TID/SNA--1410

# LIQUID ROCKET PLANT

MASTER

950 0878

## TEMPERATURE MEASUREMENT SYSTEMS

Prepared by

H. C. Chandon

Technical Report 8771:2422 1 February 1964

AEROJET-GENERAL CORPORATION
SACRAMENTO, CALIFORNIA

X-3431

# DISCLAIMER

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TECHNICAL REPORT 8771:2422

# TEMPERATURE MEASUREMENT SYSTEMS

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AEROJET-GENERAL CORPORATION
INSTRUMENTATION DEVELOPMENT DEPARTMENT
TEST INSTRUMENTATION DIVISION
LIQUID ROCKET PLANT

# FORWARD

This technical report is prepared for the Instrumentation Training Course conducted by the Test Instrumentation Division. Emphasis is placed upon the operational systems in the test area. Fundamentals for the measurement of temperature are not discussed in general because several text books containing this information are available at the Technical Library.

Suggestions and comments that would enhance the value of this technical report are invited.

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# I INTRODUCTION

There are four operational temperature measurement systems in the Liquid Rocket Plant Test Area. They are: (1) the Thermocouple System, (2) the Bridge-in-head Ambient RTT * System, (3) the Cryogenic Constant Current RTT System, and (4) the Bridge Completion RTT System.

The thermocouple system, as the name implies, is a system which measures temperature with only thermocouples. Signal conditioning for thermocouples is achieved by voltage substitution. Temperature measurements presently cover the range of -425°F to +2500°F. This system will be expanded to measure to 4200°F when the development of Tungsten-Rhenium thermocouples is completed. The basic system was designed and installed in the test area during the Titan I Liquid Rocket Engine Research and Development Test Program.

Development of the bridge-in-head ambient RTT system was completed during the initial stages of the Titan II Program. This system measures temperature with an RTT that contains all resistors in a housing such that the electrical circuit is a Wheatstone bridge. Signal conditioning for this system is also achieved by voltage substitution. This system is designed to make measurements in the 0°F to 500°F region.

The most recently developed temperature measuring system, the cryogenic constant current RTT system, was developed for the NERVA Component Test Program at Sacramento. This system measures temperature with a platinum resistance element. A four-wire system measures the platinum element resistance by measuring the voltage drop across the element caused by a constant current flowing in the circuit. The system is calibrated by resistance substitution and covers the range of 0 to 5000 ohms. RTT's have been developed to cover the region of -425°F to +75°F.

A bridge completion system is also available in the test area for measuring cryogenic temperatures. In this system a platinum element RTT forms the fourth leg of a Wheatstone bridge to measure resistance. The resistance of the RTT is measured and converted to temperature by recording the output voltage from the Wheatstone bridge circuit. The bridge completion system is also calibrated by resistance substitution. Development of this system was accomplished during the Titan I Research and Development Test Program. The system is presently undergoing modification to meet the requirements of the NERVA and M-1 programs.

Three systems are discussed in detail in this report. Since the bridge completion system is being modified, details will not be incorporated in this report until a later revision.

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* RTT is the abbreviation for resistance temperature transmitter.

## II DESIGN CONSIDERATIONS

### A. OPERATING ENVIRONMENT

Since the nature of rocket testing is hazardous, transmitters are located in the firing area which is remotely located from the signal conditioning and recording equipment. A physical separation of 500 feet is typical. The resistance of 500 feet of cable, including test stand selector relays, patching, switches, and terminations is normally between 2 and 5 ohms. The design of a measuring system must include provisions for suppressing or decreasing the effects of line resistance during calibration and data recording.

### B. ACCURACY AND REPEATABILITY

To guarantee the conformance of rocket engine hardware to the model specification, the demonstrated performance must exceed the model specification requirements by an amount equal to the maximum expected error of measurement. The development of measuring systems of high accuracy and reliability is necessary because instrumentation error can substantially increase the cost of hardware development programs.

### C. LINEARITY

The IBM 7090 and 1401 computers do not require linear transmitter outputs for data reduction. However, operational considerations make it desirable to design transmitters and measuring systems for response to linear output. In addition to simplifying computer programming and reducing computer processing time, linear systems eliminate special scale requirements for recording and indicating instruments. Personnel training requirements are decreased because system operation does not involve such complexities as manipulation of nonlinear equations.

### D. RELIABILITY

Rigid requirements have been established by Aerojet-General for a manufacturer to become a qualified source for all temperature transmitters to be used in the test area temperature measuring system. On request, each potential manufacturer must provide two representative samples for evaluation. The criterion established is that both units must withstand 20 rocket engine firings or 4000-sec cumulative running time without electrical or mechanical failure.

High operational reliability of a system results in the greatest single cost reduction to a testing program. In addition to providing valuable data, the necessity for redundant measurements is decreased, allowing the monitoring of more parameters and the reduction of costly non-productive failure analyses. Each temperature transmitter must be designed to withstand high vibration, shock, and atmospheric conditions.

## E. STANDARDIZATION

Component standardization is a fundamental requirement for the economic operation of a large-scale testing program. Standardization, both electrical and physical, permits complete interchangeability of transmitters within the test program so that only knowledge of the transmitter range is required to reduce data.

Electrical standardization requires that the output versus the temperature ratio be the same for transmitters of all ranges or types. The use of standardized transmitters makes possible the reduction of data without reference to serial numbers or individual calibration data. Transmitter standardization also permits the use of "go" and "no go" calibration equipment for periodic laboratory use, as well as interchanging system components such as power supplies and operational calibration panels.

## F. ADAPTABILITY TO FLIGHT USE

In addition to measuring temperatures in the test area, the Instrumentation Division develops flight instrumentation kits for liquid rocket engines. To successfully develop a reliable flight instrumentation kit all components must be developed for rigorous test area environments and systems, thus largely eliminating the costly simulation of rocket engine environments to test component designs for reliability.

During the past three years, the Instrumentation Division has delivered an instrumentation kit with each research and development YLR87-AJ-5 and YLR91-AJ-5 Titan II Liquid Rocket Engine. These kits are installed on the engines in the field for monitoring engine parameters on captive and flight tests. Parameters on the Titan II kits include provisioning for measurement of $T_{os}$ (oxidizer suction temperature), $T_{fs}$ (fuel suction temperature), $T_{fPOI}$ (fuel pressurant orifice inlet temperature), $T_{oPOI}$ (oxidizer pressurant orifice inlet temperature, $T_{fGCO}$ (fuel gas cooler outlet temperature) with a bridge-in-head type temperature transmitter, and $T_{Ti}$ (turbine inlet temperature) with a chromel vs alumel thermocouple.

The Instrumentation Division is presently developing temperature transmitters for the NERVA engine test series at Nevada.

## G. SAFETY

Aerojet-General, as an industrial leader in plant safety, requires that all facilities be designed so that safety for operating personnel is assured. In component design and specification writing it is essential that the environments and materials be clearly specified for the manufacture of all system components.

Compatibility of material for the construction of a temperature transmitter for direct immersion into propellant lines, and the mechanical strength of the immersed sensing probe must be assured so that no severe test stand damage or rocket engine component damage results from fire or explosion. Safety to personnel and the test stand is best controlled by clearly specifying materials and qualifying the product during actual engine firings.

# III THERMOCOUPLE SYSTEM

## A. THERMOCOUPLE CHARACTERISTICS

### 1. Seebeck Effect

In 1821 a German Physicist, Thomas J. Seebeck, discovered if two dissimilar metals are connected as shown in Figure 1, and one of the junctions is heated, relative to the other, an EMF (electromotive force) is induced in the circuit. This EMF will be induced as long as the two junctions are at differing temperatures, will vary as some function of the temperature difference, and will reduce to zero when $T_1$ equals $T_2$. Conductor A is positive with respect to B if the current flows from A to B at the cooler of the two junctions. The EMF induced is called the Seebeck Thermal EMF.

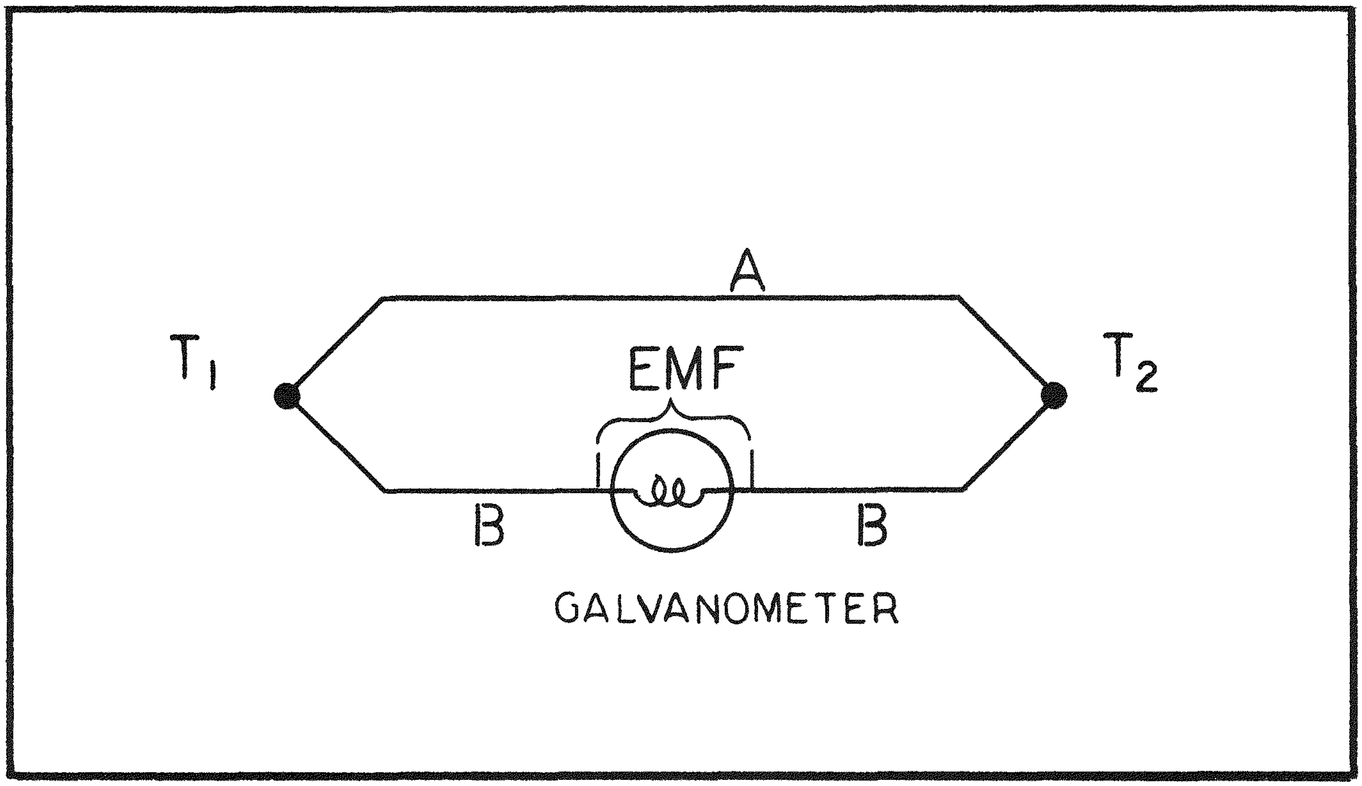
### 2. Peltier Effect

In 1834 Peltier, a French Physicist, discovered when a current flows across the junction of two dissimilar metals it gives rise to an absorption or liberation of heat. If the current flows across the junction in one direction heat is absorbed, if it flows in the other direction heat is liberated. When a current flows in the same direction as the current produced by the Seebeck Thermal EMF, heat is absorbed (heated) at the hot junction and is liberated (cooled) at the cold junction.

### 3. Thomson Effect

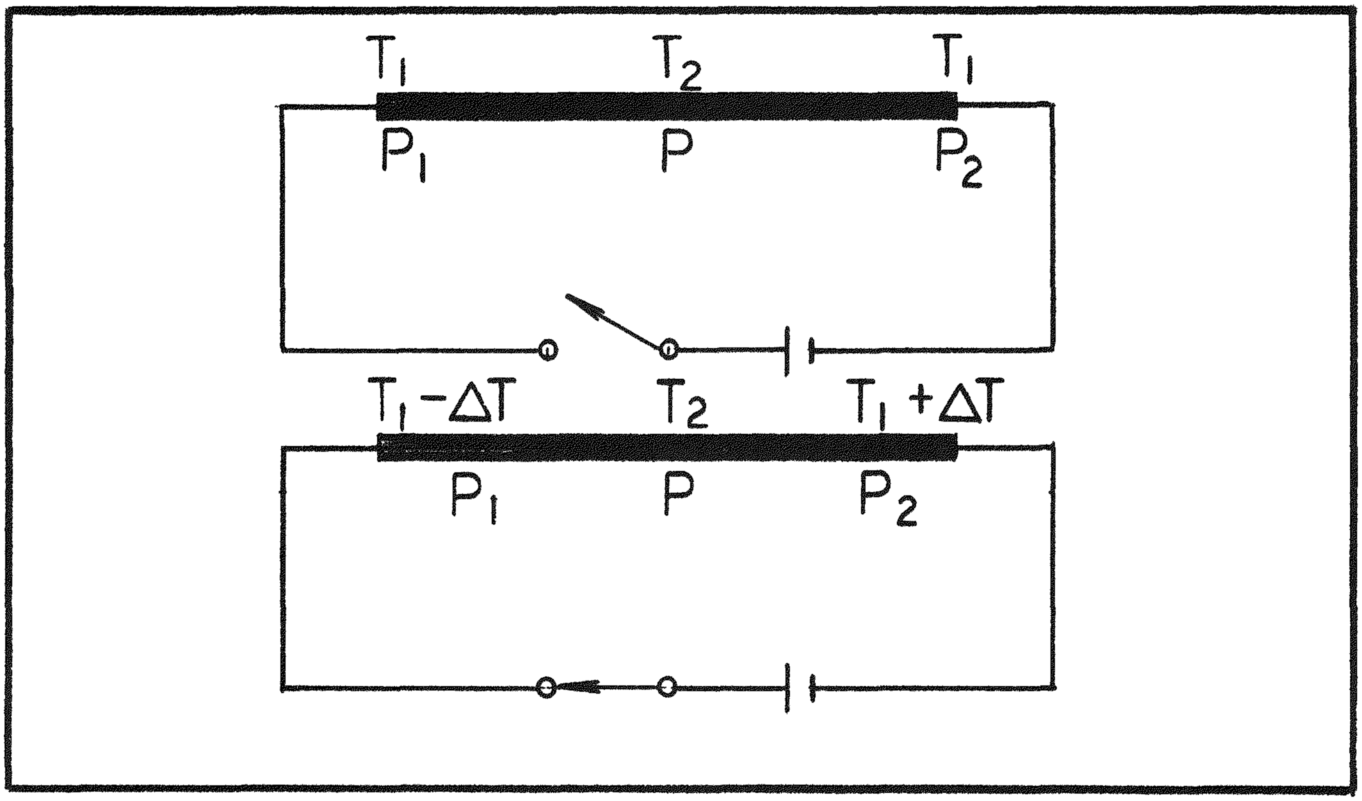
In 1851 Lord Kelvin (Sir William Thomson), an English Physicist and Mathematician, found when a current flows along a copper wire whose temperature varies from point to point, heat is liberated at any point P where the current at P flows in the direction of the flow of heat at P. He also found that heat is absorbed when the current flows in the opposite direction of the flow of heat. The opposite effect was observed for iron.

The Thomson effect is caused by unequal heating along a conductor that is carrying current. It is a reversible effect that takes place regardless of the direction of current flow. Figure 2 illustrates the Thomson effect on copper wire. The copper wire is heated at point P to a temperature $T_2$ and to $T_1$ at $P_1$ and $P_2$. If $T_2$ is higher than $T_1$ then by closing the switch $P_1$ will liberate heat and $P_2$ will absorb heat.



SEEBECK EFFECT

Figure 1



THOMSON EFFECT

Figure 2

## 4. Thermoelectric Laws

There are three laws of thermoelectricity that can be applied in the design and analysis of thermocouple circuits. They are: (1) in a closed circuit consisting of a single homogeneous wire, a current cannot be induced by the application of heat alone, (2) a third metal C may be introduced in a circuit (Figure 3) consisting of two homogeneous metals A and B with their junction at temperatures $T_1$ and $T_2$ without affecting the EMF provided $T_3$ equals $T_4$, and (3) if a pair of metals produces an EMF $E_1$ when its junctions are at $T_1$ and $T_2$, and an EMF $E_2$ when its junctions are at $T_3$ and $T_2$, then the EMF is $E_1 + E_2$ when the junctions are $T_1$ and $T_3$ (Figure 4).

The first law can be utilized in testing thermocouple materials to determine homogenity. Neglecting the Thomson effect, the EMF in any thermocouple circuit is independent of the gradients existing along the wires.

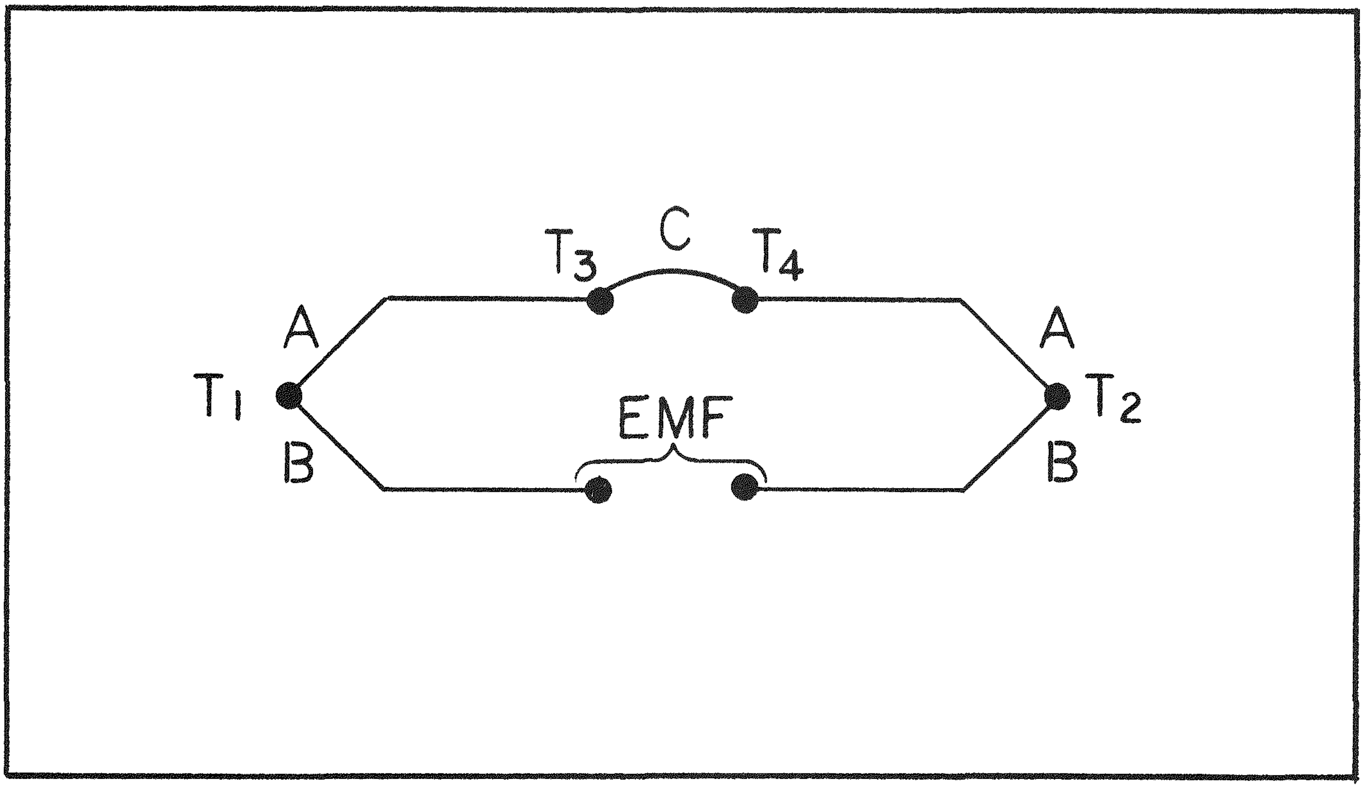
If Figure 3 is revised as shown in Figure 5, it is seen that the circuit may be used to measure temperature.

As long as $J_3$ junction temperature equals $J_4$ junction temperature, the copper in the circuit does not affect the total circuit EMF. In this circuit, junction $J_2$ is usually at the melting point of ice (reference bath junction) and junction $J_1$ is the monitor. The same reasoning may be applied to many other metal combinations. From the second law it is also deduced that if the thermal EMF's of any two metals compared with a third metal (for any given two junction temperatures) are known, then the EMF between the two metals is the algebraic sum of the two compared with the reference metal. As an example, Fe - Cn has an output of 1.940 millivolts at +100°F with reference to +32°F, and Cu - Cn has 1.517 millivolts. A copper-iron thermocouple would produce the difference between the two, or 0.423 millivolts. (Both iron and copper are positive with respect to constantan at this temperature.)

The third law permits the use of a junction (other than the usual +32°F), with a simple bias correction, for all of the millivolt data. For example, it is not economical to carry an ice junction on a missile or an aircraft, hence "hot reference" junctions have been developed ranging from +150 to +300°F. Some device has to be used for monitoring the hot reference junction temperature; this could be a resistance thermometer type.

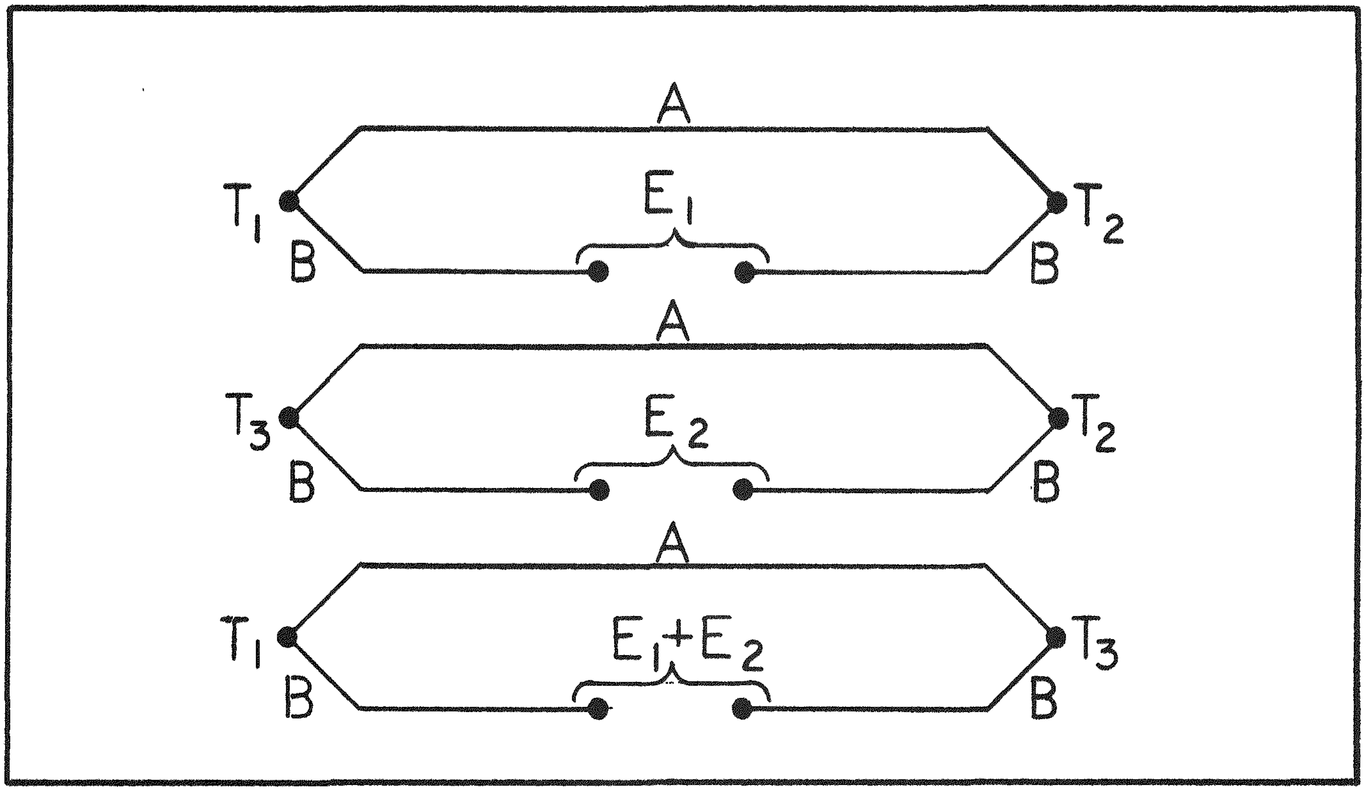
## 5. General Discussion

The useful ranges of thermocouples are determined by factors such as mechanical strength, contamination, oxidation effects, accuracies required, and output required. There is a great deal of overlapping of ranges, the choice depends upon the discretion of the user. Figure 6 shows the approximate ranges of some of the more common materials. Other characteristics for the common materials are tabulated in Figure 7.



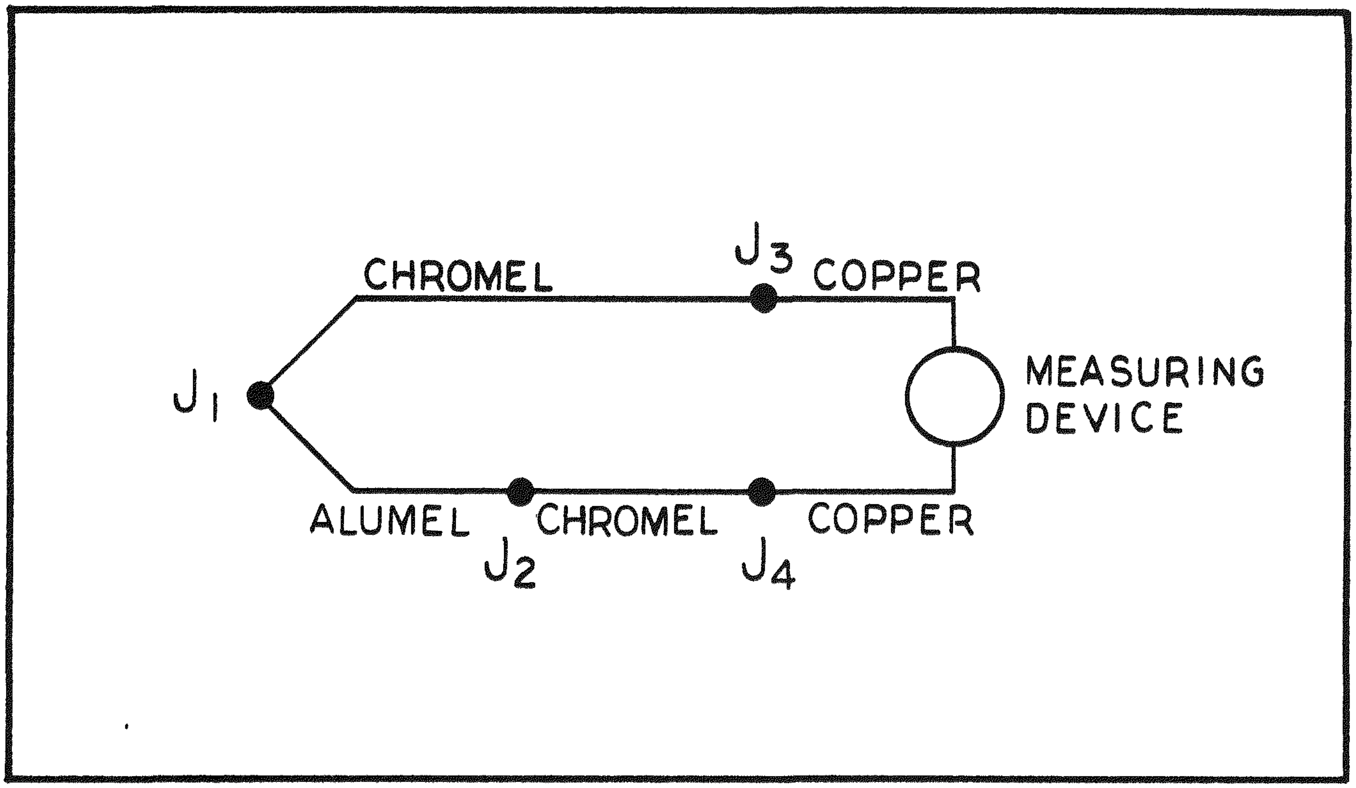
SECOND THERMOELECTRIC LAW

Figure 3



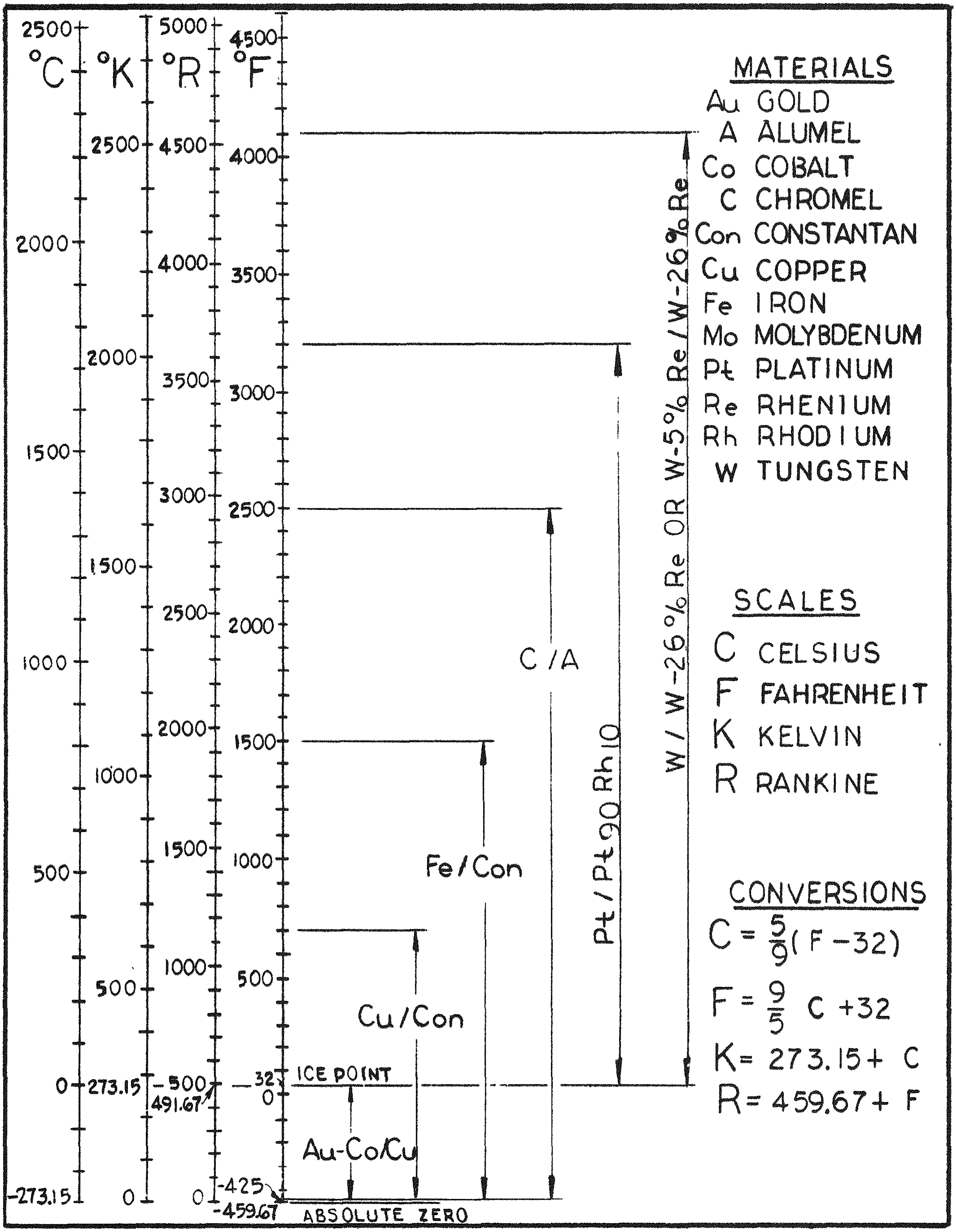
THIRD THERMOELECTRIC LAW

Figure 4



THERMOCOUPLE MEASUREMENT CIRCUIT

Figure 5



TEMPERATURE SCALES
AND GENERAL THERMOCOUPLE RANGES

| THERMOCOUPLE | ISA TYPE | RANGE (°F) | PREMIUM GRADE ACCURACY | ICE BATH REF. SENSITIVITY (MV) | PHYSICAL CHARACTERISTICS |
|---|---|---|---|---|---|
| Copper vs Constantan (C/C) | T | -425 to -300<br>-300 to -75<br>-75 to +200<br>+200 to +750 | Undefined<br>± 1%<br>± 3/4°F<br>± 3/8% | -6.2025 to 20.8052 | Copper: Positive; Reddish in color<br>Constantan: Negative; very slightly magnetic; varies between 35% to 50% Nickel, balance Copper |
| Iron vs Constantan (I/C) | J | -425 to -300<br>-300 to -100<br>-100 to 530<br>530 to 1600 | Undefined<br>± 2%<br>± 2°F<br>± 3/8% | -9.0667 to 50.05 | Iron: Positive; very magnetic<br>Constantan: Negative; very slightly magnetic; varies between 35% to 50% Nickel, balance Copper |
| Chromel vs Alumel (C/A) | K | -425 to 0<br>0 to 530<br>530 to 2500 | Undefined<br>± 2°F<br>± 3/8% | -6.4355 to 54.92 | Chromel: Positive; non-magnetic; 90% Nickel, 10% Chromium<br>Alumel: Negative; magnetic; 94% Nickel, 3% Manganese, 2% Aluminum, 1% Silicon |
| Platinum - 10% Rhodium vs Platinum (P-10R/P) | S | 32 to 1000<br>1000 to 3200 | ± 2.5°F<br>± 1/4% | 0 to 18.59 | Platinum - 10% Rhodium: Positive; 90% Platinum, 10% Rhodium<br>Platinum: Negative; 100% Platinum |
| Tungsten vs Tungsten - 26% Rhenium (W/W-26Re) | | 32 to 4200 | Undefined | 0 to 39.083 | Tungsten: Positive; 100% Tungsten<br>Tungsten - 26% Rhenium: Negative; 74% Tungsten, 26% Rhenium |
| Tungsten - 5% Rhenium vs Tungsten - 26% Rhenium (W-5RE/W-26Re) | | 32 to 4200 | Undefined | 0 to 37.045 | Tungsten - 5% Rhenium: Positive; 95% Tungsten, 5% Rhenium<br>Tungsten - 26% Rhenium: Negative; 74% Tungsten, 26% Rhenium |
| Copper vs Gold-2.1 At % Cobalt (C/2.1 At % Au-Cobalt) | | -425 to 32 | Undefined | -9.7040 to 0 | Copper: Positive; Reddish in color<br>Gold-2.1 At %Cobalt: Negative; 97.90 Atomic % Gold; 2.1 Atomic % Cobalt; Gold in color |

THERMOCOUPLE CHARACTERISTICS

Figure 7

## B. TEST AREA THERMOCOUPLES

### 1. Specifications

All thermocouples are purchased in accordance with Aerojet Specification Control Drawings and Component Specifications. It is required that all thermocouples pass a receiving inspection which includes accuracy, response time, and pressure testing. A tabulation of the various types of thermocouples used in the test area is shown in Figure 8.

### 2. EMF Vs Temperature Tables

Test data is reduced to a set of thermocouple tables which is compiled from several sources, most of which emanate from the National Bureau of Standards. This set of tables is published in Component Specification AGC-42136, Revision C, dated 23 December 1963. See Figure 9 for a tabulation of each thermocouple type, with the origin of data, for various temperature regions (taken from Component Specification AGC-42136).

A graphical presentation of the thermocouple tables is shown in Figure 10 for measurements below 32°F and in Figures 11, 12, and 13 for measurements above 32°F.

### 3. Color Coding

The thermocouple leadwire color coding used in the test area is that recommended by the ISA (Instrument Society of America), see Figure 14. To protect the fiberglass insulation from storable propellant, engine cleaning solvent, or weather damage, a protective heat shrinkable sleeve covers the thermocouple leadwires. The protective sleeve is color coded to match the tracer ISA coding which is blue for Copper-Constantan, white for Iron-Constantan, and yellow for Chromel-Alumel thermocouples.

### 4. Mounting/Installation Methods

There are two basic styles of thermocouples in the test area, the immersion and the bearing style. The immersion thermocouples are designed to be installed within a duct for measuring the stream temperature and the bearing thermocouples are designed to be installed within a well for measuring the race temperature of bearings. Suggested installation of both types is illustrated in Figures 15 and 16.

| AGC SCD | TITLE | TIP CONFIGURATION | INSTALLATION | RELEASED | AGC SPEC |
|---|---|---|---|---|---|
| 235726 | Thermocouple Immersion-Chromel-Alumel | Shielded Grounded | 3/8" Boss (As 1128A6) | 1-11-61 | 42136<br>42136/2 |
| 248888 | Thermocouple Immersion-Chromel-Alumel | Shielded Grounded | 3/8" Boss (As 1128A6) | 5-29-61 | 42136<br>42136/1 |
| 267501* thru 267548 | Thermocouple Immersion-Chromel-Alumel, Open Element | Open Element Ungrounded | 1/4" Boss (As 1128A4) | 4-17-62 | 42136<br>42136/6 |
| 267601* thru 267648 | Thermocouple Immersion-Chromel-Alumel | Shielded Grounded | 1/4" Boss (As 1128A4) | 5-8-62 | 42136<br>42136/1 |
| 267700* thru 267719 | Thermocouple Contact-Chromel-Alumel | Shielded Grounded | 1/8" Pipe Bulkhead | 6-5-62 | 42136<br>42136/3 |
| 267001* thru 267048 | Thermocouple Immersion-Copper-Constantan, Open Element | Open Element Ungrounded | 1/4" Boss (As 1128A4) | 4-17-62 | 42136<br>42136/5 |
| 267101* thru 267148 | Thermocouple Immersion-Copper-Constantan | Shielded Grounded | 1/4" Boss (As 1128A4) | 5-8-62 | 42136<br>42136/7 |
| 267200* thru 267219 | Thermocouple Contact-Copper-Constantan | Shielded Grounded | 1/8" Pipe Bulkhead | 6-5-62 | 42136<br>42136/4 |

* These part numbers are coded and describe the thermocouple type and probe length. All coded numbers are of the 267000 series.

26 [7X] [XX]

7X: Thermocouple Type

XX: Probe lengths in multiples of 0.25 inch [1]

1. With exception of <u>contact</u> thermocouples. For these the numbers correspond to: 2.0 + (XX) (.5) inches. <u>EXAMPLE</u>: Part number 267203 is a C.C. Contact thermocouple with a 2.0 + (3) (.5) = 3.5 inch probe.

Thermocouple Type Codes are as Follows:

| Code | Type |
|---|---|
| 70 | CC Immersion, Open Element |
| 71 | CC Immersion, Grounded Shielded |
| 72 | CC Contact, Grounded Shielded |
| 73 | Not Assigned |
| 74 | Not Assigned |
| 75 | CA Immersion, Open Element |
| 76 | CA Immersion, Grounded Shielded |
| 77 | CA Contact, Grounded Shielded |
| 78 | Not Assigned |
| 79 | Not Assigned |

LRP TEST AREA THERMOCOUPLES

Figure 8

| THERMOCOUPLE TYPE | APPENDIX NO. | TEMPERATURE REGION °F | ORIGIN OF DATA |
|---|---|---|---|
| C/A | I | -425 to 32<br>32 to 1299<br>1300 to 2500 | (1)<br>(2)<br>(3) |
| C/C | II | -425 to 32<br>32 to 749 | (1)<br>(2) |
| I/C | III | -425 to 32<br>32 to 1299<br>1300 to 1600 | (1)<br>(2)<br>(3) |
| C/Au-2.1 Co | IV | -425 to 32 | (1) |
| W-5 Re/W-26 Re | V | 32 to 4200 | (4) |
| W/W-26 Re | VI | 32 to 4200 | (4) |

(1) Temperature, Its Measurement and Control in Science and Industry, Volume Three, Part 2, 1962 Pages 65 to 77 - Section 6, "Low-Temperature Thermocouples," by Robert L. Powell, Lindsay P. Caywood, Jr., and M. D. Bunch, Cryogenic Engineering Laboratory, National Bureau of Standards, Boulder, Colorado.

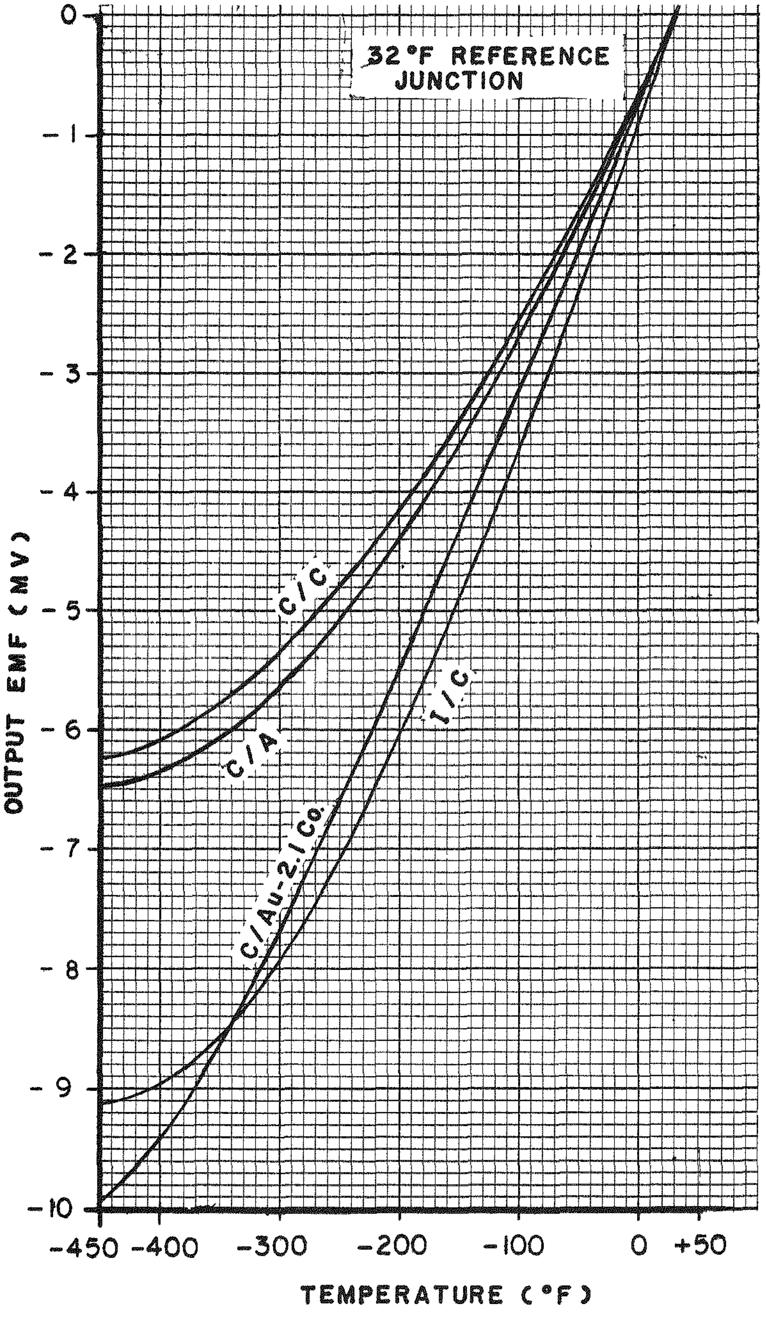
(2) Temperature, Its Measurement and Control in Science and Industry, Volume Three, Part 2, 1962, pages 51 thru 64 - Section 5, "Improved Reference Tables for Thermocouples," by Robert P. Benedict and Harold F. Ashby, Westinghouse Electric Corporation, Lester, Pa.

(3) NBS Circular 561, "Reference Tables for Thermocouples," April 27, 1955, by Henry Shenker, John I. Lauritzen, Jr., Robert J. Corruccini, and S. T. Lonberger, National Bureau of Standards, Washington, D. C.

(4) Sales Bulletin, "Tungsten-Rhenium Thermocouple Alloys," Hoskins Manufacturing Company, Thermocouple Tables Adopted 23 November 1962.

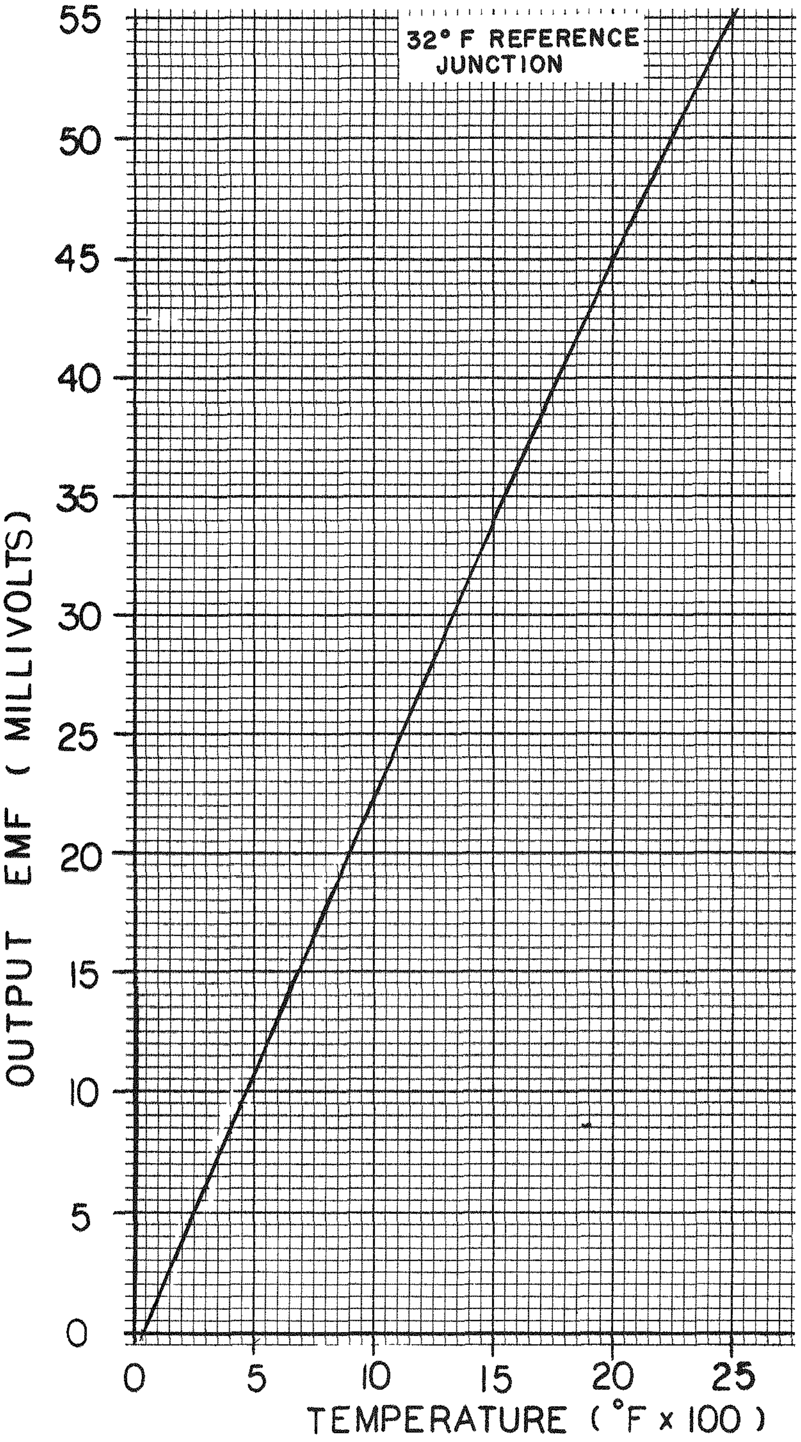
ORIGIN OF DATA FOR THERMOCOUPLE TABLES

Figure 9



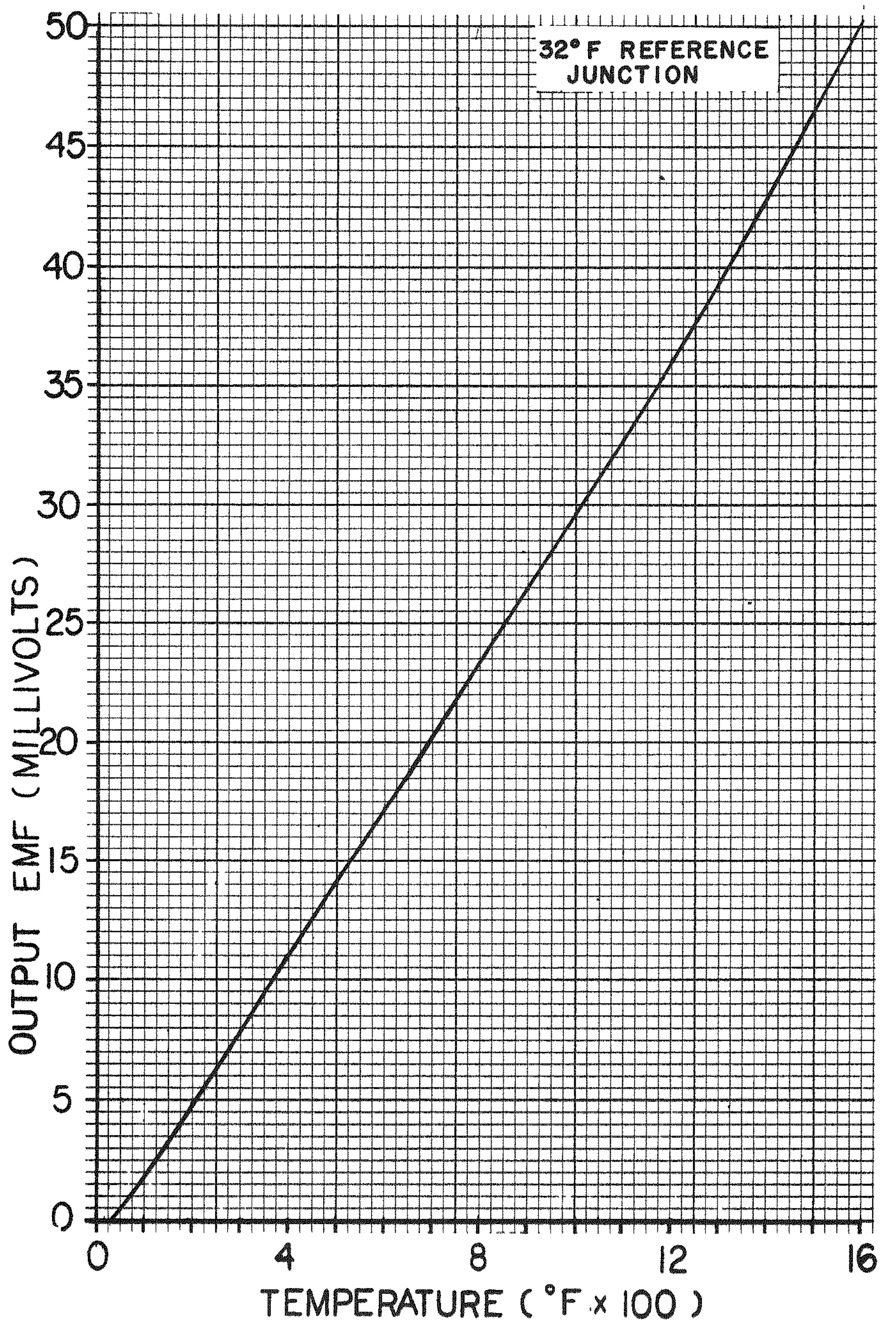
LOW TEMPERATURE EMF GRAPH FOR THERMOCOUPLE

Figure 10



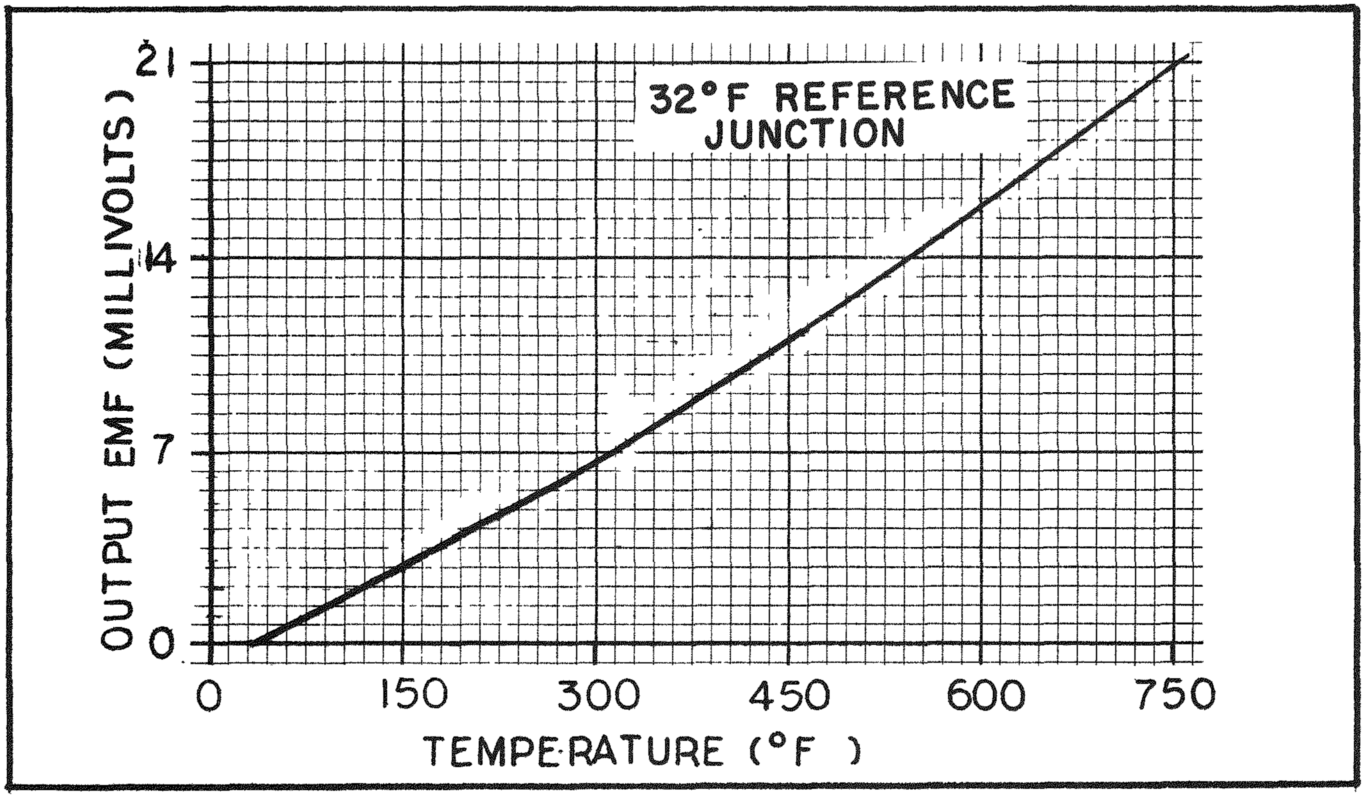
C/A TEMPERATURE EMF GRAPH

Figure 11



I/C TEMPERATURE EMF GRAPH

Figure 12



C/C TEMPERATURE EMF GRAPH

Figure 13

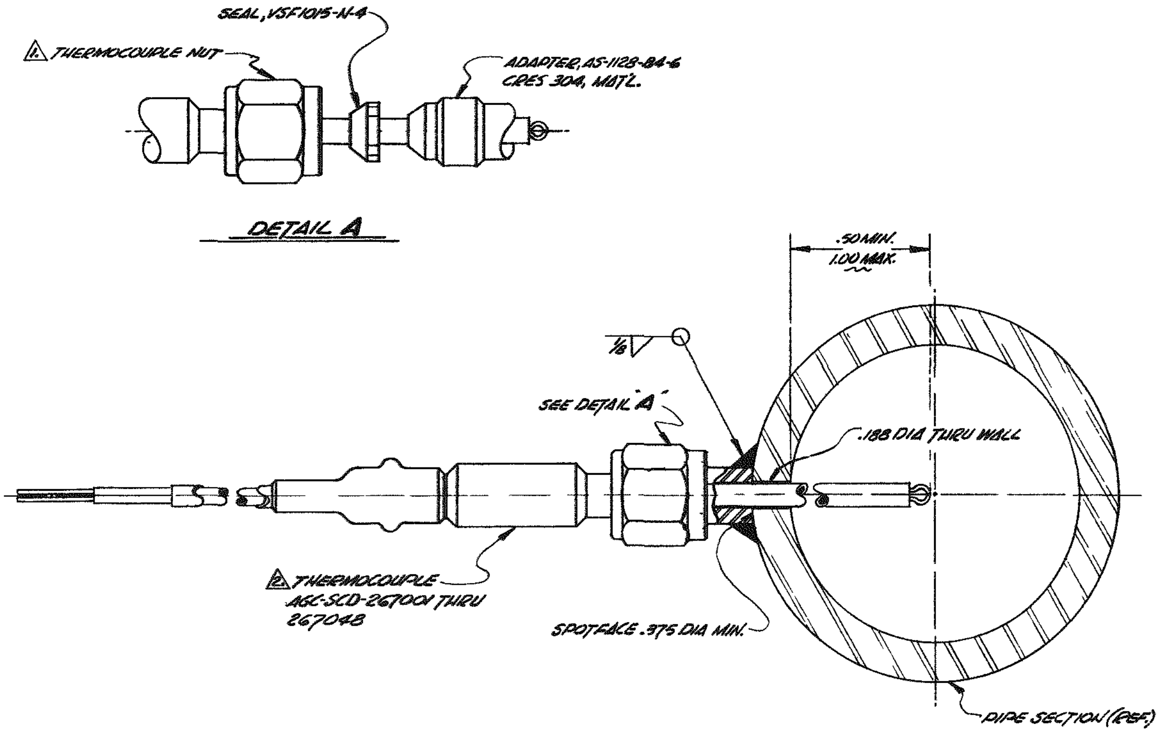
| POLARITY | | RECOMMENDED ISA THERMOCOUPLE WIRE COLOR CODING | | | |
|---|---|---|---|---|---|
| + | - | + | - | OVERALL | TRACER |
| Copper | Constantan | Blue | Red | Brown | Blue |
| Iron | Constantan | White | Red | Brown | White |
| Chromel | Alumel | Yellow | Red | Brown | Yellow |
| Platinum 90 Rhodium 10 | Platinum | (Copper) Black | (Alloy) Red | Green | |

THERMOCOUPLE LEADWIRE COLOR CODING

Figure 14

Figure 15

| LETTER | DATE | CHANGE | BY | CH'D |
|---|---|---|---|---|
| | | | | |



COPY 248072

2. SUPPLIED BY TEST DIVISION, DEPT 8770, A.G.C.

1. RECOMMENDED TORQUE 135-150 IN. LBS.

NOTES:

| | | | | |
|---|---|---|---|---|
| No. Reqd. | NEXT ASSY | MODEL | DRAFTSMAN Rowe | DATE 11-9-62 |
| HEAT TREAT | FINISH | | CHECKED | |
| TOLERANCE UNLESS OTHERWISE NOTED | | | STRESS | |
| LINEAR TOL. | .XX | ± .03 | ENGINEER O'Fassins | 11-9-62 |
| | .XXX | ± .010 | APPROVED H.C. Chandon | 11-9-62 |
| | ANGULAR TOL. | | PRODUCTION | |
| ✓ INDICATES SURFACE ROUGHNESS<br>FINISH PER MIL STD 10 UNLESS OTHERWISE NOTED | | | CUSTOMER E M Keeta | 11 9-62 |

MATERIAL

STANDARD INSTALLATION.
CRYOGENIC
THERMOCOUPLE

**AEROJET-GENERAL CORPORATION**
LIQUID ROCKET PLANT
SACRAMENTO, CALIFORNIA

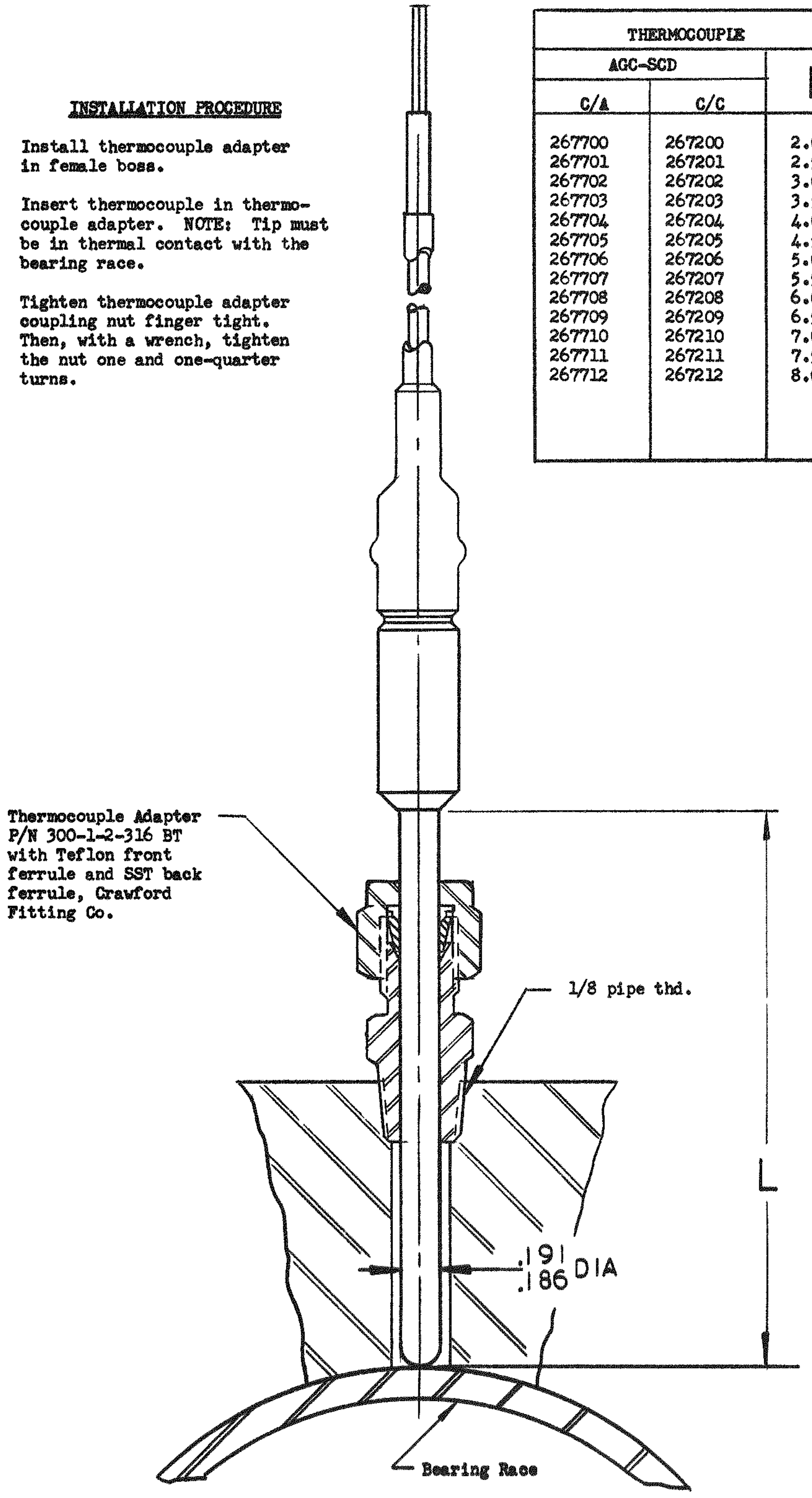
| | | | |
|---|---|---|---|
| SIMILAR TO | SCALE 2/1 | DWG. SIZE C | 248072 |
| RELEASE DATE | CAL. WEIGHT | | PART NUMBER |
| | ACT WEIGHT | | |

4 41C (1800 3 59) PRINTED ON DIEPO NO. 1020-4 CLEARPRINT FADE OUT

## INSTALLATION PROCEDURE

1. Install thermocouple adapter in female boss.
2. Insert thermocouple in thermocouple adapter. NOTE: Tip must be in thermal contact with the bearing race.
3. Tighten thermocouple adapter coupling nut finger tight. Then, with a wrench, tighten the nut one and one-quarter turns.

| THERMOCOUPLE | | |
|---|---|---|
| AGC-SCD | | L |
| C/A | C/C | |
| 267700 | 267200 | 2.00 |
| 267701 | 267201 | 2.50 |
| 267702 | 267202 | 3.00 |
| 267703 | 267203 | 3.50 |
| 267704 | 267204 | 4.00 |
| 267705 | 267205 | 4.50 |
| 267706 | 267206 | 5.00 |
| 267707 | 267207 | 5.50 |
| 267708 | 267208 | 6.00 |
| 267709 | 267209 | 6.50 |
| 267710 | 267210 | 7.00 |
| 267711 | 267211 | 7.50 |
| 267712 | 267212 | 8.00 |



BEARING THERMOCOUPLE STANDARD INSTALLATION

Figure 16

## C. THERMOCOUPLE TEMPERATURE MEASUREMENT SYSTEM

The thermocouple temperature measurement system, illustrated in Figure 17, has installations located throughout the test area. All measurements are referenced to a junction of like material held at a constant 32°F ± 0.1°F.

### 1. Electrical Diagram

Each control room channel in the test area is arranged to make measurements from the thermocouple located at any one of the test stands connected with this control room. To choose the thermocouple to be used, a test stand select panel (located in the terminal room) is remotely operated by a select panel control unit (located in the control room). The thermocouple calibrator, also located in the control room, can be manually or automatically operated. Automatic operation is provided by 28 v dc signals from the "auto-cal" panel located in each control room. The data or calibration signal (analog dc voltage) is amplified by the conventional test area dc amplifiers in the control room before entering the analog to digital converter and digital recording system.

### 2. Automatic Calibration System

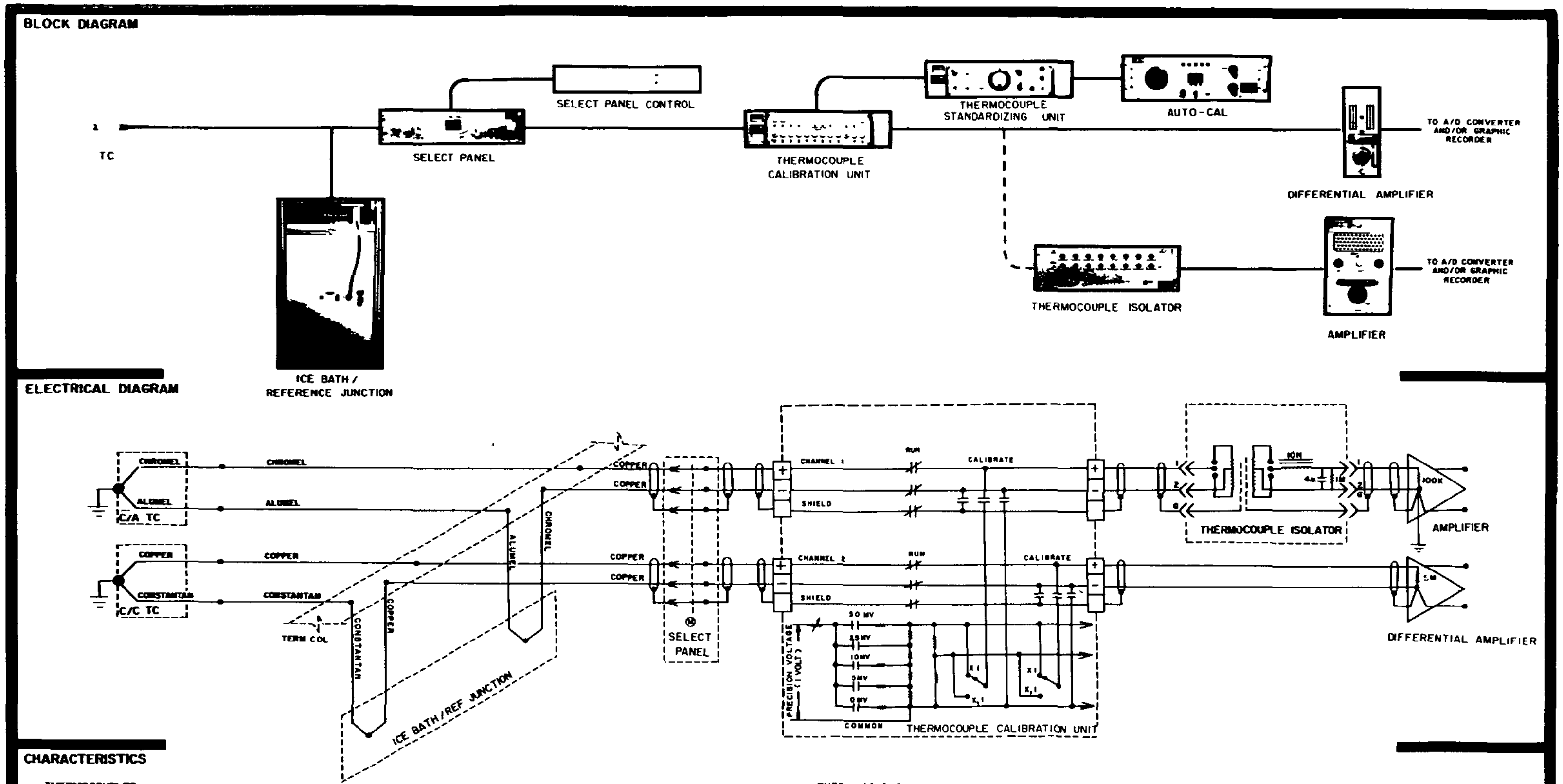
The automatic calibration system, manufactured by Beckman Systems, provides precision output voltages of 50, 25, 10, 5 and 0 millivolts when the MULTIPLIER switch is in the 1 position and 5, 2.5, 1.0, 0.5, and 0 millivolts when the MULTIPLIER switch is in the 0.1 position. These precision voltages (0.03% ± 5 $\mu$volts) are used to calibrate the digital recording system by voltage substitution.

The system consists of two main units, the standardizing unit and the calibrator unit (see Figure 18). The standardizing unit contains the precision voltage supply, provides the main front panel controls for the system, and can supply up to four calibrator units. The calibrator unit performs input to output switching and selects the various calibration voltages by means of relays. Each calibrator unit has 24 input and output channels of 2 wire plus a shield.

Details on the automatic calibration system are as follows:

a. Shielding - The shield for each pair or leads is continuous from input to output during the run mode of operation. In the calibration mode, the output shield is connected to the common side of the output (see Figure 19).

Figure 17



## CHARACTERISTICS

**THERMOCOUPLES**

| TEMP RANGE | AGC-SCD | AGC-SPEC | TYPE | TIP CONFIGURATION | MOUNTING ADAPTER | RESPONSE SEC | PRESSURE Psig | |
|---|---|---|---|---|---|---|---|---|
| | | | | | | | OPERATING | PROOF |
| 32 to 2500°F | 235726 | 42136 & 42136/2 | C/A IMMERSION, CONNECTOR | SHIELDED GROUNDED | 3/8 IN AN MALE BOSS | 1.0 MAX | 1000 | 2000 |
| 32 to 2200°F | [illegible] | 42136 & 42136/1 | C/A IMMERSION PIGTAIL | ↓ | ↓ | 5 MAX | ↓ | ↓ |
| 300 to 700°F | 267001 THRU 267048 | 42136 & 42136/5 | C/C IMMERSION, PIGTAIL | EXPOSED UNGROUNDED | 1/4 IN AN MALE BOSS | 0.25 MAX | | |
| 300 to 700°F | 267101 THRU 267148 | 42136 & 42136/7 | ↓ | SHIELDED GROUNDED | ↓ | 1.0 MAX | ↓ | ↓ |
| 32 to 500°F | 267200 THRU 267219 | 42136 & 42136/4 | C/C CONTACT, PIGTAIL | ↓ | 1/8 IN PIPE FEMALE BOSS | ↓ | 100 | 50 |
| 32 to 1000°F | 267501 THRU 267548 | 42136 & 42136/6 | C/A IMMERSION, PIGTAIL | EXPOSED UNGROUNDED | 1/4 IN AN MALE BOSS | 0.25 MAX | 1000 | 2000 |
| 32 to 2200°F | 267601 THRU 267648 | 42136 & 42136/1 | ↓ | SHIELDED GROUNDED | ↓ | 0.5 MAX | ↓ | ↓ |
| 32 to 500°F | 267700 THRU 267719 | 42136 & 42136/3 | C/A CONTACT, PIGTAIL | ↓ | 1/8 IN PIPE FEMALE BOSS | 1.0 MAX | 100 | 50 |

COLOR CODING – CHROMEL WIRE – YELLOW, ALUMEL WIRE – RED } OUTER COVERING BROWN WITH A YELLOW TRACER

COPPER WIRE – BLUE, CONSTANTAN WIRE – RED } OUTER COVERING BROWN WITH A BLUE TRACER

**THERMOCOUPLE SIMULATOR**

**ICE BATH**
MFR – HUDSON BAY CO
MODEL – CT 32-16
TEMPERATUE – 32.0 ± 0.5°F

**REFERENCE JUNCTION**
MFR – AEROJET GENERAL CORP

**SELECT PANEL**
MFR – AETRON
MODEL – FA-8030
CHANNELS – 24

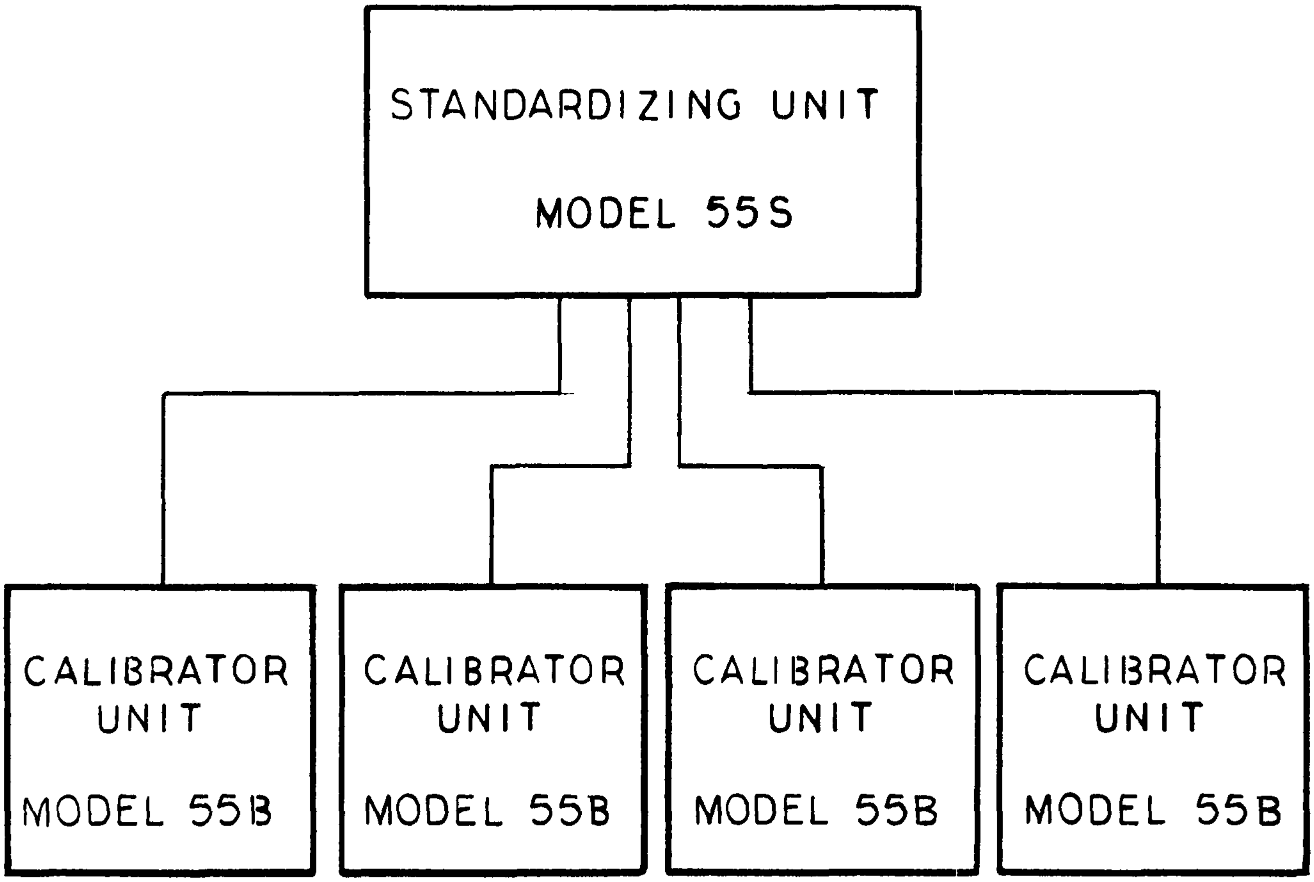
**THERMOCOUPLE CALIBRATION UNIT**
MFR BECKMAN
MODEL 55
TYPE – 2A
CHANNELS – 24

**THERMOCOUPLE STANDARDIZING UNIT**
MFR – BECKMAN
MODEL – 55
TYPE 2A
CHANNELS – 48

**THERMOCOUPLE ISOLATOR**
MFR – AEROJET GENERAL CORP
MODEL – 248755
CHANNELS – 8
COMMON MODE REJECTION – 100db

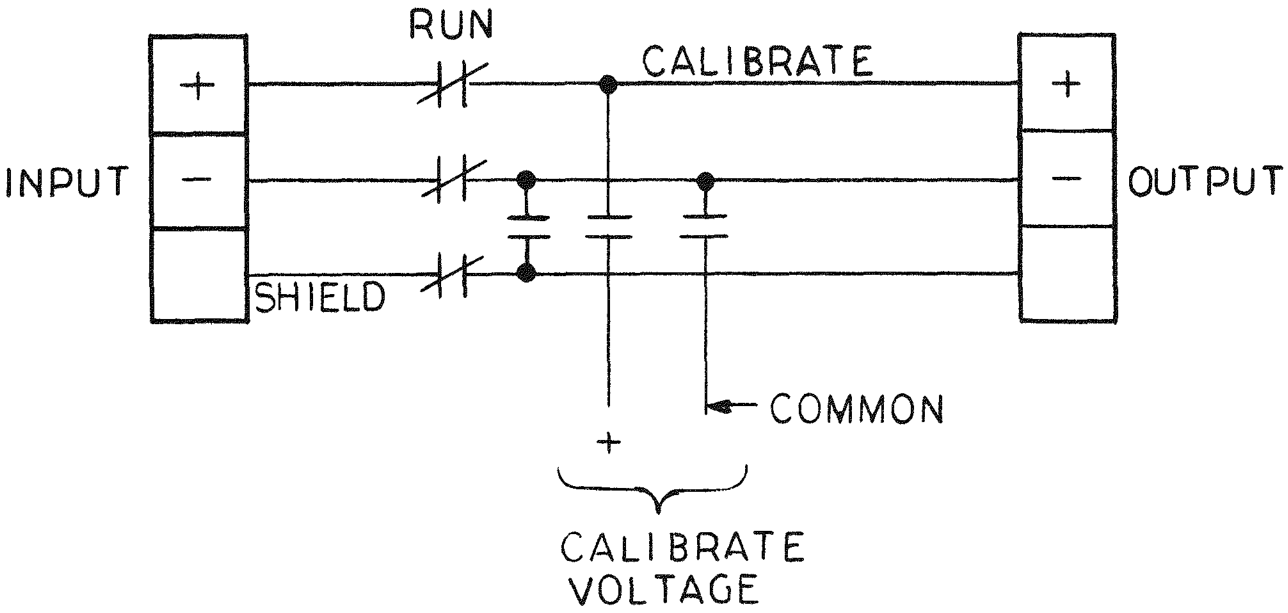
**AMPLIFIER**
MFR KINTEL
MODEL 111 OR EQUIP
GAIN – 1000 MAX
INPUT IMPEDANCE – 100K OHMS

**DIFFERENTIAL AMPLIFIER**
MFR – KINTEL
MODEL – 114 OR EQUIP
GAIN – 1000 MAX
INPUT IMPEDANCE – 5 MEG MIN
COMMON MODE REJECTION – 160db



BASIC SYSTEM

Figure 18



TYPICAL SWITCH CIRCUIT

b. Calibration Voltage - The calibration voltage used to calibrate the digital system is derived by an Ayrton shunt circuit which reduces the output of the precision power supply voltage (located on the standardizing unit) to the desired levels. The Ayrton shunt has a constant input impedance to the precision power supply (see Figure 20).

## D. DATA REDUCTION

Since all the thermocouple temperature vs EMF relationships are nonlinear, each thermocouple type has a data reduction equation which is programmed for the IBM 7090 computer. These mathematical equations were calculated by the least squares fit procedure for polynominals.

Three thermocouple combinations of copper vs constantan, iron vs constantan, and chromel vs alumel have been programmed for computer data reduction. A summary of the thermocouple code designations is tabulated in Figure 21.

### 1. Code 3 - Copper vs Constantan

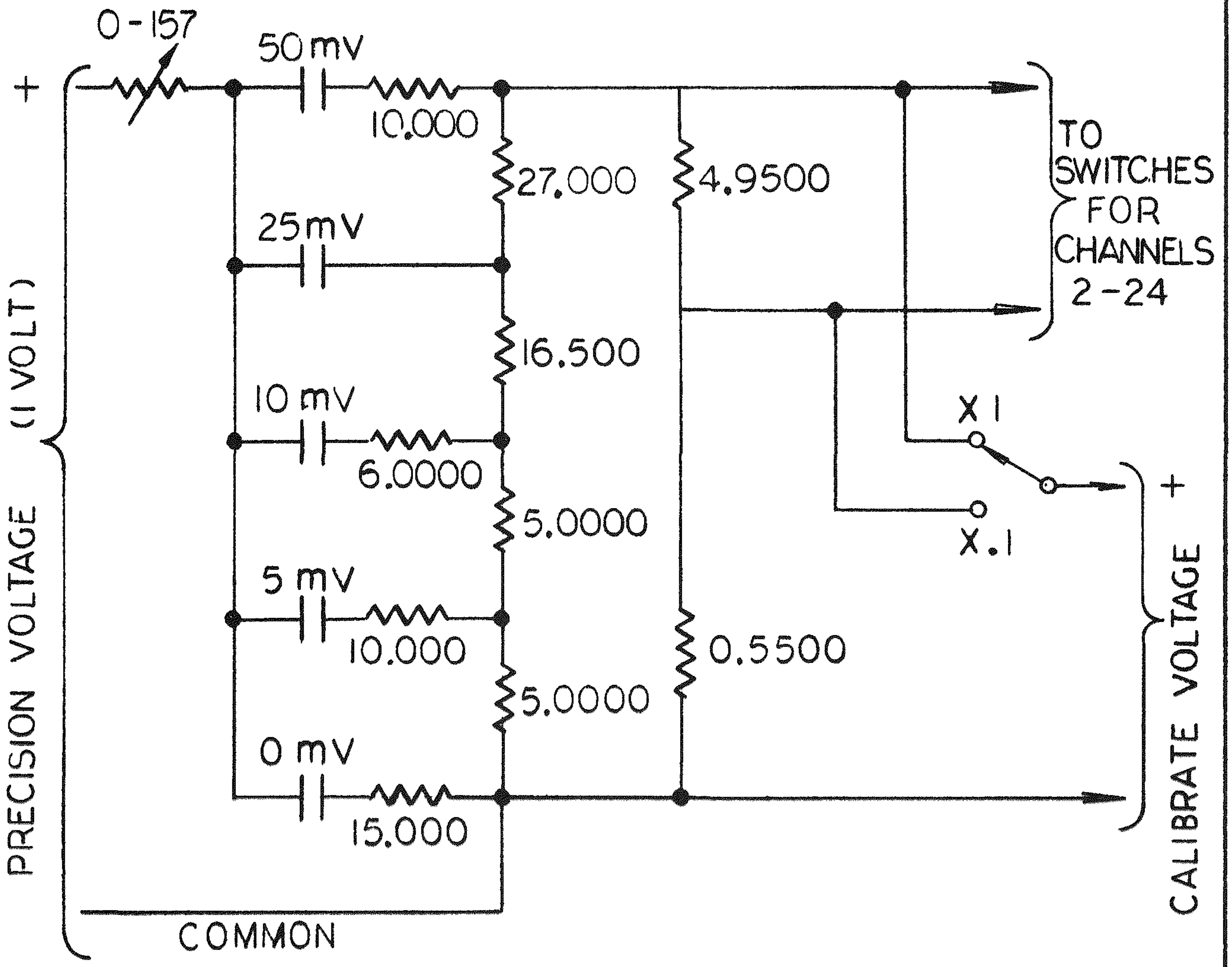
The polynominal equations for copper vs constantan thermocouples are tabulated in Figure 22.

### 2. Code 4 - Iron vs Constantan

The polynominal equations for iron vs constantan thermocouples are tabulated in Figure 23.

### 3. Code 5 - Chromel vs Alumel

The polynominal equations for chromel vs alumel thermocouples are tabulated in Figure 24.



CALIBRATION VOLTAGE CIRCUIT

Figure 20

| DESCRIPTION | THERMOCOUPLE TYPE | | |
|---|---|---|---|
| | C/C | I/C | C/A |
| Code (No.) | 3 | 4 | 5 |
| Range ($^{\circ}$F) * | -425 to +750 | -300 to +1500 | -425 to 2500 |
| Calibration Steps (%) | 0, 5, 10, 25, 50 | 0, 5, 10, 25, 50 | 0, 5, 10, 25, 50 |
| Calibration Method | Voltage Sub. | Voltage Sub. | Voltage Sub. |

* $^{\circ}$F is a function of millivolts ($^{\circ}$F - f (mv))

THERMOCOUPLE DATA REDUCTION SUMMARY

Figure 21

| | |
|---|---|
| Temperature range | -425 to -400°F |
| Millivolt range | -6.204 to -6.100 mv |
| Mathematical equation | Third degree |
| Maximum error | 0.018°F |
| Sigma squared | $1.064 \times 10^{-4}$ °F |

$$^{\circ}F = 668934.46 + 329301.91\,(\text{mv}) + 54037.746\,(\text{mv})^2 + 2957.6793\,(\text{mv})^3$$

| | |
|---|---|
| Temperature range | -400 to -375°F |
| Millivolt range | -6.100 to -5.955 mv |
| Mathematical equation | Third degree |
| Maximum error | 0.023°F |
| Sigma squared | $1.327 \times 10^{-4}$ °F |

$$^{\circ}F = 94658.797 + 47943.318\,(\text{mv}) + 8088.3573\,(\text{mv})^2 + 456.30264\,(\text{mv})^3$$

| | |
|---|---|
| Temperature range | -375 to -345°F |
| Millivolt range | -5.955 to -5.740 mv |
| Mathematical equation | Fourth degree |
| Maximum error | 0.010°F |
| Sigma squared | $4.145 \times 10^{-5}$ °F |

$$^{\circ}F = -147170.84 - 103026.91\,(\text{mv}) - 27090.083\,(\text{mv})^2 - 3167.3191\,(\text{mv})^3 - 139.09737\,(\text{mv})^4$$

| | |
|---|---|
| Temperature range | -345 to -220°F |
| Millivolt range | -5.740 to -4.410 mv |
| Mathematical equation | Fifth degree |
| Maximum error | 0.025°F |
| Sigma squared | $7.417 \times 10^{-5}$ °F |

$$^{\circ}F = 4387.1672 + 4593.8226\,(\text{mv}) + 1900.7712\,(\text{mv})^2 + 398.90203\,(\text{mv})^3 + 41.941113\,(\text{mv})^4 + 1.7779397\,(\text{mv})^5$$

| | |
|---|---|
| Temperature range | -220 to + 32°F |
| Millivolt range | -4.410 to 0.0 mv |
| Mathematical equation | Seventh degree |
| Maximum error | 0.0090°F |
| Sigma squared | $1.083 \times 10^{-5}$ °F |

$$^{\circ}F = 31.997986 + 46.519892\,(\text{mv}) - 1.4277624\,(\text{mv})^2 + 0.1075096\,(\text{mv})^3 - 0.013419154\,(\text{mv})^4 + 5.2800791 \times 10^{-3}\,(\text{mv})^5 + 1.8855408 \times 10^{-3}\,(\text{mv})^6 + 2.9533153 \times 10^{-4}\,(\text{mv})^7$$

| | |
|---|---|
| Temperature range | +32 to +750°F |
| Millivolt range | 0 to 2.080 mv |
| Mathematical equation | Seventh degree |
| Maximum error | 0.037°F |
| Sigma squared | $1.715 \times 10^{-4}$ °F |

$$^{\circ}F = 31.990188 + 46.867117\,(\text{mv}) - 1.5061342\,(\text{mv})^2 + 0.12210538\,(\text{mv})^3 - 9.2066322 \times 10^{-3}\,(\text{mv})^4 + 4.8634078 \times 10^{-4}\,(\text{mv})^5 - 1.4654069 \times 10^{-5}\,(\text{mv})^6 + 1.8545312 \times 10^{-7}\,(\text{mv})^7$$

# CODE 3 COPPER VERSUS CONSTANTAN DATA REDUCTION EQUATIONS

Figure 22

| | |
|---|---|
| Temperature range | -425 to -395°F |
| Millivolt range | -9.070 to -8.935 mv |
| Mathematical equation | Third degree |
| Maximum error | 0.048°F |
| Sigma squared | $6.313 \times 10^{-4}$ °F |

$$^{\circ}F = 584483.53 + 198693.69\,(\text{mv}) + 22516.244\,(\text{mv})^2 + 851.11608\,(\text{mv})^3$$

| | |
|---|---|
| Temperature range | -395 to-340°F |
| Millivolt range | -8.935 to -8.465 mv |
| Mathematical equation | Fourth degree |
| Maximum error | 0.041°F |
| Sigma squared | $4.453 \times 10^{-4}$ °F |

$$^{\circ}F = -925083.50 - 432692.96\,(\text{mv}) - 75933.207\,(\text{mv})^2 - 59245315\,(\text{mv})^3 -173.44211\,(\text{mv})^4$$

| | |
|---|---|
| Temperature Range | -340 to -175°F |
| Millivolt range | -8.465 to -5.490 mv |
| Mathematical equation | Seventh degree |
| Maximum error | 0.027°F |
| Sigma squared | $8.652 \times 10^{-5}$ °F |

$$^{\circ}F = 28560.729 + 30549.346\,(\text{mv}) + 13955.980\,(\text{mv})^2 + 3538.2163\,(\text{mv})^3 + 537.02996\,(\text{mv})^4 + 48.807579\,(\text{mv})^5 + 2.4598490\,(\text{mv})^6 + 0.053057314\,(\text{mv})^7$$

| | |
|---|---|
| Temperature range | -175 to +32°F |
| Millivolt range | -5.490 to 0.0 mv |
| Mathematical equation | Sixth degree |
| Maximum error | 0.030°F |
| Sigma squared | $2.267 \times 10^{-4}$ °F |

$$^{\circ}F = 32.030332 + 33.383428\,(\text{mv}) - 1.4811465\,(\text{mv})^2 - 0.55711327\,(\text{mv})^3 - 0.16410472\,(\text{mv})^4 - 2.2808882\,(\text{mv})^5 - 1.3125622 \times 10^{-3}\,(\text{mv})^6$$

| | |
|---|---|
| Temperature range | 32 to 100°F |
| Millivolt range | 0.0 to 1.940 mv |
| Machematical equation | First degree |
| Maximum error | 1.3°F |
| Sigma squared | - - - |

$$^{\circ}F = 32.00 + 34.0\,(\text{mv})$$

| | |
|---|---|
| Temperature range | 100 to 1600°F |
| Millivolt range | 1.940 to 50.05 mv |
| Mathematical equation | Third degree |
| Minimum error | 3.47°F |
| Sigma squared | 3.3717 |

$$^{\circ}F = 35.502975 + 33.172367\,(\text{mv}) + .010544767\,(\text{mv})^2 - 9.9543 \times 10^{-4}\,(\text{mv})^3$$

# CODE 4 IRON VERSUS CONSTANTAN DATA REDUCTION EQUATIONS

| | |
|---|---|
| Temperature range | -425 to -400°F |
| Millivolt range | -6.435 to -6.360 mv |
| Mathematical equation | Third degree |
| Maximum error | 0.049°F |
| Sigma squared | $7.555 \times 10^{-4}$ °F |

$$^\circ F = 2161400.7 + 1020568.2\ (mv) + 160641.44\ (mv)^2 + 8430.6692\ (mv)^3$$

| | |
|---|---|
| Temperature range | -400 to -375°F |
| Millivolt range | -6.360 to -6.240 mv |
| Mathematical equation | Third degree |
| Maximum error | 0.043°F |
| Sigma squared | $1.077 \times 10^{-3}$ °F |

$$^\circ F = 325323.92 + 156632.53\ (mv) + 25137.957\ (mv)^2 + 1346.3509\ (mv)^3$$

| | |
|---|---|
| Temperature range | -375 to -345°F |
| Millivolt range | -6.240 to -6.045 mv |
| Mathematical equation | Third degree |
| Maximum error | 0.017°F |
| Sigma squared | $8.871 \times 10^{-5}$ °F |

$$^\circ F = 44341.666 + 22214.654\ (mv) + 3703.4455\ (mv)^2 + 207.02332\ (mv)^3$$

| | |
|---|---|
| Temperature range | -345 to -245°F |
| Millivolt range | -6.045 to -5.010 mv |
| Mathematical equation | Fifth degree |
| Maximum error | 0.019°F |
| Sigma squared | $9.279 \times 10^{-5}$ °F |

$$^\circ F = 33641.527 + 31854.474\ (mv) + 12046.759\ (mv)^2 + 2283.4119\ (mv)^3 + 216.63282\ (mv)^4 + 8.2402936\ (mv)^5$$

| | |
|---|---|
| Temperature range | -245 to +32°F |
| Millivolt range | -5.010 to 0.0 mv |
| Mathematical equation | Seventh degree |
| Maximum error | 0.005°F |
| Sigma squared | $4.624 \times 10^{-6}$ °F |

$$^\circ F = 31.998161 + 45.643117\ (mv) - 0.78223138\ (mv)^2 + 0.17720064\ (mv)^3 + 5.5371686 \times 10^{-2}\ (mv)^4 + 2.9385135 \times 10^{-2}\ (mv)^5 + 5.8484883 \times 10^{-3}\ (mv)^6 + 5.1198685 \times 10^{-4}\ (mv)7$$

| | |
|---|---|
| Temperature range | +32 to +150°F |
| Millivolt range | 0.0 to 2.6620 mv |
| Mathematical equation | Seventh degree |
| Maximum error | 0.042°F |
| Sigma squared | 2.143 x 10-4 °F |

$$^\circ F = 31.996727 + 45.474447\ (mv) + 1.2486369\ (mv)^2 - 3.9533485\ (mv)^3 + 3.7234525\ (mv)^4 - 1.7225467\ (mv)^5 + 0.38515691\ (mv)^6 - 0.032823540\ (mv)^7$$

| | |
|---|---|
| Temperature range | +150 to +500°F |
| Millivolt range | 2.6620 to 10.5645 mv |
| Mathematical equation | Seventh degree |
| Maximum error | 0.074°F |
| Sigma squared | $1.108 \times 10^{-3}$ °F |

$$^\circ F = 64.303474 + 73.686307\ (mv) - 12.092758\ (mv)^2 + 2.1644342\ (mv)^3 - 0.15481195\ (mv)^4 - 1.3632387 \times 10^{-3}\ (mv)^5 + 7.2393780 \times 10^{-4}\ (mv)^6 - 2.6276978 \times 10^{-5}\ (mv)^7$$

| | |
|---|---|
| Temperature range | +500 to +1300°F |
| Millivolt range | 10.5645 to 29.3235 mv |
| Mathematical equation | Seventh degree |
| Maximum error | 0.130°F |
| Sigma squared | $2.926 \times 10^{-3}$ °F |

$$^\circ F = 33.421906 - 82.439474\ (mv) + 22.172622\ (mv)^2 - 2.0877024\ (mv)^3 + 0.11434726\ (mv)^4 - 3.6689430 \times 10^{-3}\ (mv)^5 + 6.4020393 \times 10^{-5}\ (mv)^6 - 4.6897264 \times 10^{-7}\ (mv)^7$$

| | |
|---|---|
| Temperature range | 1300 to 2500°F |
| Millivolt range | 29.3235 to 54.92 mv |
| Mathematical equation | Seventh degree |
| Maximum error | 0.472°F |
| Sigma squared | $5.894 \times 10^{-2}$ °F |

$$^\circ F = 39.077576 + 41.336080\ (mv) + 0.54220012\ (mv)^2 - 4.4772479 \times 10^{-2}\ (mv)^3 + 1.6034880 \times 10^{-3}\ (mv)^4 - 2.8551580 \times 10^{-5}\ (mv)^5 + 2.5297537 \times 10^{-7}\ (mv)^6 - 8.5724054 \times 10^{-10}\ (mv)^7$$

CODE 5 CHROMEL VERSUS ALUMEL DATA REDUCTION EQUATIONS

## IV BRIDGE-IN-HEAD AMBIENT RTT SYSTEM

### A. RTT DESIGN REQUIREMENTS

A new concept in temperature measurements was introduced at Aerojet-General after careful and detailed analysis proved the system to be feasible. The development of a bridge-in-head RTT completely satisfies all the requirements previously mentioned in Section II. All design criteria developed for the preparation of Specification Control Drawings 248820 (0 to 100°F), 244475 (0 to 200°F), and 235727 (0 to 500°F) will be presented in this section. These drawings were prepared and released by the Instrumentation Development Department for procurement of the resistance temperature transmitters. A tabulated summary of the electrical and mechanical design requirements as specified in the component specifications is shown in Figure 25. The discussion in this section will be based on a symmetrical, equal arm Wheatstone bridge balanced at 0°F, which is schematically shown in Figure 26.

#### 1. Sensing Element Characteristics

The corrosive and conductive properties of storable propellants require the sensing element be contained within a hermetically sealed protective sheath compatible with $N_2O_4$ or Aerozine 50. Stainless steel, Type 304, was selected for the sheath material because of the low oxidation rate, high strength, and ease of welding using the tungsten inert gas (TIG) process. A response time of 1.0 sec maximum was established for all test area and flight requirements. This response time (measured in water) is equivalent to a calculated response time of 0.5 sec for $N_2O_4$ or 0.7 sec for Aerozine 50 flowing at 40 ft/sec at 77°F. A hermetically sealed protective sheath or totally enclosed sensing element with a fast response time had to be developed because no commercial units are available.

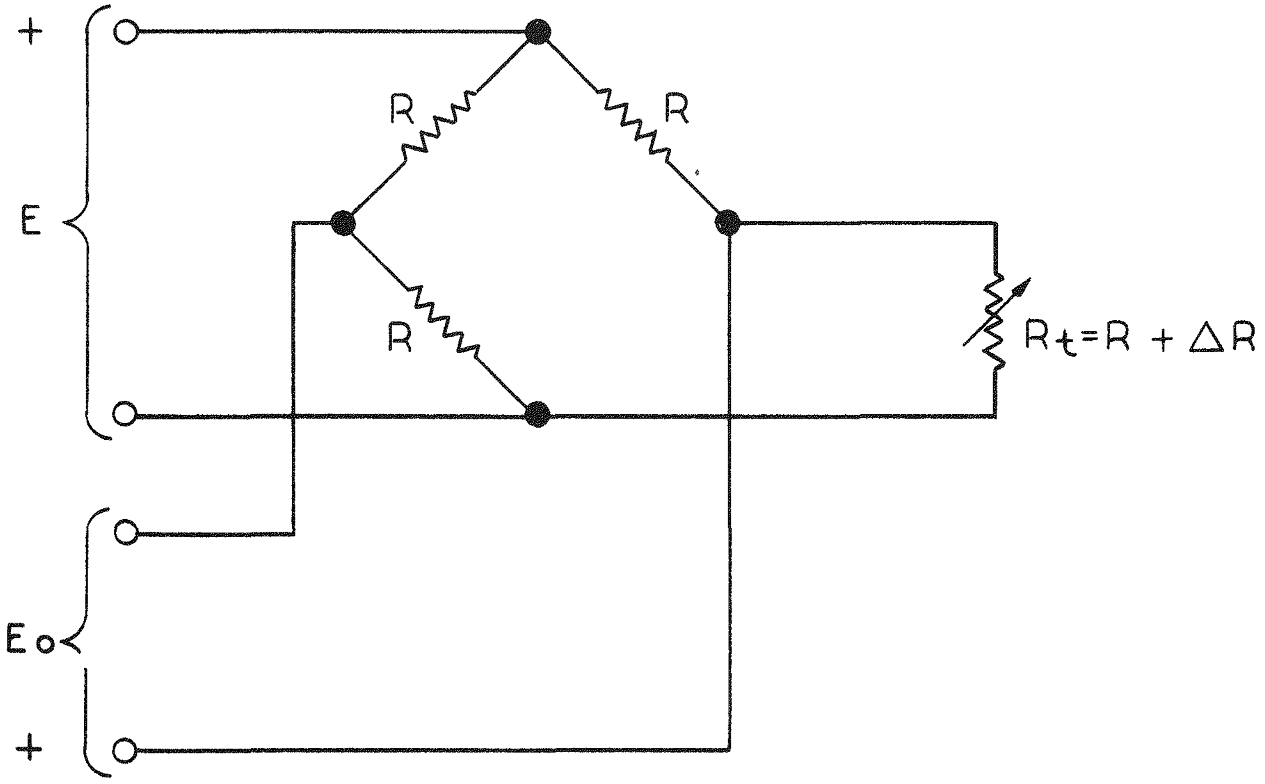
Temperature measurements are taken in lines which vary from 0.75 to 8.0 in. with flows up to 500 feet per second. To satisfy all line requirements, a maximum sensing element length of 0.5 in. (measured from the tip) was established. This length assures that all measurements can be made in the center of the stream on the smaller lines or past the boundary layers (temperature gradient from the wall) on the larger lines.

Simple calculations for pure platinum wire indicate that the upper limit on the ice-point resistance should be 200 ohms. An ice-point resistance of 200 ohms represents 43 in. of 0.001-in.-dia pure platinum wire. This can be monolayer wound on a 0.150-in.-dia mandril that is 0.18 in. long when the loops are spaced 0.001 in. apart.

| RANGE | 0 to 100°F, 0 to 200°F, or 0 to 500°F |
|---|---|
| Sensitivity | 4 mv/v |
| Accuracy | ± 0.25% |
| Linearity | ± 0.25% |
| Repeatability | ± 0.1% |
| Nominal excitation | 10 v dc |
| Input resistance | 500 ± 25 ohms |
| Input resistance shift | ± 5 ohms |
| Output resistance | 500 ± 25 ohms |
| Response time | 1 sec |
| Insulation resistance | 30 megohms at 50 v dc |
| Proof pressure | 3000 psig (dry air) |
| Operating pressure | 1500 psig (helium |
| Vibration rating | 60 g (peak) |
| Flow rating | 80 ft/sec (water) |

RTT CHARACTERISTICS

Figure 25



NOTE: (1) E – BRIDGE EXCITATION VOLTAGE (VOLTS)
(2) $E_o$ – BRIDGE OUTPUT VOLTAGE (MILLIVOLTS)
(3) R – RESISTANCE OF ONE LEG OF BRIDGE (OHMS)
(4) $R_t$ – TOTAL RESISTANCE OF SENSING ELEMENT AT ANY TEMPERATURE t (OHMS)
(5) $\Delta R$ – CHANGE IN RESISTANCE OF SENSING ELEMENT (OHMS)

SKETCH OF WHEATSTONE BRIDGE

Figure 26

### 2. Bridge-in-Head Design

A unique sensor for temperature measurements was developed using the bridge-in-head design to satisfy both the low ohmic-element design requirement and the necessity to suppress long lead-wire effects. A practical method of measuring temperature by correlation to the resistance of a wire-wound element is to make the temperature-sensitive element one leg of a Wheatstone bridge. Thus, when an excitation voltage is applied to two opposite terminals of a Wheatstone bridge, a voltage output may then be converted to temperature by comparison with a known calibration curve.

Consider a pure platinum element with an ice-point resistance of 200 ohms as the temperature-sensitive leg of a conventional Wheatstone bridge. A 200-ohm platinum element has an average slope of 0.435 ohms/°F in the temperature range of 0 to 500°F. As previously discussed, all temperature measurements are made remotely from the signal conditioning equipment (generally 500 feet, representing approximately 2.5 ohms of line resistance). Standard laboratory compensation techniques (e.g., Sieman's three- and four-wire methods) for suppressing lead wires are available. However, these techniques are not suitable for application in the test area because of the difference in any pair of leads (approximately 0.1 ohm or 0.25°F for the 200-ohm platinum element).

The most successful method of eliminating lead-resistance effects in a Wheatstone bridge circuit is to design the bridge so that no switches, relays, long leads, etc., are contained within the bridge circuit. This method led to the development of the bridge-in-head technique. In past designs for the Test Division, all temperature sensitive elements have been terminated in a Wheatstone bridge which is part of the signal conditioning panels.

### 3. Input Characteristics

The input resistance for each RTT was standardized at 500 ± 25 ohms for operation using both the existing test area power supplies and Titan II flight-regulated 10 v dc power supplies. Selection of this input resistance limits the voltage attenuation from line resistance to less than 1%, reduces shunting impedance effects from low insulation resistance, and allows preflight checkout by electrical resistance measurements. Because of changes in resistance of the element ($R_t$), a further restriction requires that the input resistance shift shall not exceed 5 ohms so that ranging of the data recording system will be within ± 0.02% of full-scale output, regardless of what temperature the sensor may be measuring.

A four-wire input circuit (made by electrically shorting Pin C to Pin E and Pin D to Pin F) is required to return the calibration voltage internally through the RTT. Thus, system operation is possible only when each operating channel has an RTT electrically attached to the input cable, and all potential errors caused by connector (pin to socket) contact resistance are compensated for by system calibration.

## 4. Output Characteristics

A maximum sensitivity of 4 mv/v is required for the Titan II pulse code modulated telemetry system. However, preliminary calculations and evaluation of a unit proved that a 50 mv/v sensitivity was feasible. To reduce the cost of data reduction and eliminate special nonlinear visual gage scales, linear output characteristics are required. This linear output was obtained by mathematical analysis, fabrication, and calibration of a prototype nickel element in the engineering laboratory. A 500 ohm output resistance for a constant impedance load on the amplifiers at the test area and a 30 megohm insulation to eliminate need for expensive differential amplifiers are also specified.

To define the density of $N_2O_4$ or Aerozine 50 for the calculation of engine $I_{sp}$ (specific impulse), it is necessary to calculate the propellant densities to within 0.25%. Nitrogen tetroxide and Aerozine 50 have approximate density versus temperature slopes of 0.08 and 0.03 lb/cu ft/°F (throughout the temperature region of 20 to 140°F). Thus, in a temperature measurement system, the error introduced by the RTT must be limited to ± 0.25% of full-scale output or 0.5°F in the 0 to 200°F range. To assure a stable element design, good solder joints, spot welds, and stable bridge resistors, a repeatability of 0.1% of full-scale output is required after temperature cycling.

## 5. Electrical Circuit Derivation

The linear output versus temperature may be equated mathematically (equations 1, 2, and 3 for the temperature ranges 0 to 100°F, 0 to 200°F, and 0 to 500°F). These equations are based on a required full-range sensitivity of 4 mv/v, linear output versus temperature, and accuracy of 0.25% of full-scale output.

$$\frac{E_o}{E} = 4.00 \times 10^{-2}\ t \pm 0.01 \qquad \text{(Eq 1)}$$

$$\frac{E_o}{E} = 2.00 \times 10^{-2}\ t \pm 0.01 \qquad \text{(Eq 2)}$$

$$\frac{E_o}{E} = 8.00 \times 10^{-3}\ t \pm 0.01 \qquad \text{(Eq 3)}$$

where: $E_o$ is the bridge output voltage in millivolts,

E is the bridge excitation voltage in volts, and

t is the temperature of the sensing element in °F.

Equations 1, 2, and 3 are graphically illustrated in Figure 27. Since the temperature t in equations 1, 2, and 3 is determined from the temperature versus resistance characteristics of the sensing element, $E_o$ can be expressed as equation 4.

$$\frac{E_o}{E} = 0.4975\ (\triangle R) - 0.0004987\ (\triangle R)^2 \qquad \text{(Eq 4)}$$

where: $E_o/E$ is the bridge sensitivity in mv/v, and

$\triangle R$ is the change in resistance of the sensing element in ohms.

Two of the more stable temperature sensing materials used in resistance thermometry are chemically pure nickel and chemically pure platinum. When mounted as a strain-free element (after stress relieving and temperature cycling), each material has a reproducibility of better than ± 0.05°F and a long-term stability of ± 0.05°F throughout the temperature range of 0 to 500°F. The resistance characteristics, as given by the American Institute of Physics, can be expressed mathematically (equations 5 and 6). Figure 28 gives a graphic presentation of equations 5 and 6.

$$R_{t(n)} = R_{32(n)} \left[0.9090 + 2.7340 \times 10^{-3}\ t + 3.4491 \times 10^{-6}\ t^2\right] \qquad \text{(Eq 5)}$$

$$R_{t(p)} = R_{32(p)} \left[0.92946 + 2.2230 \times 10^{-3}\ t - 1.7629 \times 10^{-7}\ t^2\right] \qquad \text{(Eq 6)}$$

where: $R_{t(n)}$ is the element resistance in ohms (nickel wire) at any temperature t,

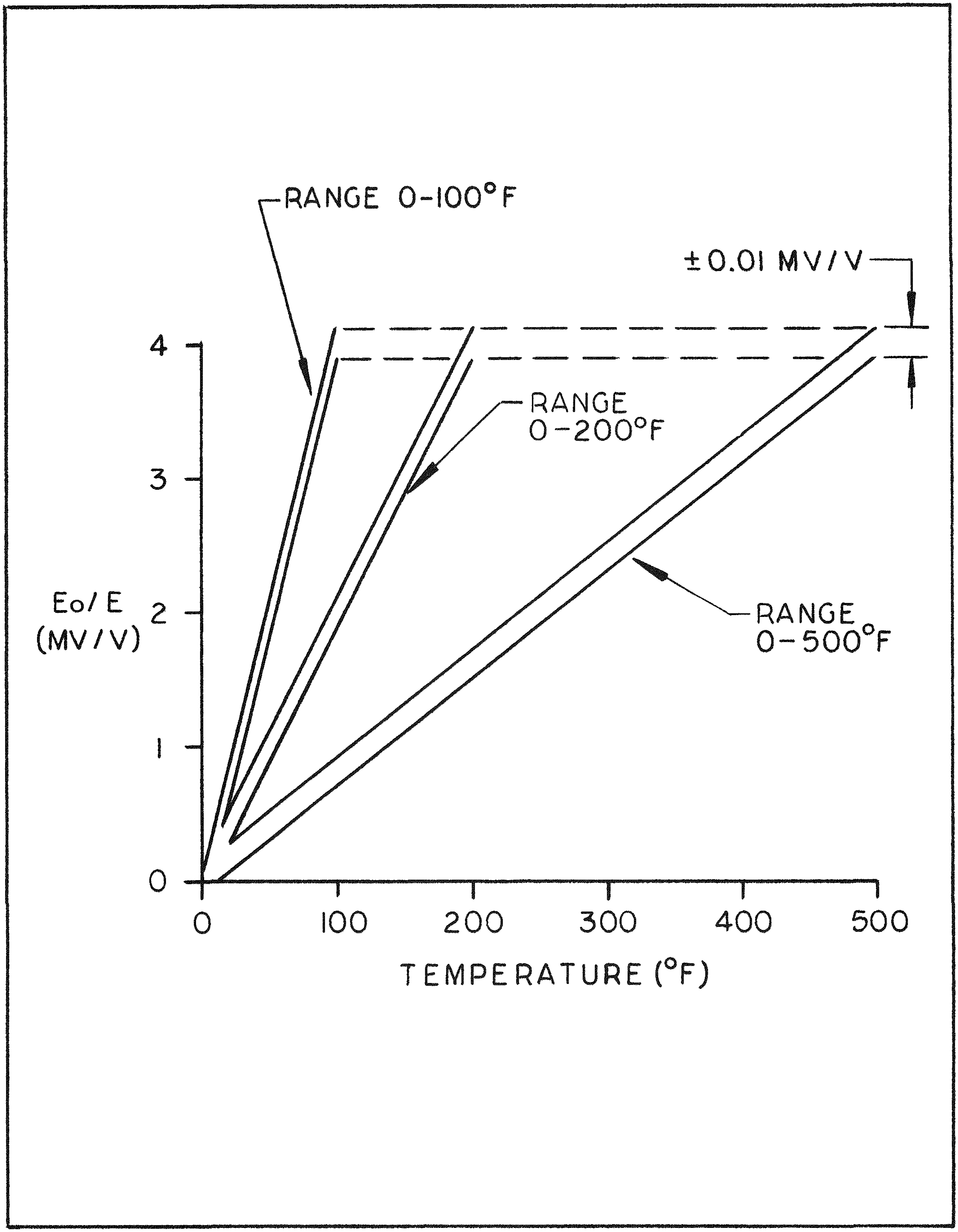
$R_{32(n)}$ is the element resistance in ohms (nickel wire) at 32°F,

$R_{t(p)}$ is the element resistance in ohms (platinum wire) at any temperature t,

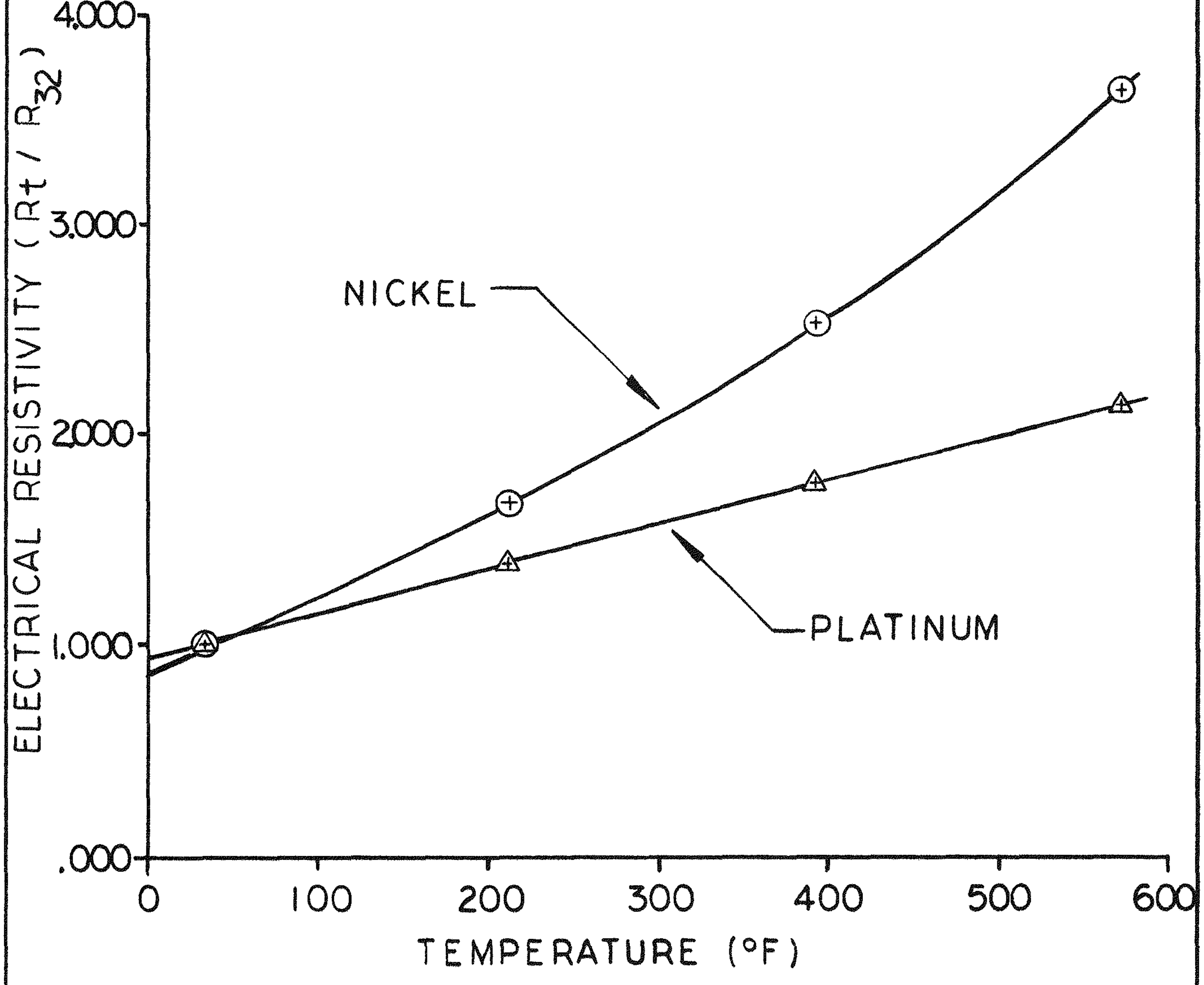
$R_{32(p)}$ is the element resistance in ohms (platinum wire) 32°F,

and

t is any element temperature in °F.



RTT TEMPERATURE VERSUS OUTPUT CHARACTERISTICS



ELECTRICAL RESISTIVITY VERSUS TEMPERATURE

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A combination of chemically pure nickel wire in series with chemically pure platinum wire, expressed mathematically, provides an exact solution to equation 4 based upon equations 5 and 6. Figure 29 shows a tabulation of resistance values for each temperature range.

Many different Wheatstone bridge configurations, other than the 500 ohm equal-arm bridge (equal-arm when the bridge is balanced at 0°F), can be designed to satisfy all the requirements outlined earlier.

### 6. Wiring Code

A modified wiring code using the strain gage system was adopted for the RTT to maintain standardization in the Liquid Rocket Plant test area (see Figure 30).

### 7. Construction and Installation

The RTT must be rugged enough to withstand the extreme vibration, shock, and humidity to which it will be subjected during the test program. The housing must be entirely stainless steel, welded by the tungsten inert gas process, and hermetically sealed for protection against propellants and humidity. There must be a maximum density for components fully encapsulated in ceramic or epoxy to assure maximum service life without costly and time consuming repairs. This design must be capable of withstanding a minimum of 50 g peak vibration and should be able to withstand 150 g vibration for the more rugged pump cavitation tests. Permanent identification is provided by engraving the part number and serial number of the manufacturer on the housing.

A mounting boss similar to those used in the Titan I Program (AS1128-6 adapter) was selected for mounting the RTT to the lines. This method of mounting reduces stem conduction caused by transferring heat from the housing to the sensing element on short stem lengths necessary on small diameter lines. The RTT can also be removed from the lines without electrically disconnecting it from drop cables and without twisting the cables. This tends to eliminate channel mixing from engine subassembly to engine subassembly.

This type of mounting allows the part to be completely self-mounted with an Aerojet-General standard adapter and eliminates the need for special adapters or brackets, see Figure 31.

| RANGE (°F) | R SERIES (OHMS) | $R_{32}$ NICKEL (OHMS) | $R_{32}$ PLATINUM (OHMS) |
|---|---|---|---|
| 0 to 100 | 467.204 | 3.5070 | 31.8551 |
| 0 to 500 | 483.498 | 1.3116 | 16.4711 |
| 0 to 500 | 493.373 | 0.41862 | 6.7204 |

RTT CALCULATED RESISTANCE VALUES

Figure 29

| CONNECTOR PIN | FUNCTION |
|---|---|
| A | Positive output signal |
| B | Negative output signal |
| C | Negative excitation |
| D | Positive excitation |
| E | Negative calibration signal (shorted to pin C) |
| F | Positive calibration signal (shorted to pin D) |

RTT WIRE CODING

Figure 30

| REVISIONS | | | | |
|---|---|---|---|---|
| SYM | ZONE | DESCRIPTION | DATE | APPROVED |

**NOTES:**

1. RECOMMENDED TORQUE 270-300 IN. LBS.
2. SUPPLIED BY TEST DIVISION, DEPT. 8770, AGC.
3. TEST STAND CABLE PLUG TO BE SAFETY WIRED TO RTT RECEPTACLE

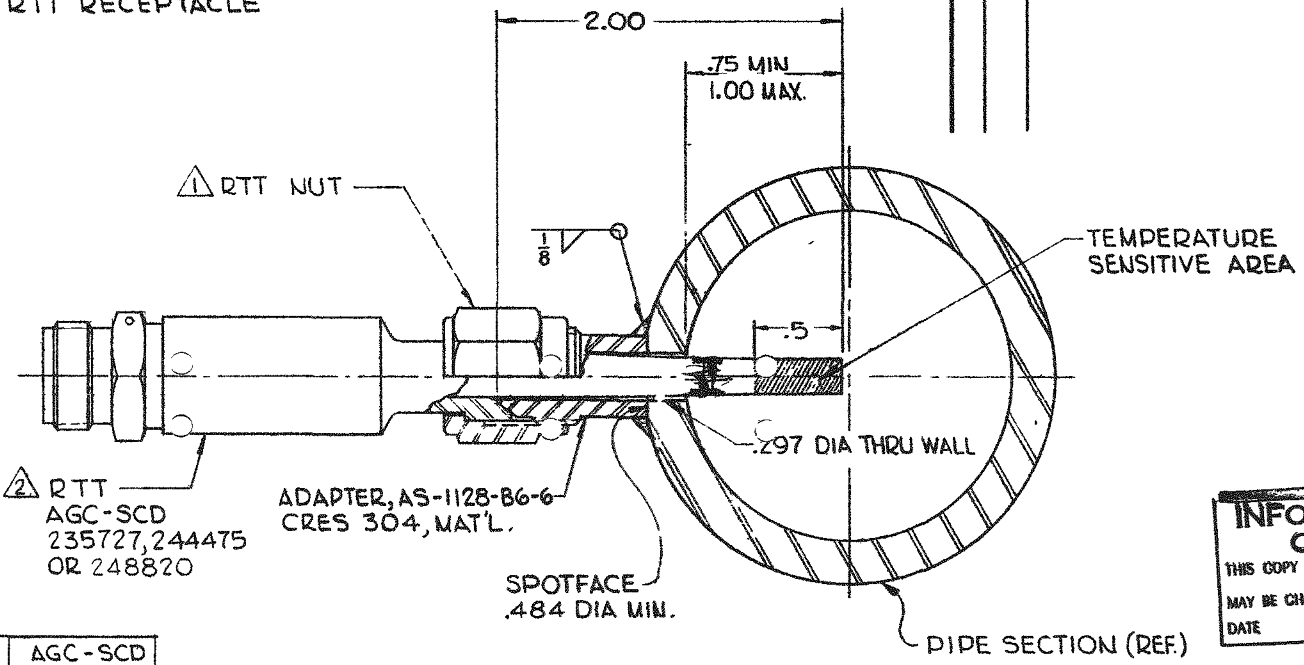

Figure 31

| MEASUREMENT RANGE - °F | AGC-SCD |
|---|---|
| 0 - 100 | 248820 |
| 0 - 200 | 244475 |
| 0 - 500 | 235727 |

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DATE

| QTY REQD | SYM | CODE IDENT NO. | PART OR IDENTIFYING NO. | NOMENCLATURE OR DESCRIPTION | MATERIAL | SPECIFICATION | UNIT WT | ZONE | ITEM NO. |
|---|---|---|---|---|---|---|---|---|---|

LIST OF MATERIALS

| | | | | | |
|---|---|---|---|---|---|
| ON | THRU | PART DASH NO. | NEXT | FINAL | NEXT ASSY | USED ON |
| EFFECTIVE SERIAL NO. | | | QTY REQD PER ASSY | | APPLICATION | |
| USAGE DATA | | DRAWING LEVEL | | | | |

UNLESS OTHERWISE SPECIFIED
DIMENSIONS ARE IN INCHES
DECIMAL TOLERANCE XX ± .03 XXX ± .010
ANGULAR TOLERANCE ± 2°
DO NOT SCALE DRAWING
TREATMENT
FINISH
SIMILAR TO:
WEIGHT CALC ACT.

DRAWN S. KURASHIGE DATE 1-23-64
CHECKED
DESIGN
PROJECT
STRESS-WEIGHT
NOMENCLATURE
FAB/MFG ENGR
DESIGN ACTIVITY APPD
CUSTOMER

AEROJET-GENERAL CORPORATION
LIQUID ROCKET PLANT - SACRAMENTO, CALIFORNIA

TITLE STANDARD INSTALLATION
AMBIENT
RTT'S

CODE IDENT. NO. 05824
DWG SIZE C
DWG NO. 701664
SCALE 2
RELEASE DATE
SHEET

## B. RTT SOURCES OF SUPPLY

Two sources of supply for the RTT, Electrowest Incorporated of Sacramento, California, and Rosemount Engineering Company of Minneapolis, Minnesota, are on the qualified product list on AGC-SCD Drawings 248820, 244475, and 235727.

### 1. Electrowest Incorporated

Electrowest Model 104A, 105A, and 107A temperature transducers are bridge-in-stem immersion type sensors which use a nickel element as the active member of the bridge circuit (See Figures 32 and 33). The natural output non-linearity for a one active arm Wheatstone bridge circuit is compensated by the nickel element combined with a series and parallel resistor.

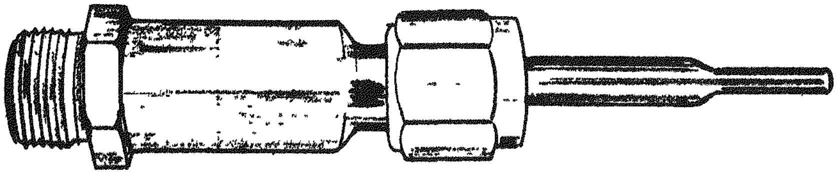
The temperature sensitive element and bridge resistors are wound on one mandrel and located within the stem. This design approach allows the temperature coefficients of the bridge components to be taken into account during calibration. By exposing the bridge elements to the same environments as the sensitive element, any minute shifts in component base resistances (imposed by virtue of temperature coefficients) are accounted for in the bridge output versus temperature calibration curve.

All transducers are hermetically sealed by TIG welded construction and all components are fully supported and encapsulated in a high temperature silicon resin. All external materials are limited to 304 stainless steel. A fast response to temperature is achieved by close contact of the temperature sensitive element with the transducer wall and by thermal isolation of the temperature element from the bridge completion resistors. Thermal insulation is provided by a vacuum chamber at the tip of the transducer.

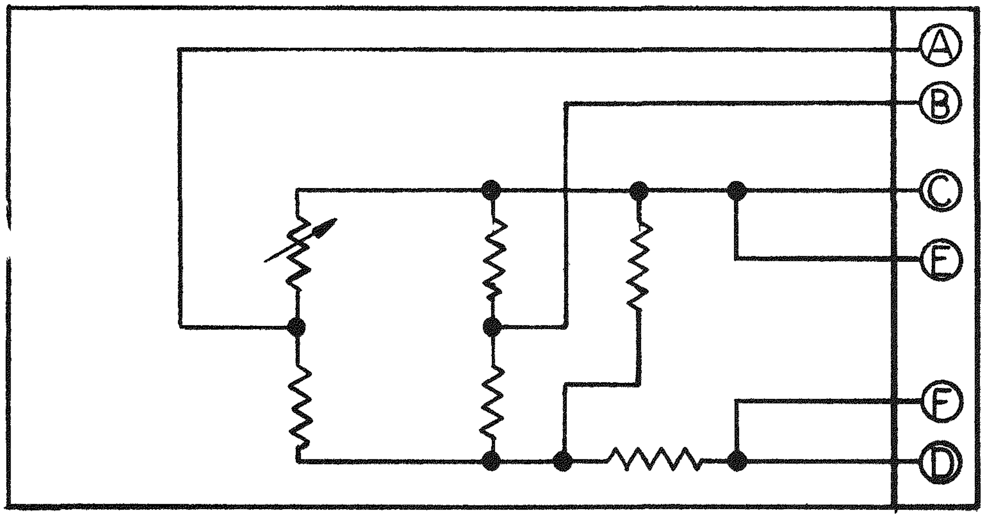
### 2. Rosemount Engineering Company

To meet the requirements previously outlined, a precision platinum resistance sensor with a complete bridge-in-head is supplied by Rosemount Engineering Company (see Figures 34 and 35).

The platinum sensing elements are mounted in sensors constructed of TIG welded 304 stainless steel. The head of the sensor contains a special bridge circuit which provides a linear $E_0$ versus T function through the various temperature ranges. The component parts of this bridge are completely encapsulated so that the sensor will withstand the severe vibration environments encountered in the Titan II Program. The location of the bridge components in the head of the sensor places them in a position of low stress during vibration and also aids in the ability of the bridge to withstand the high vibration levels.



## ELECTRICAL CIRCUIT

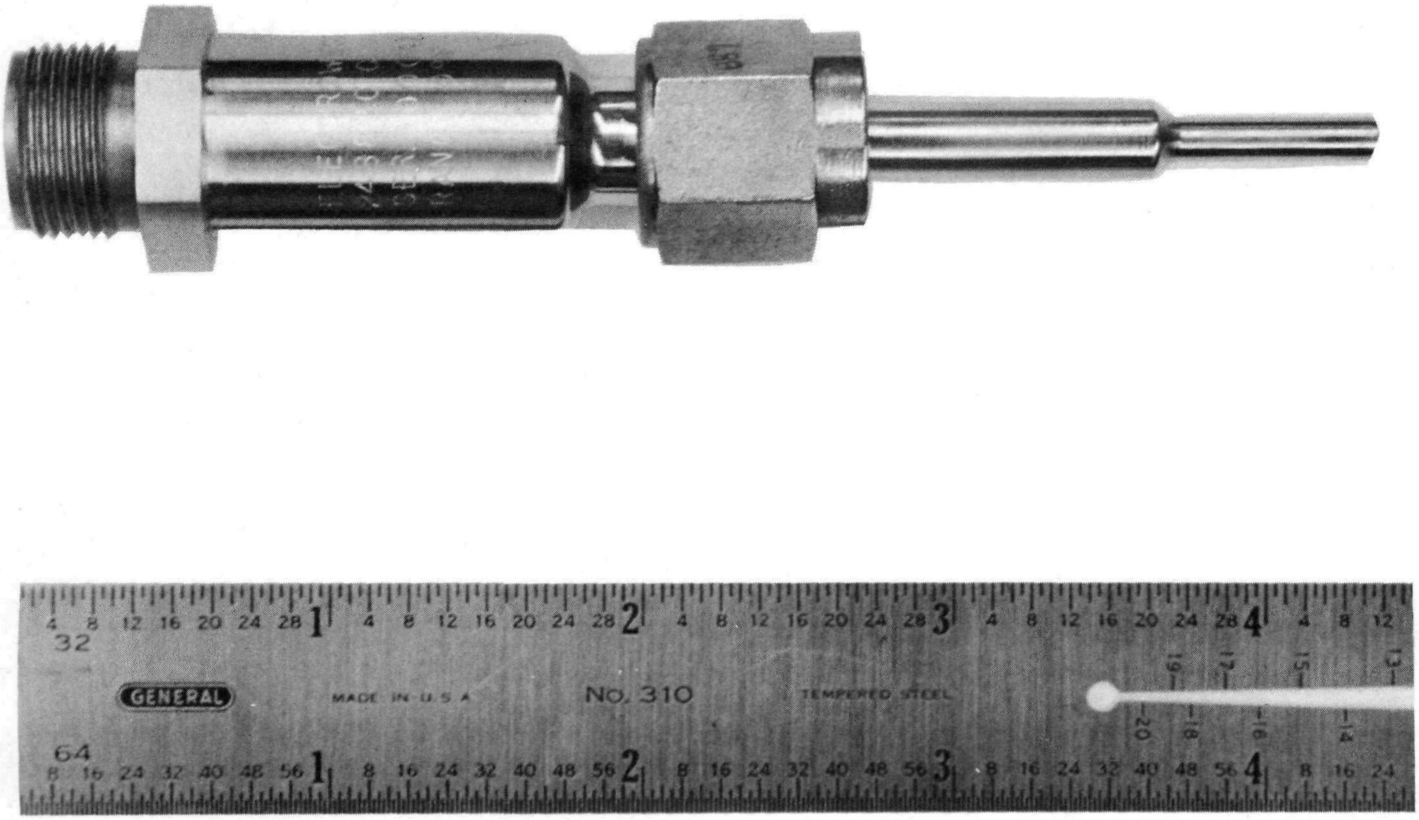


## RESISTANCE CHARACTERISTICS

| MODEL | RANGE °F | OHMS (TYPICAL) | | | | | |
|---|---|---|---|---|---|---|---|
| | | A to B | A to C | A to D | B to C | B to D | C to D |
| E-105A | 0-100 | 500 | 675 | 275 | 682 | 285 | 500 |
| E-104A | 0-200 | ↓ | ↓ | ↓ | 678 | 280 | ↓ |
| E-107A | 0-500 | ↓ | ↓ | ↓ | 675 | 277 | ↓ |

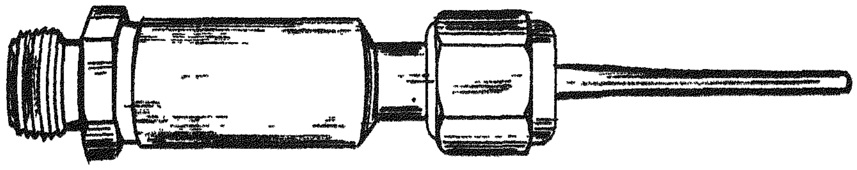
TYPICAL ELECTROWEST INCORPORATED RTT

Figure 32

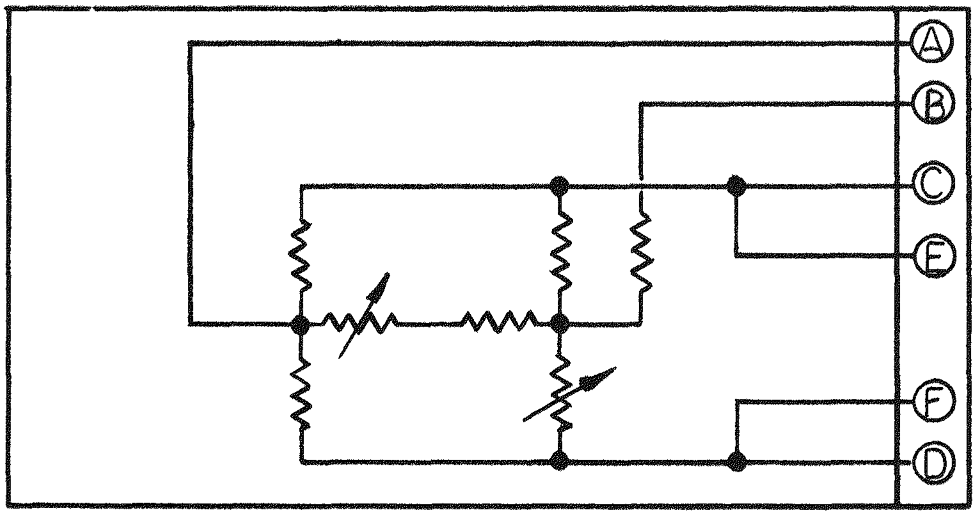


PHOTOGRAPH OF A ELECTROWEST RTT

Figure 33



## ELECTRICAL CIRCUIT

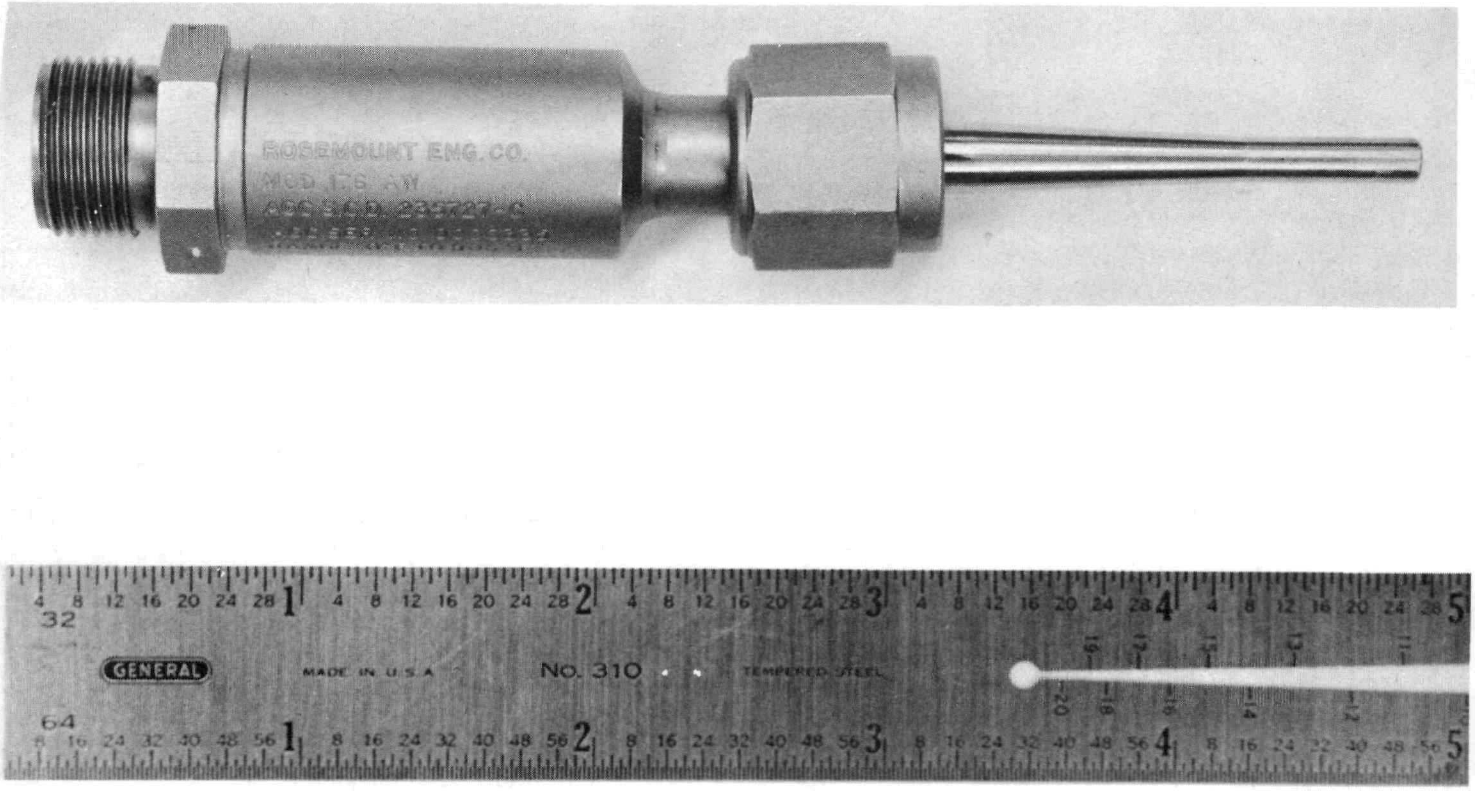


## RESISTANCE CHARACTERISTICS

| MODEL | RANGE °F | OHMS ( TYPICAL ) | | | | | |
|---|---|---|---|---|---|---|---|
| | | A to B | A to C | A to D | B to C | B to D | C to D |
| 176AY | 0-100 | 500 | 482 | 21 | 960 | 502 | 500 |
| 176AV | 0-200 | ↓ | 496 | 15 | 980 | 500 | ↓ |
| 176AW | 0-500 | ↓ | 530 | 36 | 980 | 488 | ↓ |

TYPICAL ROSEMOUNT ENGINEERING COMPANY
RTT

Figure 34



PHOTOGRAPH OF A ROSEMOUNT RTT

Figure 35

All components of the sensor that pass through areas of high stress, such as the sensor stem adjacent to the mounting nut, are completely supported and encapsulated.

The bridge design uses two precision platinum sensing elements to provide a linear output. The natural non-linearity of platinum is in the same direction as the non-linearity of a bridge circuit. Rosemount Engineering Company has added a second platinum element across the output terminals of the bridge to compensate for this non-linearity, thus providing an E versus T well within the design requirements.

## C. RTT TEMPERATURE MEASUREMENT SYSTEM

The RTT temperature measurement system, as illustrated in Figure 36, is a six-wire system designed to suppress the effects of lead-wire resistance, to use existing 10 v dc (constant voltage) power supplies, to provide accurate data, and to provide a reliable system with simplicity of operation.

All test area and flight RTT calibrations are directly traceable through secondary and primary standards to the National Bureau of Standards in Washington, D. C. Actual output of the RTT is measured directly in percent of full-scale output by application of techniques devised during the development of the calibration equipment for strain-gage transmitters.

### 1. Electrical Diagram

Each control room channel in the test area is arranged to take measurements from the RTT located at any one of the test stands connected with this control room. To choose the RTT to be used, a test stand select panel (located in the terminal room) is remotely operated by a select panel control unit (located in the control room). The RTT calibrator, also located in the control room, can be manually or automatically operated. Automatic operation is provided by 28 v dc signals from the "auto-cal" panel located in each control room. The data or calibration signal (analog dc voltage) is amplified by the conventional test area dc amplifiers in the control room before entering the analog to digital converter and digital recording system.

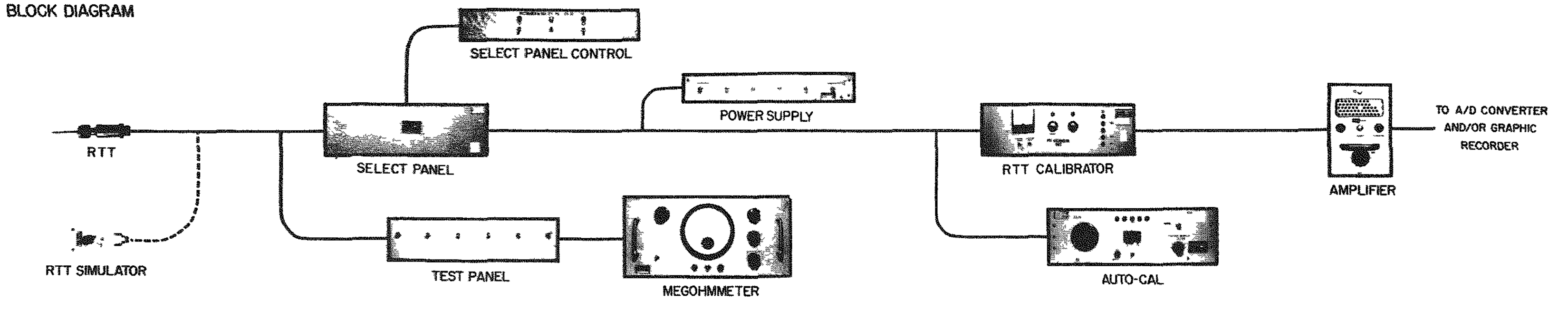
### 2. System Calibration

Calibration of the recording system is accomplished by voltage substitution. The calibration voltage is derived by a high impedance Ayrton shunt, with the RTT excitation voltage as the source. With the RTT standardized for a 4 mv/v sensitivity, zero balance of the system is accomplished by balancing the amplifier for 0% output when the RTT calibrator is in the 0% calibrate mode. The 75% ranging of the system is accomplished by manually ranging the data acquisition system for 75%

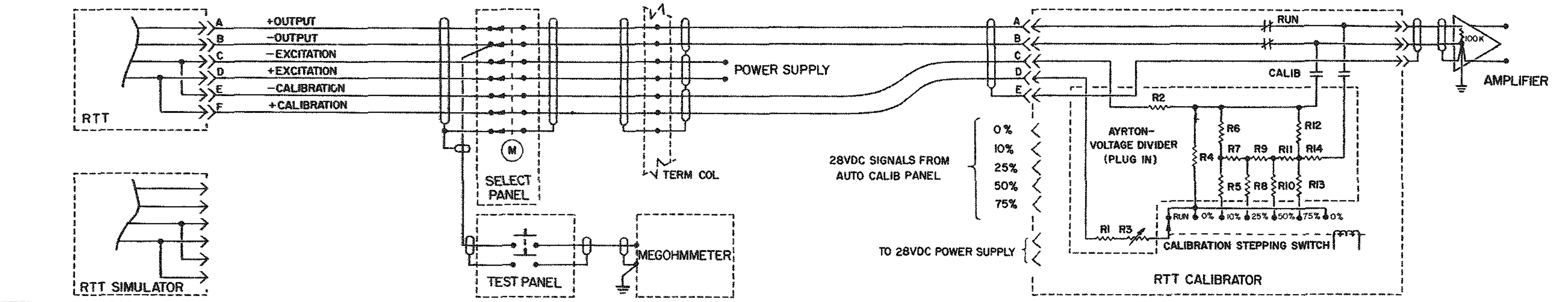
Figure 36

# STORABLE TEMPERATURE MEASUREMENT SYSTEM *

## BLOCK DIAGRAM



## ELECTRICAL DIAGRAM



## CHARACTERISTICS

### RTT

| TEMP RANGE | AGC-SCD | AGC SPEC |
|---|---|---|
| 0-100°F | 248820 | 42114 & 42114/4 |
| 0-200°F | 244475 | 42114 & 42114/2 |
| 0-500°F | 235727 | 42114 & 42114/3 |

EXCITATION—10VDC (NOMINAL)
SENSITVITY—4mV/V (INTO 100K LOAD)
ACCURACY— ±.25% of FULL SCALE
INPUT IMPEDANCE—500Ω ± 25Ω
PRESSURE—3000 PROOF, 1500 OPERATING (PSI)
INSULATION—30 MEGS. MIN
RESPONSE—1 SEC. MAX.
MATING PLUG—AGC SCD-235779

### RTT SIMULATOR

MFR—AEROJET GENERAL CORP
MODEL—E-3
SIMULATION—0 & 75% of FULL SCALE

### RTT CALIBRATOR

MFR.—AEROJET GENERAL CORP
MODEL—248248
CHANNEL—6
LINEARITY CHECK—0,10,25,50 & 75% of FULL SCALE

### POWER SUPPLY

AETRON SPEC—P1 136
VOLTAGE—10VDC
REGULATION—±0.1%

### MEGOHMMETER

MFR.—FEDERAL TELEPHONE & RADIO CO.
MODEL—S-1 (AGC MODIFIED) TERA-OHMMETER
RANGE—0-10³ (10VDC)

### AMPLIFIER

MFR—KINTEL
MODEL—111 OR EQUIV
GAIN—1000 MAX
INPUT IMPEDANCE—100K OHMS

## SYSTEM OPERATION

ZERO ADJUST—BALANCE AMPLIFIER FOR 0% of FULL SCALE (0±1 MILLISADIC COUNTS) WITH THE RTT CALIBRATOR IN THE 0% CALIBRATE MODE

RANGE ADJUST—ADJUST RANGING POTENTIOMETER FOR 75% of FULL SCALE (7500±1 MILLISADIC COUNTS) WITH THE RTT CALIBRATOR IN THE 75% CALIBRATE MODE

INSULATION CHECK—ALL CHANNELS ARE MEGGED WHEN SELECT PANEL SWITCHES ARE OPEN, THAT IS, THE AMPLIFIER GROUND IS REMOVED

LINEARITY—CALIBRATION SIGNALS OF 0,10,25,50 & 75% of FULL SCALE, ARE RECORDED BEFORE AND AFTER EACH TEST

DATA REDUCTION—NO SPECIAL CURVES REQUIRED, LINEAR OUTPUT

| TEMPERATURE | 0% RANGE | MILLISADIC COUNTS | 0000 |
|---|---|---|---|
| | 25% RANGE | | 2500 |
| | 50% RANGE | | 5000 |
| | 75% RANGE | | 7500 |
| | 100% RANGE | | 9999 |

* LRP TEST DIVISION, MEASUREMENT ENGINEERING DEPT 8770

when the RTT calibrator is in the 75% mode. Thus, accuracy for the entire system is determined largely by the Ayrton shunt voltage divider and the calibration of the RTT. Linearity of the system is also checked against the Ayrton shunt voltage divider by providing 10, 25, and 50% outputs (in addition to the 0 and 75% outputs) automatically before and after each rocket test firing.

### 3. System Simulation

All storable temperature measurement systems are periodically calibrated by substitution of a precision RTT simulator designed to provide accurate 0% (0 mv/v) and 75% (3 mv/v) output signals. With the RTT simulator electrically substituted for the RTT on the test stand, each channel may be calibrated. The calibration consists of performing the routine system zero and range adjustments and then making a direct comparison of recorded calibrator and simulator outputs. Ideally, 25 to 100 points in each position are recorded for an adequate statistical sample.

## V CRYOGENIC CONSTANT CURRENT RTT SYSTEM

Testing the NERVA liquid hydrogen pump requires an extremely precise measurement of the inlet temperature in order to obtain the vapor-pressure head for NPSH determination. For example, 5 feet of vapor-pressure head is represented by a change of 0.054°F. In order to establish an adequate design for the NPSH parameter, a measurement accuracy of the pump inlet temperature of at least ± 0.054°R is considered necessary. A program to design and develop a cryogenic temperature measuring system capable of an accuracy of 0.054°F in the temperature region of -425 to -400°F was recently completed under a NERVA funded developmental program.

Three approaches were investigated to develop RTT's capable of measuring liquid hydrogen temperatures to accuracies of 0.050°F or better; (1) the use of a platinum wire resistance element, (2) the use of a silicon semiconductor resistance element, and (3) the use of a doped germanium resistance element. The following design criteria was established: (1) there will be no standardization of RTT's at the expense of accuracy, (2) a four wire system will be used between the single sensing element and the calibration unit, and (3) the element resistance will be less than 2000 ohms.

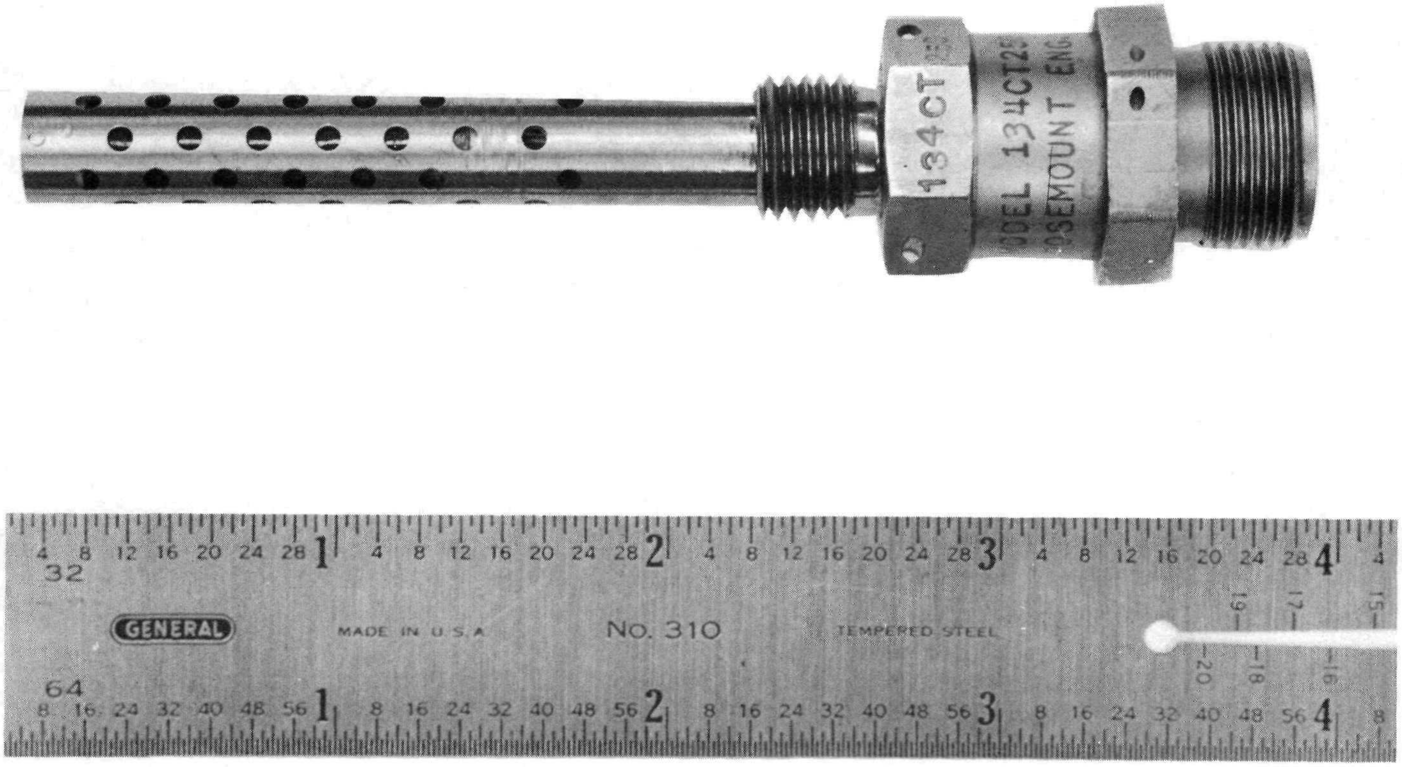
Several design concepts for the associated circuitry were considered before the selection of the constant current system. The bridge completion concept was discarded for the high accuracy measurements because of (1) lead resistance differences, (2) thermal EMF generated at the relay contacts due to the heat dissipated by relay coils, and (3) external circuit component tolerances. With the use of a constant current supply, the voltage across the resistance element can be measured without the errors that are introduced by lead resistance. This system is also compatible with the automatic calibration control system used in the test area.

The platinum element type is the only fully evaluated and qualified liquid hydrogen RTT. Extensive testing of models 134CT and 134EB, manufactured by Rosemount Engineering Company, has been completed. Additional sources, Electrowest Incorporated and Winsco Instruments and Controls, are being evaluated to an Aerojet specification.

### A. NERVA RTT DEVELOPMENTAL PROGRAMS

#### 1. Platinum Wire - Model 134CT

Rosemount Engineering Company, Minneapolis, Minnesota, submitted REC Proposal 36223A, "Proposal for Precision $LH_2$ Temperature Measuring System for Aerojet-General Corporation (IRP)," dated 23 March 1962 for review. This proposal outlines the specifications for model 134CT and the associated signal conditioning panel. Six model 134CT's were bought, evaluated, and calibrated during calendar year 1962 (see Figure 37).



MODEL 134CT PHOTOGRAPH

Figure 37

Rosemount model 134CT is designed for temperature measurements in the range of +75°F to -425°F. It uses a precision platinum resistance sensing element which is fully supported and mounted in ceramic insulation. This element is constructed of 0.0007 inch OD chemically pure platinum wire which has a standardized (non-linear) resistance curve varying from 1510.79 ohms to 5.584 at temperatures of +75°F and -425°F, respectively. The element is protected by a stainless steel guard tube with an additional support at the tip for protection to flow. This sensor is suitable for use in most hydrocarbons, gaseous or liquid air, oxygen, nitrogen, hydrogen, or helium. Aerojet's evaluation is specifically intended to cover service in gaseous or liquid hydrogen only.

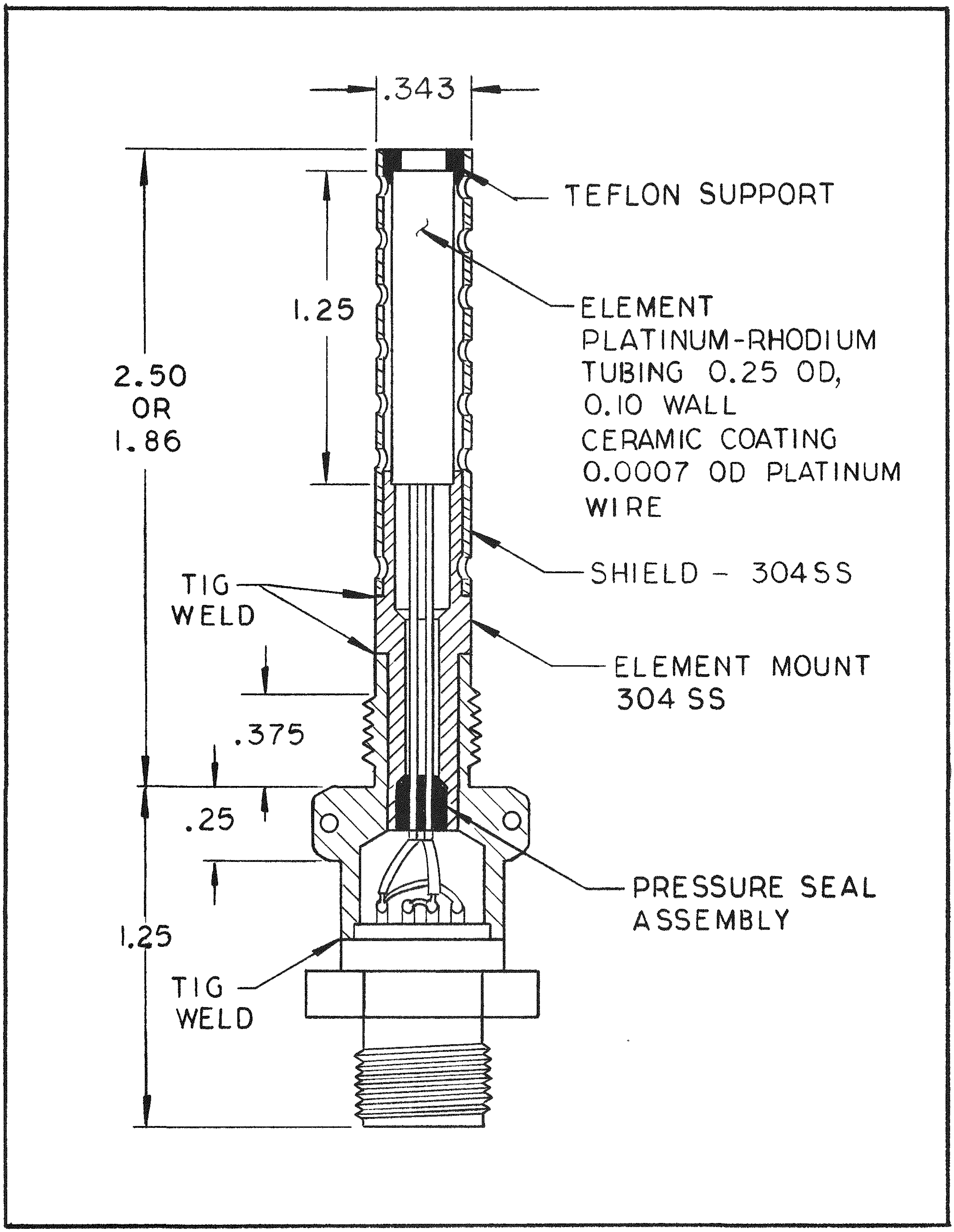
Electrical connection to the sensor is made by a standardized Aerojet plug (AGC SCD 235779) which mates with a standardized Aerojet receptacle (AGC SCD 235774). Attachment to the LRP test area lines is accomplished by mating with an AND 10050-4 female boss. All exterior materials are limited to stainless steel type 304. Construction details of model 134CT are illustrated in Figure 38.

The accuracy of model 134CT is within 0.070°F of the individual Rosemount calibration certificate and is stable within 0.020°F over the -400 to -425°F region when exposed to temperatures between room temperature and -425°F. All units are standardized within 0.217°F at -400°F and 0.141°F at -425°F to a nominal or standardized temperature versus resistance curve or tabulated data.

### 2. Platinum Wire - Model 134EB

Model 134EB platinum resistance temperature transducer, also manufactured by Rosemount Engineering Company, is an immersion type unit designed for measurements in the temperature range of +75 to -425°F. It is suitable for use in most hydrocarbons, gaseous or liquid air, oxygen, nitrogen, hydrogen or helium. Since this unit is also designed to operate in a radiation environment, all materials used in construction are radiation resistant. The temperature sensing element consists of a 90% platinum and 10% rhodium cylindrical mandrel which is wound with pure (99.9%) platinum wire that is fully supported by a ceramic insulation (containing only 0.05% $B_2O_3$) and protected by a perforated stainless steel guard tube.

Model 134EB (a radiation resistant model 134CT) is electrically and physically interchangeable with model 134CT temperature sensor. The basic difference between these two sensors is in the construction materials that are necessary for radiation resistant design. This difference necessitated the removal of the teflon bushing that supports the element mandrel at the sensor tip and the replacement of teflon insulation with a fiberglass for the internal wires. To insure the unsupported mandrel would meet vibration requirements, the mandrel used with model 134CT was shortened from 1.25 inch to 0.85 inch. The basic requirement that the platinum wire sensing area is to be contained in



MODEL 134CT CROSS SECTION

Figure 38

the last 1.0 inch of the sensor stem remains for each sensor. Model 134EB, however, retains the identical resistance to temperature relationship with an ice point resistance of 1380 ± 1.0 ohms and a residual resistance at the liquid helium boiling point (-452.1°F) of approximately 0.08% of the ice point value.

## B. TEST AREA RTT'S

### 1. Specifications

Two component specifications, AGC-42114 and AGC-42114/7, have been prepared for the procurement of cryogenic RTT's for the test area. A summary of the operational requirements is tabulated in Figure 39. Mechanical details which describe the cryogenic RTT's are contained on AGC-SCD drawing 248058 thru 248067.

### 2. Wire Coding/Electrical Circuit

The wiring code for the test area cryogenic RTT is a conventional 6 wire arrangement with A and B as output pins and C and D as input pins. Normally E and F are the calibration leadwires, but only four wires are required for the constant current system. To standardize the electrical connector with the ambient RTT and strain gage system, a six pin connector is required. The spare pins E and F are shorted internally within the RTT for possible flight applications where a bridge scheme might be used as a signal conditioning unit. The wiring code is tabulated in Figure 40.

Figure 41 shows the electrical circuit where $R_t$ is the platinum resistance which varies with temperature. Each leadwire is attached directly to the element so that thermal EMF's and leadwire resistance errors are minimized.

### 3. Mounting/Installation Methods

Standard mounting/installation methods for the cryogenic RTT's are detailed on AGC drawings 248069 and 248070 (Figures 42 and 43). Specific stem lengths of Rosemount Model 134CT RTT's are specified for a particular line size in order to obtain proper immersion depths upon installation. Mounting boss AND 10050-4 is dimensionally detailed and shown fillet welded to the outer line surface. Metallic "K seal," part number 12100CR4 (Teflon coated), is specified as a static seal suitable for cryogenic temperature environments and for operating pressures to 5000 psig. "K seals" are reusable provided they are not nicked, scratched, or bent and are installed to the specified torque values as specified on drawings 248069 or 248070. "K seals" are manufactured and distributed by the Harrison Manufacturing Company located in Burbank, California.

| | |
|---|---|
| Range | -425 to +75°F |
| Temperature resistance characteristics | Standardized curve with 5.5840 ± 0.1409 ohms at -425°F and 1510.7890 ± 1.060 ohms at +75°F |
| Accuracy | ± 0.07°F from -425 to -400°F<br>± 0.1°F from -400 to +75°F |
| Repeatability | ± 0.02°F from -425 to -270°F<br>± 0.1°F from -270 to +75°F |
| Temperature Thermal EMF characteristics | 5.2μv max at -425° F<br>to<br>30 μv max at +75°F |
| Vibration | 70 g (peak) for 1.86 inch stem<br>60 g (peak) for 2.50 inch stem<br>50 g (peak) for 4.00 inch stem<br>35 g (peak) for 6.00 inch stem<br>24 g (peak) for 8.00 inch stem<br>22 g (peak) for 8.50 inch stem<br>20 g (peak) for 9.00 inch stem |
| Response time | 250 milliseconds |
| Insulation resistance | 1000 megohms at 50 volts dc |
| Maximum current | 20 milliamperes |
| Flow | 300 fps for 1.86 inch stem<br>220 fps for 2.50 inch stem<br>135 fps for 4.00 inch stem<br>115 fps for 6.00 inch stem<br>75 fps for 8.00 inch stem<br>70 fps for 8.50 inch stem<br>65 fps for 9.00 inch stem |
| Proof pressure | 3000 psig (helium, nitrogen or dry air) |
| Operating pressure | 1500 psig (helium) |

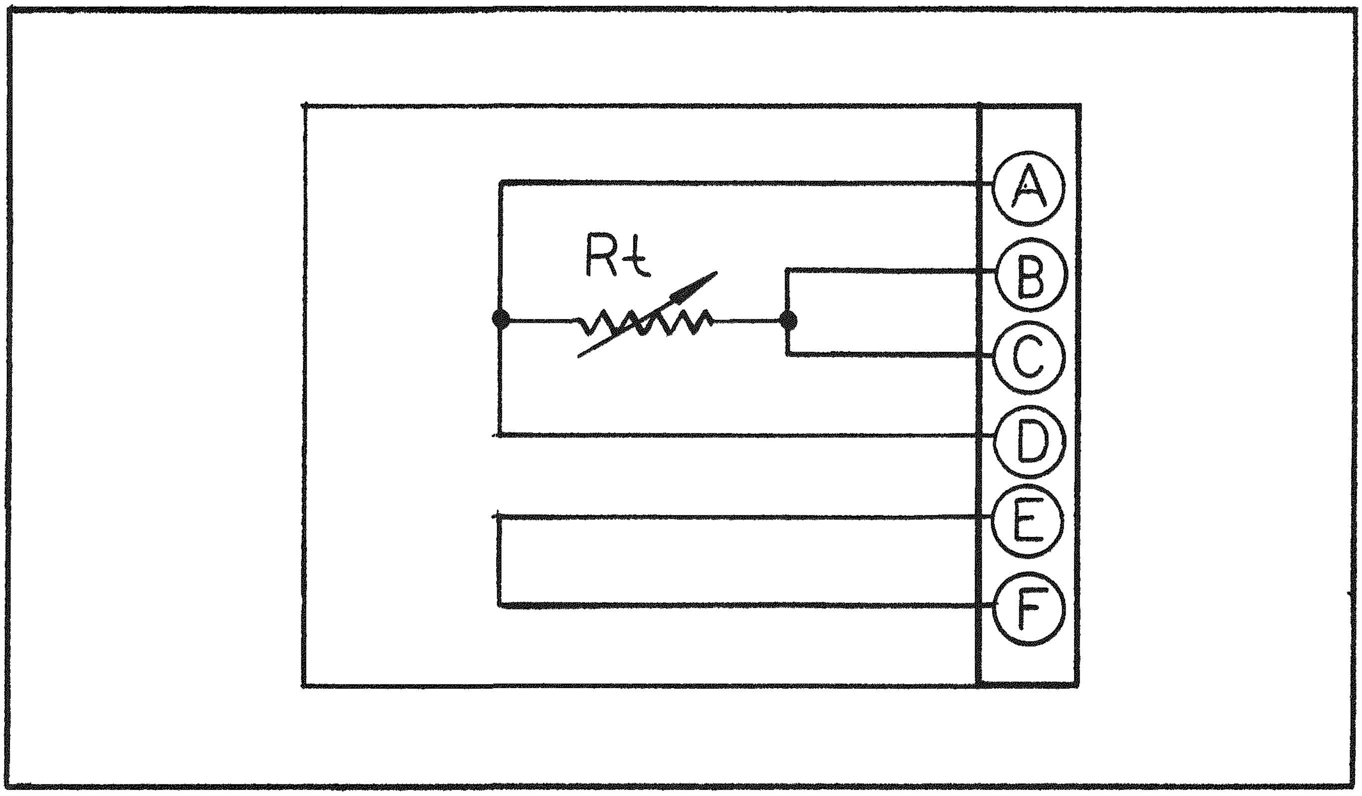
CRYOGENIC RTT CHARACTERISTICS

Figure 39

| CONNECTOR PIN | DESCRIPTION |
|---|---|
| A | Positive output signal |
| B | Negative output signal |
| C | Negative excitation current |
| D | Positive excitation current |
| E | Electrically shorted to pin F |
| F | Electrically shorted to pin E |

CRYOGENIC RTT WIRE CODING

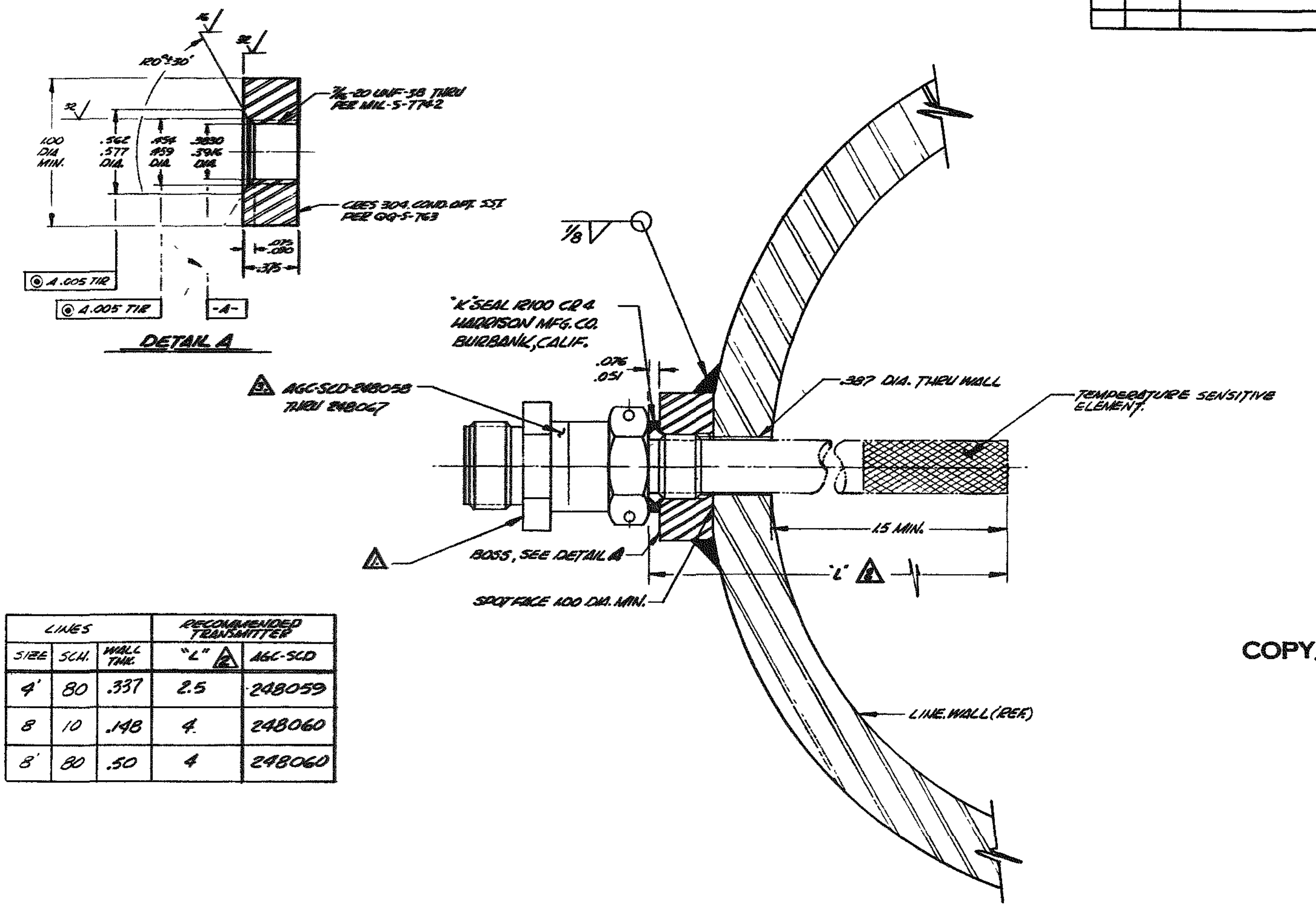
Figure 40



CRYOGENIC RTT ELECTRICAL CIRCUIT

Figure 41

| LETTER | DATE | CHANGE | BY | CH'D |
|---|---|---|---|---|
| | | | | |
| | | | | |



| LINES | | | RECOMMENDED TRANSMITTER | |
|---|---|---|---|---|
| SIZE | SCH. | WALL THK. | "L" 2 | AGC-SCD |
| 4' | 80 | .337 | 2.5 | 248059 |
| 8 | 10 | .148 | 4 | 248060 |
| 8' | 80 | .50 | 4 | 248060 |

COPY 248069

3 SUPPLIED BY TEST DIVISION, DEPT. 8770 A.G.C.

2 LENGTH L DETERMINED BY AGC-SCD-NO.

1 RECOMMENDED TORQUE 200-350 IN LBS.

NOTES:

| | | |
|---|---|---|
| No. Req. | NEXT ASSY. | MODEL |
| HEAT TREAT | FINISH | |
| TOLERANCE UNLESS OTHERWISE NOTED | | |
| LINEAR TOL. .XX | ± .03 | |
| LINEAR TOL. .XXX | ± .010 | |
| ANGULAR TOL. | | |
| ✓ INDICATES SURFACE ROUGHNESS FINISH PER MIL. STD 10 UNLESS OTHERWISE NOTED | | |

| | |
|---|---|
| DRAFTSMAN Royal | DATE 10-31-62 |
| CHECKED | |
| STRESS | |
| ENGINEER H. C. Chandon | 11-5-62 |
| APPROVED | |
| PRODUCTION | |
| CUSTOMER | 11-5-62 |

MATERIAL

STANDARD INSTALLATION
CRYOGENIC
RESISTANCE TEMPERATURE
TRANSMITTER

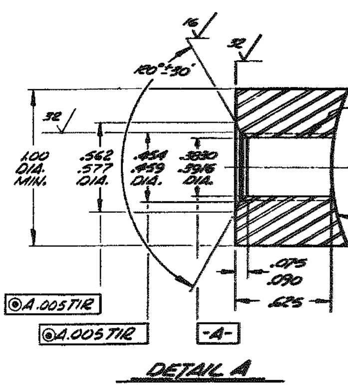
**AEROJET-GENERAL CORPORATION**
LIQUID ROCKET PLANT
SACRAMENTO, CALIFORNIA

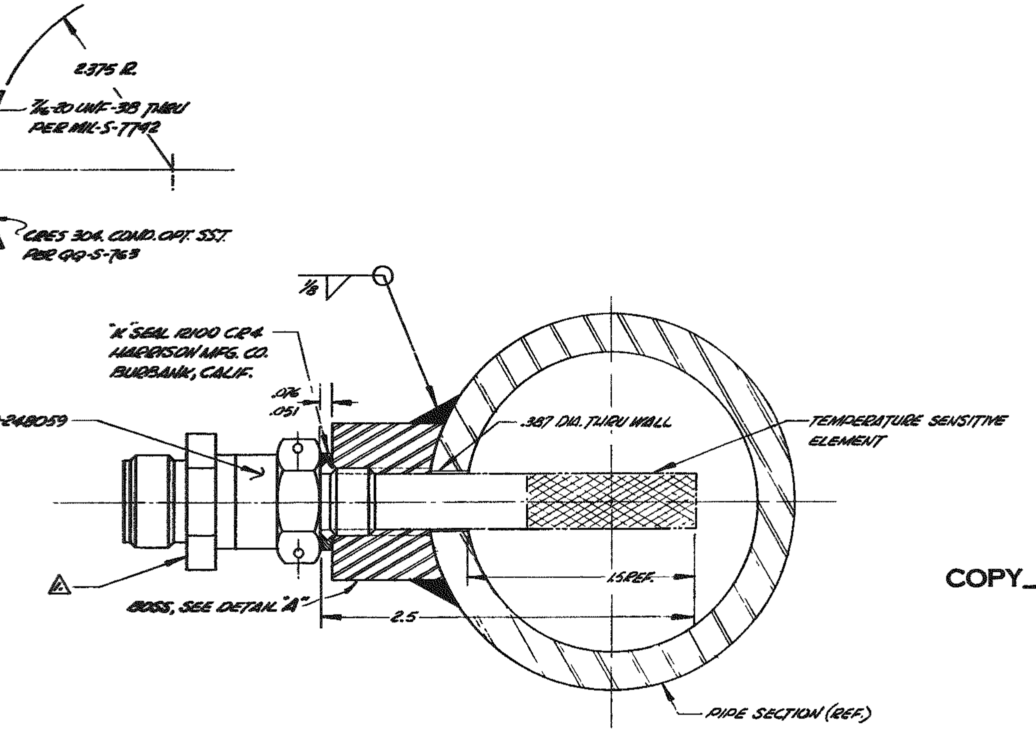
SIMILAR TO
RELEASE DATE
SCALE 2/1
CAL. WEIGHT
ACT WEIGHT
DWG. SIZE C
248067
PART NUMBER

AGC 4 41C (1500 5 59) PRINTED ON DIEPO NO. 1020-5 CLEARPRINT FADE-OUT

Figure 42

| LETTER | DATE | CHANGE | BY | CH'D |
|---|---|---|---|---|
| | | | | |





COPY 248070

| LINES | | | RECOMMENDED TRANSMITTER | |
|---|---|---|---|---|
| SIZE | SCH. | WALL THK. | LENGTH | AGC-SCD- |
| 2" | 80 | .218 | 2.5 | 248059 |
| | | | | |

2 SUPPLIED BY TEST DIVISION, DEPT. 8770, AEROJET GENERAL CORPORATION.

1 RECOMMENDED TORQUE 200-350 IN. LBS.

NOTES:

NOTE: REMOVE ALL BURRS AND SHARP EDGES

| | | | | | |
|---|---|---|---|---|---|
| | | | DRAFTSMAN Royal | DATE 11-12-62 | MATERIAL |
| No. Reqd. | NEXT ASSY. | MODEL | CHECKED | | STANDARD INSTALLATION CRYOGENIC RESISTANCE TEMPERATURE TRANSMITTER |
| HEAT TREAT | | FINISH | STRESS | | AEROJET-GENERAL CORPORATION<br>LIQUID ROCKET PLANT<br>SACRAMENTO, CALIFORNIA |
| TOLERANCE UNLESS OTHERWISE NOTED | | | ENGINEER N. C. Chanda | 11-12-62 | |
| LINEAR TOL. | .XX | ± .03 | APPROVED | | SIMILAR TO |
| | .XXX | ± .010 | PRODUCTION D. M. Wheeler | 11-12-62 | SCALE 2/1 |
| | ANGULAR TOL. | | CUSTOMER | | RELEASE DATE |
| ✓ INDICATES SURFACE ROUGHNESS<br>FINISH PER MIL STD 10 UNLESS OTHERWISE NOTED | | | | | CAL. WEIGHT<br>ACT WEIGHT |
| | | | | | DWG. SIZE C |
| | | | | | 248070<br>PART NUMBER |

(500 8 59) PRINTED ON DIEPO NO 1020-6 CLEARPRINT FADE-OUT

Figure 43

### 4. Analysis of Self-Heating

The results of a study investigating self-heating in model 134CT indicate it to be relatively free from error because of this effect. The error may be considered constant for all flow rates and proportional to the second power of the element current. The self-heating factors are $1.2 \times 10^{-1}$ watts/°F for no flow and $3.5 \times 10^{-1}$ watts/°F for flow. When under flow with a current of 3 ma, the error is only +0.0002°F.

### 5. Analysis of Frictional Heating

Studies of the orders of magnitude of the anticipated temperature errors, caused by frictional effects in high velocity $LH_2$ flows, indicate a small error because of RTT size for laminar flow. In turbulent flow the error may be expected to vary directly with the diameter. Anticipated errors for a 134CT are given in Figure 44.

### 6. Analysis of Stem Conduction

An analysis of stem conduction effects indicates the error for the 134CT to be independent of velocity for all flows above normal free convection flow. Typical errors for various RTT lengths L are given in Figure 45.

## C. CONSTANT CURRENT SYSTEM

### 1. Electrical Diagram

The constant current temperature measurement system, as illustrated in Figure 46, is a four wire system designed to suppress the effects of leadwire resistance. Each temperature sensor has a constant current passed through the platinum resistance wire sensor such that the potential voltage drop is proportional to the temperature. The RTT calibration panel, located in the Control Room, can be manually or automatically operated. Automatic operation is provided by 28 v dc signals from the "Auto-Cal" panel, also located in the Control Room. The data or calibration signal (analog dc voltage) is amplified by conventional test area dc amplifiers in the Control Room before entering the analog-to-digital converter and digital recording system, analog oscillographic, or potentiometric recorders.

### 2. RTT Selection

The criterion for selection of the model 134CT/134EB units, used for the high accuracy (± 0.054°F) liquid hydrogen temperature measurements, is ± 0.050°F, including calibration. All high accuracy measurements are to be taken on the narrow range (Code K) for greatest resolution by the system. Each Code K unit is identified by a metal tag stamped "Code K only," which is attached to the safety wire hole on the RTT housing. For the other ranges, all RTT's are manufactured to tight enough tolerances so there are no special selections required.

| VELOCITY (fps) | ERROR (°F) | FLOW TYPE |
|---|---|---|
| 10 | +0.0003 | Laminar |
| 20 | +0.0011 | Laminar |
| 40 | +0.0015 | Transitory |
| 80 | +0.0055 | Turbulent |
| 160 | +0.028 | Turbulent |
| 320 | +0.13 | Turbulent |

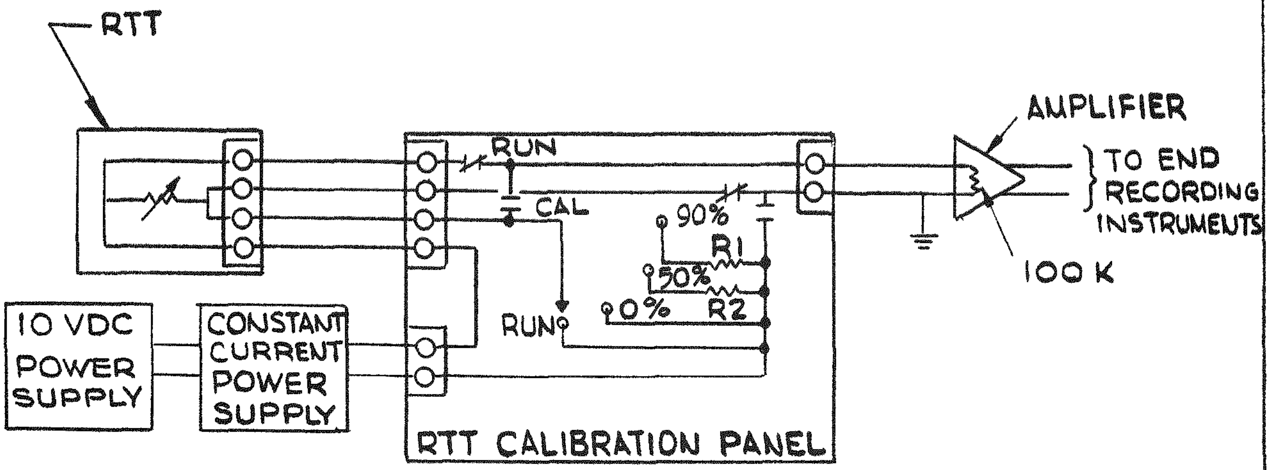
CALCULATED FRICTIONAL HEATING ERROR

Figure 44

| HEAD TEMPERATURE (°F) | L (INCHES) | ERROR (°F) |
|---|---|---|
| 68 | 2 | +2.21 |
|  | 3 | +0.41 |
|  | 4 | +0.0007 |
| -100 | 2 | +1.28 |
|  | 3 | +0.024 |
|  | 4 | +0.004 |

CALCULATED STEM CONDUCTION ERROR

Figure 45



| DIGITAL COUNTS | CODE K<br>-425 to -400°F | | CODE L<br>-425 to +75°F | | CODE N<br>-425 to -300°F | | CODE R<br>-425 to -375°F | |
|---|---|---|---|---|---|---|---|---|
| | TEMP °F | SENS m°F/DC | TEMP °F | SENS m°F/DC | TEMP °F | SENS m°F/DC | TEMP °F | SENS m°F/DC |
| 10000 | -400.00 | 2.0 | + 75.00 | 50.3 | -300.00 | 10.0 | -375.00 | 3.3 |
| 9000 | -401.96 | 2.1 | + 24.68 | 49.8 | -309.86 | 9.8 | -378.39 | 3.5 |
| 8000 | -404.05 | 2.2 | - 25.06 | 49.2 | -319.76 | 9.9 | -381.92 | 3.6 |
| 7000 | -406.31 | 2.4 | - 74.22 | 48.5 | -329.74 | 10.0 | -385.63 | 3.8 |
| 6000 | -408.76 | 2.7 | -122.73 | 47.8 | -339.78 | 10.1 | -389.56 | 4.1 |
| 5000 | -411.48 | 3.1 | -170.53 | 47.0 | -350.02 | 10.4 | -393.79 | 4.4 |
| 4000 | -414.59 | 3.7 | -217.55 | 46.1 | -360.66 | 10.9 | -398.47 | 4.9 |
| 3000 | -418.28 | 4.8 | -263.69 | 45.2 | -371.96 | 11.8 | -403.81 | 5.7 |
| 2000 | -423.07 | 5.6 | -308.89 | 45.7 | -384.53 | 13.7 | -410.33 | 7.3 |
| 1000 | - | - | -354.75 | 48.2 | -400.28 | 19.1 | -419.55 | 12.1 |
| 744 | - | - | - | - | - | - | -423.00 | 15.3 |
| 204 | - | - | - | - | -423.00 | 55.5 | - | - |
| 45 | - | - | -423.00 | 253.97 | - | - | - | - |
| Range (Ω) | 0 to 33.2118 | | 0 to 1510.7890 | | 0 to 328.2475 | | 0 to 89.8886 | |
| Calib Resistors | $R_1$: 29.891<br>$R_2$: 16.606 | | $R_1$: 1357.65<br>$R_2$: 749.73 | | $R_1$: 295.326<br>$R_2$: 163.855 | | $R_1$: 80.976<br>$R_2$: 45.033 | |

NOTE: This is the interim system installed in C zone.

# CONSTANT CURRENT TEMPERATURE MEASUREMENT SYSTEM

Figure 46

A statistical Gaussian distribution analysis of thirty model 134CT units, manufactured by Rosemount, indicated that 44% would be within ± 0.05°F of the average curve as specified in Component Specification AGC-42136/7. A summary of this analysis at the temperature point of -425°F is tabulated in Figure 47. Since the vendor calibration accuracy is ± 0.07°F in the -425 to -400°F region, it is necessary to calibrate each RTT at three points to make a final Code K selection.

### 3. System Calibration

Calibration of the recording system is accomplished by resistance substitution for each temperature sensor. With all 134CT temperature sensors standardized, a zero system balance is accomplished by balancing the amplifier for zero output when the RTT calibration panel is in the 0% calibrate mode. The 90% ranging of the system is accomplished by manually ranging the data acquisition system for 90% when the RTT calibration panel is in the 90% calibrate mode. Linearity of the system is automatically checked by resistance substitution at the 50% step before and after each simulator test.

### 4. System Simulation

Each channel in the test area is periodically checked by system calibration using an RTT simulator. The simulator for the constant current system is a high accuracy, four wire resistor. Two points are provided, the 0 and 90% steps. Presently there are three ranges of RTT simulators available for the test area, Codes K, L, and N.

The calibration of a channel consists of performing the routine system zero and range adjustments, then making a direct comparison of recorded calibrator and simulator outputs. Ideally, 25 to 100 points are recorded in each position for an adequate statistical sample.

## D. ROSEMOUNT MODEL 134CT/134EB DATA REDUCTION

Standardized data reduction curves and tables for the Model 134CT platinum RTT's have been computed. These curves are designated as Code K for the range -425 to -400°F, Code L for the range -425 to +75°F, Code N for the range -425 to -300°F, and Code R for the range -425 to -375°F. Equations for all four codes are tabulated in Figures 48, 49, 50, and 51.

| RTT ACCURACY (°F) | TOTAL UNITS FALLING WITHIN (%) |
|---|---|
| ± 0.01 | 20.6 |
| ± 0.02 | 32.4 |
| ± 0.025 | 32.4 |
| ± 0.03 | 35.2 |
| ± 0.04 | 41.4 |
| ± 0.05 | 44.1 |
| ± 0.09 | 67.2 |
| ± 0.23 | 100.0 |

RTT GAUSSIAN DISTRIBUTION AT -425°F

Figure 47

| | |
|---|---|
| Temperature Range | -425 to -400°F |
| Digital Count Range | 1681 to 10,000 DC |
| Maximum Error | 0.005°F |
| Sigma Squared | 0.002°F |
| Equation | Seventh degree |

$$\begin{aligned} {}^{\circ}F = & -442.37109 + 1.6234102 \times 10^{-2} (DC) - 5.0805788 \times 10^{-6} (DC)^{2} \\ & + 1.1953123 \times 10^{-9} (DC)^{3} - 1.8070175 \times 10^{-13} (DC)^{4} \\ & + 1.6701989 \times 10^{-17} (DC)^{5} - 8.5719676 \times 10^{-22} (DC)^{6} \\ & + 1.8679217 \times 10^{-26} (DC)^{7} \end{aligned}$$

CODE K PLATINUM RTT
EQUATION FOR DATA REDUCTION

Figure 48

| | |
|---|---|
| Temperature Range | -425 to -405°F |
| Digital Count Range | 37 to 169 DC |
| Maximum Error | 0.0014°F |
| Sigma Squared | 0.00095°F |
| Equation | Seventh degree |

$$
\begin{aligned}
{}^{\circ}F = {} & -444.49750 + 0.90984241\,(DC) - 1.6557175 \times 10^{-2}\,(DC)^{2} \\
& + 2.2453721 \times 10^{-4}\,(DC)^{3} - 1.9615216 \times 10^{-6}\,(DC)^{4} \\
& + 1.0490178 \times 10^{-8}\,(DC)^{5} - 3.1161110 \times 10^{-11}\,(DC)^{6} \\
& + 3.9301205 \times 10^{-14}\,(DC)^{7}
\end{aligned}
$$

| | |
|---|---|
| Temperature Range | -405 to -310°F |
| Digital Count Range | 169 to 1975 DC |
| Maximum Error | 0.0296°F |
| Sigma Squared | 0.0141°F |
| Equation | Seventh degree |

$$
\begin{aligned}
{}^{\circ}F = {} & -425.57505 + 0.15526697\,(DC) - 2.4652838 \times 10^{-4}\,(DC)^{2} \\
& + 3.4716237 \times 10^{-7}\,(DC)^{3} - 3.0426326 \times 10^{-10}\,(DC)^{4} \\
& + 1.5892428 \times 10^{-13}\,(DC)^{5} - 4.5061942 \times 10^{-17}\,(DC)^{6} \\
& + 5.3248948 \times 10^{-21}\,(DC)^{7}
\end{aligned}
$$

| | |
|---|---|
| Temperature Range | -310 to +75°F |
| Digital Count Range | 1975 to 10,000 DC |
| Maximum Error | 0.00241°F |
| Sigma Squared | 0.006°F |
| Equation | Seventh degree |

$$
\begin{aligned}
{}^{\circ}F = {} & -396.31059 + 4.2762449 \times 10^{-2}\,(DC) + 4.3803946 \times 10^{-7}\,(DC)^{2} \\
& + 2.8781279 \times 10^{-11}\,(DC)^{3} - 5.9391925 \times 10^{-15}\,(DC)^{4} \\
& + 4.2713884 \times 10^{-19}\,(DC)^{5} - 1.3890318 \times 10^{-23}\,(DC)^{6} \\
& + 1.6681522 \times 10^{-28}\,(DC)^{7}
\end{aligned}
$$

## CODE L PLATINUM RTT DATA REDUCTION EQUATIONS

**Figure 49**

| | |
|---|---|
| Temperature Range | -425 to -400°F |
| Digital Count Range | 170 to 1015 DC |
| Maximum Error | 0.005°F |
| Sigma Squared | $4.843 \times 10^{-6}$ °F |
| Equation | Seventh Degree |

$$\begin{aligned}{}^{\circ}F = {} & -422.22848 + 0.15746195\ (DC) - 4.7602390 \times 10^{-4}\ (DC)^2 \\ & + 1.0817962 \times 10^{-6}\ (DC)^3 - 1.5790439 \times 10^{-9}\ (DC)^4 \\ & + 1.4095260 \times 10^{-12}\ (DC)^5 - 6.9921055 \times 10^{-16}\ (DC)^6 \\ & + 1.4744148 \times 10^{-19}\ (DC)^7\end{aligned}$$

| | |
|---|---|
| Temperature Range | -400 to -300°F |
| Digital Count Range | 1015 to 10,000 DC |
| Maximum Error | 0.0247°F |
| Sigma Squared | $8.670 \times 10^{-5}$ °F |
| Equation | Seventh Degree |

$$\begin{aligned}{}^{\circ}F = {} & -424.02368 + 0.030682832\ (DC) - 8.9710335 \times 10^{-6}\ (DC)^2 \\ & + 2.4216929 \times 10^{-9}\ (DC)^3 - 4.0945451 \times 10^{-13}\ (DC)^4 \\ & + 4.1546378 \times 10^{-17}\ (DC)^5 - 2.2995336 \times 10^{-21}\ (DC)^6 \\ & + 5.3205046 \times 10^{-26}\ (DC)^7\end{aligned}$$

CODE N PLATINUM RTT
DATA REDUCTION EQUATIONS

**Figure** 50

| | |
|---|---|
| Temperature Range | -425 to -400°F |
| Digital Count Range | 621 to 3697 DC |
| Maximum Error | 0.005°F |
| Sigma Squared | $4.668 \times 10^{-6}$ °F |
| Equation | Seventh Degree |

$$
\begin{aligned}
{}^{\circ}F = {} & -442.26203 + 4.3388334 \times 10^{-2}\,(DC) - 3.6192092 \times 10^{-5}\,(DC)^{2} \\
& + 2.2701812 \times 10^{-8}\,(DC)^{3} - 9.1490904 \times 10^{-12}\,(DC)^{4} \\
& + 2.2550333 \times 10^{-15}\,(DC)^{5} - 3.0882738 \times 10^{-19}\,(DC)^{6} \\
& + 1.7973022 \times 10^{-23}\,(DC)^{7}
\end{aligned}
$$

| | |
|---|---|
| Temperature Range | -400 to -375°F |
| Digital Count Range | 3697 to 10,000 DC |
| Maximum Error | 0.0029°F |
| Sigma Squared | $3.07 \times 10^{-6}$ °F |
| Equation | Fourth Degree |

$$
\begin{aligned}
{}^{\circ}F = {} & -425.45079 + 9.2319597 \times 10^{-3}\,(DC) - 8.1955377 \times 10^{-7}\,(DC)^{2} \\
& + 5.5699943 \times 10^{-11}\,(DC)^{3} - 1.5613553 \times 10^{-15}\,(DC)^{4}
\end{aligned}
$$

# CODE R PLATINUM RTT EQUATIONS FOR DATA REDUCTION

Figure 51