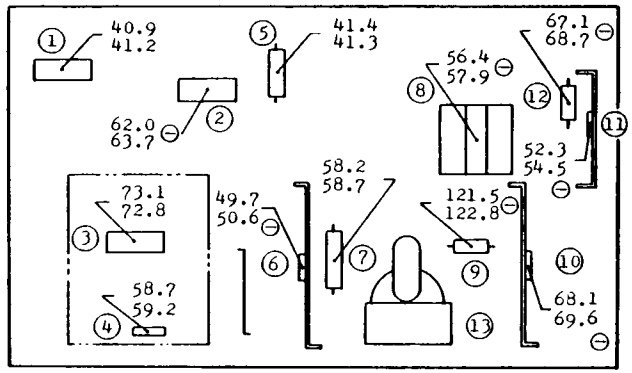
FIGURE 8.7. Component and Air Temperatures in the Receiver With Vent Set V Closed

TABLE 8.2. Integrated Circuit and Transistor Temperature and Failure Rate Decrease Due To Blocking Vent Set V

| Component | Temperature Decrease (°C) | Component Failure Rate Decrease (%) |
|---|---|---|
| IC310 | none | none |
| IC640 | 0.7 | 2.7 |
| IC201 | 2.4 | 9.1 |
| IC202 | 1.9 | 7.1 |
| IC580 | 1.2 | 10.5 |
| Q400 | 1.4 | 3.0 |
| Q501 | 1.0 | 3.3 |

| COMPONENT NUMBER | NAPCEC DESIGNATION | COMPONENT |
|---|---|---|
| 1 | IC310 | Integrated Circuit |
| 2 | IC640 | Integrated Circuit |
| 3 | IC201 | Audio IF |
| 4 | IC202 | Audio IF |
| 5 | R456 | 5 Watt Resistor |
| 6 | IC580 | Vertical Output Integrated Circuit |
| 7 | R513 | 7 Watt Resistor |
| 8 | T401 | Transformer |
| 9 | R505 | 5 Watt Resistor |
| 10 | Q501 | Switch Mode Regulator |
| 11 | Q400 | Horizontal Output Transistor |
| 12 | R408 | 5 Watt Resistor |
| 13 | T504 | Flyback Transformer |




NOTE:

The upper number shown at each location is the measured temperature for the vents blocked as shown at the upper right of this figure.

The lower number is the measured temperature at the same location for the baseline, all vents open case.

All temperatures are in degrees Celsius.

The results are for a picture and sound setting of no transmitter signal and no volume.

The picture control knobs labeled Color, Tint, Picture, Bright, and Sharp were set at their clockwise most position.

⊕ indicates a temperature increase due to the blocked vent(s).

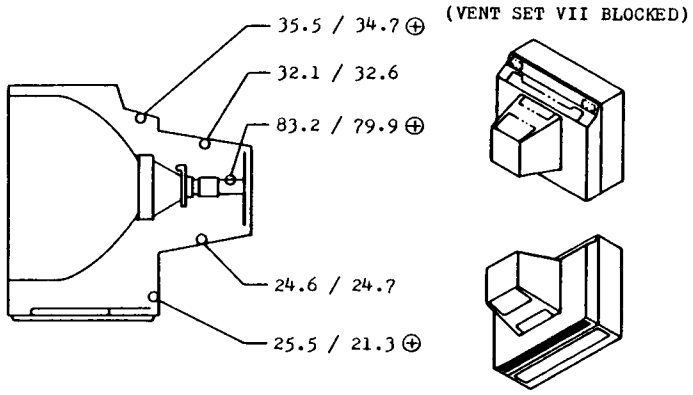
⊖ indicates a temperature decrease due to the blocked vent(s).

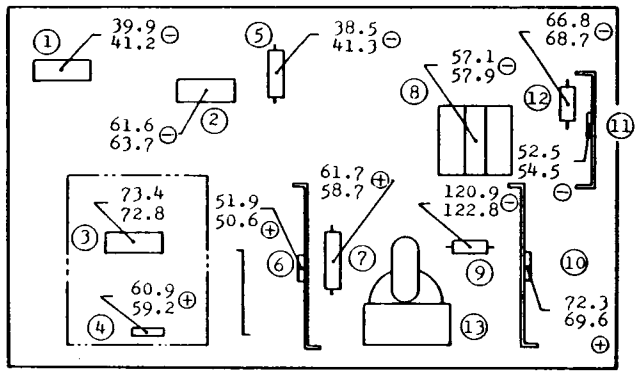
FIGURE 8.8. Component and Air Temperatures in the Receiver With Vent Set VI Closed

now the temperature changes are more evenly distributed around the circuit board (67% for the front half of the circuit board and 50% for the back half). The most important temperature changes are for IC640, IC580, Q501, and Q400 which decrease by 1.7°C, 0.9°C, 1.5°C, and 2.2°C. These changes correspond to component failure rate decreases of 6.4%, 7.9%, 4.9%, and 4.8%, respectively. The only component temperature increase was the picture tube neck which went up by 1.6°C, which is within the bounds previously discussed. This modification is acceptable.

Figure 8.9 shows the result of closing vent set VII on the bottom of the cabinet back. Blocking this set of bottom cabinet vents causes a pattern of temperature increases and decreases. All components on the front half of the main circuit board over vent set VIII experience temperature drops or remain constant. Components IC310, IC640, and Q400 experience temperatures drop of 1.3°C, 2.1°C, and 2.0°C respectively. Components IC202, IC580, and Q501 temperatures increase by 1.7°C, 1.3°C, and 2.7°C respectively for a reliability decrease of about 14.0%, 13.5%, and 8.8% respectively. Since the temperatures of the components (IC580 and Q501) mounted on the aft heat sinks increase, this modification is unacceptable by criteria 5 and 6.

| COMPONENT NUMBER | NAPCEC DESIGNATION | COMPONENT |
|---|---|---|
| 1 | IC310 | Integrated Circuit |
| 2 | IC640 | Integrated Circuit |
| 3 | IC201 | Audio IF |
| 4 | IC202 | Audio IF |
| 5 | R456 | 5 Watt Resistor |
| 6 | IC580 | Vertical Output Integrated Circuit |
| 7 | R513 | 7 Watt Resistor |
| 8 | T401 | Transformer |
| 9 | R505 | 5 Watt Resistor |
| 10 | Q501 | Switch Mode Regulator |
| 11 | Q400 | Horizontal Output Transistor |
| 12 | R408 | 5 Watt Resistor |
| 13 | T504 | Flyback Transformer |




NOTE:

The upper number shown at each location is the measured temperature for the vents blocked as shown at the upper right of this figure.

The lower number is the measured temperature at the same location for the baseline, all vents open case.

All temperatures are in degrees Celsius.

The results are for a picture and sound setting of no transmitter signal and no volume.

The picture control knobs labeled Color, Tint, Picture, Bright, and Sharp were set at their clockwise most position.

⊕ indicates a temperature increase due to the blocked vent(s).

⊖ indicates a temperature decrease due to the blocked vent(s).

FIGURE 8.9. Component and Air Temperatures in the Receiver With Vent Set VII Closed

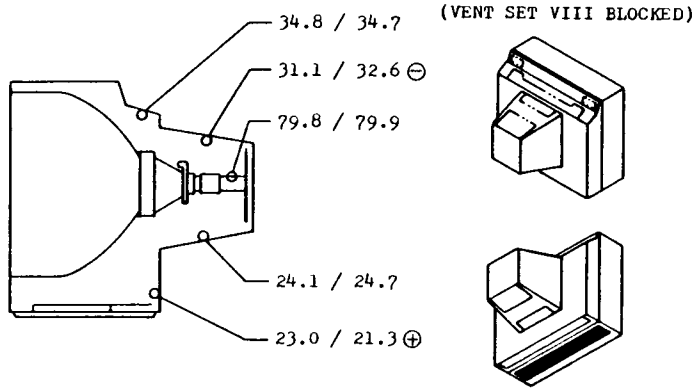
Figure 8.10 show the results of closing vent set VIII on the bottom of the forward section of the cabinet. This modification had the opposite effect of the previous test. The temperatures of components IC310 and IC640 increase by 2.4°C and 0.9°C, respectively for failure rate increases of 22.7% and 7.5%, respectively. The temperatures of components IC201, IC202, IC580, Q501, and Q400 decrease by 3.3°C, 3.7°C, 2.9°C, 1.9°C, and 0.7°C. This results in failure rate decreases for the integrated circuits IC201, IC202, and IC580 of about 15.1%, 13.8%, and 25.4%. The transistor reliabilities experience a 6.2% improvement in the failure rate for the switch mode regulator and a 1.5% improvement in the failure rate for the horizontal output. This modification is unacceptable, however, because the large increase in the temperature of IC310 violates criterion 6.

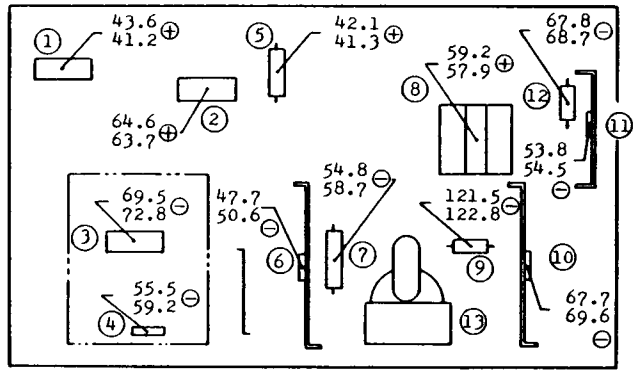
Blocking Pairs of Vent Sets

The next set blocked vent experiments was to simultaneously close pairs of vent sets. This was done to get some indication of how the pairs would alter the temperatures in view of how individual sets behaved. It was hoped that these tests would also provide some insight into the results of last three blocked vent tests.

Figure 8.11 shows the effect of closing bottom cabinet vents, sets VII and VIII. This causes a 1°C to 3°C

| COMPONENT NUMBER | NAPCEC DESIGNATION | COMPONENT |
|---|---|---|
| 1 | IC310 | Integrated Circuit |
| 2 | IC640 | Integrated Circuit |
| 3 | IC201 | Audio IF |
| 4 | IC202 | Audio IF |
| 5 | R456 | 5 Watt Resistor |
| 6 | IC580 | Vertical Output Integrated Circuit |
| 7 | R513 | 7 Watt Resistor |
| 8 | T401 | Transformer |
| 9 | R505 | 5 Watt Resistor |
| 10 | Q501 | Switch Mode Regulator |
| 11 | Q400 | Horizontal Output Transistor |
| 12 | R408 | 5 Watt Resistor |
| 13 | T504 | Flyback Transformer |




NOTE:

The upper number shown at each location is the measured temperature for the vents blocked as shown at the upper right of this figure.

The lower number is the measured temperature at the same location for the baseline, all vents open case.

All temperatures are in degrees Celsius.

The results are for a picture and sound setting of no transmitter signal and no volume.

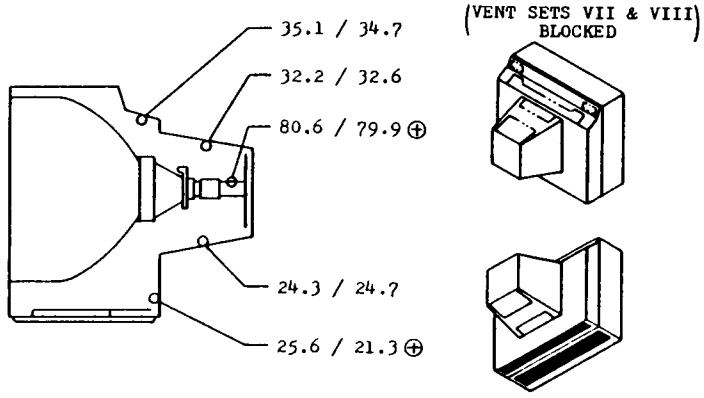
The picture control knobs labeled Color, Tint, Picture, Bright, and Sharp were set at their clockwise most position.

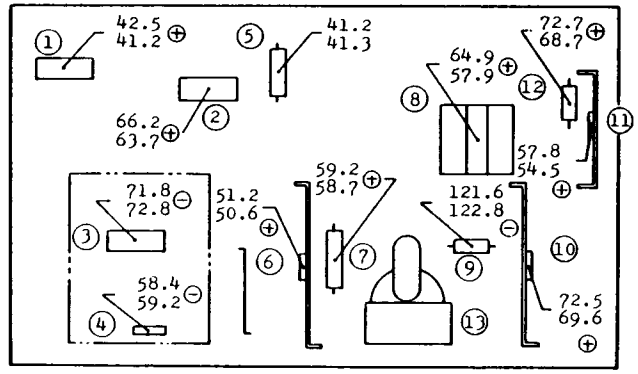
⊕ indicates a temperature increase due to the blocked vent(s).

⊖ indicates a temperature decrease due to the blocked vent(s).

FIGURE 8.10. Component and Air Temperatures in the Receiver With Vent Set VIII Closed

| COMPONENT NUMBER | NAPCEC DESIGNATION | COMPONENT |
|---|---|---|
| 1 | IC310 | Integrated Circuit |
| 2 | IC640 | Integrated Circuit |
| 3 | IC201 | Audio IF |
| 4 | IC202 | Audio IF |
| 5 | R456 | 5 Watt Resistor |
| 6 | IC580 | Vertical Output Integrated Circuit |
| 7 | R513 | 7 Watt Resistor |
| 8 | T401 | Transformer |
| 9 | R505 | 5 Watt Resistor |
| 10 | Q501 | Switch Mode Regulator |
| 11 | Q400 | Horizontal Output Transistor |
| 12 | R408 | 5 Watt Resistor |
| 13 | T504 | Flyback Transformer |




NOTE:

The upper number shown at each location is the measured temperature for the vents blocked as shown at the upper right of this figure.

The lower number is the measured temperature at the same location for the baseline, all vents open case.

All temperatures are in degrees Celsius.

The results are for a picture and sound setting of no transmitter signal and no volume.

The picture control knobs labeled Color, Tint, Picture, Bright, and Sharp were set at their clockwise most position.

⊕ indicates a temperature increase due to the blocked vent(s).

⊖ indicates a temperature decrease due to the blocked vent(s).

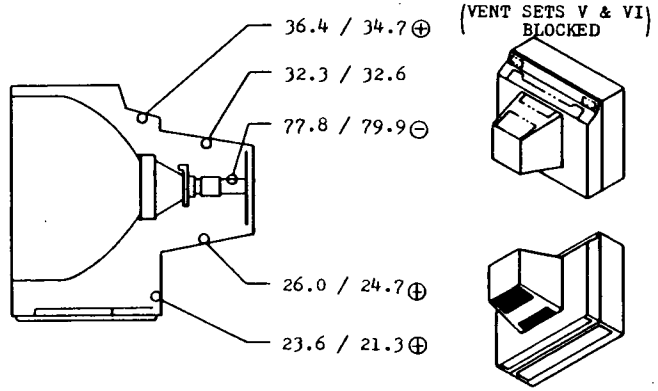
FIGURE 8.11. Component and Air Temperatures in the Receiver With Vent Sets VII and VIII Closed

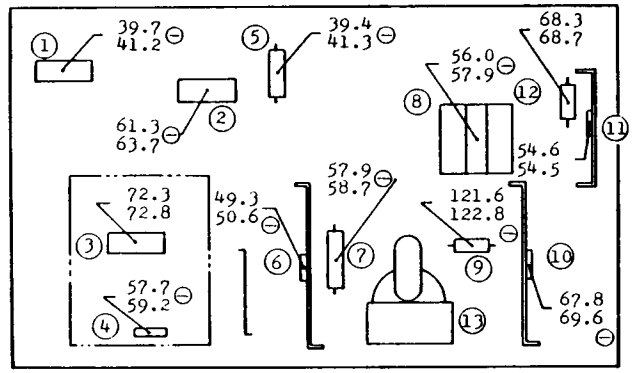
increase in the temperatures of the components attached to the three main heat sinks, but there is a small decrease in the temperature of the audio IC's. The decrease in failure rate for these components is about 4% for IC201 and 5% for IC202. There is also a 2.5°C increase in the temperature of IC640, which corresponds to a 21% increase in failure rate. Because of the temperature increase of the heat sink mounted components and the large temperature increase of IC640, this was an unacceptable modification (criteria 5 and 6).

Closing the bottom extension vents (sets V and VI) as shown in Figure 8.12, causes a general decrease, or no change at all, of the component temperatures on the main circuit board. The most important temperature drops were for IC580 (1.3°C) and Q501 (1.8°C), which were 11.4% and 5.9% decreases in failure rate as shown in Table 8.3. Since they are attached to heat sinks, the reliability increase can be traded for cost savings in smaller heat sinks. This is an acceptable modification.

Figure 8.13 show the results of closing the top extension vents (sets III and IV). This causes an increase in temperature for most of the main circuit board components. These increases are evenly distributed around the circuit board and include the heat sink mounted components, IC580 and Q501. Moreover, components IC201 and IC640 experience temperature increases greater than or

| COMPONENT NUMBER | NAPCEC DESIGNATION | COMPONENT |
|---|---|---|
| 1 | IC310 | Integrated Circuit |
| 2 | IC640 | Integrated Circuit |
| 3 | IC201 | Audio IF |
| 4 | IC202 | Audio IF |
| 5 | R456 | 5 Watt Resistor |
| 6 | IC580 | Vertical Output Integrated Circuit |
| 7 | R513 | 7 Watt Resistor |
| 8 | T401 | Transformer |
| 9 | R505 | 5 Watt Resistor |
| 10 | Q501 | Switch Mode Regulator |
| 11 | Q400 | Horizontal Output Transistor |
| 12 | R408 | 5 Watt Resistor |
| 13 | T504 | Flyback Transformer |




NOTE:

The upper number shown at each location is the measured temperature for the vents blocked as shown at the upper right of this figure.

The lower number is the measured temperature at the same location for the baseline, all vents open case.

All temperatures are in degrees Celsius.

The results are for a picture and sound setting of no transmitter signal and no volume.

The picture control knobs labeled Color, Tint, Picture, Bright, and Sharp were set at their clockwise most position.

⊕ indicates a temperature increase due to the blocked vent(s).

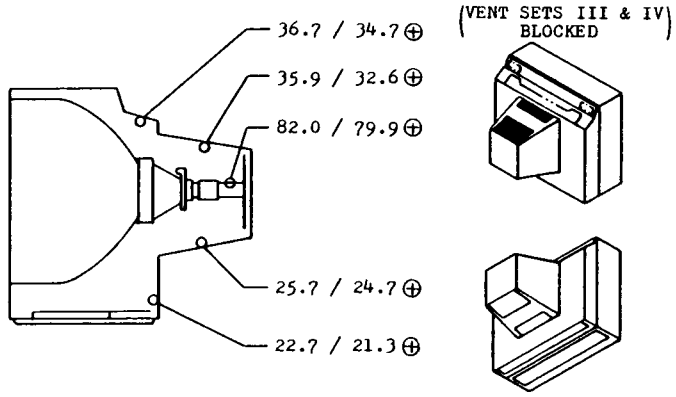
⊖ indicates a temperature decrease due to the blocked vent(s).

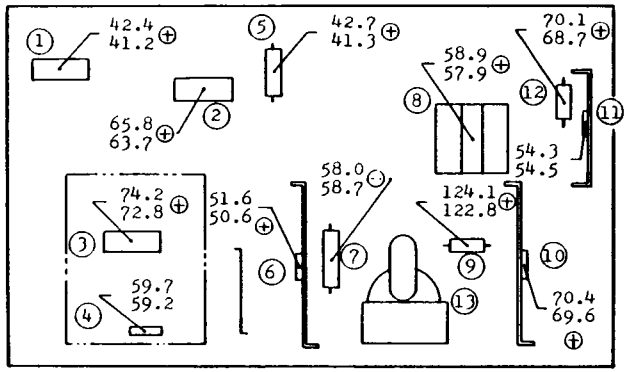
FIGURE 8.12. Component and Air Temperatures in the Receiver With Vent Sets V and VI Closed

TABLE 8.3. Integrated Circuit and Transistor Temperature and Failure Rate Decrease Due To Blocking Vent Set V and VI

| Component | Temperature Decrease (°C) | Component Failure Rate Decrease (%) |
|---|---|---|
| IC310 | 1.5 | 9.3 |
| IC640 | 2.4 | 9.2 |
| IC201 | none | - |
| IC202 | 1.5 | 5.6 |
| IC580 | 1.3 | 11.4 |
| Q400 | none | - |
| Q501 | 1.8 | 5.9 |

| COMPONENT NUMBER | NAPCEC DESIGNATION | COMPONENT |
|---|---|---|
| 1 | IC310 | Integrated Circuit |
| 2 | IC640 | Integrated Circuit |
| 3 | IC201 | Audio IF |
| 4 | IC202 | Audio IF |
| 5 | R456 | 5 Watt Resistor |
| 6 | IC580 | Vertical Output Integrated Circuit |
| 7 | R513 | 7 Watt Resistor |
| 8 | T401 | Transformer |
| 9 | R505 | 5 Watt Resistor |
| 10 | Q501 | Switch Mode Regulator |
| 11 | Q400 | Horizontal Output Transistor |
| 12 | R408 | 5 Watt Resistor |
| 13 | T504 | Flyback Transformer |




NOTE:

The upper number shown at each location is the measured temperature for the vents blocked as shown at the upper right of this figure.

The lower number is the measured temperature at the same location for the baseline, all vents open case.

All temperatures are in degrees Celsius.

The results are for a picture and sound setting of no transmitter signal and no volume.

The picture control knobs labeled Color, Tint, Picture, Bright, and Sharp were set at their clockwise most position.

⊕ indicates a temperature increase due to the blocked vent(s).

⊖ indicates a temperature decrease due to the blocked vent(s).

FIGURE 8.13. Component and Air Temperatures in the Receiver With Vent Sets III and IV Closed

equal to the allowable limit. Thus, this is an unacceptable modification by criteria 5 and 6.

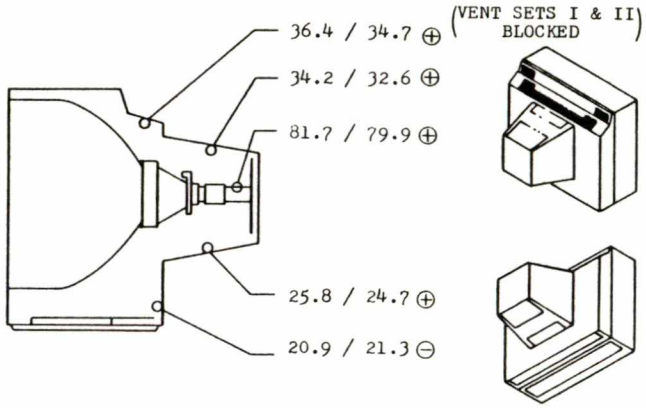
Figure 8.14 shows the effect of closing vent sets I and II. There is an improvement in main circuit board temperatures. The components mounted on heat sinks show temperature decreases. The temperatures of components IC580, Q501, and Q400 drop by 0.8°C, 0.7°C, and 2.8°C, which corresponds to failure rate decreases of 7.0%, 2.2%, and 6.0%. The primary temperature increases occur at the top of the cabinet where there is a 1°C to 2°C increase in air temperatures. This has no adverse effect on reliability. Integrated circuits, IC640 and IC201, increase in temperature by 1.6°C and 1.0°C for failure rate increases of 13.3% and 7.9%. Also, the picture tube neck temperature increases by 2.2°C. Because the temperature increase of component IC640, this is an unacceptable modification by criterion 6.

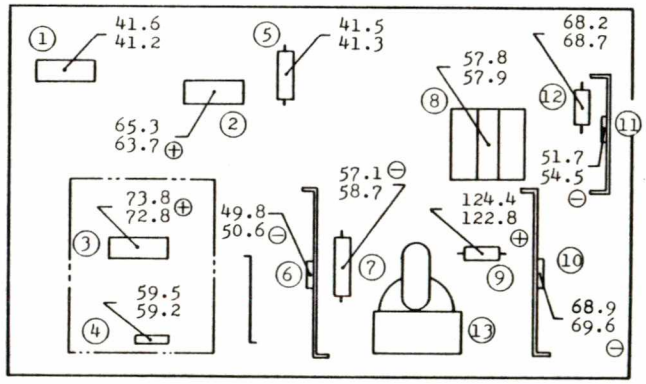
At this point, it was decided that blocking additional pairs of vent sets would not be significantly superior to blocking the bottom extension vents. More importantly, it was believed that enough experience had been gained to begin to examine more extreme cases.

Blocking Three or More Vent Sets

The final blocked vent tests involved closing all the extension vents, closing all top cabinet and extension

| COMPONENT NUMBER | NAPCEC DESIGNATION | COMPONENT |
|---|---|---|
| 1 | IC310 | Integrated Circuit |
| 2 | IC640 | Integrated Circuit |
| 3 | IC201 | Audio IF |
| 4 | IC202 | Audio IF |
| 5 | R456 | 5 Watt Resistor |
| 6 | IC580 | Vertical Output Integrated Circuit |
| 7 | R513 | 7 Watt Resistor |
| 8 | T401 | Transformer |
| 9 | R505 | 5 Watt Resistor |
| 10 | Q501 | Switch Mode Regulator |
| 11 | Q400 | Horizontal Output Transistor |
| 12 | R408 | 5 Watt Resistor |
| 13 | T504 | Flyback Transformer |




NOTE:

The upper number shown at each location is the measured temperature for the vents blocked as shown at the upper right of this figure.

The lower number is the measured temperature at the same location for the baseline, all vents open case.

All temperatures are in degrees Celsius.

The results are for a picture and sound setting of no transmitter signal and no volume.

The picture control knobs labeled Color, Tint, Picture, Bright, and Sharp were set at their most clockwise position.

⊕ indicates a temperature increase due to the blocked vent(s).

⊖ indicates a temperature decrease due to the blocked vent(s).

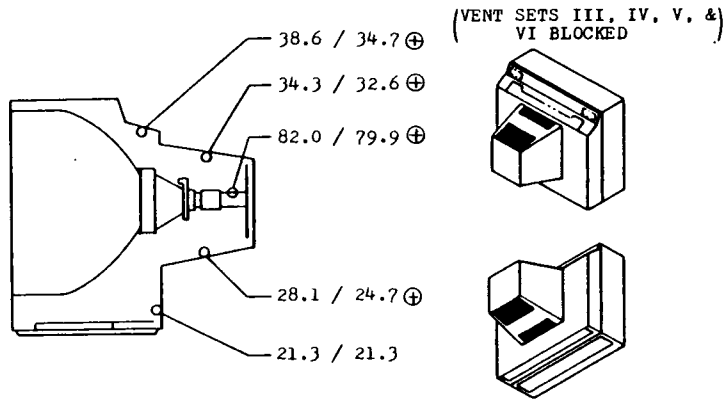
FIGURE 8.14. Component and Air Temperatures in the Receiver With Vent Sets I and II Closed

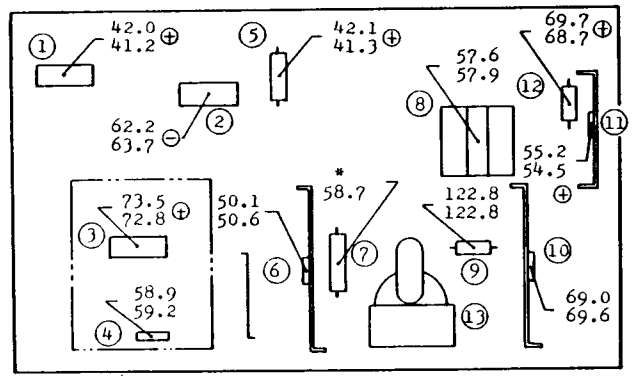
vents, or closing all cabinet and extension vents. Closing all the extension vents was considered primarily because of the theoretical improvement to the chimney effect. It also is attractive from a manufacturing and safety viewpoint.

For the case of all extension vents (sets III, IV, V, and VI) blocked, the largest temperature drop of 1.5°C was experienced by component IC640. The results are shown in Figure 8.15. Half of the components on the main circuit board experience no change or a slight (less than 1°C) drop in the component temperature. The remaining components experience temperature increases. If this configuration improves the chimney effect, the improvement is offset by the increased recirculation of hot air in the extension which results in a 3°C increase in the picture tube neck temperature and a general increase in the extension air temperatures. Moreover, the temperature of Q400 increased by 0.7°C for a failure rate increase of 1.5%; thus, this is an unacceptable modification by criterion 5.

The possibility of closing all top vents (sets I,II,III, and IV) is particularly attractive since it would result in a reduction of the probability of electrical accidents by liquid spillage or penetration of vent openings by electrical conductors. As expected, all of the measured temperatures increase. For this case,

| COMPONENT NUMBER | NAPCEC DESIGNATION | COMPONENT |
|---|---|---|
| 1 | IC310 | Integrated Circuit |
| 2 | IC640 | Integrated Circuit |
| 3 | IC201 | Audio IF |
| 4 | IC202 | Audio IF |
| 5 | R456 | 5 Watt Resistor |
| 6 | IC580 | Vertical Output Integrated Circuit |
| 7 | R513 | 7 Watt Resistor |
| 8 | T401 | Transformer |
| 9 | R505 | 5 Watt Resistor |
| 10 | Q501 | Switch Mode Regulator |
| 11 | Q400 | Horizontal Output Transistor |
| 12 | R408 | 5 Watt Resistor |
| 13 | T504 | Flyback Transformer |




* Thermocouple Failure.

NOTE:

The upper number shown at each location is the measured temperature for the vents blocked as shown at the upper right of this figure.

The lower number is the measured temperature at the same location for the baseline, all vents open case.

All temperatures are in degrees Celsius.

The results are for a picture and sound setting of no transmitter signal and no volume.

The picture control knobs labeled Color, Tint, Picture, Bright, and Sharp were set at their clockwise most position.

⊕ indicates a temperature increase due to the blocked vent(s).

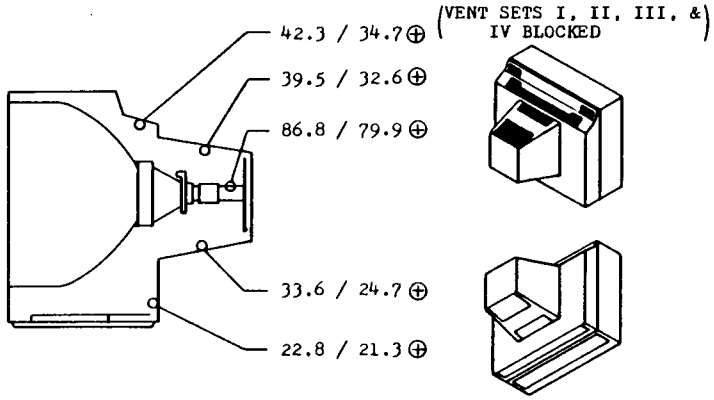
⊖ indicates a temperature decrease due to the blocked vent(s).

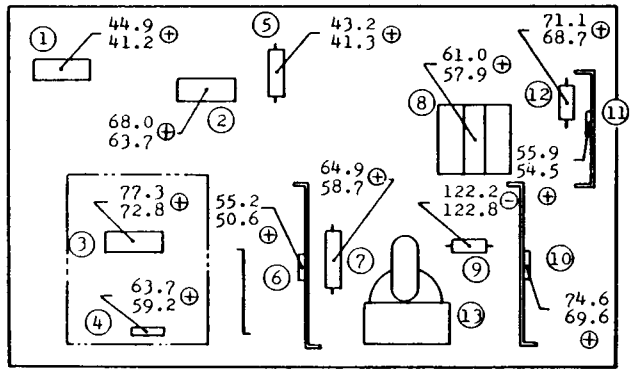
FIGURE 8.15. Component and Air Temperatures in the Receiver With All Extension (Cup) Vents Closed

the highest temperature increase of 7°C occurs at the picture tube neck, which was deemed to be unacceptably large. Also, the transformer temperature increases by 10.6°C which exceeds the set limit. The results are shown in Figure 8.16. In general the temperature increases vary from 1 to 5°C. The reliability of the integrated circuits degrade significantly as shown in Table 8.4. None of the resistors exceed the temperature limit previously set. As the table clearly shows, this modification is unacceptable by criteria 3, 4, 5, and 6.

Closing all vents is attractive in reducing manufacturing and tooling costs. It also almost eliminates the electrical shock hazard and significantly improves the structural integrity and aesthetics of the cabinet. Figure 8.17 shows the results of the all vents closed case. The highest temperature increases are for the air at the top of the cabinet which change by 4°C to 10°C. The largest component temperature increase was 10.6°C for the transformer. The effect of blocking all vents is equivalent to increasing the inlet air temperature by about 9°C. The transformer temperature increases by an unacceptable 10.6°C degrees. Moreover the integrated circuit temperatures increase by 5 - 10°C. This is clearly the worst case as Table 8.5 shows; thus, the modification is not acceptable by criteria 3, 4, 5 and 6.

| COMPONENT NUMBER | NAPCEC DESIGNATION | COMPONENT |
|---|---|---|
| 1 | IC310 | Integrated Circuit |
| 2 | IC640 | Integrated Circuit |
| 3 | IC201 | Audio IF |
| 4 | IC202 | Audio IF |
| 5 | R456 | 5 Watt Resistor |
| 6 | IC580 | Vertical Output Integrated Circuit |
| 7 | R513 | 7 Watt Resistor |
| 8 | T401 | Transformer |
| 9 | R505 | 5 Watt Resistor |
| 10 | Q501 | Switch Mode Regulator |
| 11 | Q400 | Horizontal Output Transistor |
| 12 | R408 | 5 Watt Resistor |
| 13 | T504 | Flyback Transformer |




NOTE:

The upper number shown at each location is the measured temperature for the vents blocked as shown at the upper right of this figure.

The lower number is the measured temperature at the same location for the baseline, all vents open case.

All temperatures are in degrees Celsius.

The results are for a picture and sound setting of no transmitter signal and no volume.

The picture control knobs labeled Color, Tint, Picture, Bright, and Sharp were set at their clockwise most position.

⊕ indicates a temperature increase due to the blocked vent(s).

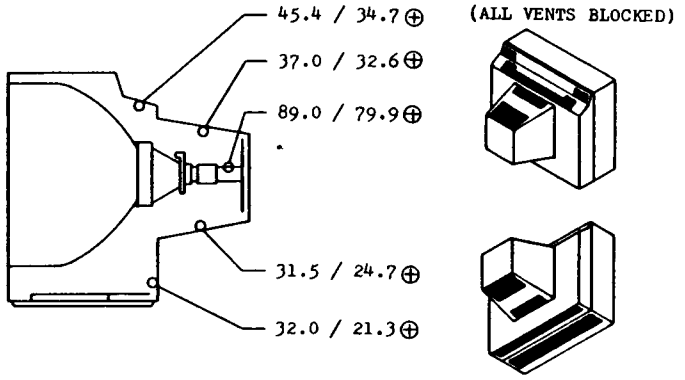
⊖ indicates a temperature decrease due to the blocked vent(s).

FIGURE 8.16. Component and Air Temperatures in the Receiver With Vent Sets I, II, III, and IV Closed

TABLE 8.4. Integrated Circuit and Transistor Temperature and Failure Rate Increase Due To Blocking Vent Sets I, II, III, and IV

| Component | Temperature Increase (°C) | Component Failure Rate Increase (%) |
|---|---|---|
| IC310 | 3.7 | 35.0 |
| IC640 | 4.3 | 35.8 |
| IC201 | 4.5 | 35.7 |
| IC202 | 4.5 | 37.0 |
| IC580 | 4.6 | 47.9 |
| Q400 | 1.4 | 3.0 |
| Q501 | 5.0 | 16.3 |

| COMPONENT NUMBER | NAPCEC DESIGNATION | COMPONENT |
|---|---|---|
| 1 | IC310 | Integrated Circuit |
| 2 | IC640 | Integrated Circuit |
| 3 | IC201 | Audio IF |
| 4 | IC202 | Audio IF |
| 5 | R456 | 5 Watt Resistor |
| 6 | IC580 | Vertical Output Integrated Circuit |
| 7 | R513 | 7 Watt Resistor |
| 8 | T401 | Transformer |
| 9 | R505 | 5 Watt Resistor |
| 10 | Q501 | Switch Mode Regulator |
| 11 | Q400 | Horizontal Output Transistor |
| 12 | R408 | 5 Watt Resistor |
| 13 | T504 | Flyback Transformer |




NOTE:

The upper number shown at each location is the measured temperature for the vents blocked as shown at the upper right of this figure.

The lower number is the measured temperature at the same location for the baseline, all vents open case.

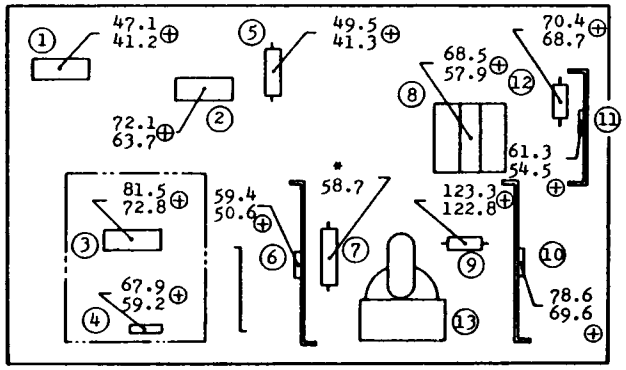
All temperatures are in degrees Celsius.

The results are for a picture and sound setting of no transmitter signal and no volume.

The picture control knobs labeled Color, Tint, Picture, Bright, and Sharp were set at their clockwise most position.

⊕ indicates a temperature increase due to the blocked vent(s).

⊖ indicates a temperature decrease due to the blocked vent(s).




* Thermocouple Failure.

FIGURE 8.17. Component and Air Temperatures in the Receiver With All Vent Sets Closed

TABLE 8.5. Integrated Circuit and Transistor Temperature and Failure Rate Increase Due To Blocking All Vents

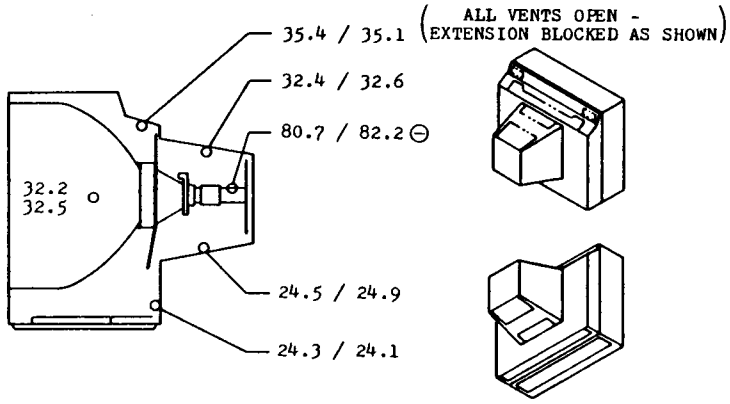
| Component | Temperature Increase (°C) | Component Failure Rate Increase (%) |
|---|---|---|
| IC310 | 5.9 | 81.8 |
| IC640 | 8.4 | 122.2 |
| IC201 | 8.7 | 69.0 |
| IC202 | 8.7 | 102.7 |
| IC580 | 8.8 | 125.0 |
| Q400 | 6.8 | 16.4 |
| Q501 | 9.0 | 29.3 |

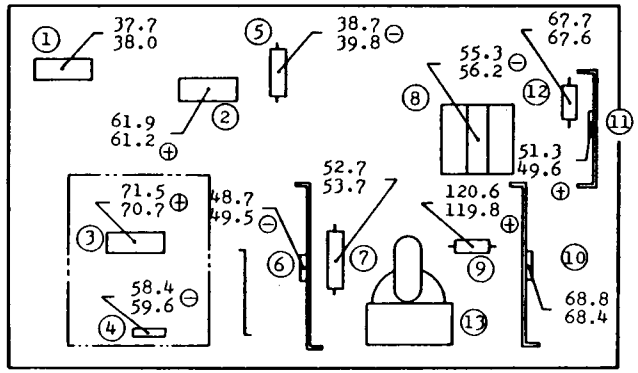
### 3. Blocked Extension (Cup) Comparison to Baseline Temperatures

This set of tests is another attempt to improve the chimney effect as discussed in Chapter V. In these tests the extension (cup) was sealed off from the main body of the cabinet by a cardboard insert. The results of the blocked extension tests are presented in a manner similar to the blocked vent tests. Two values of temperature are shown at each measuring location. The upper value is the measured temperature with the cardboard insert blocking the flow between the extension and the main body of the cabinet. The lower number is the "all vents open" case. The baseline all vents open case was rerun a third time and is used in the comparison to reduce the errors associated with the reproducability.

If this modification were to be used in a production model receiver, it must be simple, quick, and inexpensive to install. Thus, the partition was attached without any adhesives to completely seal the extension from the main cabinet. The tightest seal that could be obtained in this manner was a 0.2 cm gap around the perimeter of the partition. For the initial test, the fit between the cardboard partition and the cabinet was degraded by a 1.3 cm gap at the extension bottom. Figure 8.18 shows the results of the first temperature test with the partition.

| COMPONENT NUMBER | NAPCEC DESIGNATION | COMPONENT |
|---|---|---|
| 1 | IC310 | Integrated Circuit |
| 2 | IC640 | Integrated Circuit |
| 3 | IC201 | Audio IF |
| 4 | IC202 | Audio IF |
| 5 | R456 | 5 Watt Resistor |
| 6 | IC580 | Vertical Output Integrated Circuit |
| 7 | R513 | 7 Watt Resistor |
| 8 | T401 | Transformer |
| 9 | R505 | 5 Watt Resistor |
| 10 | Q501 | Switch Mode Regulator |
| 11 | Q400 | Horizontal Output Transistor |
| 12 | R408 | 5 Watt Resistor |
| 13 | T504 | Flyback Transformer |




NOTE:

The upper number shown at each location is the measured temperature for the extension blocked

The lower number is the measured temperature at the same location for the baseline, all vents open case.

All temperatures are in degrees Celsius.

The results are for a picture and sound setting of no transmitter signal and no volume.

The picture control knobs labeled Color, Tint, Picture, Bright, and Sharp were set at their clockwise most position.

⊕ indicates a temperature increase due to the blocked extension.

⊖ indicates a temperature decrease due to the blocked extension.

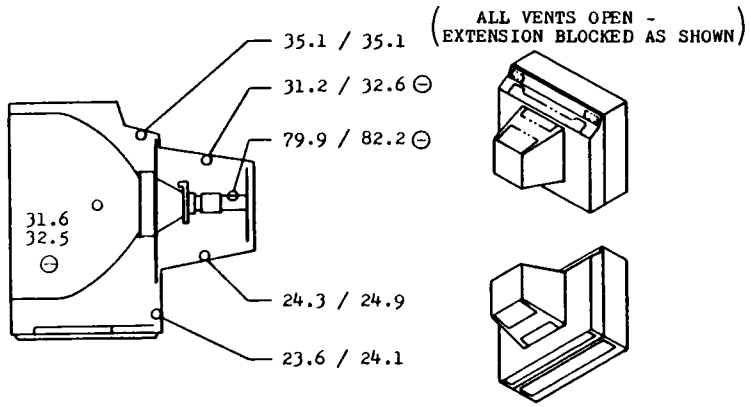
FIGURE 8.18. Component and Air Temperatures in the Receiver With Extension Blocked by Cardboard Partition With a 1.3 cm Offset at the Bottom

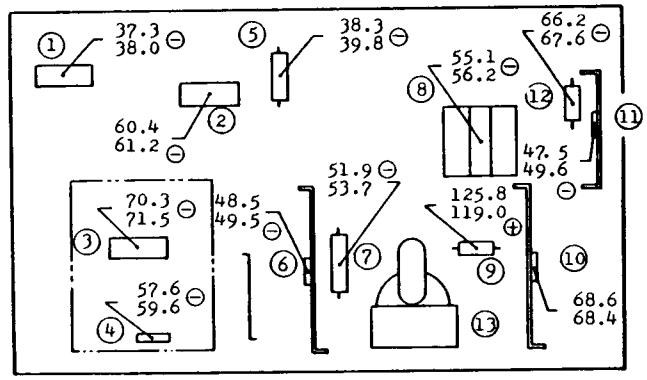
The temperatures generally decrease, but the changes are on the order of 2°C or less. The worst change in temperature is a 1.7°C increase for Q400. This represents a 3.7% drop in reliability and is not an acceptable by the criteria established for the blocked vent tests.

For the second test, the 0.2 cm gap was not degraded. Figure 8.19 shows the results. Most temperatures either drop or stay the same. The exception to this is resistor R505 which experiences a 6°C increase. The reliability improves as shown by the drops in component failure rates in Table 8.6. This configuration is much better than the previous one tested, and it demonstrates the importance of minimizing the gap between the partition and the wall. This modification is acceptable.

A quick flow visualization test was also performed to see how much air flow from the main cabinet leaked into the extension. Smoke was injected into the forward cabinet. In both cases leakage of air from the main cabinet to the extension was not noticeable. It is believed that the primary cause for the temperature differences between the blocked extension and baseline cases is the improvement in the chimney effect.

| COMPONENT NUMBER | NAPCEC DESIGNATION | COMPONENT |
|---|---|---|
| 1 | IC310 | Integrated Circuit |
| 2 | IC640 | Integrated Circuit |
| 3 | IC201 | Audio IF |
| 4 | IC202 | Audio IF |
| 5 | R456 | 5 Watt Resistor |
| 6 | IC580 | Vertical Output Integrated Circuit |
| 7 | R513 | 7 Watt Resistor |
| 8 | T401 | Transformer |
| 9 | R505 | 5 Watt Resistor |
| 10 | Q501 | Switch Mode Regulator |
| 11 | Q400 | Horizontal Output Transistor |
| 12 | R408 | 5 Watt Resistor |
| 13 | T504 | Flyback Transformer |




NOTE:

The upper number shown at each location is the measured temperature for the extension blocked

The lower number is the measured temperature at the same location for the baseline, all vents open case.

All temperatures are in degrees Celsius.

The results are for a picture and sound setting of no transmitter signal and no volume.

The picture control knobs labeled Color, Tint, Picture, Bright, and Sharp were set at their clockwise most position.

⊕ indicates a temperature increase due to the blocked extension.

⊖ indicates a temperature decrease due to the blocked extension.

FIGURE 8.19. Component and Air Temperatures in the Receiver With Extension Blocked by Cardboard Partition With a 0.2 cm Offset

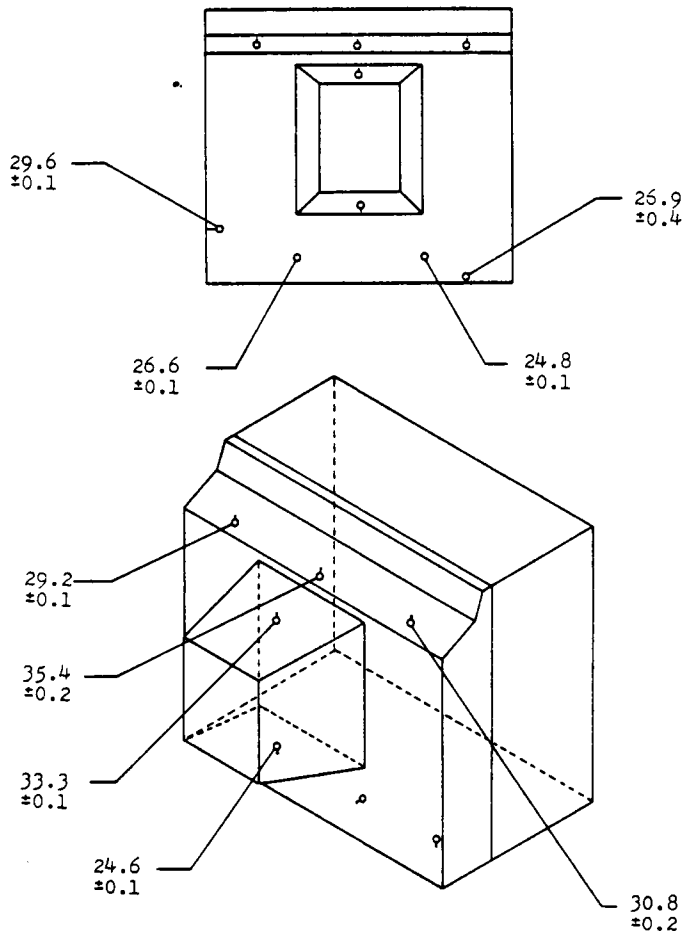
TABLE 8.6. Blocked Extension (Cup) Effect on Integrated Circuit and Transistor Temperature and Reliability

| Component | Temperature Decrease (°C) | Component Failure Rate Decrease (%) |
|---|---|---|
| IC310 | 0.7 | 4.4 |
| IC640 | 0.8 | 3.1 |
| IC201 | 1.2 | 5.5 |
| IC202 | 2.0 | 7.5 |
| IC580 | 1.0 | 8.8 |
| Q400 | 2.1 | 4.5 |
| Q501 | none | none |

## 4. Air Temperature Survey of the Baseline Receiver

Since an experimental simulator was to be built, it was necessary to measure the air temperatures within the receiver. The comparison between the receiver air temperatures and the experimental simulator will be made later in this chapter.

Thermocouples mounted on a wooden rod were placed in the receiver. The spacing between thermocouples was 5.1 cm for the bottom 7 thermocouples and 2.5 cm between the 7th and 8th thermocouple (see Figures 5.4 on page 40 and Figure 5.5 on page 41). Figure 8.20 and 8.21 show the results of these tests. Three things are evident from this data. First, the results clearly show that air in the enclosure is thermally stratified. The temperature at the top of the cabinet is greater than that of the bottom by about 10°C. The significance of this is that it indicates there is some upward flow in the cabinet. Secondly, at the locations near the circuit board, the air temperature is about 27°C, but there is a jump in the air temperature between thermocouples 3 and 4 on the left side (facing the front of the receiver) of the receiver. This rapid increase in air temperature is an indication of a hot plume adjacent to the picture tube. This plume originates on the circuit board. In the plume the air temperature is about 37°C, as the flow moves higher, it




NOTE :

The first number shown at each location is the measured temperature.

The second number is the standard deviation of the measured temperature.

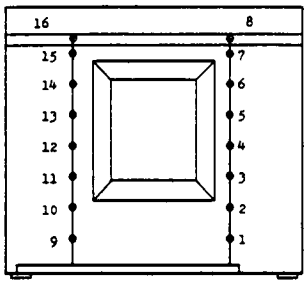
All temperatures and their standard deviations are in degrees Celsius.

All cabinet vents are open.

The results are for a picture and sound setting of no transmitter signal and no volume.

The picture control knobs labeled Color, Tint, Picture, Bright, and Sharp were set at their most clockwise position.

FIGURE 8.20. Typical Air Temperatures in Receiver With All Vents Open




| Thermocouple Position | Temperature (Celsius) | Standard Deviation (Celsius) |
|---|---|---|
| 1 | 26.9 | 0.1 |
| 2 | 27.2 | 0.2 |
| 3 | 30.2 | 0.1 |
| 4 | 35.7 | 0.1 |
| 5 | 34.3 | 0.1 |
| 6 | 33.0 | 0.1 |
| 7 | 32.7 | 0.1 |
| 8 | 31.2 | 0.1 |
| 9 | 27.1 | 0.1 |
| 10 | 27.6 | 0.2 |
| 11 | 30.2 | 0.1 |
| 12 | 32.3 | 0.1 |
| 13 | 31.5 | 0.1 |
| 14 | 30.8 | 0.1 |
| 15 | 30.3 | 0.1 |
| 16 | 30.3 | 0.1 |

NOTE :

All cabinet vents are open.

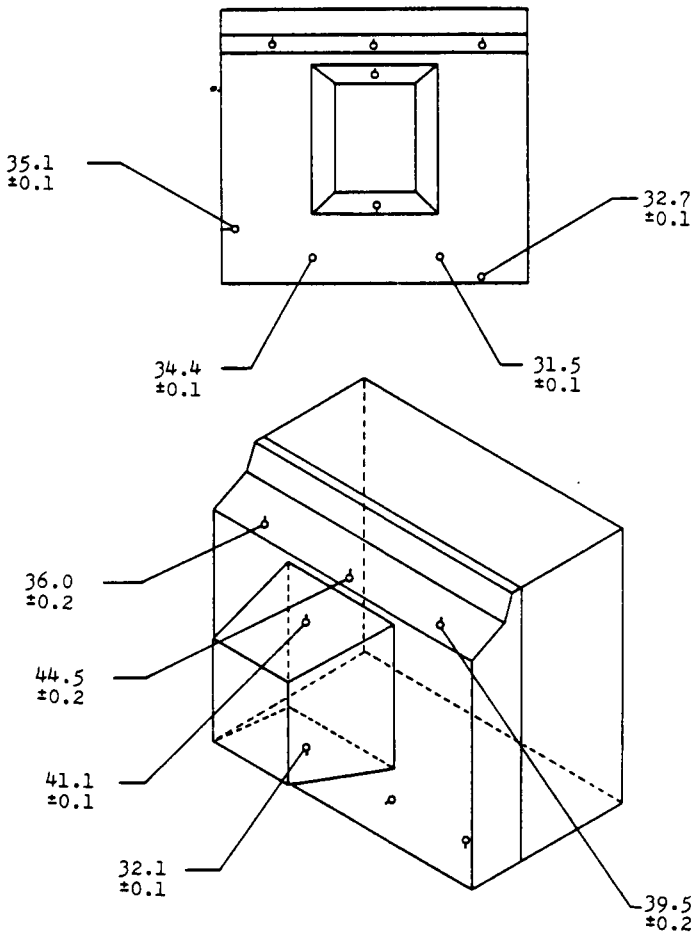
The results are for a picture and sound setting of no transmitter signal and no volume.

The picture control knobs labeled Color, Tint, Picture, Bright, and Sharp were set at their most clockwise position.

FIGURE 8.21. Air Temperature Gradients in Receiver With All Vents Open

cools to about 30°C on the left side. On the right side the temperature changes are smaller, but the cooling of the flow as it reaches the top of the cabinet does appear. This cooling is due to either the flow losing thermal energy to the walls, mixing of the upward flow with cooler air or some combination of both of these effects. Thirdly, the left side cabinet air temperatures are higher than the right side by 1 to 5°C. Thus, the flow on the left side should be of a slightly higher velocity because of the greater buoyancy force generated.

The results of the all-vent-closed tests are shown in Figures 8.22 and 8.23. They are similar to the previous test results except that the temperatures are 7 to 10°C higher for all vents blocked. For this case, the air stratification is less than the all vents open case. The temperature difference between the top and bottom for the left side is 2.8°C for all vents blocked verses 4.3°C for all vents open and on the right side 1.4°C for all vents blocked verses 3.2°C for all vents open. Still, the left side of the receiver has from 1 to 4°C higher air temperatures. The cooling trend of the air as it moves into the upper half of the cabinet also occurs in this test. The temperature increase from circuit board to the horizontal centerline is about 10°C for both cases. Before continuing this disscussion any further, the flow visualization results need to be introduced.




NOTE :

The first number shown at each location is the measured temperature.

The second number is the standard deviation of the measured temperature.

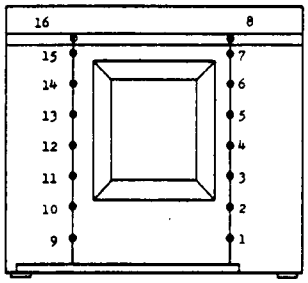
All temperatures and their standard deviations are in degrees Celsius.

All cabinet vents are open.

The results are for a picture and sound setting of no transmitter signal and no volume.

The picture control knobs labeled Color, Tint, Picture, Bright, and Sharp were set at their most clockwise position.

FIGURE 8.22. Typical Air Temperatures in Receiver With All Vents Closed




| Thermocouple Position | Temperature (Celsius) | Standard Deviation (Celsius) |
|---|---|---|
| 1 | 34.8 | 0.1 |
| 2 | 36.3 | 0.1 |
| 3 | 39.6 | 0.1 |
| 4 | 44.8 | 0.1 |
| 5 | 42.9 | 0.1 |
| 6 | 41.8 | 0.1 |
| 7 | 41.3 | 0.1 |
| 8 | 36.0 | 0.1 |
| 9 | 37.6 | 0.1 |
| 10 | 37.5 | 0.1 |
| 11 | 38.8 | 0.1 |
| 12 | 40.3 | 0.1 |
| 13 | 37.8 | 0.1 |
| 14 | 38.5 | 0.1 |
| 15 | 40.8 | 0.1 |
| 16 | 38.9 | 0.2 |

NOTE :

All cabinet vents are open.

The results are for a picture and sound setting of no transmitter signal and no volume.

The picture control knobs labeled Color, Tint, Picture, Bright, and Sharp were set at their most clockwise position.

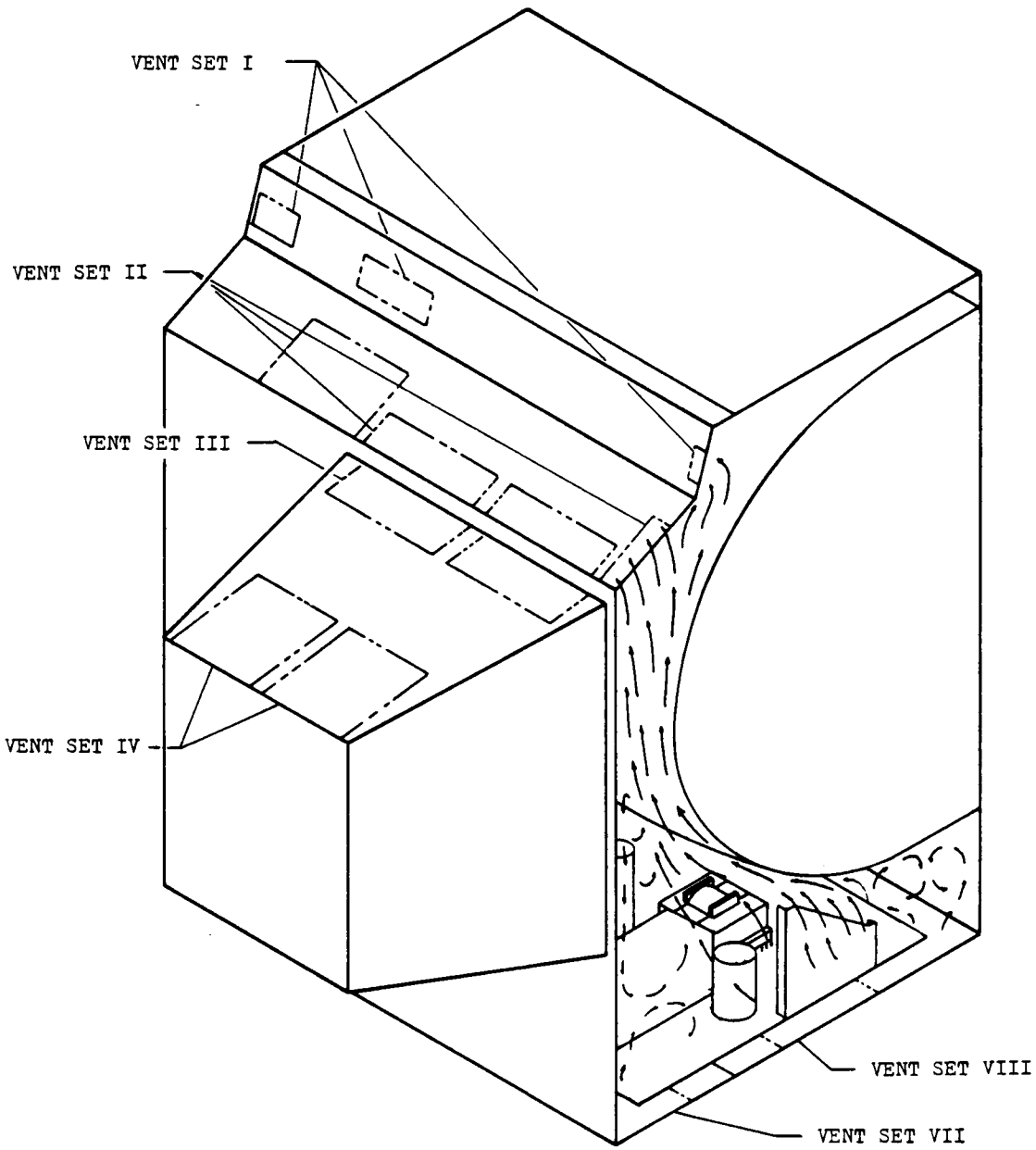
FIGURE 8.23. Air Temperature Gradients in Receiver With All Vents Closed

# 5. The Flow Visualization Results

## The Flow Visualization Results for the Baseline Receiver

The results of the flow visualization tests were recorded on a video tape for the baseline case with all vents open. Sketches based on these video tapes were drawn. For the baseline case, the receiver was operating under the standard conditions previously described. The arrow lengths represent the relative magnitudes of the flow velocities, but in the isometric views, the true arrow lengths are slightly distorted. The uncertainty for the flow velocities is on the order of 50%. The flow velocity estimates are made by placing a strip of graph paper on the picture tube and extension wall. By measuring the amount of time it takes a feature of the smoke pattern to move some length along the grid, it is possible to estimate the velocity.

Figure 8.24 shows a plane perpendicular to the picture screen at approximately 13 cm from the left side (looking at the screen) of the receiver. Ambient air is drawn in from the bottom cabinet vents (vent sets VII and VIII). Hot air leaves through the top cabinet vents (vent sets I and II). Much of the flow adjacent to the back cabinet wall is moving downward. The flow is transferring heat to the wall and is, thus, cooling, increasing in density, and




TEST CONDITIONS:

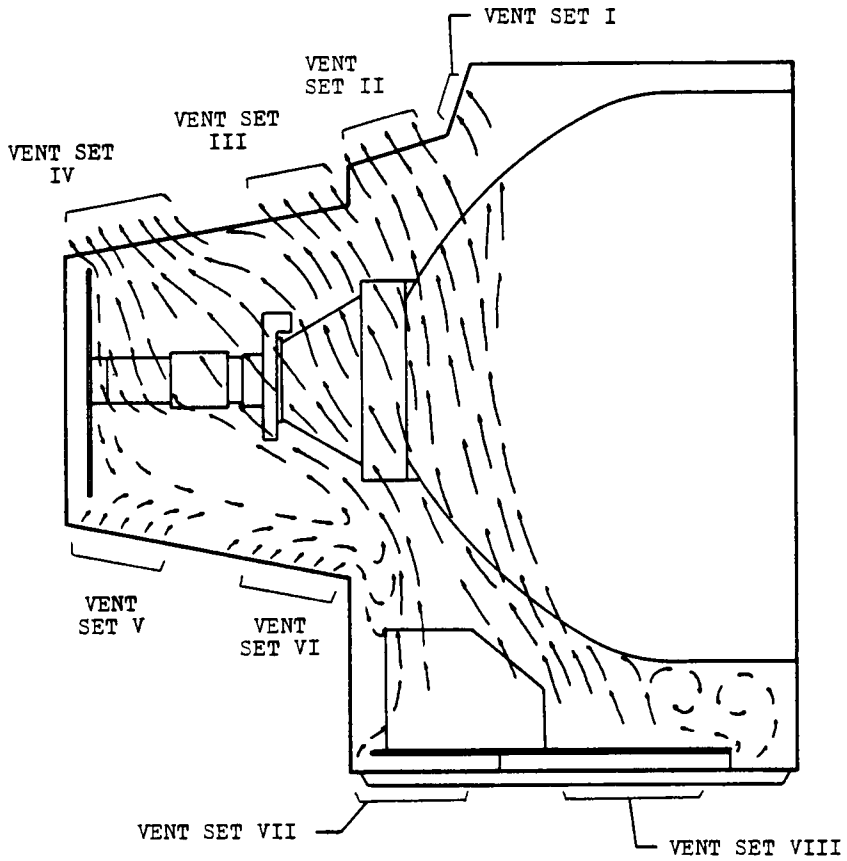
The results are for a picture and sound setting of no transmitter signal and no volume.

The picture control knobs labeled Color, Tint, Picture, Bright, and Sharp were set to their most clockwise position.

FIGURE 8.24. Typical Flow Pattern in Receiver, 13 cm From Left Side With All Vents Open

losing buoyancy. There is some small local recirculation at the forward most part of the receiver away from the components. The fastest flow is along the picture tube wall. This is the hottest flow according to the baseline air temperature measurements shown in Figures 8.20 (on page 122) and 8.21 (on page 123). Also, note that the sketch is a time average of the flow inside the receiver. Near the top of the receiver the flow velocity and direction changes with time. The most dramatic example of this unsteadiness is the flow adjacent to the upper back cabinet wall. This flow may be upward or downward because the shape of the recirculation zone is constantly changing. This is due in part to the flow separation from the upper half of the picture tube surface which creates areas of unsteady flow in the upper part of the cabinet as is clearly shown by the video tapes.

Figure 8.25 shows a plane perpendicular to the picture tube screen at approximately 18 cm from the left side of the receiver. The top extension vents (vent sets III and IV) are outlets for the heated air. The bottom extension vents (vent sets V and VI) are inlets. The incoming air from these vents does not appear to reach the main circuit board. Instead, it is entrained in the hot air flow from the main cabinet that spills into the extension. Thus, it does not appear that the extension inlet air has a cooling effect on components on the main circuit board.




NOTE:

Relative magnitude of velocity is given by arrow length.

Velocity Scale: $14\left(\frac{cm}{sec}\right)$/ cm

TEST CONDITION:

The results are for a picture and sound setting of no transmitter signal and no volume.

The picture control knobs labeled Color, Tint, Picture, Bright and Sharp were set to their most clockwise position.

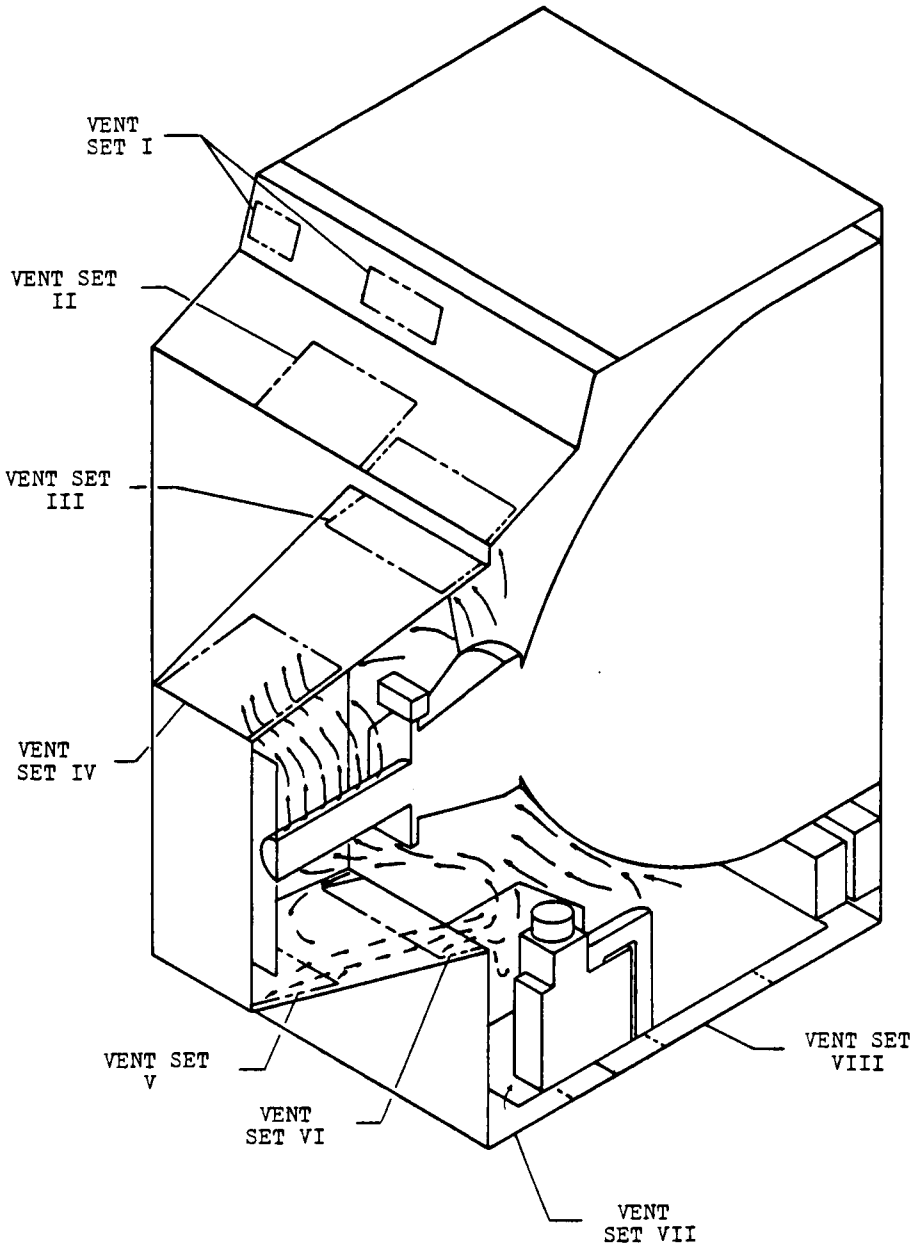
**FIGURE 8.25. Typical Flow Pattern in Receiver, 18 cm From Left Side With All Vents Open**

The air flow that separates from the picture tube is considerable. It appears to circulate around the picture tube neck and carry this additional energy out the top extension vents (vent sets III and IV). The video tapes show that there is a line of demarcation between the smoke-marked flow from the main cabinet and the unmarked air drawn from the extension bottom vents. This signifies that there is little mixing between the two flows until the forward part of the extension.

Figure 8.26 shows the flow in a plane perpendicular to the picture tube screen at the picture tube centerline. The most important feature shown in this sketch is the plume coming off the picture tube neck, which appears to behave as a horizontal heated cylinder.

Figure 8.27 shows the flow in a plane perpendicular to the picture screen at approximately 30 cm from the left side of the receiver. The results are identical to those shown in Figure 8.25. The air flow appears to be symmetric with respect to the picture tube centerline in the vicinity of the extension.

Figure 8.28 shows a plane perpendicular to the picture screen at approximately 41 cm from the left side of the receiver. Here the incoming air from vent set VII and some downward air flow adjacent to the wall mix and move forward just over the top of the main circuit board. As this flow gain energy, buoyancy forces create an upward

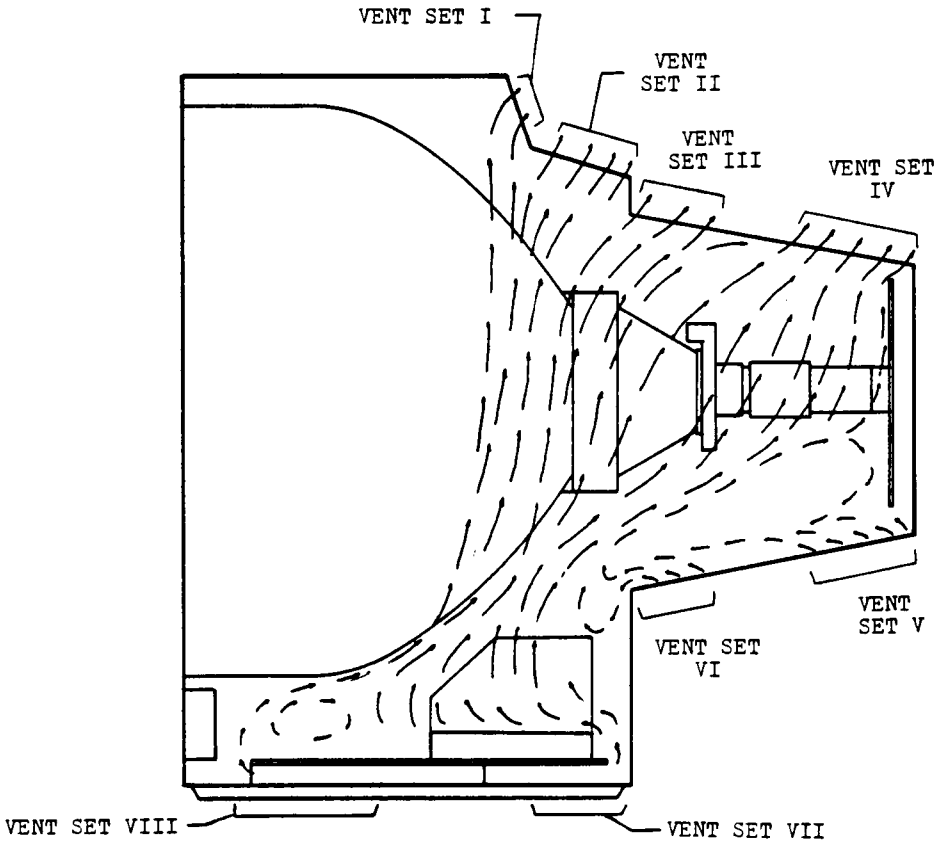



TEST CONDITION:

The results are for a picture and sound setting of no transmitter signal and no volume.

The picture control knobs labeled Color, Tint, Picture, Bright and Sharp were set to their most clockwise position.

FIGURE 8.26. Typical Centerline Flow Pattern in Receiver With All Vents Open




NOTE:

Relative magnitude of velocity is given by arrow length.

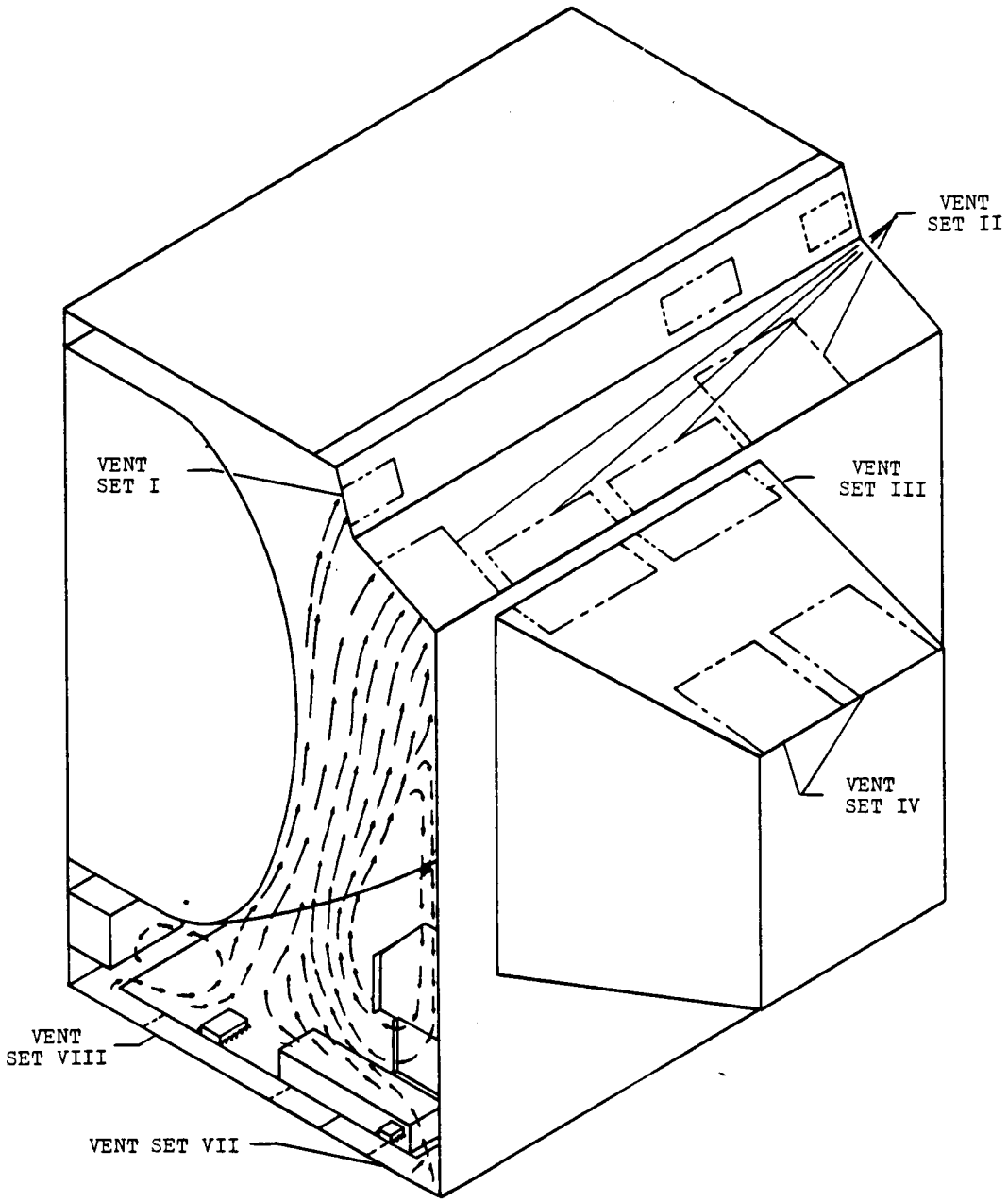
Velocity Scale: $14\left(\frac{cm}{sec}\right)$/ cm

TEST CONDITION:

The results are for a picture and sound setting of no transmitter signal and no volume.

The picture control knobs labeled Color, Tint, Picture, Bright and Sharp were set to their most clockwise position.

**FIGURE 8.27. Typical Flow Pattern in Receiver, 30 cm From Left Side With All Vents Open**




TEST CONDITIONS:

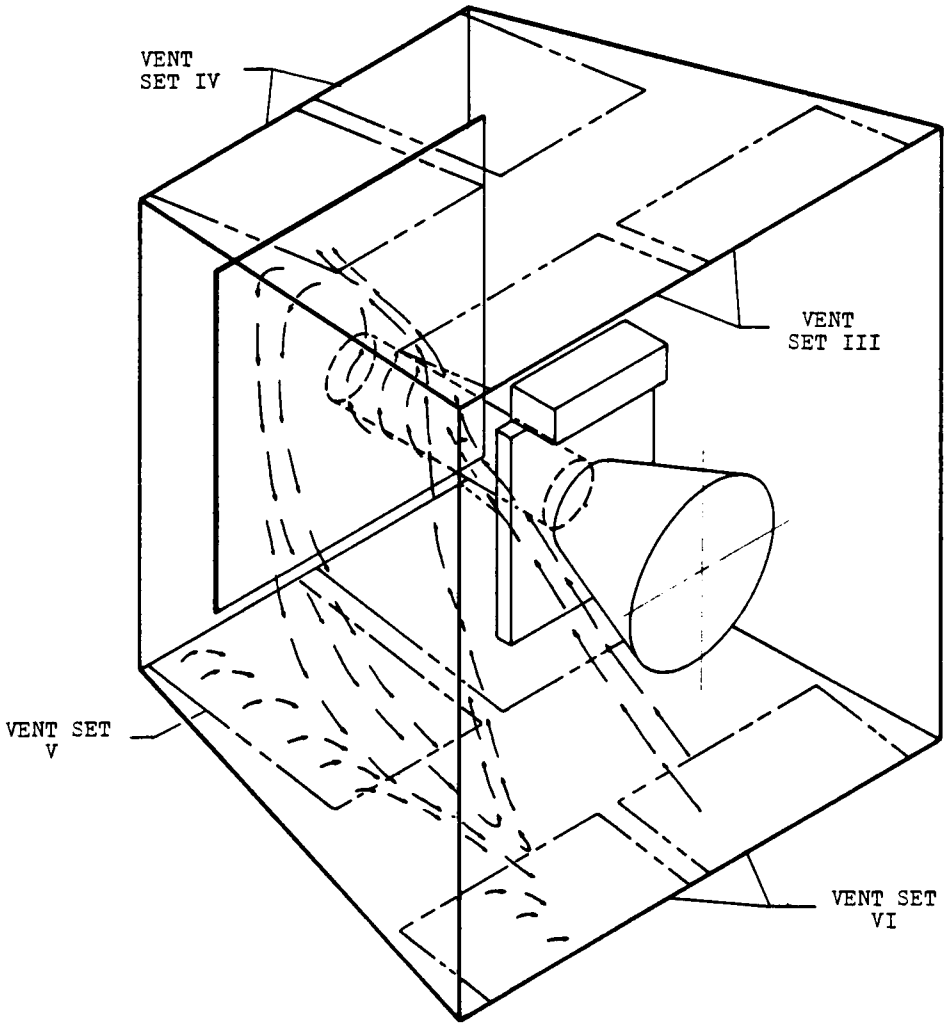
The results are for a picture and sound setting of no transmitter signal and no volume.

The picture control knobs labeled Color, Tint, Picture, Bright, and Sharp were set to their most clockwise position.

FIGURE 8.28. Typical Flow Pattern in Receiver, 41 cm From Left Side With All Vents Open

motion to generate a plume adjacent to the picture tube. Also, a plume generated by the hot components at the front end of the circuit board splits around the picture tube. Most of the flow moves upward and toward the back along the picture tube surface, but some of the plume moves forward adjacent to the bottom of the picture tube and recirculates in the forward section of the lower cabinet. Some air from vent set VIII is entrained in this flow while an the rest of the air flows back and is entrained by the plume. This is in the vicinity of components IC640 and R456.

Figure 8.29 shows a isometric sketch of the typical flow path in the extension. The recirculating flow in the extension is 3 dimensional. The picture tube neck acts like a heated cylinder and generates a plume of hot air. This plume and the air flow from the main cabinet try to escape through the top extension vents. Part of the air flow cannot escape because of insufficient vent area and is forced back toward the sides of the extension. This flow turns downward along the walls and forward in the extension. About 20% of the total air flow that entered the extension from the cabinet does not exit through the extension top vents. This is a crude estimate based on observation. The flow moves forward as it approaches the bottom and moves parallel with the incoming air from vent sets V and VI. There is some mixing of the flows as they




TEST CONDITION:

The results are for a picture and sound setting of no transmitter signal and no volume.

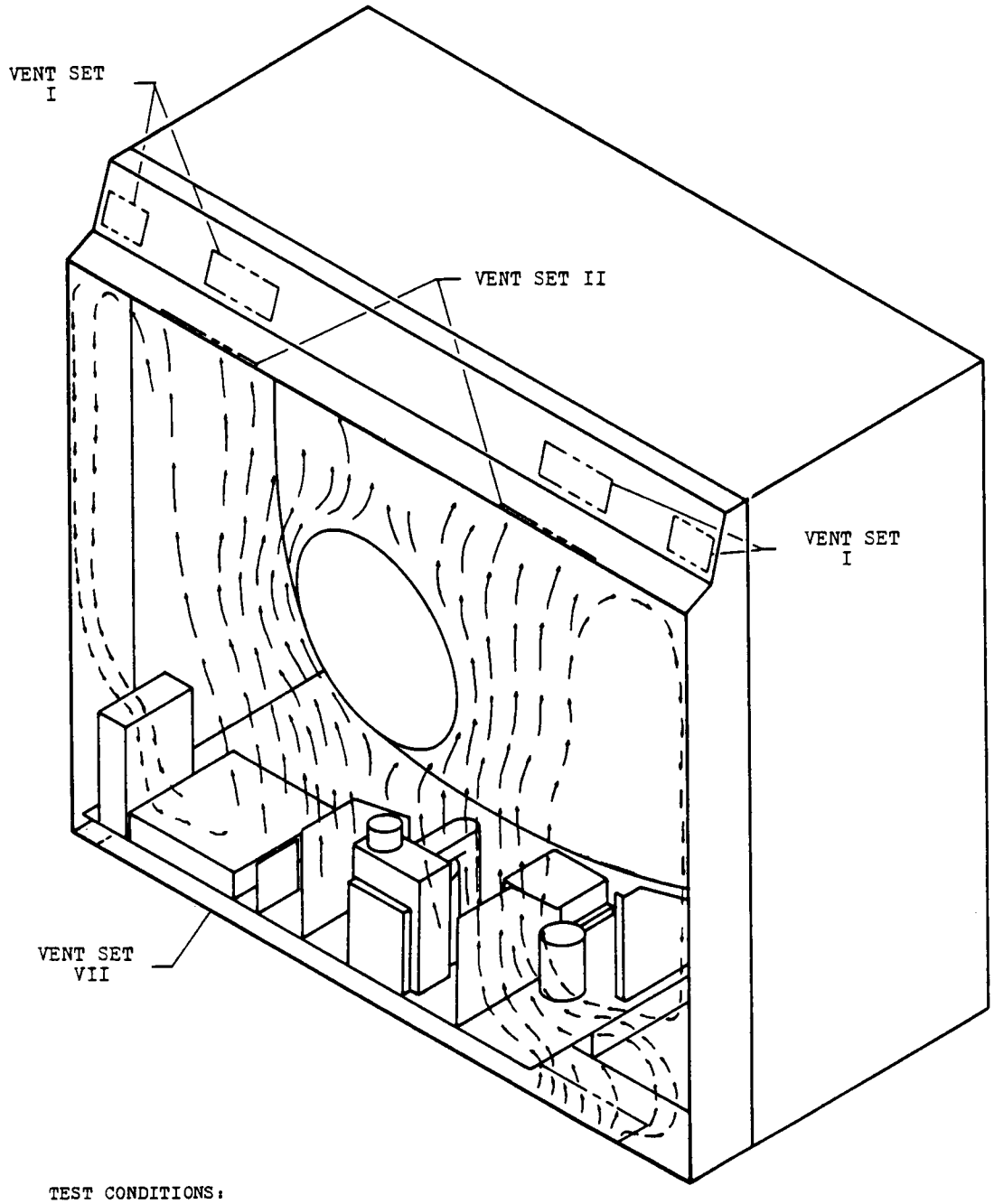
The picture control knobs labeled Color, Tint, Picture, Bright and Sharp were set to their most clockwise position.

**FIGURE 8.29. Typical Flow Path Through Extension With All Vents Open**

move further forward until they reach and are entrained by the hot plume from the main circuit board. The cumulative flow either leaves through the top extension vents or retraces the path previously described.

At the far aft end of the extension, the air between the small vertically mounted circuit board and the back wall of the cup is stagnant and marked with smoke. This indicates that little, if any, flow from the bottom extension vents reaches this area.

Figure 8.30 shows a plane parallel to the picture tube face approximately 26 cm from the front of the receiver. The hot plume from the main circuit board dominates the flow in the center of the receiver, but it helps to create two large recirculation zones on the left and right sides. These zones appear in Figures 8.24 (page 128) and 8.28 as recirculation adjacent to the back wall. The left side appears to be larger because of the offset of the circuit board to the right. The cooling effect of the walls causes a downward low velocity flow on the order of 2 to 3 cm/sec. On the left side, this flow mixes with incoming flow from the unmasked vents of sets VII and VIII. This flow is drawn toward the circuit board around the heat sinks for the switch mode regulator and the horizontal output transistor. On the right side, The flow mixes with some of the incoming air from vent sets VII and VIII. The flow moves toward the forward, center part of the circuit




TEST CONDITIONS:

The results are for a picture and sound setting of no transmitter signal and no volume.

The picture control knobs labeled Color, Tint, Picture, Bright, and Sharp were set to their most clockwise position.

FIGURE 8.30. Typical Flow Pattern Parallel to Picture Tube Face in Receiver with All Vents Open

board. Thus, it appears that the left side of the circuit board would be more sensitive to increases in mass flow through vent sets VII and VIII than the right side.

Summary of the All Vents Open Results

From the flow visualization tests, the general flow pattern can be described as follows. Air is drawn in from the bottom extension and cabinet vents (sets V, VI, VII, and VIII). Air flow velocity at the these vents is on the order of 2.5 cm/sec. Air from the bottom cabinet vents is drawn over the circuit board. As it passes the hot components, it accelerates upward until a maximum velocity of about 10 cm/sec is reached around the horizontal centerline of the picture tube. Some of the flow moves vertically around the picture tube and exits out the top cabinet vents (sets I and II). But, a large amount of the air flow separates from the picture tube and spills into the cabinet extension. This flow either exits through the top extension vents (sets III and IV) or recirculates in the upper half of the extension as shown in Figures 8.25 (page 130), 8.26 (page 132), 8.27 (page 133), and 8.29. The air flow that does not exit through the top extension vents is forced toward the sides of the extension. This flow moves downward along the walls and mixes with part of the incoming air from vent sets V and VI. The air flow in the lower half of the extension also moves forward and

either enters the main cabinet or is entrained by the air flow entering the extension from the cabinet.

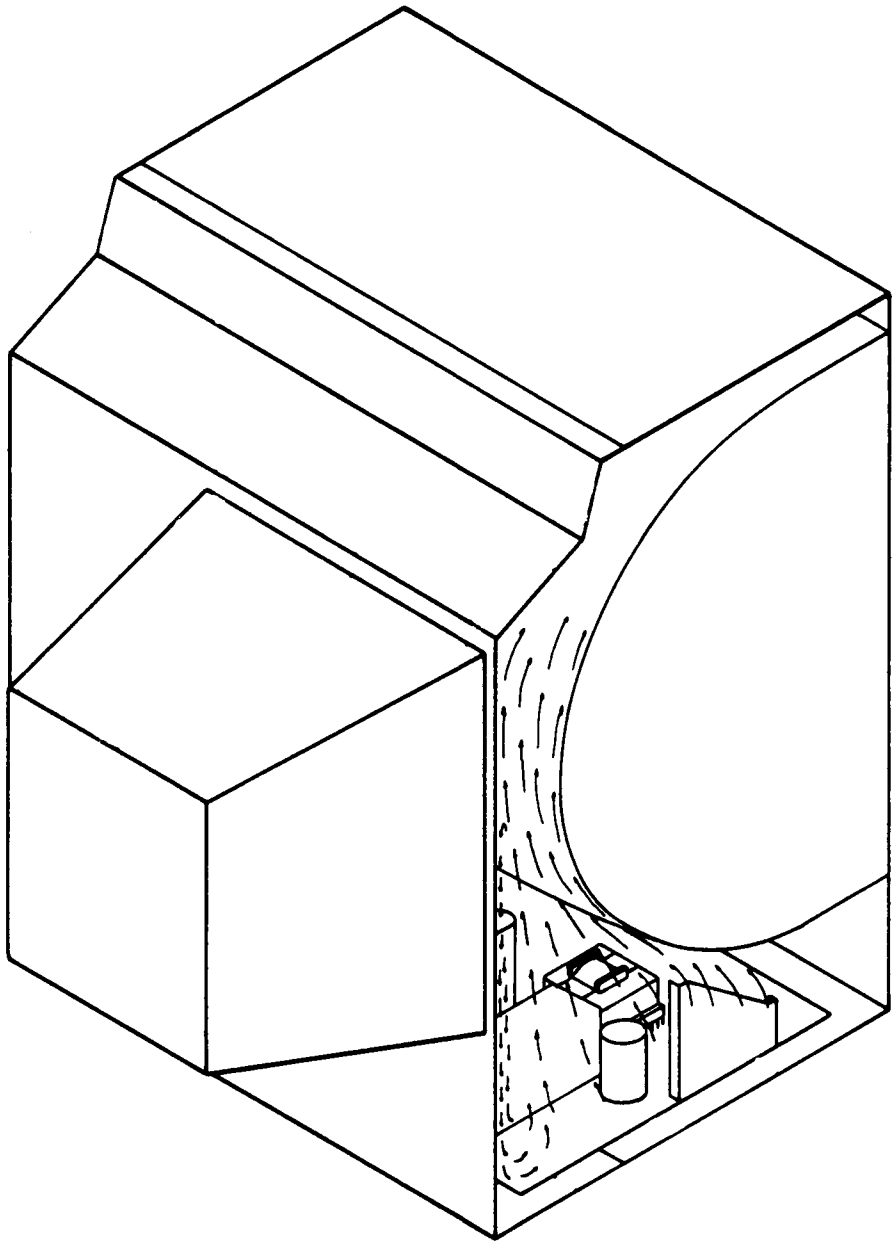
Some flow recirculates in the central areas of the main cabinet on either side of the extension entrance. Downward flow is present along the side walls and back wall of the main cabinet. The walls appear to cool the hot air and, thus, cause a downward flow.

The flow visualization helps explain some of the results of the temperature tests. As the temperature data indicated, there is a plume adjacent to the picture tube and there is a great deal of mixing at the top of the cabinet along with some cooling of the flow adjacent to the cabinet walls.

Flow Visualization With All Vents Blocked

In contrast to the all vents open case, all vents were blocked and the flow visualization tests were repeated. The video camera was not capable of recording the flow details because the smoke distributes itself uniformly throughout the cabinet. This appears as a haze on video tape, but by close visual inspection of the flow in the laboratory, it is possible to examine the flow patterns. Sketches based on the observations were drawn during the testing.

Figure 8.31 shows a plane approximately 13 cm from the



TEST CONDITIONS:

The results are for a picture and sound setting of no transmitter signal and no volume.

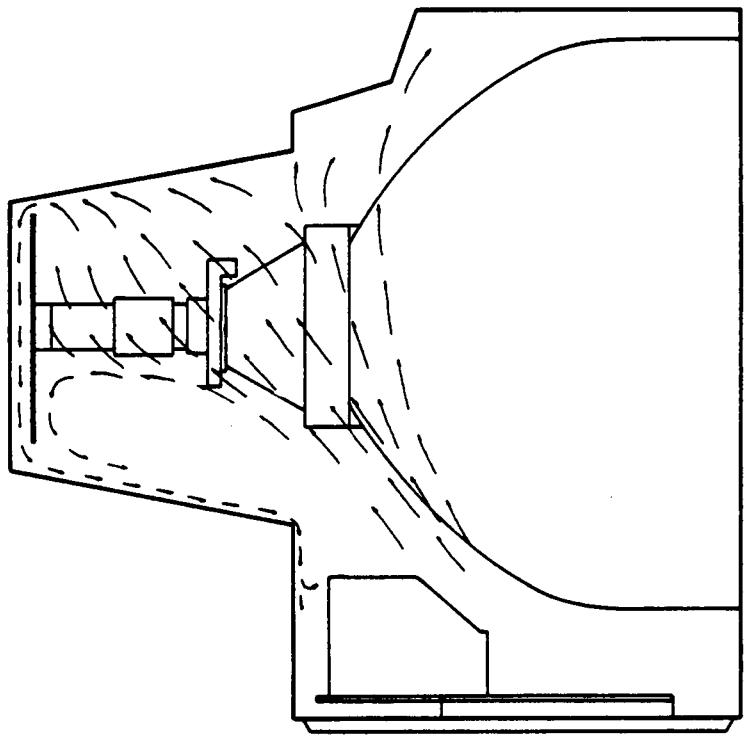
The picture control knobs labeled Color, Tint, Picture, Bright, and Sharp were set to their most clockwise position.

FIGURE 8.31. Typical Flow Pattern in Receiver, 13 cm From Left Side With All Vents Closed

left side (looking at the picture screen) of the receiver. The air adjacent to the wall cools and moves downward at a velocity of 2 - 3 cm/sec. The flow pattern is similar to that found in the baseline case (see Figure 8.24 on page 128) in that the flow still accelerates upward from the main component board, but the plume is thicker and the downward flow is slower along the back wall of the cabinet.

Figure 8.32 shows a plane approximately 18 cm from the left side of the receiver. Some of the flow separates from the picture tube and spills into the extension. The recirculation at the bottom of the extension is less and the air flow into the extension is less than in the baseline case (see Figure 8.25 on page 130). Also, there is some air flow between the vertical circuit board and the back wall of the extension. There is a boundary layer of relatively cool air moving toward the front of the extension. This flow moves forward into the cabinet and is entrained by the plume from the main circuit board or moves downward to the bottom of the cabinet.

Figure 8.33 shows a plane at the picture tube centerline. There is a plume generated by the picture tube neck and some recirculation underneath the neck similar to the all vents open case of Figure 8.26 (see page 132).



NOTE:

Relative magnitude of velocity is given by arrow length.

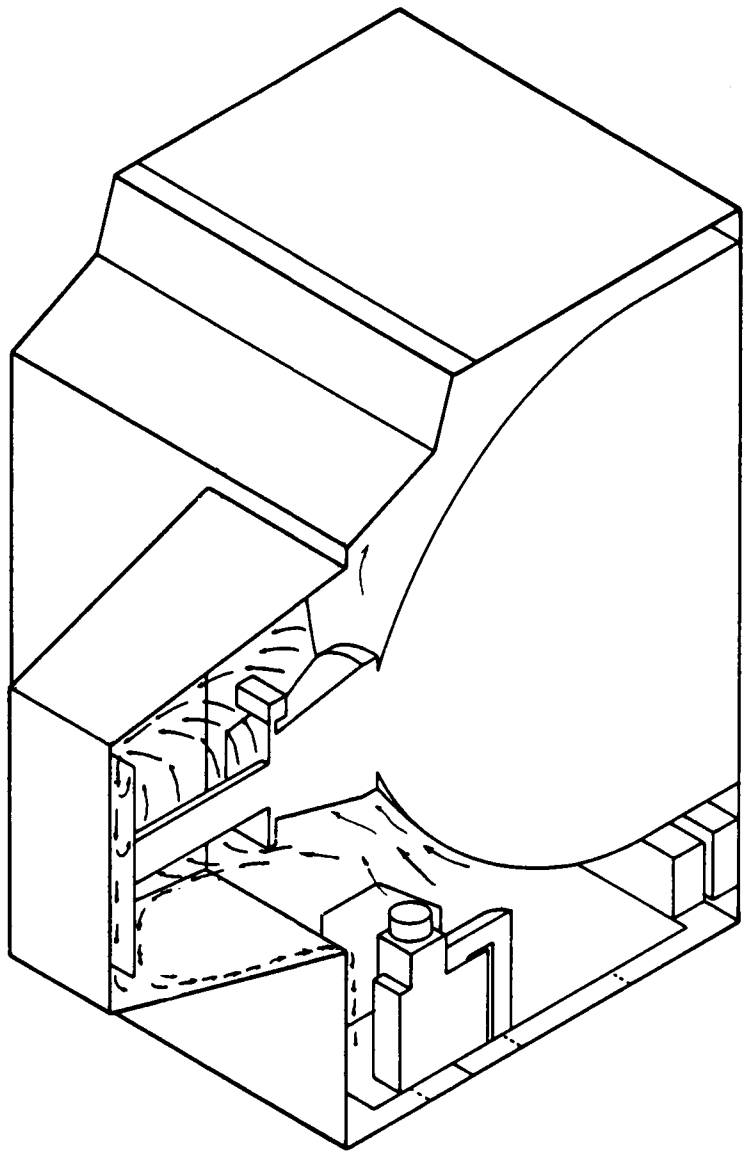
Velocity Scale: $14\left(\frac{cm}{sec}\right)$/ cm

TEST CONDITION:

The results are for a picture and sound setting of no transmitter signal and no volume.

The picture control knobs labeled Color, Tint, Picture, Bright and Sharp were set to their most clockwise position.

FIGURE 8.32. Typical Flow Pattern in Receiver, 18 cm From Left Side With All Vents Closed



TEST CONDITION:

The results are for a picture and sound setting of no transmitter signal and no volume.

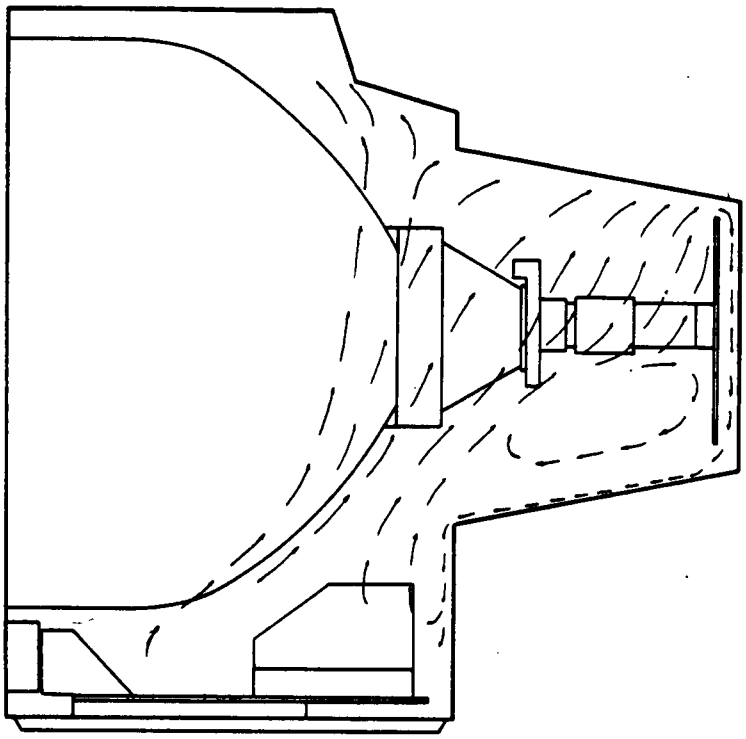
The picture control knobs labeled Color, Tint, Picture, Bright and Sharp were set to their most clockwise position.

FIGURE 8.33. Typical Flow Pattern in Receiver Centerline With All Vents Closed

Figure 8.34 shows a plane approximately 30 cm from the left side of the receiver. This is identical to the opposite side of the extension. The recirculation in the extension spans the width of the lower section of the extension. In comparison to the baseline case, the recirculation region is larger and occurs at a position lower in the extension.

Figure 8.35 shows a plane approximately 41 cm from the left side of the receiver. This has the same flow trends as the baseline case, except now the downward air flow velocities are 1 - 2 cm/sec greater than the downward air flow velocities of the baseline case (see baseline case in Figure 8.28 on page 134). The corner between the angled step and the back wall of the cabinet redirects some of the upward moving air flow downward. As a result, the vertical height of the recirculation zone has increased in comparison to the baseline case.

Figure 8.36 shows the typical flow pattern in the extension. The recirculation is greater. A boundary layer of cool air is formed at the bottom of the extension. This flow moves toward the front of the receiver where it is entrained by the flow from the main cabinet to the extension. Unlike the all vents open case, the recirculation zone extends into the lower part of the extension. There is less air flow into the extension from the main cabinet. The air flow out the



NOTE::

Relative magnitude of velocity is given by arrow length.

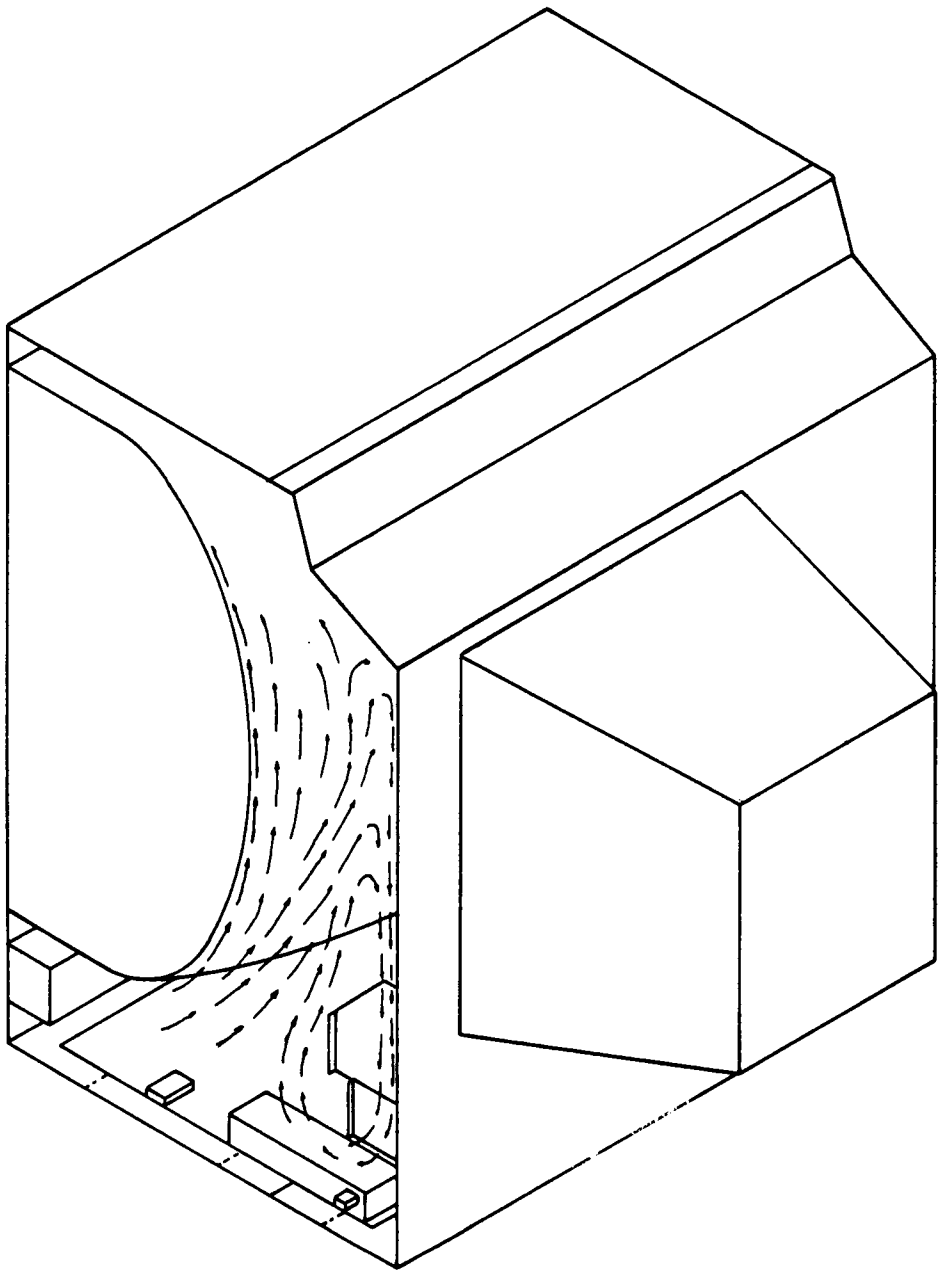
Velocity Scale: $14\left(\frac{cm}{sec}\right)$/ cm

TEST CONDITION:

The results are for a picture and sound setting of no transmitter signal and no volume.

The picture control knobs labeled Color, Tint, Picture, Bright and Sharp were set to their most clockwise position.

FIGURE 8.34. Typical Flow Pattern in Receiver, 30 cm From Left Side With All Vents Closed

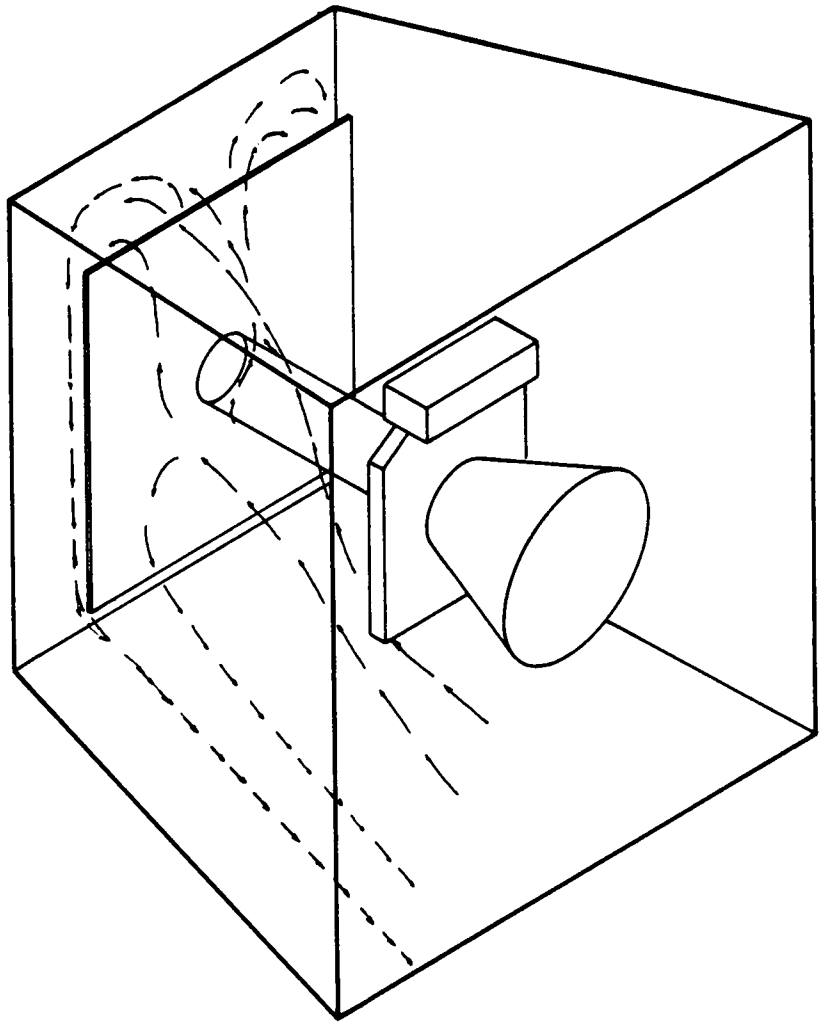


TEST CONDITIONS:

The results are for a picture and sound setting of no transmitter signal and no volume.

The picture control knobs labeled Color, Tint, Picture, Bright, and Sharp were set to their most clockwise position.

FIGURE 8.35. Typical Flow Pattern in Receiver, 41 cm From Left Side With All Vents Closed



TEST CONDITION:

The results are for a picture and sound setting of no transmitter signal and no volume.

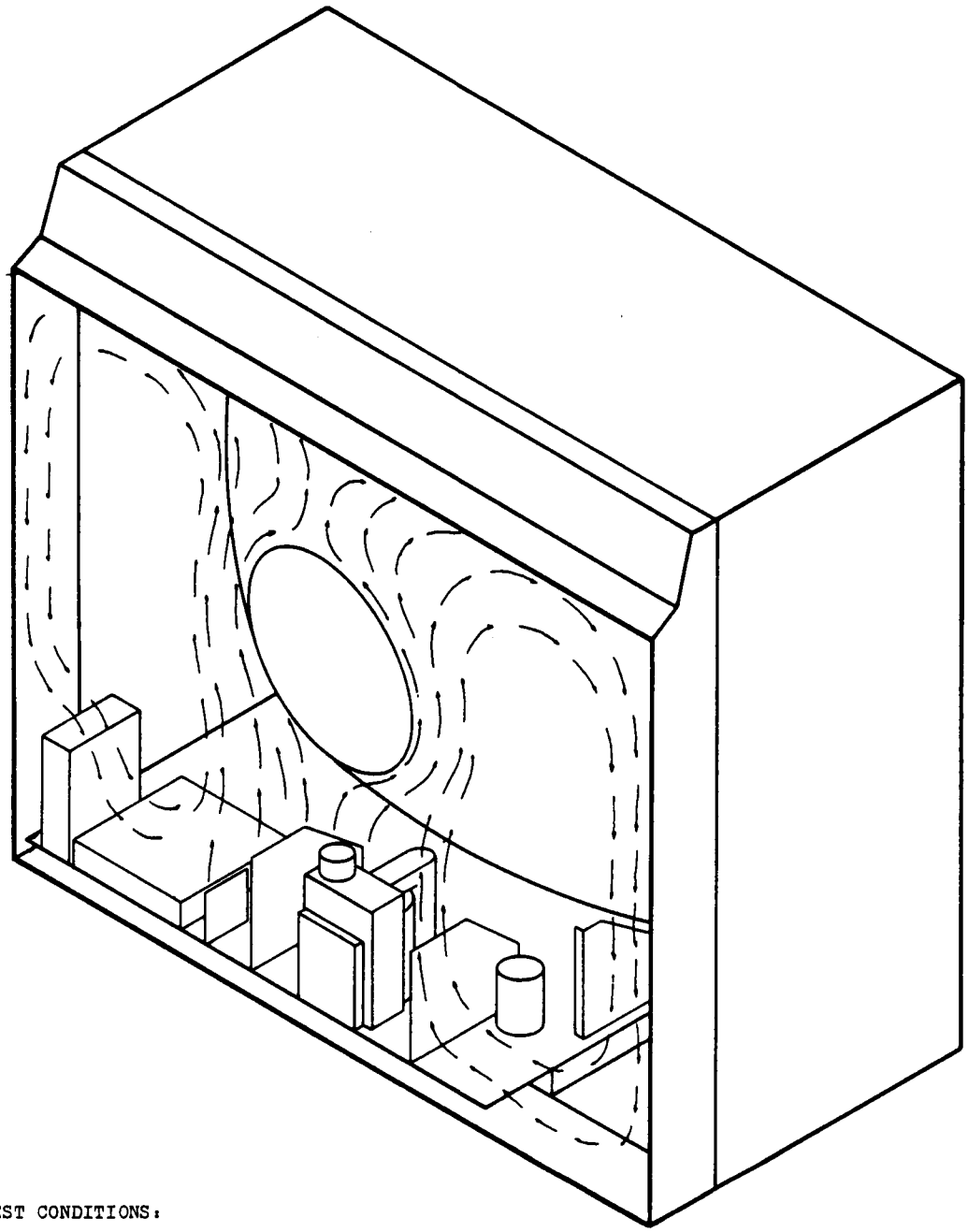
The picture control knobs labeled Color, Tint, Picture, Bright and Sharp were set to their most clockwise position.

FIGURE 8.36. Typical Flow Path Through the Extension (Cup) With All Vents Closed

lower third of the extension is either entrained in the plume from the main circuit board or sinks toward the bottom of the cabinet. This may be reducing the temperature increase of the local components like IC580, T504, and Q501, but their temperatures are already unacceptably high. The air flow out the extension may also be reentering the extension by mixing with the part of a plume from the main circuit board that enters the extension.

Figure 8.37 shows a plane parallel to and approximately 26 cm from the front of the receiver. The plume to the main circuit board still dominates the center section of the receiver, but now the downward flows at the left and right side cabinet walls are twice as fast as the baseline case (4 - 10 cm/sec versus 1 - 5 cm/sec for the baseline case as shown in Figure 8.30 on page 138).

A summary of the flow visualization data for the all vents closed case is presented in Figure 8.38. It shows the general flow trend in the receiver. Compared to the baseline case, the 3 main recirculation zones (2 at the sides of the cabinet and 1 in the extension) appear in the same general location. Since the vents are blocked, the recirculation is stronger. As vents are blocked, the all vents open case flow pattern must change to be more like the extreme case of all vents blocked. Heated air

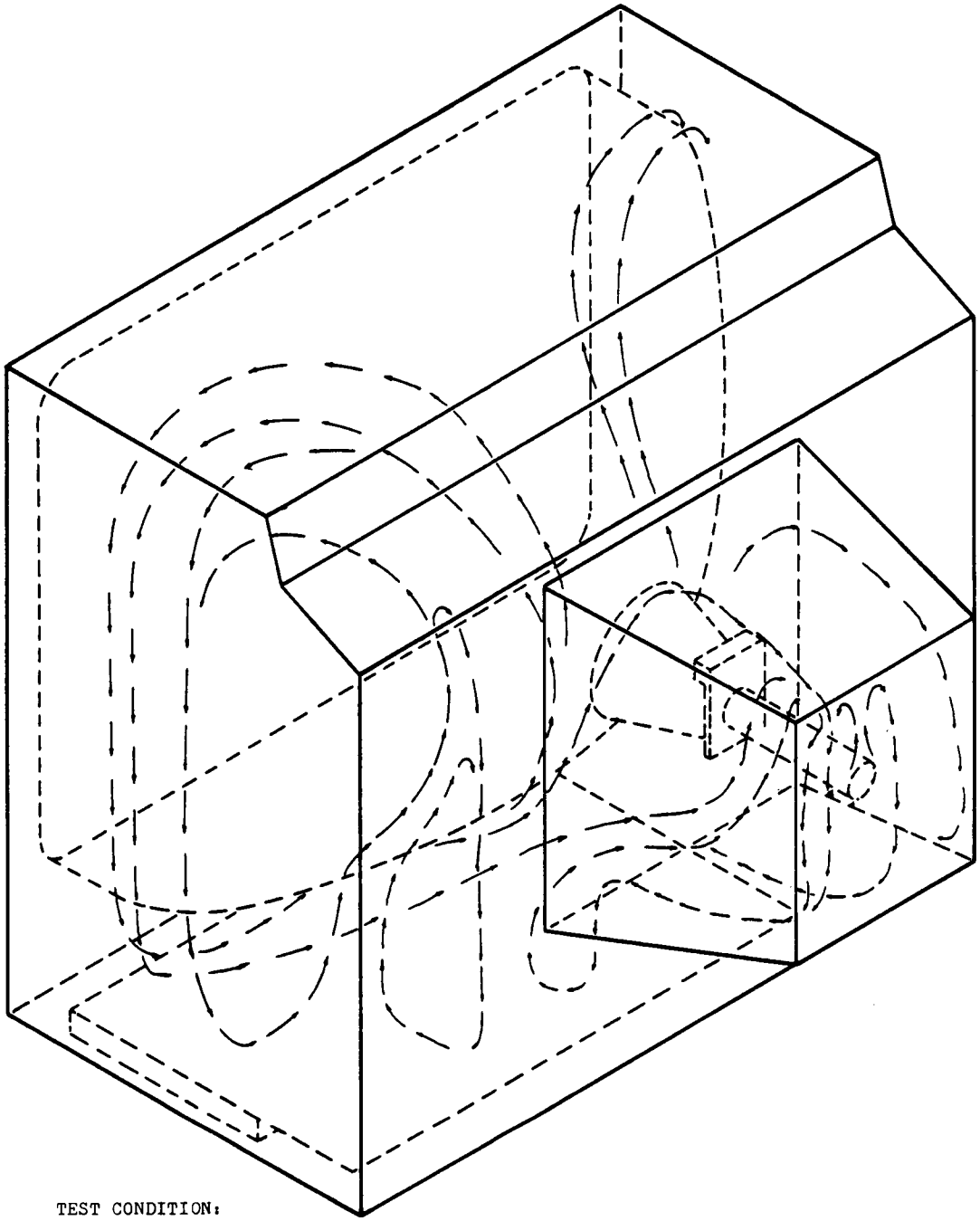


TEST CONDITIONS:

The results are for a picture and sound setting of no transmitter signal and no volume.

The picture control knobs labeled Color, Tint, Picture, Bright, and Sharp were set to their most clockwise position.

FIGURE 8.37. Typical Flow Pattern Parallel to Picture Tube Face in Receiver With All Vents Closed



TEST CONDITION:

The results are for a picture and sound setting of no transmitter signal and no volume.

The picture control knobs labeled Color, Tint, Picture, Bright and Sharp were set to their most clockwise position.

FIGURE 8.38. Typical Flow Path in Receiver With All Vents Closed

will rise by the buoyancy force generated. If there is no outlet at the top of the cabinet, the flow will be forced downward to create or strengthen some form of recirculating flow between the upward plume and the downward flow. Even for a less extreme case, it is expected that blocking any top vents would also increase recirculation.

### 6. Correlation of the Results From the Temperature and Flow Visualization Tests

Because of the component temperature improvements when vent sets V and VI were blocked, a set of flow visualization tests were performed to examine the flow inside the extension for this case. The test conditions were identical to the previous flow visualization tests. There are no sketches. The following comments about the extension flow are based on visual observations in the laboratory.

For vent set V blocked, flow moving into the extension from the main cabinet appears to decrease. This modification improves the mixing of the inlet air from vent set VI and the spill into the extension and may be why the top extension air and picture tube neck temperatures registered a decrease of 2.7°C and 1.6°C. A large stagnation zone is created in the area of vent set

V, but there are no components in this area. The air temperature at the bottom of the extension is not significantly larger. Continuity (for negligible compressibility) dictates that if vent set V is blocked, then either the mass flow out vent sets III and IV must drop, the mass flow through vent set VI must increase, the mass flow from the cabinet to the extension must increase or there must be some combination of changes such that mass in equals mass out. For this condition, the mass flow through vent set VI has increased, but there also appears to be less flow from the cabinet to the extension and no significant change in the air flow out the top extension vents (sets III and IV). The decrease in air flow entering the extension from the main cabinet is good because it partially decouples the cabinet (hot air) and the extension air flows.

For the case of blocking vent set VI only, the flow coming in from vent set V does appears to increase slightly. The incoming air mixes with the incoming spill further back in the extension than for the baseline all vents open case. This creates the impression that the air flow from the cabinet to the extension has increased. Also, this could be the reason for no temperature change in the bottom extension air temperature and a small (0.9°C) decrease in the top extension air temperature.

There appears to be no visible change in the mass flow out the top extension vents.

From the flow visualization cases examined, it is possible to at least partially explain some of the temperature patterns of the blocked vent and blocked extension tests. All top vents sets (I, II, III, and IV) are outlets for the heated air. Closing off top vents should increase the recirculation around the picture tube and/or in the extension. An indication of this would be the increase in the temperatures of the components mounted on the forward part of the main circuit board. The components on the forward right section of the main circuit board tend to experience either no improvement or a degradation in reliability when either vent set I, II, III, IV, or combinations of I, II, III, and IV are blocked. The right side should be worse than the left because vent sets VII and VIII are completely masked by the right side of the circuit board and only partially masked by the left side. The flow visualization tests show that the air from vent sets VII and VIII flowing past the left side heat sinks. Moreover, the blocked vent tests for vent set VII and VIII confirm the importance of the air flow from these vents for component cooling in the board region adjacent to the vent sets. The effect of blocking vent set VII and later VIII also imply that unblocked vents partially compensate for the blockage of

inlet vents. Blocking either vent set VII or VIII led to dramatic temperature increases on the section of the main circuit board that was over the blocked vent set and decreases on the section that was over the unblocked set. Theory would say that there is no improvement in the chimney effect. Since vent sets VII and VIII are the lowest vents in the cabinet, this modification might even reduce the effect because a larger fraction of the air in would enter through the extension bottom vents and increase the short circuiting of the chimney effect. Either there is an increase in the mass flow through the unblocked bottom vent or there is an improvement in the air flow pattern over the section of the circuit board adjacent to the unblocked vent set. If there is a negligible increase in the pressure loss across the unblocked bottom vent set (flow velocities are so low that this seems reasonable), and since the power dissipation is constant, then the energy of the air is the same as in the all vents open case and the air would be heated to the same or higher temperatures (when compared to the baseline case). The heated air flow would develop roughly the same magnitude of buoyancy forces and would, thus, reach the same upward velocities with the same air density. The end result is that the mass flow out the top vents would be the same as before. Continuity would dictate that the

mass flow out be matched by mass flow in through the remaining unblocked vents.

Consider the alternative, the air flow pattern is improved with no increase in air flow. Vent set VII represents 32.4% of the total inlet vent area while vent set VIII represents 40.6% (see Figure 3.3, page 14); thus, the mass flow would decrease by at least this percentage and, since the energy dissipation is fixed, the air temperatures everywhere should increase along with the buoyancy force and the upward velocity. For vent set VII blocked, the experimental data shows a 4.2°C increase in the bottom cabinet air temperature and a 0.8°C increase at the top of the cabinet, but there is no increase in the extension air temperatures. For vent set VIII blocked, the bottom air temperature increased by 1.7°C and the top cabinet air temperature remained constant. Also, the top extension air temperature decreased by 1.5°C and the bottom extension air temperature remained constant. The flow visualization sketches for the baseline case show that in the vicinity of the top thermocouple the flow in the center of a plume from the circuit board. The implication of the air temperature data is that there is a combination of an increase in air flow and an improvement in the amount of energy transfered to the air. If this is the case then it is unwise to randomly add inlet vents during design phase of the packaging of the receiver. To

maximize the effect of an individual vent, the number of vents must be minimized to a certain extent. In the extreme case, if the number of inlet vents are reduced too much, the pressure loss across the vents will become significant (because of increased flow velocities required to maintain a given mass flow rate) and will reduce the chimney effect.

## 7. Numerical Simulator Results

Using the computer program described in chapter VI, the all vents open case was modeled. The output is shown in Figure 8.39. The power dissipation was 21.5 cal/sec or approximately 90 watts. The ambient temperature was 20°C and the average wall temperature was taken to be 27°C. The ratio of energy convected to the air that leaves through the vents to the total energy convected to the enclosure air is n. This ratio was calculated to be 0.564. There was not possible to verify the accuracy of the ratio, but using this value of n in the computer program gives plate and air temperatures of 55.1°C and 30.7°C which are close to the estimated average circuit board and cabinet air temperatures of 54.0°C (based on the observation and temperature measurements of the main circuit board during the initial part of the experimental

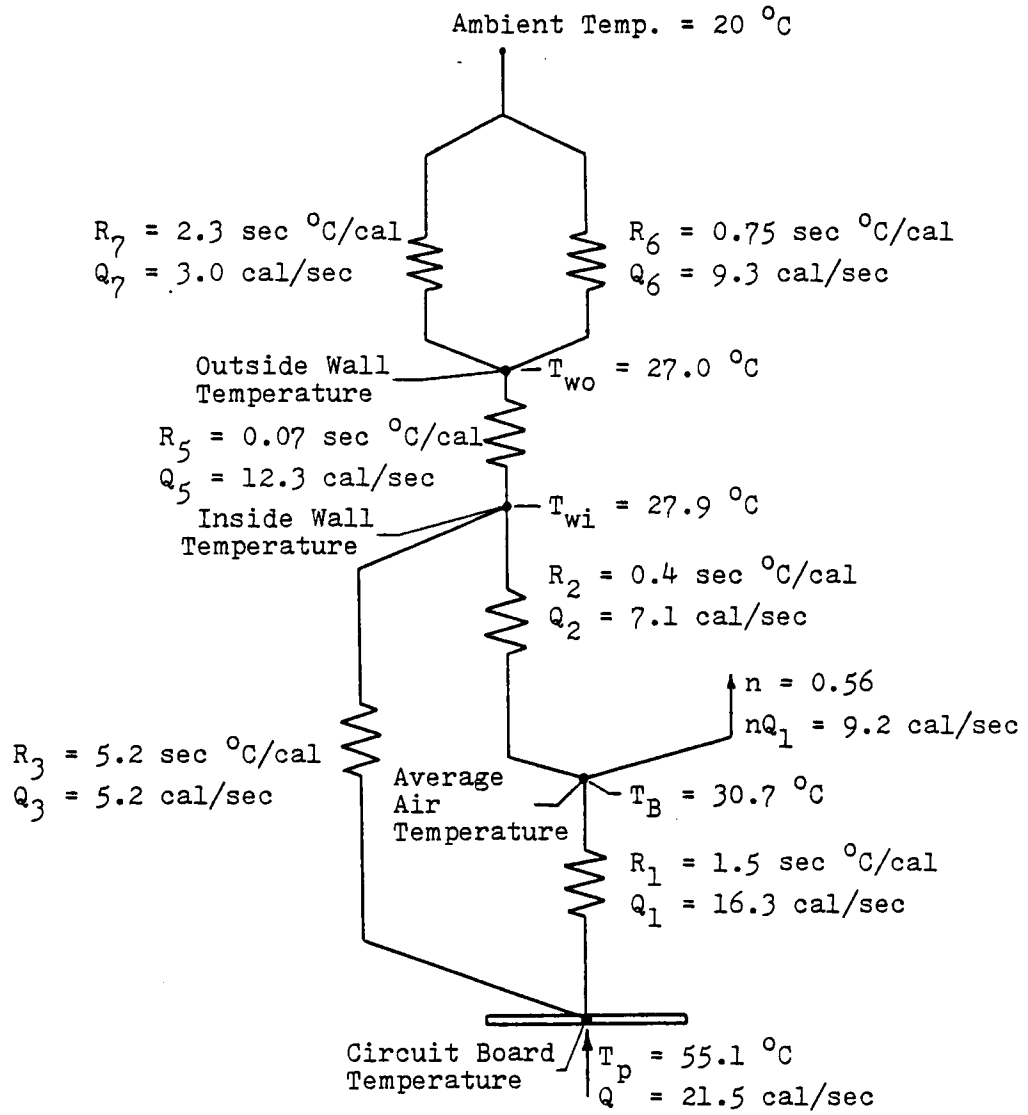



FIGURE 8.39. Thermal Model Results For Base Case With All Vents Open

study) and 30.7°C (average temperature based on air temperature measurements).

For the all vents closed case ( n=0.0 ), the results are also good. The average air temperature increase is about 9.1°C, which corresponds well with the 7 - 10°C increases in cabinet air temperature measured for the all vents blocked case. Moreover, the circuit board temperature increased by 8.0°C, the outside wall temperatures increased by 5.1°C, and the inside wall temperature increased by 5.8°C. These temperatures are of the same magnitude of temperature changes measured in the actual receiver between the all vents open case and the all vents blocked case. The results of this are shown in Figure 8.40. If the circuit board temperature change is representative of the component temperature changes in a receiver; then, 8°C can be added to the measured temperatures of the components for the baseline case. Table 8.7 shows how the temperature increase would affect selected integrated circuit and transistor component reliabilities.

A set of parametric studies were performed to examine what parameters would cause the largest changes in the enclosure wall, air, and circuit board temperatures. First, the wall thermal conductivity was varied. These results are shown in Figure 8.41. This shows that for all vents open, that as the wall thermal conductivity

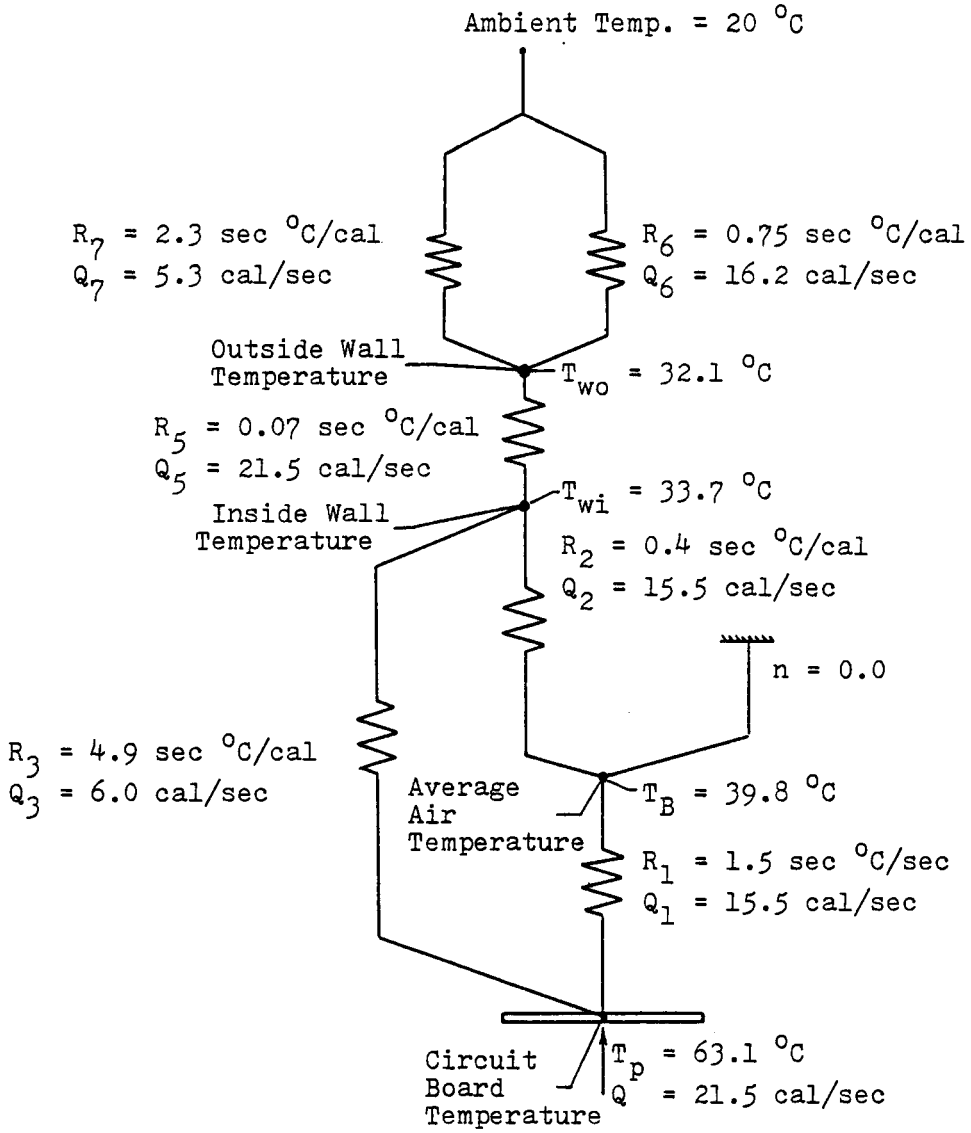



FIGURE 8.40. Thermal Model Results For All Vents Closed

TABLE 8.7. Increases in Integrated Circuit and Transistor Temperature and Failure Rate Predicted By the Numerical Simulator For an All Vents Blocked Test

| Component | Operating Temperature (°C) | Component Failure Rate Increase (%) |
|---|---|---|
| IC310 | 49.2 | 112 |
| IC640 | 71.7 | 117 |
| IC201 | 80.8 | 64 |
| IC202 | 67.2 | 108 |
| IC580 | 58.6 | 109 |
| Q400 | 62.5 | 19 |
| Q501 | 77.6 | 26 |

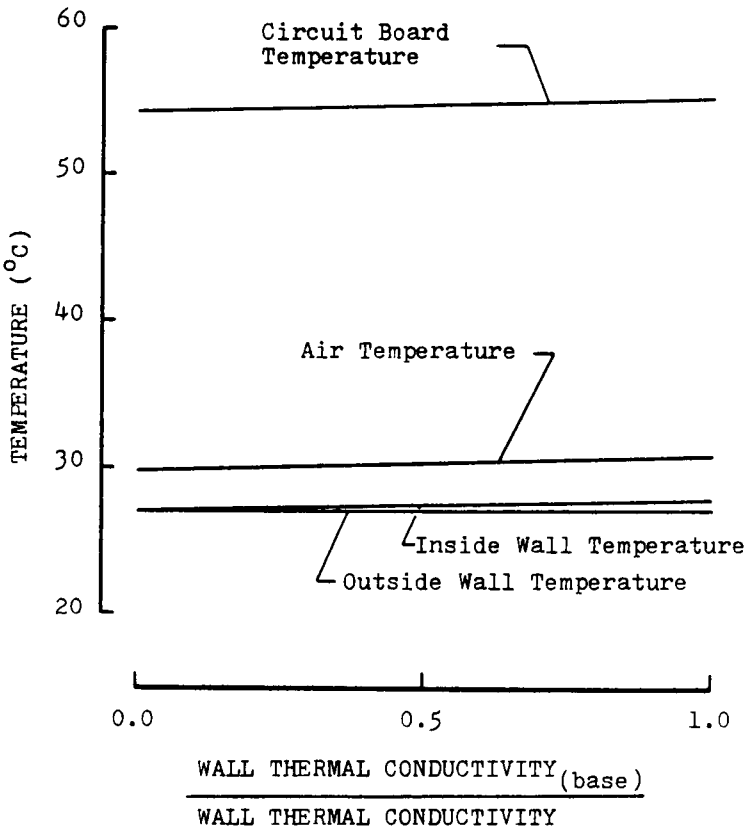



FIGURE 8.41. Temperature Sensitivity to Enclosure Wall Thermal Conductivity With All Vents Open

becomes infinitely large, the circuit board temperature decreases by about 1°C which would represent only a 1 - 5% increase in component reliability. If the radiative resistances drop by increasing the combined emissivities of the cabinet and the plate, a significant drop in plate temperature can be achieved. Typically, the emissivity is a function of temperature, but for this study, it is assumed to be a constant. Figure 8.42 shows that doubling the combined emissivity from 0.12 to 0.24 can cause the circuit board temperature to decrease by about 5°C, which corresponds to a 10 - 30% reliability improvement.

One potential improvement could be the addition of internal fins to the inside wall of the cabinet. The optimal design of such fins, however, is not a trivial problem. This would reduce the thermal resistance of the walls, but they would also cause a pressure loss between the inlet and outlet that would reduce the amount of air flow so the energy fraction, n, would be reduced. Figure 8.43 shows that the circuit board temperature is not sensitive to this modification for a drop in n to 0.50. As the convective resistance of the cabinet walls drops to a quarter of its base case value, the plate temperature drops to 54.1°C.

Another possible method of improving the cooling are to add more vent area or improve the chimney effect. These methods can be investigated by varying the ratio of

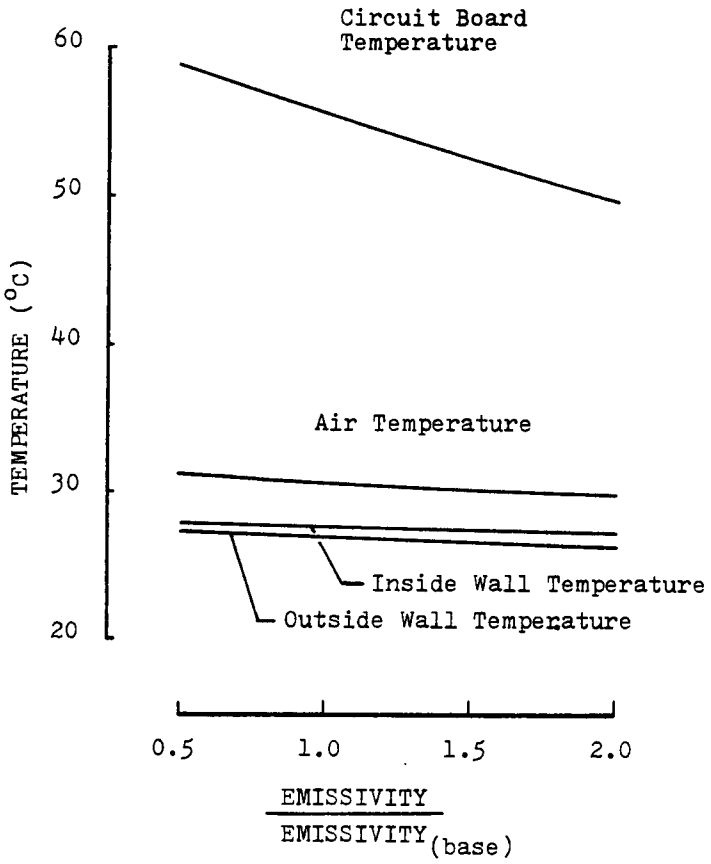



FIGURE 8.42. Temperature Sensitivity to Enclosure Wall and Circuit Board Emissivity

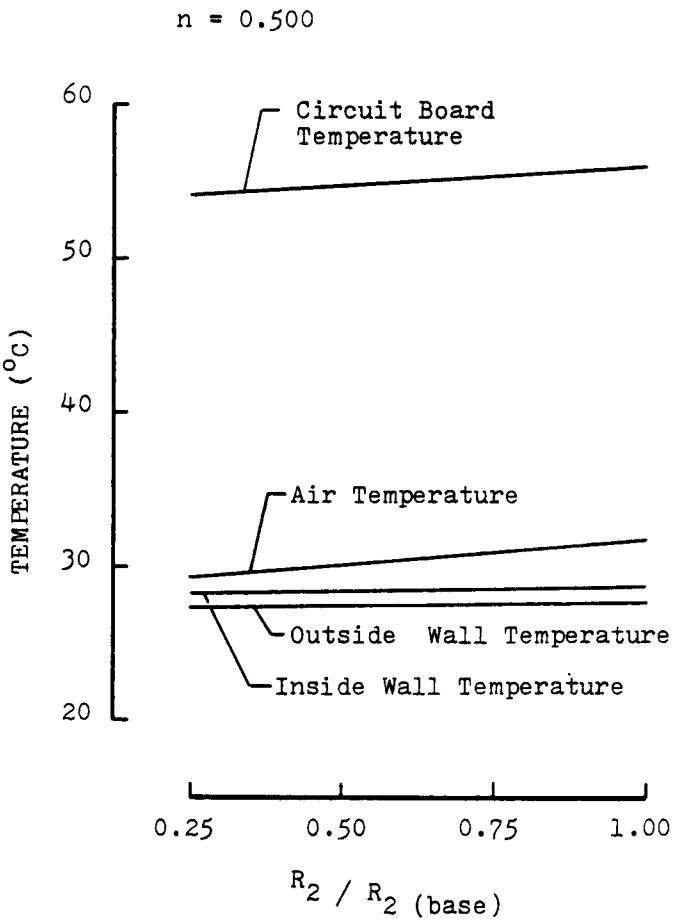



FIGURE 8.43. Temperature Sensitivity to Enclosure Wall Heat Transfer Coefficient

the energy convected to the air that leaves through the vents to the total amount of energy that is convected to the enclosure air (n). Figure 8.44 shows this trade off. Again the circuit board temperature decrease is on the order of 4°C, which corresponds to a 7 - 20% improvement in the integrated circuit and transistor reliabilities.

Finally, a sensitivity study was performed with all vents closed. Figure 8.45 shows that improving the circuit board heat transfer coefficient can have a significant impact on the circuit board temperature. Doubling the circuit board heat transfer coefficient (or halving the thermal resistance) caused a 10°C drop its temperature which would bring the component operating temperatures down to the baseline (all vents open) case.

Thus, this study clearly that the highest priority for improving component cooling is to improve the transfer of thermal energy from the circuit board to the enclosure air or enclosure wall. Reducing the thermal resistance of the heat path from the wall to ambient or from the enclosure air to the enclosure wall have only second order effects.

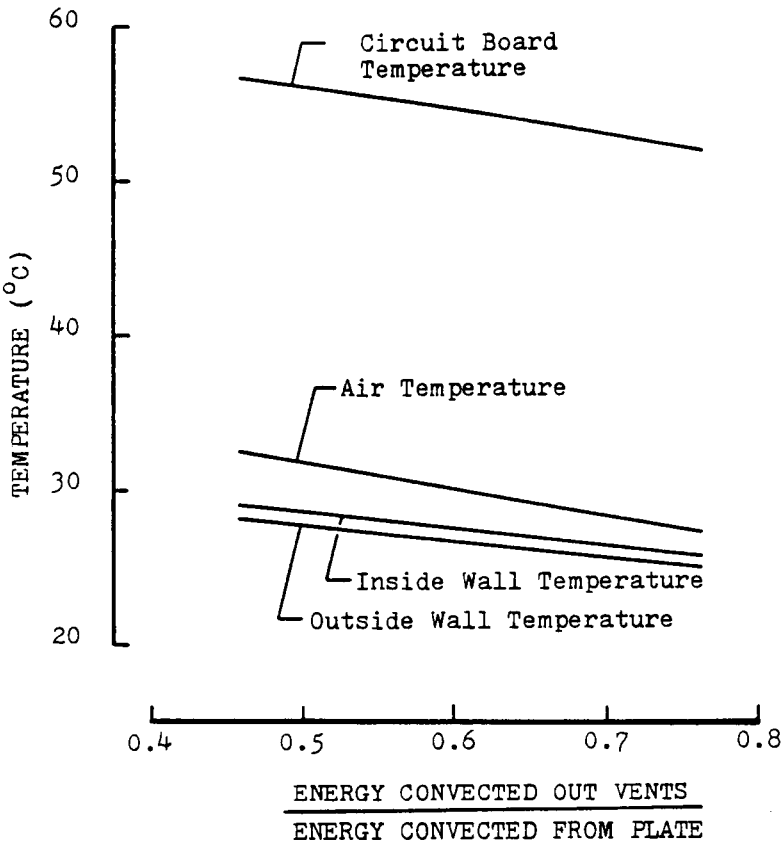



**FIGURE 8.44.** Temperature Sensitivity to Increase in Energy Convected Out the Cabinet Vents

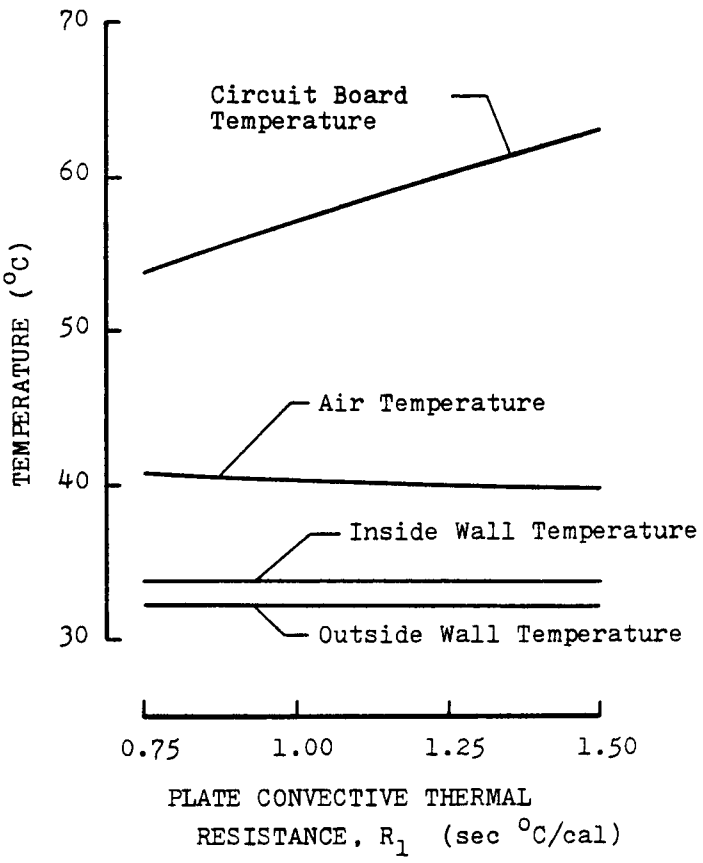


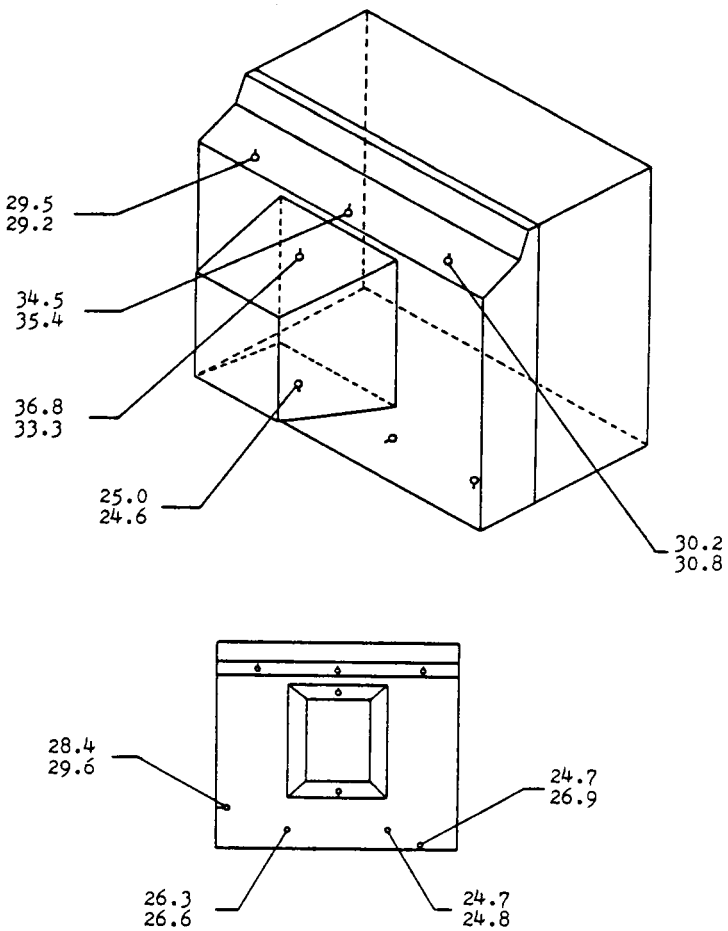

FIGURE 8.45. Temperature Sensitivity to Increase in Circuit Board Heat Transfer Coefficient With All Vents Closed

## 8. Experimental Simulator Temperature Results

### Simulation of All Vents Open Case

The results of the simulator temperature verification tests are shown in Figures 8.46 and 8.47. They are comparisons between the simulator and the production model receiver air temperatures. The top numbers are the simulator while the bottom numbers are the baseline receiver all vents open case. Note that for this case, the vent pattern matched the receiver. To accomplish this, it was necessary to close off several of the top cabinet vents because there are more vents on the simulator than the actual receiver. The power setting in the simulator was 85 watts. The power setting was based partially on the 97 watt power input the baseline case for the receiver. It has been estimated that about 91 to 94 watts of power is dissipated as heat in the production model receiver cabinet. The power setting used was the highest value that would provide reasonable air temperatures, match trends in temperature variation, match flow velocities, and match flow patterns. The primary concern was to match the temperature trends and flow patterns. This means that 10°C differences are acceptable if the trends match and are of the same magnitude.

The air temperature measurements given in Figure 8.46 show that the simulator and receiver are in close




NOTE :

The first number shown at each location is the measured temperature in the simulator.

The second number is the measured temperature in the receiver.

All temperatures are in degrees Celsius.

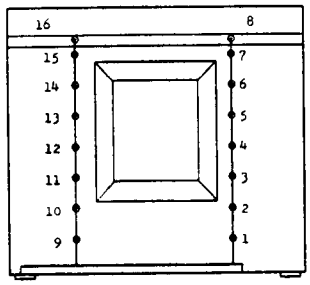
All simulator and receiver vents are open.

Power dissipated in simulator is 85 watts - 10 watts to picture tube
75 watts to circuit board

The receiver results are for a picture and sound setting of no transmitter signal and minimum volume.

The receiver picture control knobs labeled Color, Picture, Bright, Tint, and Sharp were set to their most clockwise positions.

FIGURE 8.46. Comparison of the Air Temperatures in the Simulator and the Production Model Receiver With All Vents Open




| Thermocouple Position | Temperature (Celsius) Production Model Receiver | Simulator |
|---|---|---|
| 1 | 26.9 | 28.9 |
| 2 | 27.2 | 27.8 |
| 3 | 30.2 | 36.3 |
| 4 | 35.7 | 35.7 |
| 5 | 34.3 | 34.6 |
| 6 | 33.0 | 33.6 |
| 7 | 32.7 | 33.0 |
| 8 | 31.2 | 33.8 |
| 9 | 27.1 | 28.6 |
| 10 | 27.6 | 30.6 |
| 11 | 30.2 | 38.7 |
| 12 | 32.3 | 38.0 |
| 13 | 31.5 | 33.1 |
| 14 | 30.8 | 31.2 |
| 15 | 30.3 | 32.0 |
| 16 | 30.3 | 32.8 |

NOTE :

The first number shown at each location is the measured temperature in the simulator.

The second number is the measured temperature in the receiver.

All temperatures are in degrees Celsius.

All simulator and receiver vents are open.

Power dissipated in simulator is 85 watts - 10 watts to picture tube
75 watts to circuit board

The receiver results are for a picture and sound setting of no transmitter signal and minimum volume.

The receiver picture control knobs labeled Color, Picture, Bright, Tint, and Sharp were set to their most clockwise positions.

FIGURE 8.47. Comparison of the Vertical Air Temperature Gradients in the Simulator and the Production Model Receiver With All Vents Open

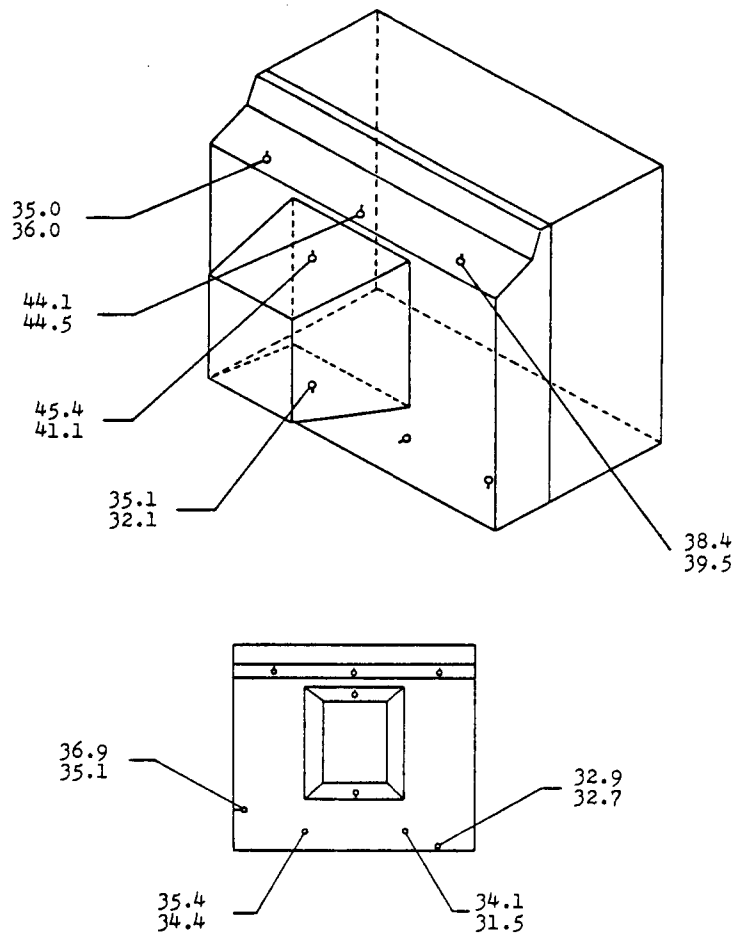
agreement with one another. The largest temperature difference is at the top of the extension where the simulator is 3.5°C higher than the receiver. The lumping of the picture tube heat sources into the one Thermofoil heater on the mock picture tube causes nearby air to be warmer than in the production model receiver. The second largest temperature difference is at the bottom left side of the cabinet where the simulator air temperature is 2.2°C lower than the receiver. The other seven air temperature measurements are within 2°C of each other.

For the air temperature gradient measurements shown in Figure 8.47, the temperature jump on the left side due to the hot plume adjacent to the picture tube occurs at a lower position in the simulator (see thermocouples 3 and 4 shown in Figure 8.47). Thus, in comparing the temperature at a particular position, the worst error is at 15 cm from the circuit board (thermocouple 3 for the air thermal gradient measurement) where there is a 6.1°C difference. Yet, the temperature difference between the left side top and bottom for the simulator is 4.9°C versus 4.3°C for the receiver. Also, the trend in temperature change with respect to the vertical height is the same for both the simulator and the receiver. The simulator left side air temperature increases to a peak of 36.3°C at a height of 14.6 cm, then, decreases to 33.8°C at the outlet vents. Likewise, the receiver left side air

temperature increases to a peak of 35.7°C at a height of 19.7 cm, then, decreases to 31.2°C. The higher simulator air temperatures imply that the simulator will also have higher upward air velocities because of larger buoyancy forces. A strong plume also appears on the simulator right side (see thermocouples 9 - 16). The simulator right side peak temperature is 38.7°C versus 32.3°C for the receiver, but the temperature difference between the bottom and top cabinet temperatures is 4.2°C for the simulator versus 3.2°C for the receiver. Also, the temperature trends with respect to the vertical height match. The simulator temperature increases to a peak of 38.7°C, then drops to 33.1°C, and remains relatively constant to the outlet vents. The receiver temperature increases to a peak of only 32.3°C, then drops to 31.5°C, and remains relatively constant to the outlet vents over the same vertical distance.

Simulation of All Vents Closed

To demonstrate that the simulator would faithfully model the impact of vent changes on temperatures and air flow patterns, the case of all vents closed was also examined. The temperature data for this case is given in Figure 8.48 and 8.49. For the air temperature measurments shown in Figure 8.48, the match is close. The largest temperature difference is at the extension top




NOTE :

The first number shown at each location is the measured temperature in the simulator.

The second number is the measured temperature in the receiver.

All temperatures are in degrees Celsius.

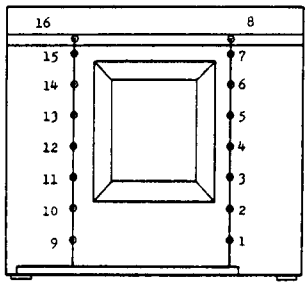
All simulator and receiver vents are closed.

Power dissipated in simulator is 85 watts - 10 watts to picture tube
75 watts to circuit board

The receiver results are for a picture and sound setting of no transmitter signal and minimum volume.

The receiver picture control knobs labeled Color, Picture, Bright, Tint, and Sharp were set to their most clockwise positions.

FIGURE 8.48. Comparison of the Air Temperatures in the Simulator and the Production Model Receiver With All Vents Closed




| Thermocouple Position | Temperature (Celsius) Production Model Receiver | Simulator |
|---|---|---|
| 1 | 34.8 | 36.5 |
| 2 | 36.3 | 37.8 |
| 3 | 39.6 | 42.3 |
| 4 | 44.8 | 43.2 |
| 5 | 42.9 | 43.9 |
| 6 | 41.8 | 43.6 |
| 7 | 41.3 | 44.6 |
| 8 | 36.0 | 45.1 |
| 9 | 37.6 | 40.3 |
| 10 | 37.5 | 39.6 |
| 11 | 38.8 | 41.6 |
| 12 | 40.3 | 37.6 |
| 13 | 37.8 | 37.1 |
| 14 | 38.5 | 38.8 |
| 15 | 40.8 | 43.5 |
| 16 | 38.9 | 43.3 |

NOTE :

The first number shown at each location is the measured temperature in the simulator.

The second number is the measured temperature in the receiver.

All temperatures are in degrees Celsius.

All simulator and receiver vents are closed.

Power dissipated in simulator is 85 watts - 10 watts to picture tube
75 watts to circuit board

The receiver results are for a picture and sound setting of no transmitter signal and minimum volume.

The receiver picture control knobs labeled Color, Picture, Bright, Tint, and Sharp were set to their most clockwise positions.

FIGURE 8.49. Comparison of the Vertical Air Temperature Gradients in the Simulator and the Production Model Receiver With All Vents Closed

where the air in the simulator is 4.3°C warmer than in the actual receiver. There is also a 2.6°C difference between the simulator and the receiver at the bottom left side of the back wall of the cabinet.

The vertical air temperature gradients in the simulator and the production model receiver have the same trend with respect to temperature change. All temperatures are within 5°C of each other except at the top of the cabinet where thermocouple 8 is located (see Figure 8.49). Here the receiver air temperature drops from 41.3 to 36.0°C, which is about 9°C lower than the equivalent simulator temperature.

## 9. Experimental Simulator Flow Visualization Results

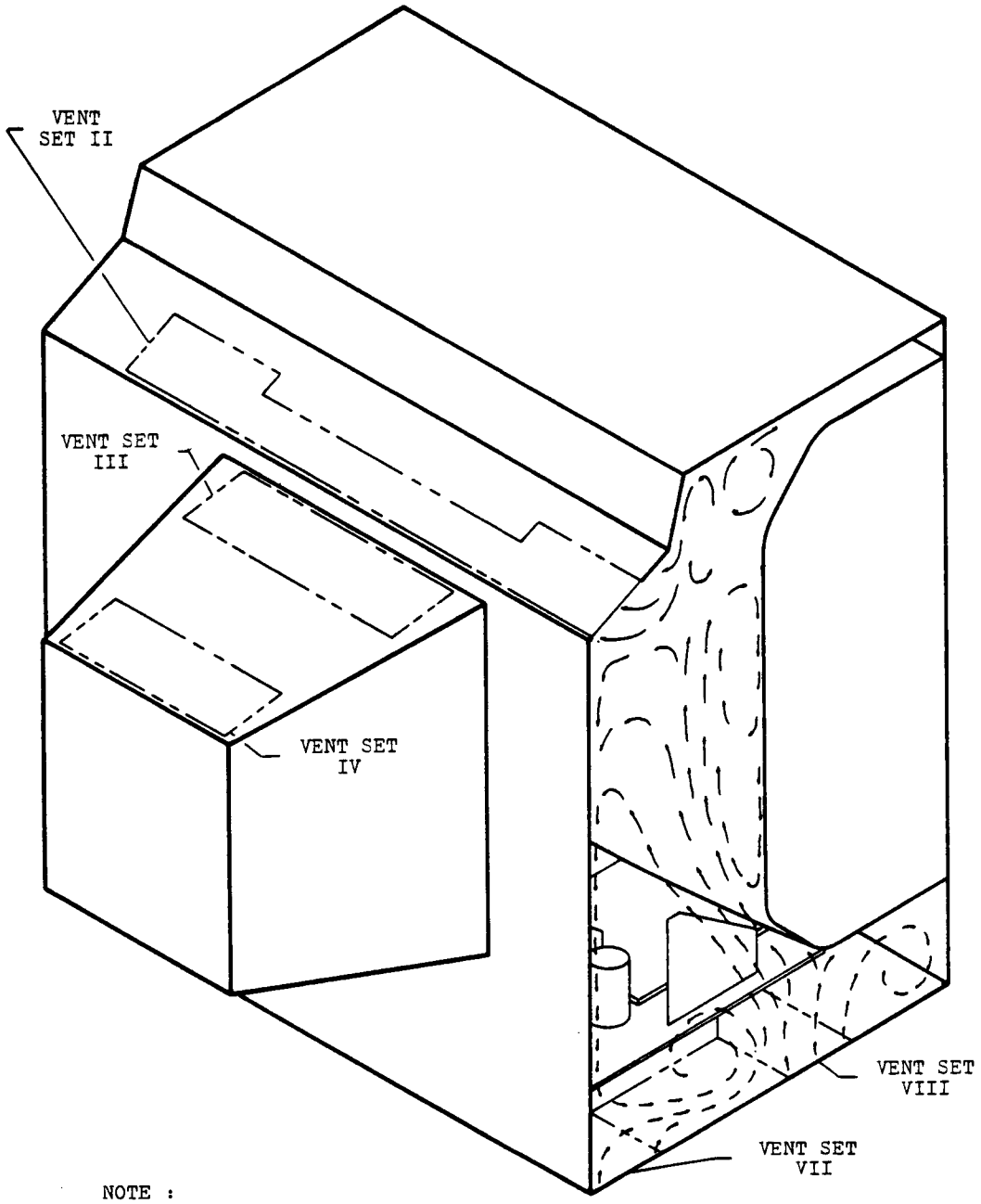
For the flow visualization tests, the power settings were varied from 80 to 100 W. Note that as power increased, the most significant change was an increase in the flow velocity, but the flow pattern remained approximately the same for the different power settings. The downward air flow velocity along the sides of the cabinet and the upward flow velocities in the center of the cabinet for the highest power setting were greater than those of the lowest power setting. Also, from observation, the amount of air flow into the extension

from the main cabinet appears to increased slightly as power level is increased.

The flow visualization tests were video taped. Sketches based on the video tape show that the flow field in the simulator for the 85 watt power setting and all vents open. These sketches can be compared to the sketches drawn for the production model receiver.

Figure 8.50 shows a plane approximately 6 cm from the left side (looking a the picture screen) of the receiver. This figure shows recirculation zones adjacent to the picture tube model being generated by the flow separation of the low velocity flow. These zones disappear near the horizontal center of the cabinet because of the higher velocity flow there. Note that the recirculation creates an outline that is closer to the actual picture tube shape.

Figure 8.51 shows a plane approximately 13 cm from the left side of the receiver. Smoke marked air is drawn into the cabinet through vent sets VII and VIII at the bottom of the cabinet. The air flow through the bottom vents has a velocity around 3 - 4 cm/sec, which is around 1 cm/sec faster than the actual receiver. Thus, it appears that there is an increase in the air flow into the cabinet. Nevertheless, the flow patterns of the simulator compare favorably with the baseline case shown in Figure 8.24 on page 128.

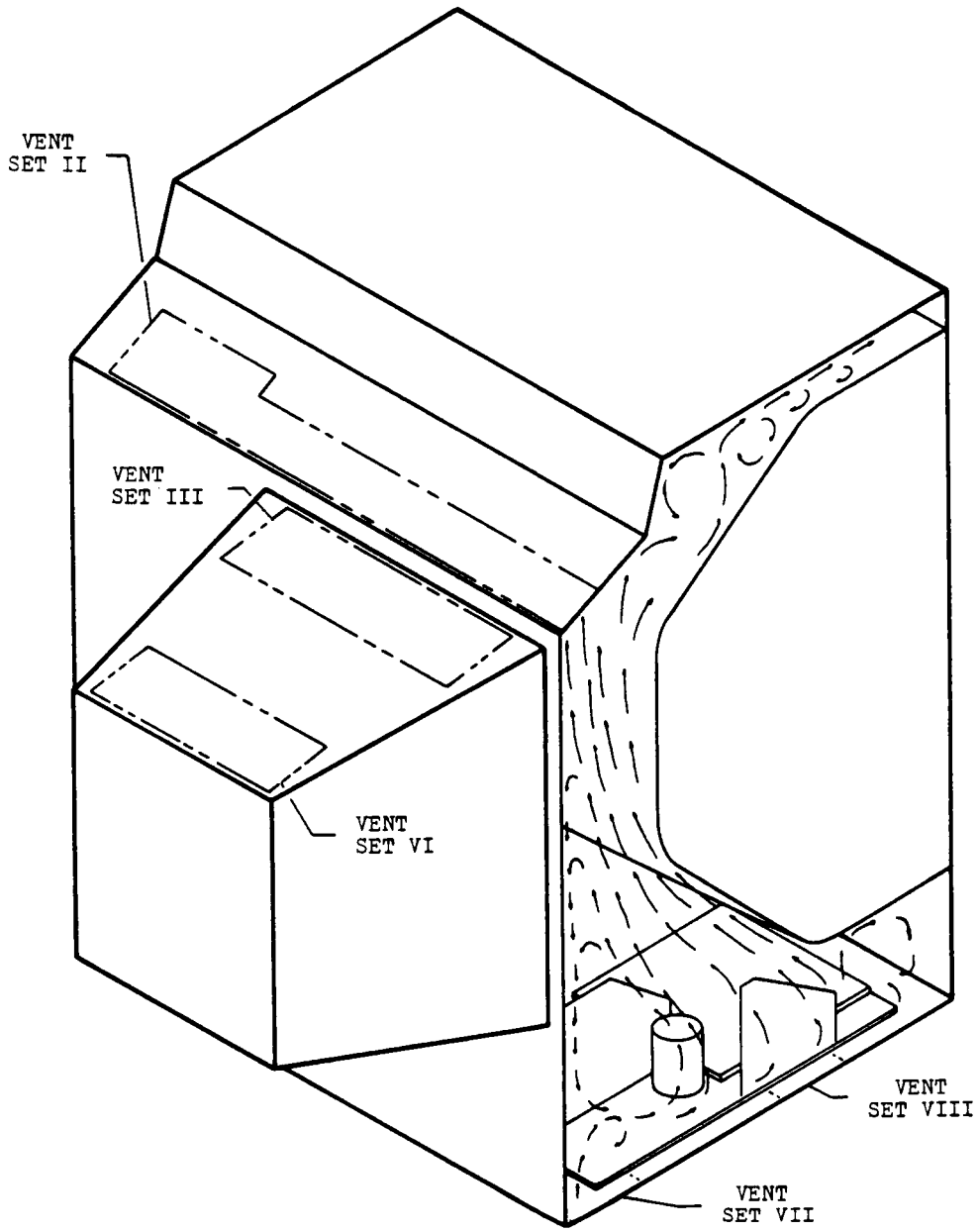



NOTE :

Power dissipated is 85 watts: 10 watts to the picture tube.
75 watts to the circuit board.

Simulator vent areas are identical to that of the baseline receiver with all vents open.

FIGURE 8.50. Typical Flow Pattern in Simulator, 6 cm From Left Side With All Vents Open




NOTE :

Power dissipated is 85 watts: 10 watts to the picture tube.
75 watts to the circuit board.

Simulator vent areas are identical to that of the baseline receiver with all vents open.

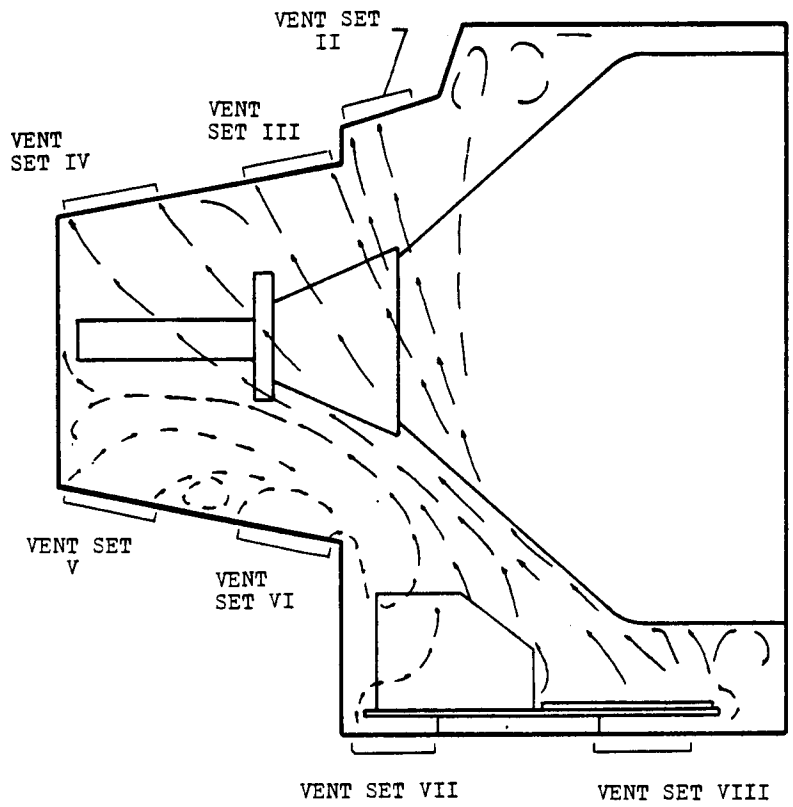
FIGURE 8.51. Typical Flow Pattern in Simulator, 13 cm From Left Side With All Vents Open

Figure 8.52 shows a plane approximately 18 cm from the simulator left side (see Figure 8.25 on page 130). Flow separates from the picture tube and flow spills into the extension in the same manner observed in the receiver.

Figure 8.53 shows a plane a the picture tube centerline (see Figure 8.26 on page 132). The plume from the neck is a stronger and thus, more distinct. Also, the recirculation under the neck similar to that found in the production model receiver exists. Many more details of the flow around the front cabinet can be seen in the simulator than the production model receiver.

Figure 8.54 shows a plane approximately 30 cm from the receiver left side (see Figure 8.27 on page 133). The flow patterns are the same as those observed on the opposite side of the extension. The incoming air from the bottom extension vents is moving at a velocity of 2 - 4 cm/sec as opposed to the 1 - 3 cm/sec flow of the baseline receiver. This flow creates a recirculation zone between vent sets V and VI. There is a layer of stagnant air in the location adjacent to the bottom extension wall between vent sets V and VI of the receiver, but the layer is only on the order of 0.3 cm thick.

Figure 8.55 shows a plane approximately 41 cm from the receiver left side (see Figure 8.28 on page 134). The recirculation zone adjacent to the back wall extends too far forward at the bottom of the simulator. The heat flux




NOTE :

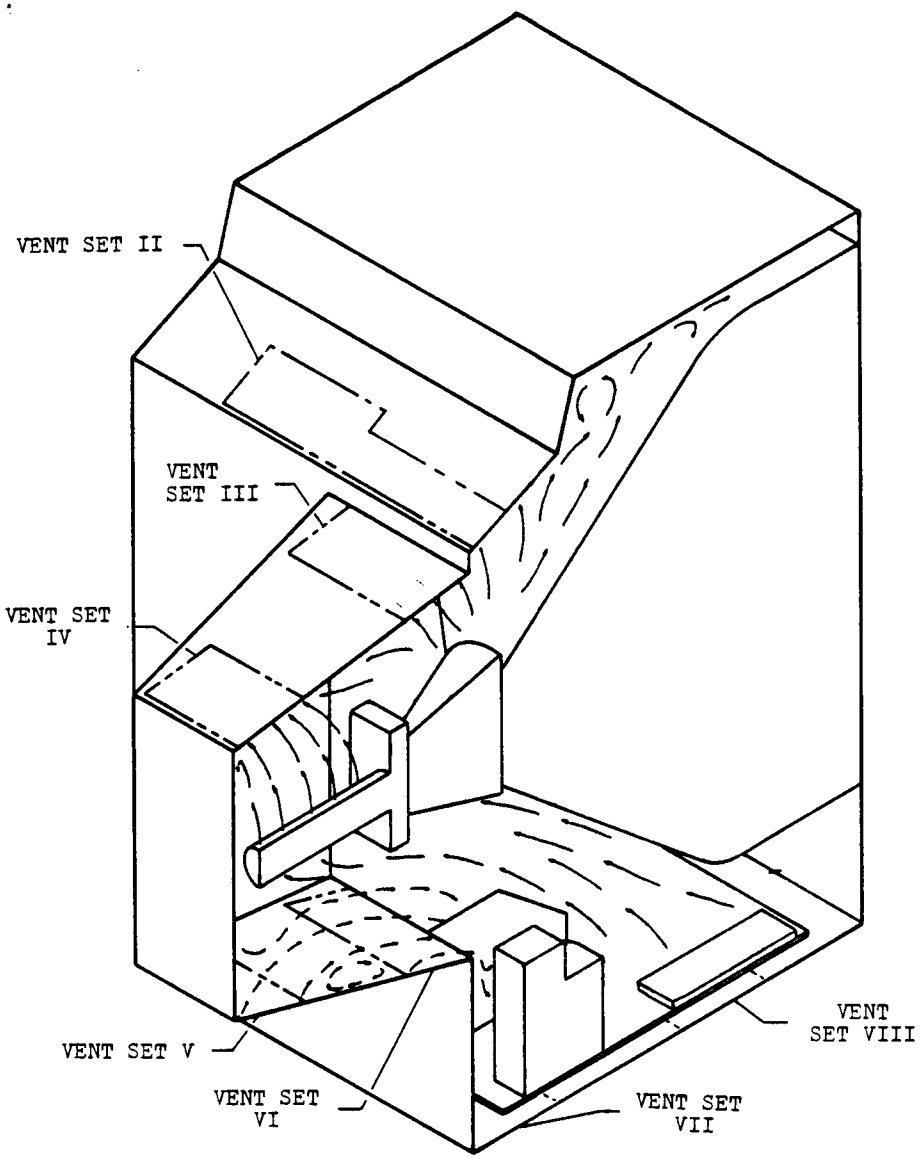
Power dissipated is 85 watts: 10 watts to the picture tube.
75 watts to the circuit board.

Simulator vent areas are identical to that of the baseline receiver with all vents open.

Relative magnitude of velocity is given by arrow length.

Velocity Scale: 14 $\left(\frac{cm}{sec}\right)$ / cm

FIGURE 8.52. Typical Flow Pattern in Simulator, 18 cm From Left Side With All Vents Open

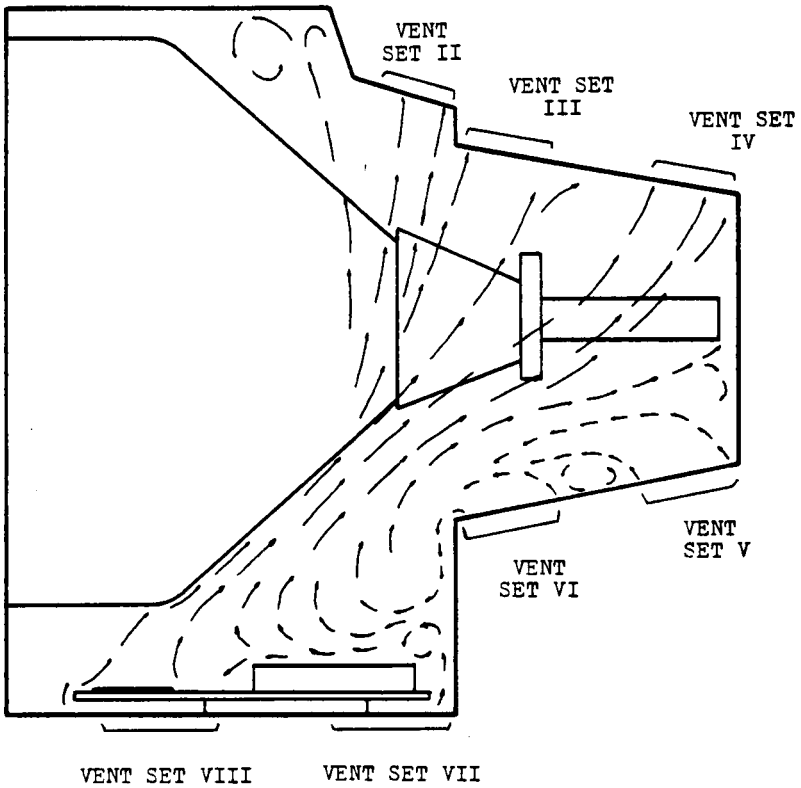



NOTE :

Power dissipated is 85 watts: 10 watts to the picture tube.
75 watts to the circuit board.

Simulator vent areas are identical to that of the baseline receiver with all vents open.

FIGURE 8.53. Typical Centerline Flow Pattern in Simulator With All Vents Open




NOTE :

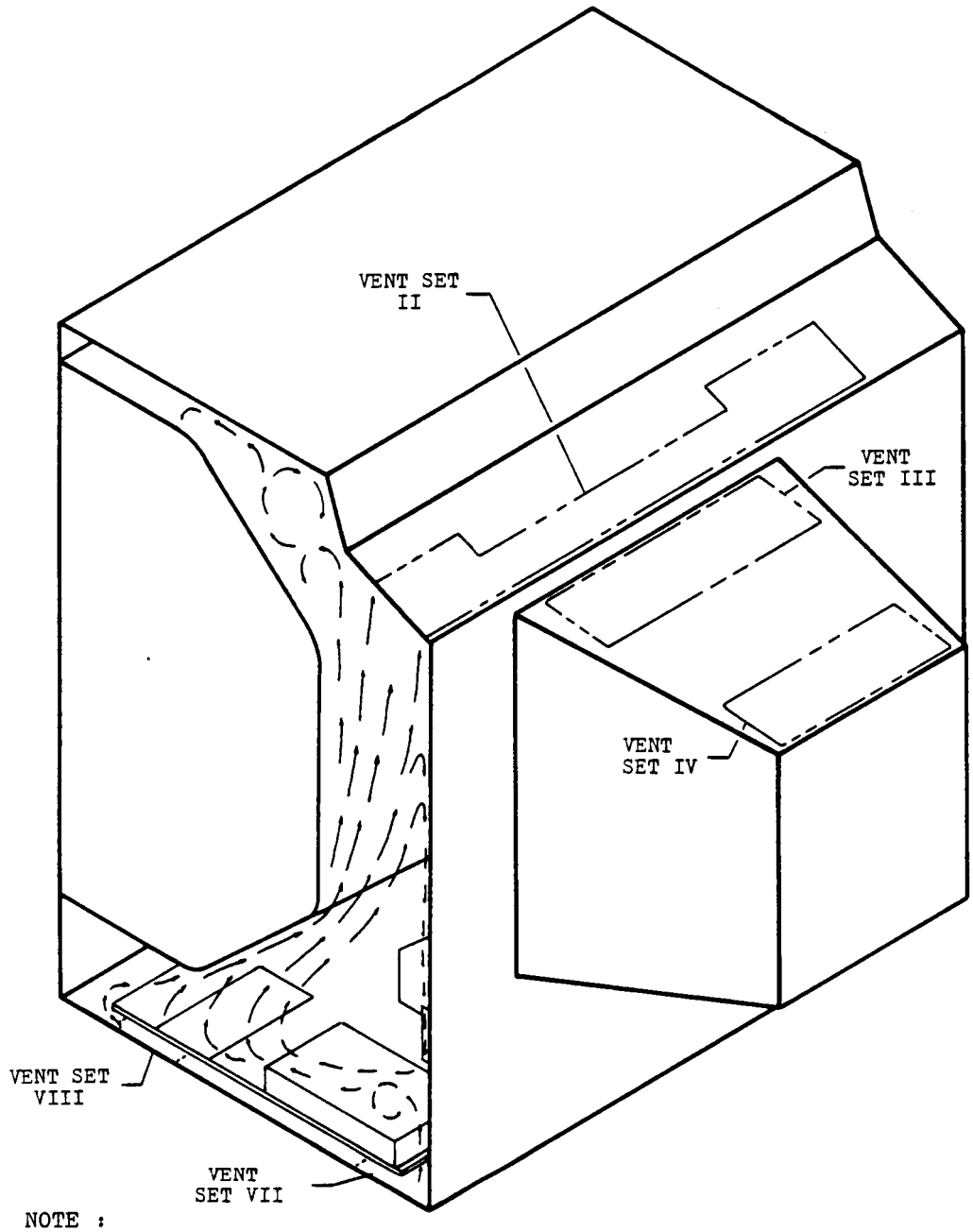
Power dissipated is 85 watts: 10 watts to the picture tube.
75 watts to the circuit board.

Simulator vent areas are identical to that of the baseline receiver with all vents open.

Relative magnitude of velocity is given by arrow length.

Velocity Scale: 14 $\left(\frac{cm}{sec}\right)$ / cm

FIGURE 8.54. Typical Flow Pattern in Simulator, 30 cm From Left Side With All Vents Open




NOTE :

Power dissipated is 85 watts: 10 watts to the picture tube.
75 watts to the circuit board.

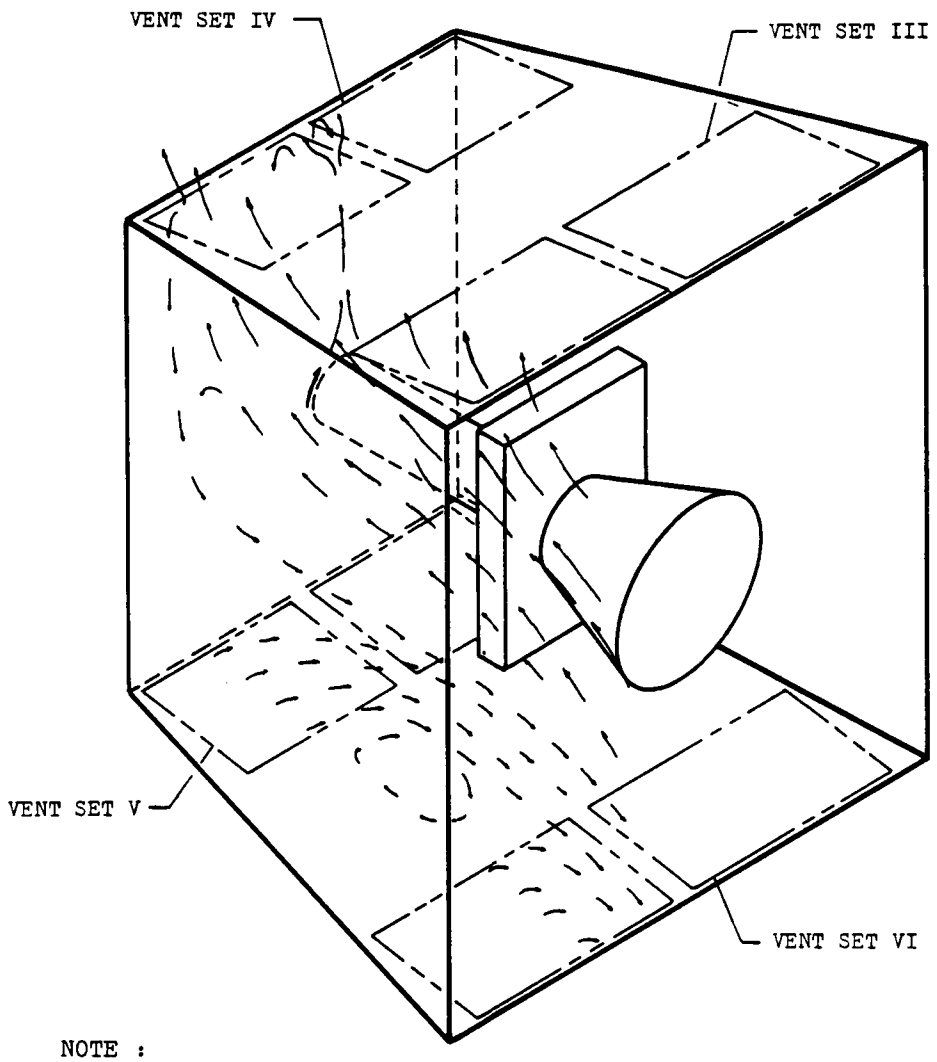
Simulator vent areas are identical to that of the baseline receiver with all vents open.

FIGURE 8.55. Typical Flow Pattern in Simulator, 41 cm From Left Side With All Vents Open

at the aft end of the circuit board model is still too low despite the addition of an aluminum plate to bias the heat flow from the Thermofoil heater to the rear of the cabinet.

Figure 8.56 shows the typical flow pattern in the extension. The the flow pattern in the simulator matches that of the receiver as shown in Figure 8.29 (see page 136). As with the receiver, the is hot air flow from the main cabinet to the extension. Most of the hot air escapes through the top extension vents (sets III and IV). The air flow that does not exit through the top extension vents, is pushed toward the extension side walls, then, downward and toward the front of the extension. Although the sketch does not show it, there is a greater amount of mixing between the incoming air from the bottom extension vents and the recirculating hot extension air. There is still a region of demarcation between the flows, but it is less distinct. As with the receiver, the flows move forward until they are entrained by the hot plume from the main circuit board that spills into the extension. Overall, the velocity of the air flow into the extension is higher for the simulator than the baseline case.

Figure 8.57 shows a plane parallel to the picture tube face (see Figure 8.30 on page 138). The recirculation zones on the left and right sides of the main cabinet

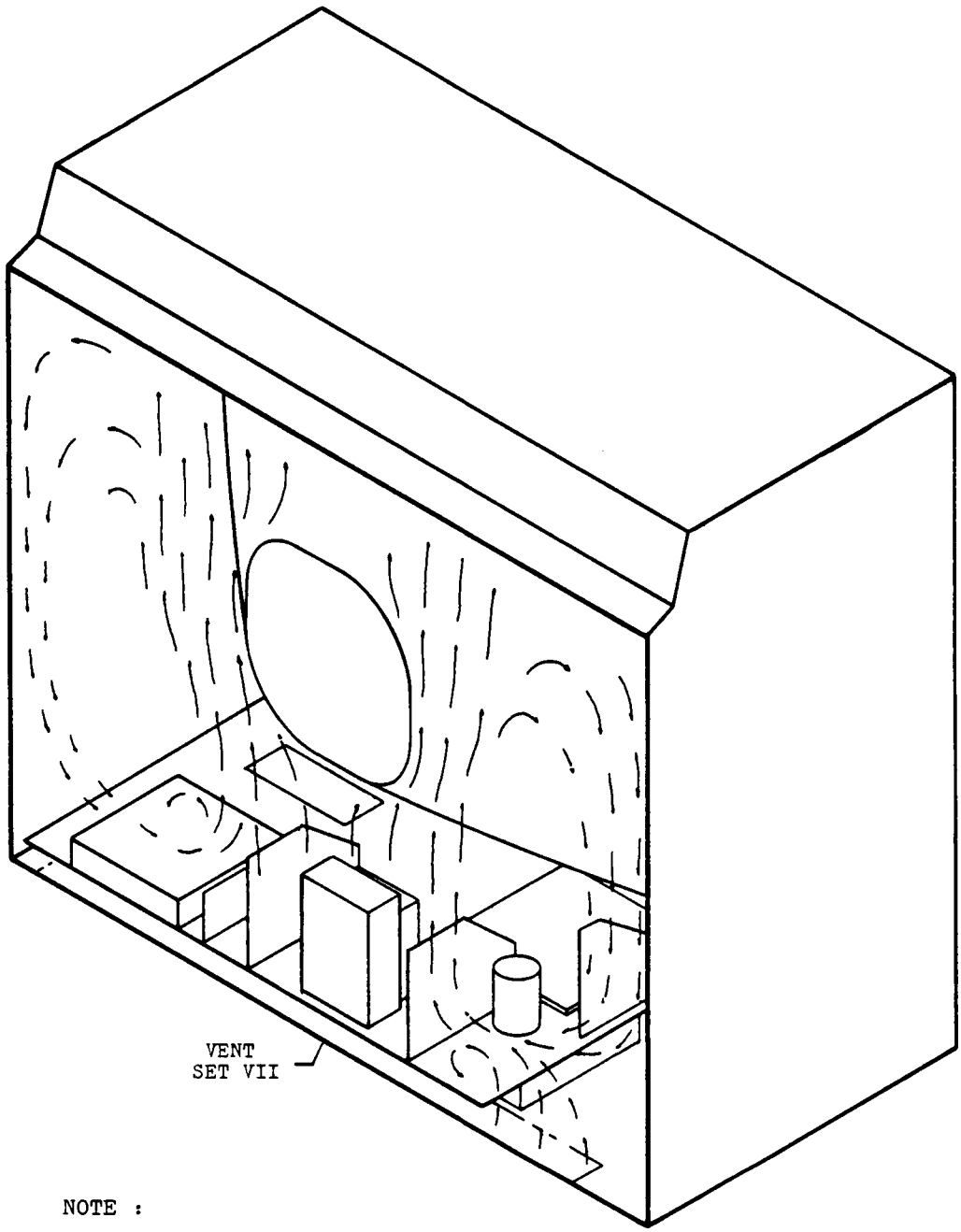



NOTE :

Power dissipated is 85 watts: 10 watts to the picture tube.
75 watts to the circuit board.

Simulator vent areas are identical to that of the baseline receiver with all vents open.

FIGURE 8.56. Typical Flow Path Through Simulator Extension With All Vents Open




NOTE :

Power dissipated is 85 watts: 10 watts to the picture tube.
75 watts to the circuit board.

Simulator vent areas are identical to that of the baseline receiver with all vents open.

FIGURE 8.57. Typical Flow Pattern Parallel to Picture Tube Face in Simulator With All Vents Open

appear in both devices, but the simulator's have larger downward velocities (about 2 - 3 cm/sec). The center plume generated by the heat sources on the circuit board is narrower in the simulator, presumably because of the lumping of simulator heat sources into a narrower region.

The flow visualization tests demonstrate the advantage of an the increase in transparent cabinet surfaces. It is much easier to examine the air flow in all parts of the simulator than in the production model receiver. Also, the simulator flow patterns do match those found in the receiver well enough to predict where the major recirculation zones will occur. Although the temperatures are higher in some areas of the simulator, the overall temperature trends do match those in the production model receiver. Another difference between the simulator and the receiver is that the simulator flow velocities are about 2 to 8 cm/sec higher than the receiver. Either the pressure drop across the vents is too low, or the heater power settings are too high. Also, because of the simplified geometry of the picture tube model, there is a difference in the flow pattern at the left and right ends of the picture tube, but it is not expected to have a significant effect on the component temperatures.

# CHAPTER IX

# CONCLUSIONS AND RECOMMENDATIONS

## 1. Blocked Vent and Blocked Extension Test Conclusions

The temperature and flow visualization tests demonstrate the sensitivity of component temperatures to changes in cabinet vent areas. Table 9.1 is a summary of the results of the blocked vent and blocked extension tests. The acceptability of a cabinet modification is defined in Chapter VIII, Section 3. No combination of blocked vent configurations decreased all the temperatures, but several will either reduce or not affect the main circuit board component temperatures. The largest increases in reliability are the blocked vents V, VI, and V and VI. It appears from the temperature data that the lower vents of the extension are not required if a small temperature increase in the extension can be tolerated.

Of the acceptable blocked vent tests, blocking sets I, IV, V, or VI separately yield decreases in a heat sink mounted component. Thus, it may be possible to reduce manufacturing costs by eliminating one of these vent sets and reduce the size of the heat sink. Another possibility is to make a marginally unacceptable

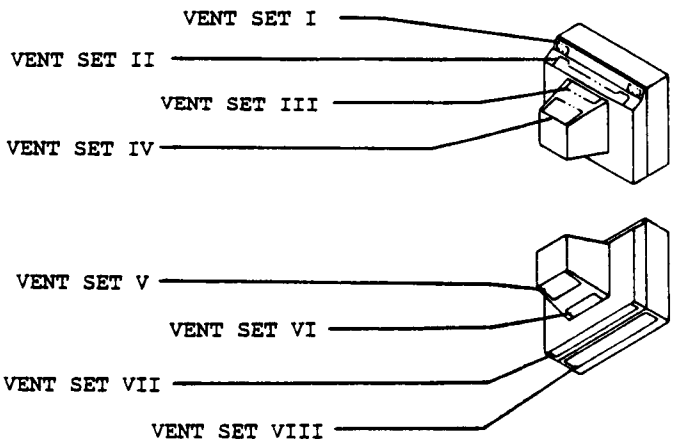
## Table 9.1. Summary of Blocked Vent and Blocked Extension Test

| Receiver Modification | Acceptable Modification | Criteria Violated if Not Acceptable |
|---|---|---|
| Blocked Vent Set(s) | | |
| I | yes | - |
| II | no | 5 |
| III | no | 6 |
| IV | yes | - |
| V | yes | - |
| VI | yes | - |
| VII | no | 5 & 6 |
| VIII | no | 6 |
| VII & VIII | no | 5 & 6 |
| V & VI | yes | - |
| III & IV | no | 5 & 6 |
| I & II | no | 6 |
| III, IV, V, & VI | no | 5 |
| I, II, III, & IV | no | 3, 4, 5 & 6 |
| I - VIII | no | 3, 4, 5 & 6 |
| Blocked Extension, With 1.3 cm Gap | no | 5 |
| Blocked Extension, With 0.2 cm Gap | yes | - |

Acceptability is based on component temperature increase limits.

The limits are:
- Resistors - 15°C (criteria 2)
- Picture tube neck - 5°C (criteria 3)
- Transformer - 7°C (criteria 4)
- Heat sink mounted components - 0.0°C (criteria 5)
- Integrated circuits - 1.4°C (criteria 6)

Air Inlet Vent Sets : V, VI, VII, and VIII
Air Outlet Vent Sets : I, II, III, and IV



modification into an acceptable one by adding heat sinks or relocating components. Once a circuit board design is set, however, it is typically too costly to shift components around. For all of the blocked vent tests, the greatest number of integrated circuit and transistor temperature drops (6 improvements in component reliability) occurs when vent set VI is blocked. Failure rate decreases in this case range from 2.7 to 10.5%. This would eliminate 12% of the inlet vent area or 23.2 $cm^2$ of vent area. Vent set IV is also the highest set of downward-facing vents and is, therefore, the worst "short circuit" of the chimney effect. The largest elimination of vent area occurs when vent sets V and VI are blocked. This would remove 51.9 $cm^2$ or 27% of the downward-facing vent area. Five of the integrated circuits and transistors experienced temperature drops for this case with resulting reliability improvements between 5.6 and 11.4%. Because of the large reliability improvements, coupled with a large reduction in vent area, blocking both vent sets V and VI is the preferred modification of the blocked vent tests.

If blocking upward-facing vents is preferred; then, blocking vent set IV is the largest top blocked vent set that was acceptable. This would eliminate 23.2 $cm^2$ or 22% of the upward-facing vent area. The drawback of this modification is that the temperatures of components IC640,

R456, and R408, the picture tube neck, and the air at the top of the extension all increase.

Another promising idea is to partition the main cabinet off from the extension (cup). This modification causes failure rates of the integrated circuits and transistors to decrease between 3.1 to 8.8%. The main drawback of the is the increased manufacturing cost. Moreover, if a sufficiently tight seal cannot be maintained, some components may operate 1 - 2°C higher. Thus, an essentially "foolproof" method of installing the partition between the cabinet and the extension and insuring its integrity throughout the life span of the receiver would have to be developed. The cost of adding a partition between the cabinet and the extension may be offset by cost savings from the reduction in the heat sink size or in the reliability improvement. With the blocked extension, there is no loss in vent area, and the components in the extension and the components in the cabinet have separate cooling air flows. Coupled with the improvement in the chimney effect there should be an increase in the air flow through the receiver, since the blocked extension provides lower component operating temperatures everywhere. The gap at the bottom of the partition destroys the improvement in the chimney effect, which, implies that keeping the flows separate alone is not enough to reduce component temperatures. Blocking

both vent sets V and VI appears to be superior to employing a blocked extension because it is easier to implement and, although there is one less recorded temperature decrease for the blocked vent case than the blocked extension case, the decreases that do occur are about 1 to 2% larger.

Elimination of all vents is a very attractive potential modification from a safety and manufacturing viewpoint. A "no vent design" without other modifications is not recommended on the basis of reliability data, but if one is desired, then two modifications listed below should be explored. First, heat removal from the circuit board must be regarded as the highest priority. Reorienting the circuit board should improve the heat transfer coefficient. Vertical surfaces typically have higher natural convection heat transfer coefficients than horizontal surfaces.

Secondly, the recirculating air flow adjacent to the cabinet walls transfer heat to the walls. This air flow is moving downward along the back and side walls of the cabinet. Placing the temperature sensitive components along the side or back edges of the circuit board would expose these components to cooler downward air flow of a recirculation zone and, thus, would reduce the operating temperature of the component. More elaborate solutions such as modifying the component emissivity, but they seem

impractical from a manufacturing viewpoint.

When vents were blocked, the magnitude of the temperature increases were relatively small. In general when comparing the baseline, "all vent open", case with the blocked vent cases, the temperature increases or decreases were less than 5°C. Even for the extreme case of blocking all vents, the temperature increases were typically less than 10°C. Thus, it appears that any reduction in vent area on the baseline receiver that causes unacceptably high component temperatures can be made acceptable.

A practically important case that must be addressed whenever vent modifications are considered is "operation" when the receiver is turned off. The baseline receiver has a "instant on" circuit, which reduces the warm up time required by the receiver. One component in this circuit, resistor R456, registered temperatures in the 120°C - 124°C temperature range with the set turned off. This circuit is always active unless the receiver is unplugged. Some particular vent configuration may have an impact on the temperatures of the components of this circuit, but this possibility was not studied in this research project.

## 2. Recommendations For Future Receiver Temperature Testing

During the course of performing receiver component temperature measurements, several shortcomings of the experiments were uncovered that could not be corrected during the course of the experimental program. These are listed below.

1) Additional components should be included in the examination. A couple of integrated circuits were hidden in shielded boxes and, thus, were not instrumented.

2) Temperature tests should be performed with a receiver that is totally dedicated to the temperature measurements so that the thermocouples can be permanently installed with electrically insulating epoxy.

3) The data acquisition system should be modified for future tests to store the thermocouple output on demand and calculate the average and standard deviation for all temperature runs. This is a very time consuming process to do manually.

4) The instrumentation should include transducers for measuring the power input, or more precisely, the current drawn and the voltage, at the plug and at the cathode heater pins.

5) A higher power light source should be used to allow

camera angles perpendicular to the light plane to be used and, thus, provide higher quality video tapes.

## 3. The Numerical Simulator

A numerical simulator is a valuable tool. The simple model developed was calibrated using experimental data. Without the calibration, the model may give misleading results. More sophisticated models currently under development do not suffer from this drawback. The numerical model results underscore the fact that the most important aspect of the cooling problem is the transfer of heat away from the circuit board. For a partial enclosure, if energy cannot be removed from the circuit board, then reducing other thermal resistances in the heat flow path between the components and the ambient will have only a second order effect. Effort needs to be focused on the convective and radiative heat transfer coefficients of the components and circuit board. Increasing the thermal radiation by modifying the emissivity is expensive. It would require applying some type of coating to the components and/or circuit board. For example, many metallic oxides have emissivities in the 0.8 to 0.95. Flat black lacquer paint ($\varepsilon \approx 0.95$) is also an option. This does not seem practical from a manufacturing standpoint and the heat conduction from the heat source to the case

outer surface may be reduced if the coating has a low conductivity. Since the emissivities of all of the components are unknown, it is difficult to predict any possible reductions in component temperatures, if any, that would be caused by modifying the emissivities. In contrast, improving the convection coefficient may be relatively simple. Possible ways of increasing the convection coefficient include mounting the circuit board vertically or moving the circuit board to uncover the bottom vents. If the circuit board cannot be moved, then holes or slots in the circuit board may help improve the flow of air past the hotter components. It would be interesting to examine the effect of drilling 1 - 5 mm diameter holes in the circuit board adjacent to hot resistors, integrated circuits, and transistors. All of these possible modifications should be investigated in future studies.

## 4. The Experimental Simulator

As a design tool, the simulator provides a fast, economical way to examine the impact of a given cabinet geometry, vent pattern, distribution of heat sources on a circuit board, or a particular board location on component temperatures. For temperature testing, the simulator is capable of duplicating the air temperature field.

The simulator is clearly superior to the receiver for flow visualization testing. With a transparent table top, it would even be possible to examine the flow underneath the circuit board. The simple model used in this research is capable of duplicating the flow paths and recirculation zones that occur in the production model receiver. The addition of extra heat source models, a geometrically correct picture tube model, and extra component detail (especially at the forward section of the receiver around the controls) will provide an even better model.

Current trends in television receiver packaging appear to be aggravating the thermal design problem. Even if future television receivers are packaged in radically different cabinets, the simulator demonstrates that it should be possible to economically model the receiver before major company resources are committed to the production of new designs.

## 5. Important Vent Design Considerations

The results of the blocked vent and blocked extension tests and the flow visualization tests, allow vent design several general conclusions to be drawn. These considerations, which should be valid for any cabinet geometry, are as follows:

1) As vents eliminated, move the most temperature

critical components should be relocated near the outer edges of the circuit board as near as possible to active inlet vents.

2) Eliminating outlet vents has a greater impact on the creation of zones of recirculating flows than eliminating inlet vents.

3) Eliminating inlet vents that short circuit the chimney effect is superior to eliminating outlet vents that short circuit the chimney effect. Since there is a tradeoff between maximizing the chimney effect and increasing recirculation when outlet vents that short circuit the chimney effect are eliminated. An increase in the size of a recirculating flow will expose additional components to hot air flow, which should cause an increase in their temperatures.

4) Mass flow through active inlet vents tends to increase to compensate for reduced flows that occur due to eliminating other inlet vent.

5) The number of inlet vents should be minimized and the temperature critical component should be placed near them. At the same time the number of outlet vent should be maximized.

6) To improve the chimney effect, vents at other than the top or bottom of the enclosure should be eliminated.

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# APPENDICES

# APPENDIX A

# UNCERTAINTY ANALYSIS

An uncertainty analysis was performed for the temperature measurements. There were two different test setups used for the temperature measurements. The first used an ice bath reference junction and a seventh order curve fit to convert thermocouple output (in millivolts) to temperature. The second setup used an electronic ice point and a fourth order curve fit to convert thermocouple output to temperature.

Error introduced into the temperature measurenents comes from several sources. The thermocouple an lead wire error is estimated to be ±1.0°C by the wire manufacturer. All thermocouple wire was taken from the same spool; thus, the thermocouples should all have about the same error. There is measurement error introduced by the data sampler. Measured voltage error is ±0.00003 mV plus 0.003% of the millivolt reading. The error caused by the data sampler is so small that it can be ignored. These are fixed errors in the test setup. Additional error is introduced by variations in the reference temperature and by the inexactness of the conversion of thermocouple millivolt output to temperature.

## 1. Seventh Order Curve Fit and Ice Bath Reference Junction

A seventh order curve fit was used in initial temperature tests and blocked vent tests. The expression used is given below.

$$T = 25.889347897 \cdot V - 0.366006670 \cdot V^2 - 0.536749212 \cdot V^3 + 0.388477456 \cdot V^4 - 0.135293163 \cdot V^5 + 0.023396843 \cdot V^6 - 0.001588515 \cdot V^7$$

Where T is the measured temperature (°C), and V is the average absolute voltage (mV).

An ice bath was used as the reference junction temperature. The ice bath temperature was between 0.0 - 0.5°C (this corresponds to 0.000 - 0.0193 mV). The ice bath temperature was measured using a mercury thermometer. The uncertainty in the measured reference temperature is:

$$w_T = \frac{\partial T}{\partial V} \cdot w_V$$

where $w_T$ is the temperature uncertainty in °C and $w_V$ is the voltage uncertainty in mV. The results of this analysis are shown in Table A-1. The curve fit introduces additional error. This error is given in Table A-2. To calculate the total error in the uncorrected temperature, the temperature uncertainty due to the voltage uncertainty, the error in the curve fit and the manufacturer listed thermocouple uncertainty of ±1°C are

Table A-1. Temperature Uncertainty Due to Uncertainty in Measured Voltage With Ice Bath Reference Junction

| Temperature (°C) | Absolute Voltage (mV) | $\partial T/\partial V$ | Voltage Uncertainty $w_V$ (mV) | Temperature Uncertainty $w_T$ (°C) |
|---|---|---|---|---|
| 20 | 0.789 | 24.85 | 0.0193 | 0.48 |
| 60 | 2.467 | 22.88 | 0.0193 | 0.44 |
| 100 | 4.277 | 21.36 | 0.0193 | 0.41 |
| 110 | 4.749 | 19.99 | 0.0193 | 0.39 |
| 120 | 5.227 | 15.98 | 0.0193 | 0.31 |

Table A-2. Error in Temperature Due to Seventh Order Curve Fit With Ice Bath Reference Junction

| Actual Temperature (°C) | Curve Fit Temperature (°C) | Difference in Temperatures (°C) |
|---|---|---|
| 20.00 | 20.05 | 0.05 |
| 60.00 | 60.00 | 0.00 |
| 100.00 | 100.03 | 0.03 |
| 110.00 | 109.85 | 0.15 |
| 120.00 | 118.60 | 1.40 |

combined using the method of Kline and McClintok. The resulting temperature uncertainty is the total uncertainty for the uncorrected temperature. This is given in Table A-3.

Table A-3. Temperature Uncertainty Without Room Temperature Correction

| Temperature (°C) | Temperature Uncertainty (°C) |
|---|---|
| 20 | 1.11 |
| 60 | 1.09 |
| 100 | 1.08 |
| 110 | 1.08 |
| 120 | 1.75 |

Component temperatures are corrected for differences between actual room temperature and the "standard" room temperature. This correction adds to the uncertainty of a second thermocouple measurement, but eliminates the uncertainty due to the common ice bath. The temperature correction is performed using the following equation:

$$T_c = T_{act} - (T_r - 20°C)$$

where $T_c$ is the corrected room temperature (°C), $T_{act}$ is the measured temperature of component (°C), and $T_r$ is the measured room temperature (°C). Using Kline and McClintock's method, the uncertainty is:

$$w_{Tc} = \left[ \left( \frac{\partial T_c}{\partial T_{act}} w_T \right)^2 + \left( \frac{\partial T_c}{\partial T_r} w_{Tr} \right)^2 \right]^{1/2}$$

The variable $w_{Tr}$ is the uncertainty of measured room temperature (°C) and $w_T$ is the temperature uncertainty caused by the curve fit and the fixed error of the thermocouple. Thus, the total uncertainty in measured temperature after room temperature correction is given in Table A-4.

Table A-4. Temperature Uncertainty With Room Temperature Correction

| Temperature (°C) | Total Uncertainty (°C) |
|---|---|
| 20 | 1.42 |
| 60 | 1.42 |
| 100 | 1.42 |
| 110 | 1.42 |
| 120 | 1.99 |

A component temperature is measured with the same thermocouple for all the blocked vent tests and all the partitioned cabinet tests. Therefore, the fixed errors of a given thermocouple will cancel out when temperatures are subtracted from one another.

$$\Delta T_C = T_C - T_C'$$

where $T_C$ is the component temperature for the baseline case and $T_C'$ is the same component temperature for a modified receiver. The only source of uncertainty is the curve fit. Using Kline and McClintock's method, the

uncertainty of the temperature change is:

$$w_{\Delta T_C} = \left[ \left( \frac{\partial \Delta T_C}{\partial T_C} w_{T_C} \right)^2 + \left( \frac{\partial \Delta T_C}{\partial T_C'} w_{T_C}' \right)^2 \right]^{1/2}$$

Where $w_{T_C}$ is the uncertainty of the measured component temperature (for the baseline case) due to the curve fit and $w_{T_C}'$ is the uncertainty of the measured component temperature (for a blocked vent of partitioned cabinet case) due to the curve fit. Also, the values of the partial derivatives are:

$$\partial \Delta T_C / \partial T_C = 1.0$$

$$\partial \Delta T_C / \partial T_C' = 1.0$$

For the values of $w_{T_C}$ and $w_{T_C}'$ are on the order of 0.1°C then the uncertainty in the temperature change is 0.14°C. This number does not include, however, many minor variations in receiver operation between different tests. Thus, from experimental observation it is estimated that the true temperature change uncertainty is on the order of 0.7°C.

2. Fourth Order Curve Fit and Electronic Ice Point Cell

A fourth order curve fit was used for blocked extension tests and simulator tests and air temperature measurements for simulator verification. The least squares curve fit was derived for a temperature range of -

10°C to 150°C. The expression used is given as:

$$T = 25.88000923 \cdot V - 0.704096843 \cdot V^2 + 0.029157958 \cdot V^3 - 0.029157958 \cdot V^4$$

Where T is the measured temperature in °C and V is the average absolute voltage in mV. An Omega Electronic Ice Point Cell was used as reference junction temperature. The temperature is in the range of ±0.1°C or ±0.00386 mV. The fixed thermocouple error of ±1.0°C is also adding to the total temperature uncertainty. Using a method developed by Kline and McClintock, the temperature uncertainty, $w_T$, is:

$$w_T = \frac{\delta T}{\delta V} \cdot w_V$$

Where:

$$\delta T/\delta V = -0.001121164 \cdot V^3 + 0.087473874 \cdot V^2 - 1.408193686 \cdot V + 25.88000923$$

Table A-5 gives the temperature uncertainty due to the uncertainty in the millivolt output from the thermocouple.

Table A-6 gives the error introduced by the fourth order curve fit.

Table A-7 lists the total temperature uncertainty with the fixed thermocouple error (±1.0°C) for a range of temperatures.

Table A-5. Temperature Uncertainty Due to Measured Voltage Uncertainty With Electronic Ice Point Reference Junction

| Temperature (°C) | Absolute Voltage (mV) | ∂T/∂V | Temperature Uncertainty $w_T$ (°C) |
|---|---|---|---|
| 20 | 0.789 | 24.8 | 0.10 |
| 60 | 2.467 | 22.9 | 0.09 |
| 100 | 4.277 | 21.4 | 0.08 |
| 130 | 5.712 | 20.5 | 0.08 |

Table A-6. Temperature Error Due to Fourth Order Curve Fit

| Actual Temperature (°C) | Curve Fit Temperature (°C) | Difference in Temperatures (°C) |
|---|---|---|
| 20.000 | 19.995 | 0.005 |
| 60.000 | 59.988 | 0.012 |
| 100.000 | 99.996 | 0.004 |
| 130.000 | 129.980 | 0.020 |

Table A-7. Total Measured Temperature Uncertainty With Electronic Ice Point Reference Junction and Fourth Order Curve Fit

| Temperature (°C) | Total Uncertainty (°C) |
|---|---|
| 20 | 1.01 |
| 60 | 1.00 |
| 100 | 1.00 |
| 130 | 1.00 |

Component temperatures are corrected for differences between actual room temperature and the "standard" room temperature. The error due to the reference junction is eliminated by the subtraction of the component and room temperature difference. The temperature correction is performed using the following equation:

$$T_C = T_{act} - (T_r - 20°C)$$

where $T_C$ is the corrected room temperature in °C, $T_{act}$ is the measured temperature of component in °C, and $T_r$ is the measured room temperature in °C.

Using Kline and McClintock's method, the uncertainty is:

$$w_{Tc} = \left[ \left( \frac{\partial T_C}{\partial T_{act}} w_T \right)^2 + \left( \frac{\partial T_C}{\partial T_r} w_{Tr} \right)^2 \right]^{1/2}$$

where $w_{Tc}$ is the uncertainty of corrected temperature in °C and $w_{Tr}$ is the uncertainty of measured room temperature in °C. The variable $w_{Tr}$ is about 1.01°C while:

$$\partial T_C / \partial T_{act} = 1.0$$

$$\partial Tc / \partial T_r = 1.0$$

Thus, the total uncertainty in measured temperature after room temperature correction is given in Table A-8.

Table A-8. Temperature Uncertainty With Room Temperature Correction

| Temperature (°C) | Total Uncertainty (°C) |
|---|---|
| 20 | 1.41 |
| 60 | 1.41 |
| 100 | 1.41 |
| 130 | 1.41 |

# APPENDIX B

# THE THERMAL RESISTANCE MODEL COMPUTER PROGRAM

A computer code for the numerical model was written. The computer code is written in the BASIC an will execute on a personal computer (IBM PC or compatible). Input data required to run the program are given below:

Q - The power dissipation from the circuit board, cal/sec.

$R_1$ - Convection thermal resistance from the circuit board to the air, sec °C/cal.

$R_2$ - Convection thermal resistance between the internal cabinet air and the cabinet wall, sec °C/cal.

$R_5$ - Conduction thermal resistance through the cabinet wall, sec °C/cal.

$R_6$ - Convection thermal resistance between the cabinet wall and the ambient air, sec °C/cal.

COR - Correction factor to the radiation thermal resistance (R3) of the circuit board.

CR7 - Correction factor to the radiation thermal resistance (R7) of the outside cabinet wall.

TA - Ambient temperature, °C.

TWO - Outside wall temperature estimate, °C.

TP - Circuit board temperature estimate, °C.

There are five unknowns and four independent equations. The unknowns are the circuit board temperature, the average air temperature inside the cabinet, the inside cabinet wall temperature, the outside cabinet wall

temperature, and the energy fraction, n. The user must estimate an outside wall temperature and a circuit board temperature and iterate on them to get a particular value of the energy fraction, n. To execute the code, type "RUN" and the code will begin to ask for input data.

Output data are given below:

$Q_1$ - energy convected to the air inside the cabinet, cal/sec.

$Q_2$ - Energy convected out the vents, cal/sec.

$Q_3$ - Energy radiated to the cabinet walls, cal/sec.

$Q_5$ - Energy conducted through the cabinet walls, cal/sec.

$Q_6$ - Energy convected from the cabinet walls to the ambient, cal/sec.

$Q_7$ - Net energy radiated from the cabinet wall to the ambient, cal/sec.

n - Ratio of energy convected from the circuit board to the energy convected out the vents.

$R_3$ - Radiation thermal resistance between the circuit board and the cabinet wall, sec °C/cal. This is a function of circuit board and cabinet wall temperatures.

$R_7$ - Radiation thermal resistance between the cabinet wall and the ambient, sec °C/cal. This is a function of cabinet outside wall and ambient temperatures.

A listing of the program is given below:

```
1000 REM ************************************************
1010 REM
1020 REM ELECTRICAL RESISTANCE MODEL
1030 REM
1040 REM JAN. 15, 1988.
1050 REM
1060 REM  This will model a constant heat flux plate
1070 REM     inside a partial enclosure.
1080 REM  This is a user interactive program.
1090 REM  The user must make estimates of the outside wall
1100 REM     temperature and the circuit board temperature.
1110 REM
1120 REM
1130 REM     Inputs:
1140 REM
1150 REM       COR - Multipication factor for the radiation
1160 REM             thermal resistance, R3.
1170 REM       CR7 - Multipication factor for the radiation
1180 REM             thermal resistance, R7.
1190 REM         Q - Power dissipated by the circuit board,
1200 REM             cal/sec.
1210 REM        TA - Ambient air temperature, deg C.
1220 REM        R1 - Convection thermal resistance between the
1230 REM             circuit board and the internal cabinet
1240 REM             air, sec deg C/cal.
1250 REM        R2 - Convection thermal resistance between the
1260 REM             internal cabinet air and the cabinet
1270 REM             wall, sec deg C/cal.
1280 REM        R5 - Conduction thermal resistance of the
1290 REM             cabinet wall, sec deg C/cal.
1300 REM        R6 - Convection thermal resistance between the
1310 REM             cabinet wall and the ambient,
1320 REM             sec deg C/cal.
1330 REM
1340 REM     Outputs:
1350 REM
1360 REM        NU - Ratio of [the energy convected from the
1370 REM             circuit board to ambient through the
1380 REM             cabinet vents] to [the total energy
1390 REM             convected to the inside air]
1400 REM        Q1 - Energy convected to the internal air,
1410 REM             cal/sec.
1420 REM        Q2 - Energy convected to from the internal air
1430 REM             to the cabinet wall, cal/sec.
1440 REM        Q3 - Net energy radiated to the inside cabinet
1450 REM             wall from the circuit board, cal/sec.
1460 REM        Q5 - Energy conducted through the cabinet wall,
1470 REM             cal/sec.
1480 REM        Q6 - Energy convected from the outside cabinet
1490 REM             wall to the ambient air, cal/sec.
1500 REM        Q7 - Net energy radiated from the outside cabinet
1510 REM             wall to the ambient, cal/sec.
1520 REM        R3 - Radiation thermal resistance between the
1530 REM             circuit board and the cabinet wall,
1540 REM             sec deg C/cal.
```

(program listing continued)

```
1550 REM        R7 - Radiation thermal resistance between the
1560 REM             outside cabinet wall and the ambient,
1570 REM             sec deg C/cal.
1580 REM        TB - Average air temperature inside the
1590 REM             cabinet, deg C.
1600 REM        TP - Circuit board temperature, deg C.
1610 REM       TWI - Average inside cabinet wall temperature,
1620 REM             deg C.
1630 REM       TWO - Average outside cabinet wall temperature,
1640 REM             deg C.
1650 REM
1660 REM ******************************************************
1670 REM
1680 INPUT "Power dissipated by circuit board, cal/sec";Q
1690 INPUT "Ambient Air Temp., deg C";TA
1700 INPUT "R1, sec. deg C/cal";R1
1710 INPUT "R2, sec. deg C/cal";R2
1720 INPUT "R5, sec. deg C/cal";R5
1730 INPUT "R6, sec. deg C/cal";R6
1740 INPUT "First estimate of Outside Wall Temp., deg C";TWO
1750 REM
1760 REM  ATWO - outside wall temperature in Kelvin.
1770 REM  ATA - ambient temperature in Kelvin.
1780 ATWO = TWO+273!
1790 ATA = TA + 273!
1800 INPUT "Input multiplication factor of R7"; CR7
1810 REM  The constant 1.226E-08 includes a combined
1820 REM    emissivity of 0.9.
1830 R7 = ((TWO-TA) / ((1.226E-08 * (ATWO^4 - ATA^4))))
1840 R7 = R7*CR7
1850 DELT = TWO - TA
1860 Q6 = DELT / R6
1870 Q7 = DELT / R7
1880 TWI = R5 * (Q6 + Q7) +TWO
1890 Q5 = Q6 + Q7
1900 PRINT "Q7 = ";Q7, "R7 = ";R7
1910 PRINT "Q6 = ";Q6, "R6 = ";R6
1920 PRINT "Q5 = ";Q5, "R5 = ";R5
1930 PRINT "Inside Wall Temp. = ";TWI
1940 INPUT "R3 multiplication factor ";COR
1950 INPUT "Estimate for circuit board temp., deg. C ";TP
1960 ATP = TP +273!
1970 ATWI = TWI +273
1980 DEL = TP - TWI
1990 REM The constant 1.226E-08 includes a combined
2000 REM    emissivity of 0.9 .
2010 R3 = DEL / (1.226E-08 *(ATP^4 - ATWI^4))
2020 R3 = R3*COR
2030 Q3 = DEL / R3
2040 Q2 = Q5 - Q3
2050 Q1 = Q - Q3
2060 NU = 1 - Q2/Q1
```

(program listing continued)

```
2070 PRINT "NU = ";NU
2080 PRINT "Q3 = ";Q3,"R3 = ";R3
2090 PRINT "Q2 = ";Q2,"R2 = ";R2
2100 PRINT "Q1 = ";Q1,"R1 = ";R1
2110 REM
2120 TB = Q2*R2 + TWI
2130 TPN = Q1*R1 + TB
2140 PRINT "Average Air Temp = ";TB,"New circuit board temp = ";TPN
2150 REM
2160 DELTEM = TP - TPN
2170 ABSDT = ABS(DELTEM)
2180 PRINT "Absolute value of circuit board temp. diff. = ";ABSDT
2190 IF ABSDT<.0001 GOTO 2210
2200 GOTO 1700
2210 END
```

To match the baseline case given in Figure 8.39 on page 158, the following inputs were used:

Q = 21.5 cal/sec

TA = 20.0 °C

R1 = 1.5 sec °C/cal

R2 = 0.4 sec °C/cal

R5 = 0.07 sec °C/cal

R6 = 0.75 sec °C/cal

TWI = 27.0 °C

COR = 8

CR7 = 3

TP = 55.138°C

# APPENDIX C

# RELIABILITY DATA FOR

# TRANSISTORS AND INTEGRATED CIRCUITS

Silicon PNP type transistor reliability curves were generated using data from Table 5.1.3.1-8 in MIL-HDBK-217D. For this type of transistor, base failure rate (failures for 1 million hours) is plotted as a function of component junction temperature in Figure C-1. A curve is given for stress ratios, s, of 0.4, 0.5, 0.6, and 0.7. Stress ratio is defined as the ratio of the operational power dissipation to the maximum allowable power dissipation. The horizontal output transistor is believed to operate at a stress ratio of 0.6. The switch mode regulator is assumed to operate at the worst case stress ratio of 0.7.

Non-hermetic integrated circuit reliability data was obtained from MIL-HDBK-217D. Figure C-2 shows temperature acceleration factor, which is proportional to failure rate given as a function of junction temperature. Different types of integrated circuits have different acceleration factors. All integrated circuit failure rate increases are based on the worst slope curve. All integrated circuit failure rate decreases are based on the lowest slope curve.

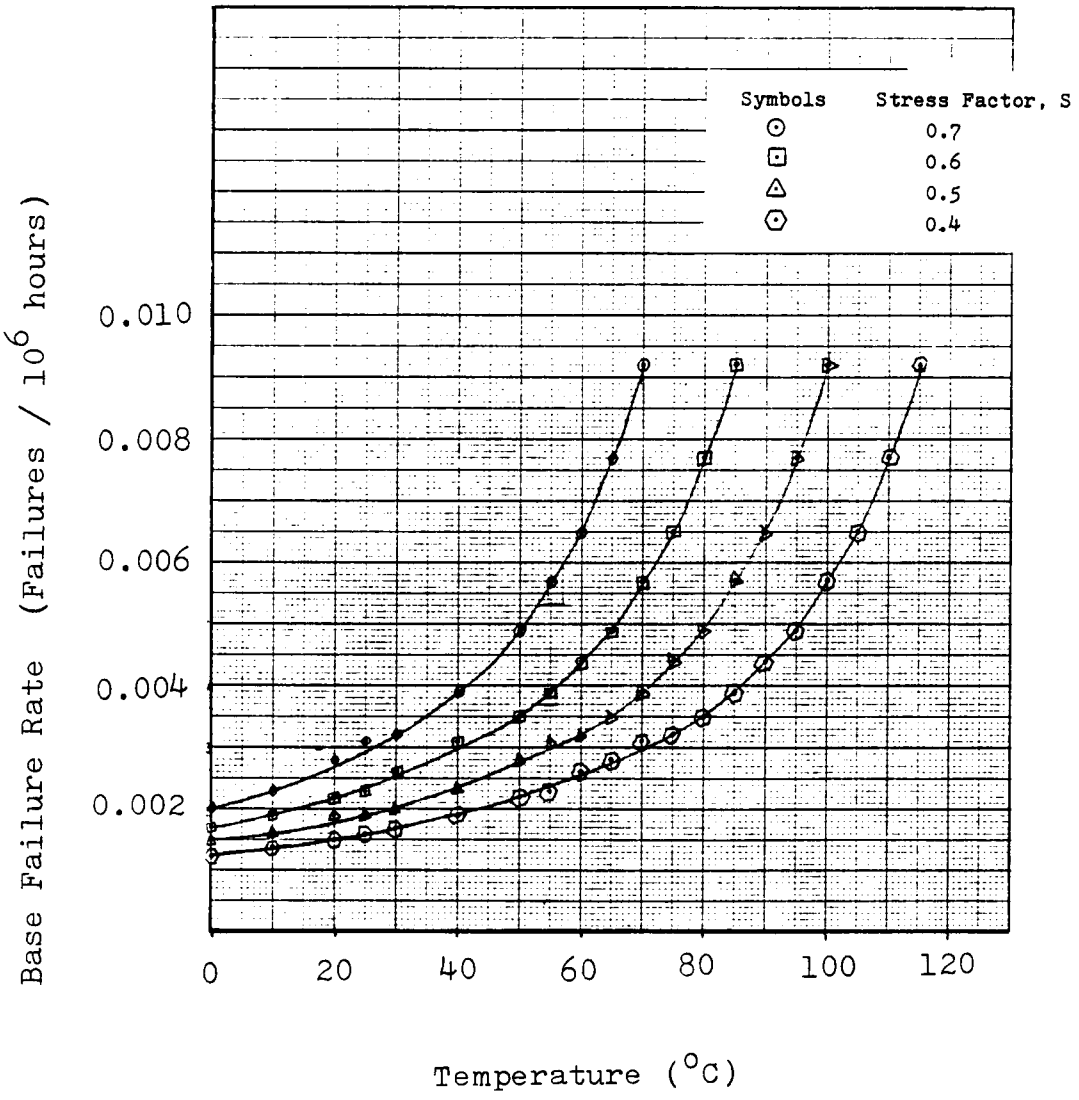



Figure C-1. Transistor Failure Rate Based on Data From MIL-HDBK-217D

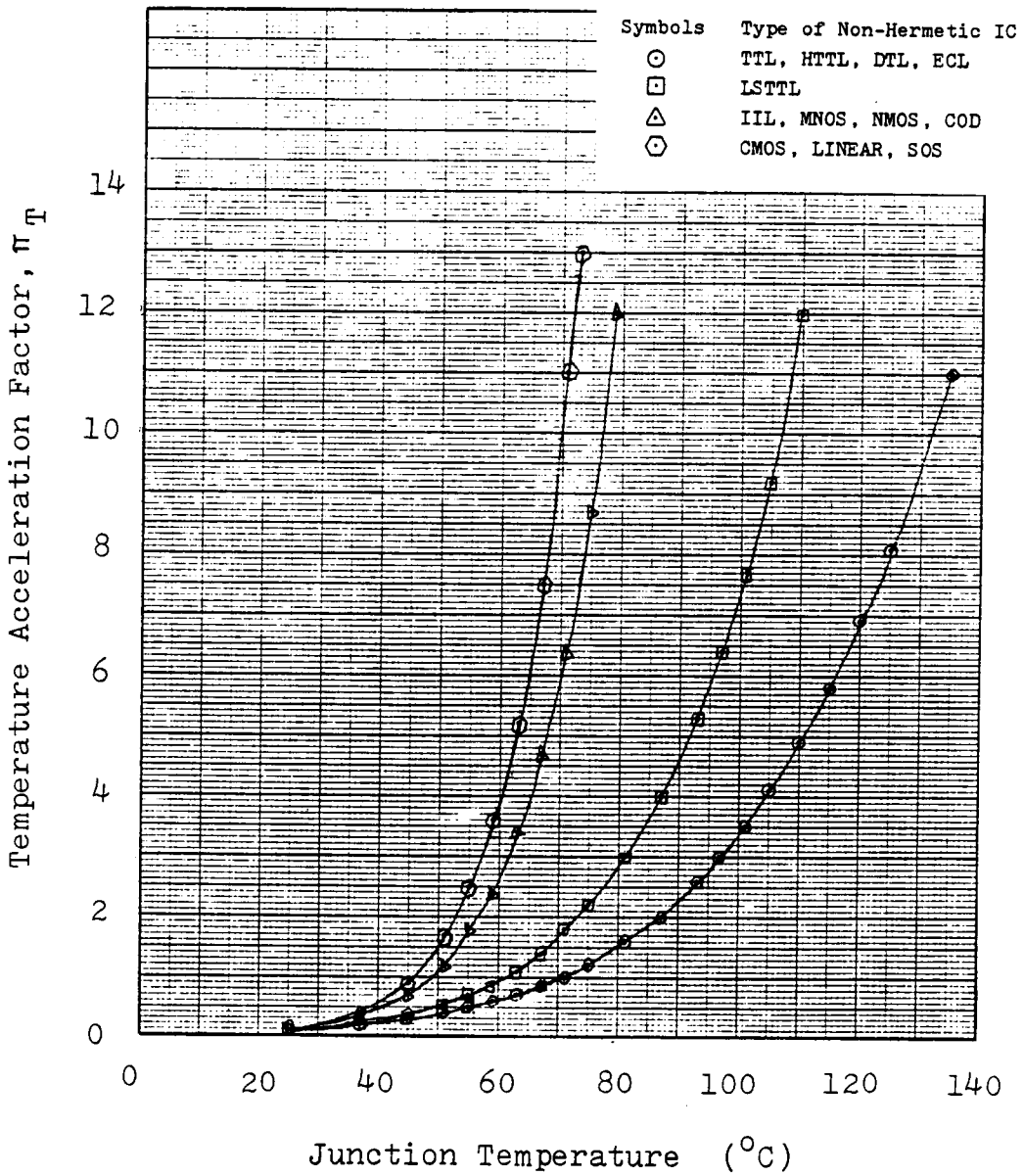



Figure C-2. Integrated Circuit Temperature Acceleration Factor Based on Data From MIL-HDBK-217D

# VITA

Michael S. Yuki was born in Fresno, California on July 8, 1961. He attended elementary and high school in Cleveland, Tennessee. From September 1979 to June 1984 he attended the University of Tennessee, Knoxville where he received a Bachelor of Science Degree in mechanical engineering.

After graduation, he spent two years in St. Louis, Missouri as a propulsion engineers for McDonnell Douglas Astronautics Company. In September 1986, he was granted a educational leave of absence to attend the the Graduate School of the University of Tennessee, Knoxville.

The author is a member of the Institute of Aeronautics and Astronautics and the American Society of Mechanical Engineers. Mr. Yuki will return to McDonnell Douglas Astronautics Company after graduation.