WORLDWIDE ENGINEERING STANDARDS	Test Procedure	GMW8288

General Specification for Thermal Evaluations Using Thermocouple and Infrared Imaging Methods

1 Introduction

Note: Nothing in this standard supercedes applicable laws and regulations.

Note: In the event of conflict between the English and domestic language, the English language shall take precedence.

1.1 Purpose. This standard specifies standard thermocouple and infrared imaging thermal measurement methods for components with electrical/electronic content that shall be used for thermal evaluations, unless otherwise specified.

1.2 Applicability. This standard applies to components with Electrical/Electronic (E/E) content to measure thermal properties.

1.3 Remarks. This standard defines the following two temperature measurement methods for components with E/E content that are used in a vehicle environment:

- Thermocouple (TC).
- Infrared (IR) imaging.

Note: E/E Subsystem Technical Specifications (SSTSs) and /or Component Technical Specifications (CTSs) take precedence over this standard.

2 References

Note: Only the latest approved standards are applicable unless otherwise specified.

2.1 External Standards/Specifications.

ASNT SNT-TC-1A	IATF 16949	ISO 9000

2.2 GM Standards/Specifications.

None

2.3 Additional References.

- CG3811 Thermal Evaluations Worksheet.
- E/E SSTSs and CTSs.

3 Resources

3.1 Facilities. The test facilities shall have the equipment and personnel expertise required to execute the procedures described within this document. All facilities and test equipment shall be IATF 16949 or ISO 9000 certified.

3.1.1 Calibration. The test facilities and equipment shall be in good working order and shall have a valid calibration label.

3.1.2 Alternatives. Alternative test facilities and equipment may also be used. However, all measuring variables as specified in this standard shall be determined correctly with respect to their physical definition.

3.2 Equipment.

3.2.1 Calibration. All equipment that is used for conducting thermal measurements shall have valid calibration labels.

3.2.2 Working Condition. All temperature measurement equipment shall demonstrate proper operation prior to the temperature measurement.

3.2.3 Parameter Definition and Tolerance. Unless stated otherwise, Table 1 shall define the test environmental parameters and tolerances to be used.

Table 1: Environmental Parameters and Tolerances

Parameter	Tolerance
Temperature	As Specified, ± 3 °C
Test Time	As Specified, ± 0.5%
Room Ambient Relative Humidity	30% to 70%

Unless stated otherwise, Table 2 shall define the measurement equipment tolerances to be used.

Table 2: Measure Equipment Tolerances

Parameter	Tolerance
Temperature	± 0 °C
Voltage	As Specified, ± 0.1 V (as measured at the component)
Current	As Specified, ± 1%

3.2.4 Thermal Test Chamber. The test chamber shall be capable of a temperature range of -40 °C to +100 °C minimum for evaluations of passenger compartment components. A -40 °C to +160 °C chamber is required for engine compartment components. The chamber shall have access ports for the interface and instrumentation wiring.

3.2.5 IR-Specific Equipment.

3.2.5.1 Calibration of IR Equipment. If absolute temperature-scale readings are required (as opposed to simple thermal pattern viewing or relative temperature readings), then the IR camera shall be calibrated to the emissivity of the materials being imaged prior to the thermal evaluation procedure.

Calibration shall be performed per the recommended procedures of the camera manufacturer. Separate calibration shall be performed for each combination of filters, lenses, and window materials used in the procedure. Window materials are to be calibrated for each IR camera wavelength range setting used.

It is recommended that the IR camera used in electrical component or printed circuit board thermal assessments be calibrated and filtered for peak performance in the 15 °C to 150 °C range. Better performance in this temperature range is achieved by using a camera that detects in the 8 µm to 14 µm spectral region instead of the 3 µm to 5 µm spectral region. The camera shall be mounted on a tripod or an equivalent fixture to ensure image stability.

3.2.5.2 Image Display, Capture, and Recording. The IR camera shall be linked to or include a real-time imaging display. The equipment shall be capable of producing an electronic copy of the IR image(s) to use for evaluation and documentation purposes.

If a dynamic thermal evaluation is required to monitor thermal changes over time or operation conditions, it is recommended that a digital image recording system be used. This allows an entire sequence of a transient event to be captured and allows the procedure to be repeatedly played back after the evaluation for detailed analysis or documentation purposes.

It is recommended that the system microphone, if available, be used by the equipment operator to provide a running narrative during the procedure. The narrative can be used to flag the start of the evaluation, timing of condition changes, and document observations or comments. This audio commentary is beneficial when reviewing or analyzing the evaluation.

3.2.5.3 IR Image Processing Systems. Infrared image processing systems are recommended for situations involving thermal evaluations of complex components or when highly accurate evaluations or highly detailed report documentation is required.

An IR imaging processing system typically consists of a general-purpose personal computer equipped with an IR camera interface and IR image processing software. These systems allow enhanced analysis of an infrared evaluation in real-time or during recording playback. Typical features of image processing systems include:

- Image zooming.
- Thermal Image color scale adjustments to improve image resolution.
- Automated image comparison and display windows that allow the temperatures of operator-defined points to be displayed and tracked in either text or analog graphics display formats.
- Printouts of selected images complete with captions, scaling, and graphs for report documentation.

The makers of the IR camera typically can provide either camera-compatible complete image processing systems or the appropriate add-on equipment to upgrade a general-purpose personal computer into an IR image processing system. IR camera manufacturers can also provide the interface specifications for acquiring an imaging processing system or equipment from third party vendors.

3.3 Test Vehicle/Test Piece. The thermal evaluation procedures defined in this document are intended to be flexible and adaptable for use in Development, Design Validation, Product Validation, and current product evaluation. Test samples used for development may range from breadboard or other forms of concept demonstrations to actual production samples. Test samples used for Design Validation shall be production-intent design and materials. Test samples used for Product Validation shall be manufactured on production tooling, with production materials and processes. Test samples used for current product evaluations shall be from normal production lots.

3.4 Test Time. Test time will vary based on the number and types of evaluations required, as well as the setup required, for each test. Setup for each evaluation will involve preparations for the measurement instrumentation, simulation of power and loads, and fixturing/orientation of the test sample.

3.5 Test Required Information. The test requester shall complete CG3811, GMW8288 Thermal Evaluations Worksheet, and provide this to the test facility. The purpose of the GMW8288 Thermal Evaluations Worksheet is to provide detailed instructions to the test facility regarding the measurement method, data to be collected, fixturing/orientation of the test sample, electrical loading, and other test-specific information to be used during the evaluation. The test requester shall obtain the GMW8288 Thermal Evaluations Worksheet (CG3811) from the GM Global Document Management (GDM) database, the GM Component Validation Engineer (CVE), the GM Environmental Subject Matter Expert (ENV SME), or GM Supply Power. It is also available to suppliers through IHS Global Incorporated.

3.6 Personnel/Skills.

3.6.1 General. Knowledge of the applicable thermal measurement methods and equipment.

3.6.2 IR Specific Operator Certification. It is recommended that the thermographer performing IR imaging shall be trained and certified to at least an American Society of Nondestructive Testing (ASNT) SNT-TC-1A Level II or equivalent.

4 Procedure

4.1 Preparation.

4.1.1 General.

4.1.1.1 Measurement Method Determination. Determine which thermal measurement method, i.e., Thermocouple or Infrared Thermography, is needed for the goals of the evaluation.

Thermocouple measurement is used to measure the thermal response of specific circuits, areas, or parts on the circuit board or component. The thermocouple must be attached to that specific point of interest, such that the thermal measurement will be localized at that specific point. Thermocouple measurement is used to determine if the point of interest is self-heating as expected or if it is overheating beyond performance or material requirements. Also, this is recommended as a thermal measurement method in instances where areas of interest are not accessible by Infrared Thermography methods.

Infrared Thermography is used to locate, measure, and visualize the thermal gradient response and identify the high stress hot spots of the component as it undergoes various operating conditions. Thermography can be used to assess issues related to current flow and material integrity by means of tracking the heat signature during these conditions. Thermography also provides the ability to detect the following: thermal overstress design issues, faulty or failed parts/components, inadvertent current leakages, and thermal performance changes caused by other overstress, wear out aging mechanisms, or short circuit conditions. Refer to Appendix C: Introduction to IR Thermal Imaging for further information.

4.1.1.2 Component Test Interface. The component shall be connected to the actual or simulated vehicle interfaces and loads required to operate the component as per the CTS. The GM Design Release Engineer (DRE) or Product Development Team (PDT) shall define load extremes or variation conditions appropriate to the component at the temperature limits if not defined in the CTS. Adequately sized wiring and fusing to handle the worst-case current load shall be used.

4.1.1.3 Component Mounting Orientation. If applicable, the component shall be mounted in an orientation necessary to perform and evaluate any mechanical or visual interface functions. If the component is expected to internally self-heat (> 10 °C or more at the maximum required operating temperature), it shall be mounted in its in-vehicle orientation or, for the situation of multiple vehicle applications, the worst-case thermal orientation.

Note: Thermal worst-case orientation is when the heat dissipated from high powered internal parts is allowed to rise, flow over, or be trapped around more thermally sensitive parts.

4.1.1.4 Operating Performance Measurements. Appropriate, calibrated instruments shall be used to measure and verify the performance of the component. Sufficient data shall be collected to document proper electrical performance during the thermal evaluations.

For power dissipation and self-heating evaluations, the voltage and current of the power supply, key power outputs, and any input/output needed to calculate component power dissipation shall be measured and documented as defined by the PDT for key activation and loading conditions during the thermal evaluation.

E/E components which also perform mechanical, audio, and/or visual/display functions shall be instrumented/monitored as appropriate for the application to measure, record and verify the operation of these functions in accordance with their CTS requirements, as defined by the PDT.

4.1.1.5 Functional and Thermal Measurements Implementation. The supplier or organization responsible for performing the thermal evaluation is responsible for developing the specific test script and the means for performing the functional, electrical, and thermal measurements deemed relevant for the component by the PDT. These procedures are to be approved by General Motors (GM) prior to testing.

4.1.1.6 Thermal Evaluations Determination and Worksheet. Refer to the subparagraphs in 4.3 for guidelines to determine which thermal evaluations and methods are required for the component. These paragraphs provide the typical evaluation objective for vehicular E/E components in the Purpose, Background, Applicability, Procedure, and Criteria for each test. Additional requirements may be defined in the CTS of the component to be tested. The GM DRE or PDT shall review these objectives against the requirements and design features of the component.

The GMW8288 Thermal Evaluations Worksheet (CG3811) shall be used to document which thermal evaluations are required for the component. The worksheet is editable such that the test requester shall select, from a pre-determined list, the desired thermal evaluation method to perform, as well as enter additional information to denote each procedure's setup, component configuration, and evaluation objective as selected by the PDT. This worksheet shall be included as part of each test's documentation.

4.1.2 Preparation for Thermocouple Measurements.

4.1.2.1 Thermocouple Measurements Requirements. Thermal data shall be collected by means of an automated data logger (preferred) or strip chart at a rate of at least three (3) times per minute. The number and types of component internal parts or materials to be temperature-monitored shall be determined by the PDT. Monitoring selections shall be based on the function and criticality of the component and the circuit designer's knowledge of the expected points of high-power dissipation. As a minimum, the following thermal measurements are recommended and should be included if deemed appropriate by the PDT:

a. **Chamber Air Temperature** to monitor the temperature of the air surrounding the component.

b. **Component Internal Air Temperature** for enclosed or partially enclosed components (preferably near the center of the component, microprocessors, or any analog signal circuits of the component).

c. **Part Temperature(s).** The following as determined by the PDT:

- Microprocessor(s).
- Integrated Circuits (IC).
- High Power Resistors.
- Power driver transistors.
- Insulated Gate Bipolar Transistors (IGBT).
- Other power driver ICs that are capable of high duty cycles, or continuous operation, or dissipate the largest amounts of power.

d. **Optional Circuit Board Temperature.** Of the expected coolest area of the component/part or circuit board.

e. **Optional Miscellaneous.** The temperature of other internal parts or features of the component that could produce useful information. Examples include: New ICs, power diodes or ballast resistors, onboard sensors, motors or actuators, boards, nuts and bolts, attachments, etc., as determined by the PDT.

f. **Optional Controls and Contact Surface Temperatures.** Knobs, buttons, switches, or exposed surfaces that could be touched by passengers. Used to ensure that self-heating above room temperature does not raise the contact temperature to a level that is unacceptable to operate. Unless otherwise specified, use > 44 °C (> 111 °F) as a temperature that is uncomfortable to touch and if exposed directly for an extended period of time, can cause potential skin-damage.

4.1.2.2 Thermal Sensors and Placement. When locating and attaching thermocouples or sensors it is important to select an attachment configuration that is consistent with the type of thermal information required. Examples include:

- When an air temperature measurement is required, it is important that the sensing element is openly exposed to and held in the air space of interest.
- When measuring a surface temperature, it is important that the sensing element has good thermal connectivity with the surface and isolation from the ambient air.
- If the surface is electrically charged, the sensing element shall be electrically insulated from the surface in order to ensure that the measurement is not corrupted and that the sensor does not affect component operation.
- If the component is potted, encapsulated, or coated, the sensing element may be attached prior to potting or coating.
- If the objective of the test is to evaluate heat-trapping effects, the sensing element shall be attached to the component, inside of its housing, or to a simulation of the housing.

When measuring an interior temperature of a design feature, the parts may need to be modified to place the sensing element at the point of interest. For situations where it is not possible to implant an internal sensing element or modify small parts, (such as integrated circuits or transistor packages), consider using a thicker layer of epoxy over the sensing element. This provides additional thermal insulation over the sensing element to provide a measurement that is closer to an interior temperature than a surface temperature. This technique is more effective for situations where the response of a part to environmental temperatures is the point of interest, rather than situations where the part's self-heating is the point of interest.

4.1.2.3 Attachment of Thermal Sensors. Sensing elements are preferably attached with epoxies. Taping usually is not strong enough to hold a sensing element for the duration and stresses of the tests, and mechanical fasteners can add a thermal inertia mass that could act as a heat sink and alter the thermal responses.

When using epoxy, it is essential that excessive epoxy does not drip or flow under the Printed Circuit Board (PCB) parts, onto other PCB parts, or across or between different material surfaces. This is critical because thermal expansion of the epoxy could induce stresses between PCB parts or surfaces that could lift or break design features. This could cause the part/component to fail for reasons of incorrect instrumentation setup which would invalidate the evaluation.

4.1.2.4 Component Orientation. Since heat rises, and can be affected by air convection, the orientation and airflow around a part/component will impact the temperature of the design features of the component. For thermocouple measurements, consider positioning the component on the test surface horizontally, vertically, and/or in-vehicle position, depending on the worst-case heating effects for purpose of the test. Also, consider environmental effects of the ambient air flow in the test facility.

4.1.3 Preparation for Infrared Imaging.

4.1.3.1 Component Orientation. Since heat rises, and can be affected by air convection, the orientation and airflow around a part/component will impact the temperature of the design features of the component. Each evaluation will need to consider the thermal impact that orientation will have on the component under test and balance this against the need for enabling the IR camera to view the features of primary thermal interest. The characteristics of three typical component orientations are discussed in Table 3. In each of these orientations, the procedure may be conducted either with still air, or with an airflow rate that duplicates in-vehicle conditions.

Table 3: Component Orientation for Infrared Thermographic Evaluation

Component Orientation	Description
Horizontal	The component is laid flat on a bench or fixture with the side that generates the most heat pointing up. The IR camera is placed perpendicular to the surface of interest, either directly overhead or offset above the component to capture the effect of open convection. If more than one surface generates heat or is to be scanned, each surface may be imaged separately by rotating the component or by moving the camera.
Vertical	The component is positioned or fixtured into a vertical orientation with the camera positioned perpendicularly, in front of the surface of interest. If more than one surface generates heat or is to be scanned, each surface may be imaged separately by rotating the component or by moving the camera.
In-Vehicle Orientation	The component shall be fixtured to match the intended in-vehicle orientation. The IR camera is positioned perpendicular to the surface of interest to view the heat generating surfaces(s).

4.1.3.2 IR Imaging Guidelines. Accurate IR imaging requires a visible line of sight between the component/surface of interest and the IR camera. If a direct line of sight is not possible, an IR mirror (a polished shiny reflective metal mirror) may be used to reflect the thermal image to the IR camera. Some evaluations may require the packaging or housing of the component to be opened, removed, or may have a section(s) removed to allow the IR camera to view internal parts. If there is a concern that housing removal/modifications may impact the thermal response, then the housing, section(s) of the housing, or removed sections may be replaced with an IR transparent material. A list of some common IR transparent materials is provided as a reference in Table 4.

Table 4: Infrared Transparent Evaluation Material References

Material	Useable Temperatures	Description/Application
Window Insulation Sheeting Film (Type Clean) Not Ultraviolet (UV) or IR Tinted	up to 40 °C (104 °F)	Indoor Window Insulator Kits are available from 3M (or other manufacturers) in various sizes. These are shrinkable clear plastic films.
High Temperature Oven Bags	up to 200 °C (392 °F)	A high temperature flexible plastic bag that can be cut into sheets with high Infrared energy transmissibility. Reference Reynolds Oven Bags products (produced by Reynolds Metals, Consumer Product Division):

Material	Useable Temperatures	Description/Application
		• Large Size: 40.6 cm × 44.5 cm (16 in × 17.5 in). • Extra Large Size: 48.3 cm x 59.7 cm (19 in × 23.5 in).

4.1.3.3 IR Imaging of Circuit Traces, Leads, and Other Shiny/Polished Metal Surfaces. Proper emissivity calibration is critical any time accurate infrared imaging of shiny or polished metal objects are required. While shiny metal surfaces are excellent reflectors of IR energy from other sources, metals are also excellent conductors of thermal energy, but unfortunately, they are also poor IR emitters of their own thermal energy. This means that a metal object may get hot and its temperature may be accurately measured by a thermocouple, but that temperature may not be accurately measured by an IR camera. If the temperatures of shiny metal features (such as component leads, uncoated PCB circuit traces, and heat sinks) are significant to the evaluation, a flat black paint dot may be applied to the metal feature of interest. The flat black paint dot will provide adequate emissivity to radiate an accurate thermal image of the temperature it absorbs from any metal object. Matte or flat finish styles of solder mask materials can improve the emissivity of masked PCB traces.

4.1.3.4 Infrared Imaging Setups. Typical infrared thermal evaluation setups are discussed in the following. The Thermocouple measurement requirements defined in 4.1.2.1 may be used with these evaluation setups to provide additional information or as a calibration reference point.

4.1.3.4.1 Shielded Bench Top IR Scanning Setup. The shielded bench top setup (reference Figure 1) is used for quick IR scans to identify the location of thermal hotspots and to assess general thermal performance patterns under room ambient conditions. This procedure is performed on a bench top at room ambient temperature of 23 °C. The bench shall be isolated from direct air drafts, i.e., doors, windows, or heating/ ventilation ducts, etc.

A thermally insulated support fixture (such as wood or plastic) shall be used to minimize thermal contact between the component and the work surface. The supports shall be positioned to minimize contact with the expected hot spots of the component. Design the setup to allow all sides of interest of the component to be rotated to a position that can be viewed by the IR camera. The camera typically is mounted to either have an overhead or side view of the component.

The component shall be centered in a box or employ some other form of draft barrier to prevent room airflow from cooling the component. The top of the box/draft barrier may be open, or an optional cover made of an IR transparent material may be used.

Some evaluations may require the housing to be removed to allow the IR camera to view internal parts. If there is a concern that housing removal/modifications may impact the thermal response, the component may be contained either in its housing modified with IR viewing window over the features of interest or in an IR transparent structure designed to simulate the heat containment characteristics of the housing (reference 4.1.3.2 and 4.1.3.4.4). An IR transparent cover or film shall be used over the viewing window modifications to limit convection heat losses. Reference Table 4.

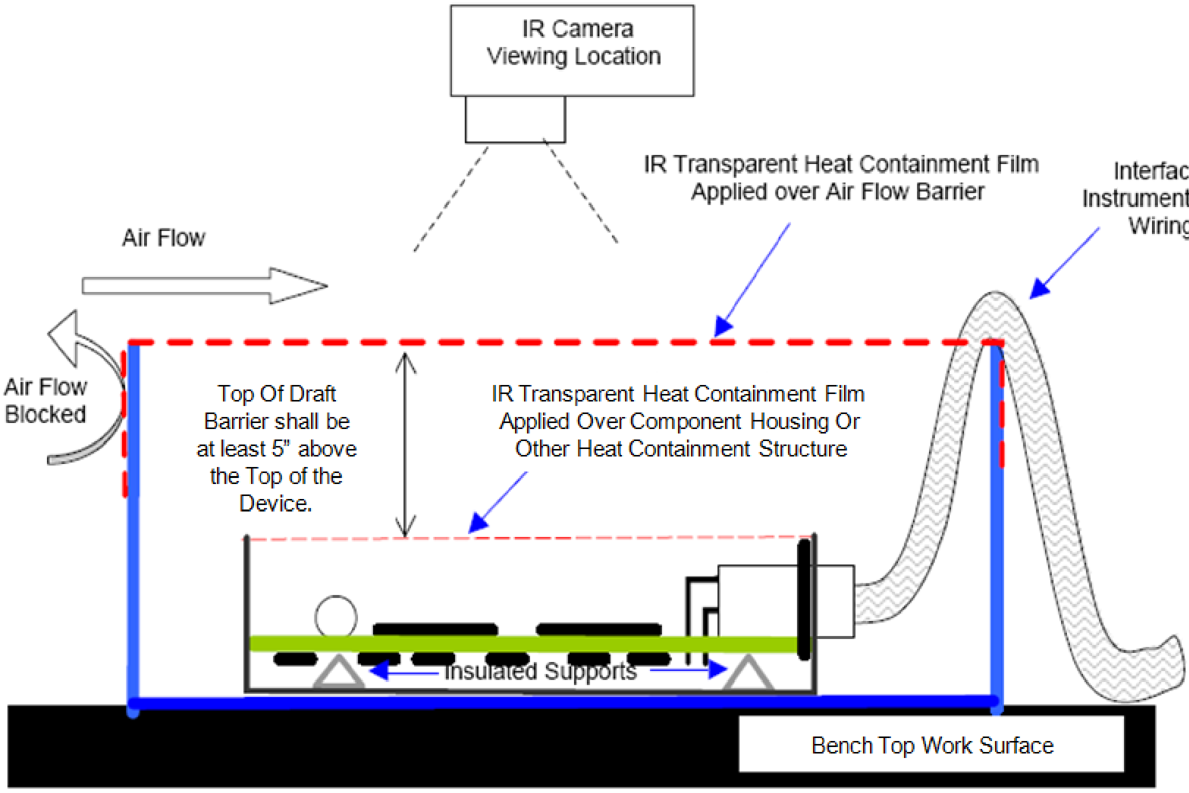

Figure 1: Diagram of an Overhead View Setup for Bench Top Infrared Imaging that Minimizes Thermal Connectivity and Air Flow Heat Loss Effects

4.1.3.4.2 Thermal Chamber IR Imaging Setup. The Thermal Chamber setup is used for more detailed IR scans to assess the following: hot spots and their worst-case thermal performance patterns, and equilibrium times under extreme thermal conditions.

In this setup, the component is placed or fixtured for viewing in a thermal chamber that is equipped with an IR transparent viewing window or port. This provides an observation point to the IR camera, which is mounted outside the chamber. Reference Figure 2.

Note: Most types of glass absorb an amount of IR energy which could cause significant measurement errors. Windows made out of IR transparent materials shall be used or the camera shall be calibrated to adjust for the IR energy loss of a glass window.

Another alternative is to use a chamber with an instrumentation tunnel large enough for the camera lens to view through. A chamber with two access tunnels on opposing sides is preferred as it allows the IR camera to be moved to observe two sides of the component. Therefore, there is no need to stop the test to change the orientation of the component in the chamber.

The viewing window, port, or tunnel may be covered with an IR transparent, high temperature oven bag referenced in Table 4 to maintain chamber heat retention.

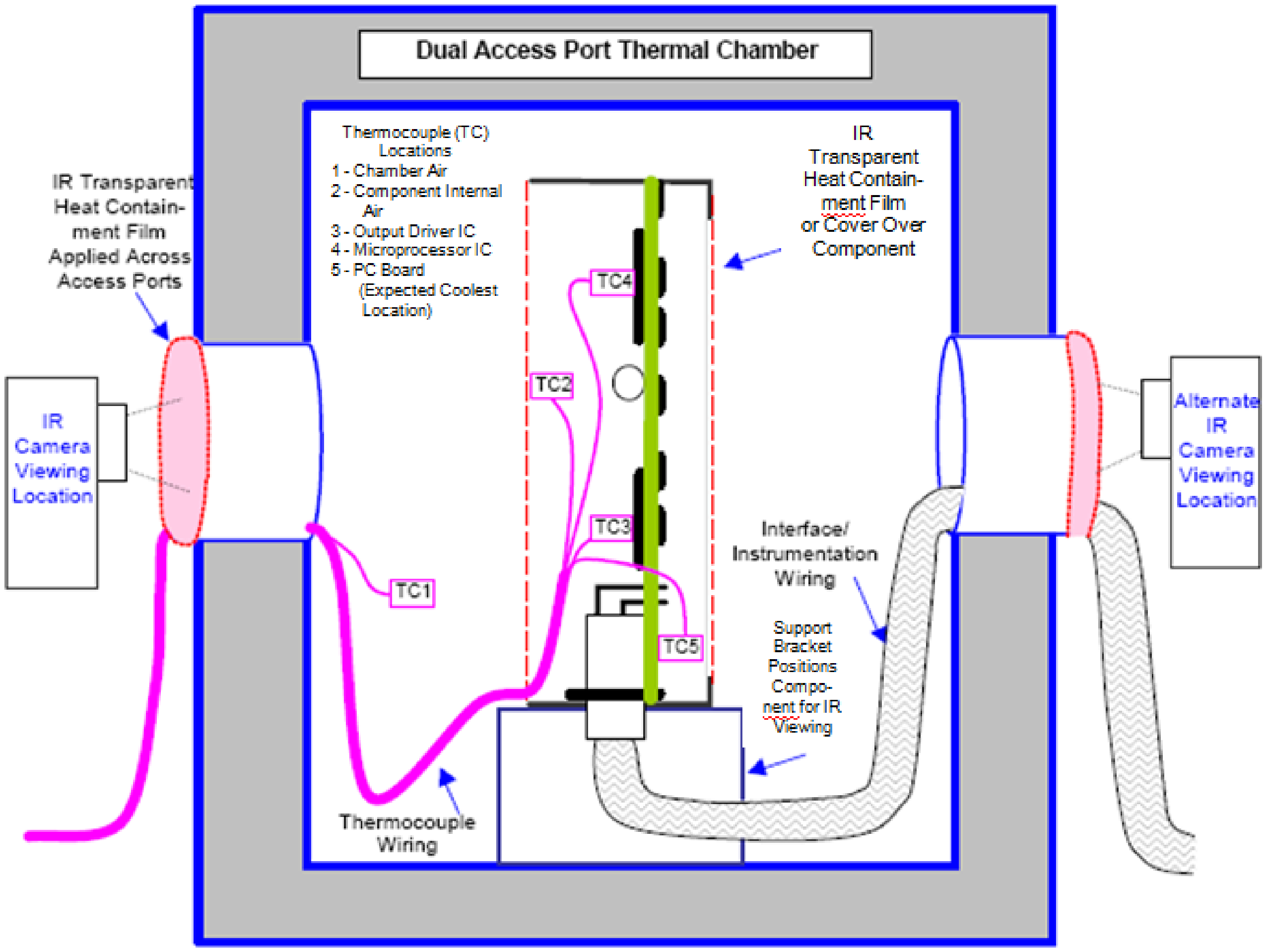

Figure 2: Diagram of a Typical Dual Port Thermal Chamber Setup for Infrared Imaging

4.1.3.4.3 Packaging/Housing External IR Imaging Setup. This setup is used to evaluate the thermal energy that is conducted through the component housing to evaluate the heat transfer efficiency of the packaging. This setup can also be used to determine the temperature of exposed surfaces or control knobs to evaluate if they can become too hot for human contact.

The setup of the component is similar to the shielded bench top of 4.1.3.4.1. The component is placed within a box-like structure with an IR transparent film cover designed to prevent room airflow from cooling the component. The IR camera is mounted over the component.

The only difference from the setup of 4.1.3.4.1 is that the component is placed in the structure fully assembled, without any modification for internal viewability and with the surface of interest exposed to the camera. The component can then be activated with the IR camera viewing/recording the surface level thermal effects produced by the operation of the component.

4.1.3.4.4 Simulated Package/Housing IR Imaging Setup. This setup is used to evaluate the effect of internal airflow or airflow restriction of a housing on internal heat generating components. In this setup, the internal parts are removed from their housing or case and placed in a test box, housing, or case made of an IR transparent material. Reference Table 4. The test packaging is to be designed to simulate the size and shape of the actual packaging. The use of an IR transparent material allows the thermal response of the internal features to be viewed.

This procedure may be performed in a thermal chamber or on a lab bench.

4.2 Conditions.

4.2.1 Environmental Conditions.

4.2.1.1 Thermal Loading Conditions. Perform evaluations using the thermal loading conditions according to the procedures described in 4.3.

4.2.1.2 Electrical Loading Conditions. Select the worst-case electrical loading conditions, as this is critical to developing a meaningful and accurate evaluation. The component shall be connected to real or simulated inputs and loads to allow operation in accordance with the CTS requirements. Output loads should be electrically equivalent to the actual loads to simulate peak or worst-case loading conditions to maximize component self-heating and power dissipation in accordance with the output loading guidelines shown in Table A1, Electrical Loading Conditions, in Appendix A.

The thermal performance of E/E components is a function of:

a. The instantaneous, continuous, and simultaneous electrical loading conditions of the component.

b. The amount of power that is dissipated in the component.

c. How effective the component transfers heat.

These factors influence the self-heating temperature a component will reach which affects the electrical/functional performance and/or the reliability/durability of the component. These factors are influenced by the design features. Thus, early and relevant thermal evaluations provide direction for creating a robust design.

Perform evaluations using the supply voltage conditions according to the procedures described in 4.3.

4.2.2 Test Conditions. Deviations from the requirements of this standard shall have been agreed upon. Such requirements shall be specified on component drawings, test certificates, reports, etc.

4.2.2.1 Deviation Documentation. Deviations shall be documented in the GMW8288 Thermal Evaluations Worksheet (CG3811).

4.3 Instructions.

4.3.1 Instructions for Thermocouple and Infrared Evaluations. The following evaluations apply to thermocouple and infrared imaging thermal measurement methods:

- Low Temperature Evaluation.
- High Temperature Evaluation.
- Room Temperature Thermal Equilibrium Evaluation.
- Occupant Accessible Control Surface Temperature Evaluation.
- Peak Temperature Evaluation with Worst-Case Loading.

The following evaluation applies only to infrared imaging thermal measurement methods:

- IR Evaluation of Short Circuits.

4.3.1.1 Low Temperature Evaluation.

Purpose. This procedure is to measure the temperature of parts on a circuit board to verify that they are within their operating temperature range when exposed to low temperature environments and various electrical loading conditions. Also, this procedure measures the temperature rise in parts (rate of increase and total temperature increase) to verify that the physical capability of the materials/parts are not exceeded when exposed to low temperature environments and various electrical loading conditions.

Background. Circuit performance and functional operation at low temperature extremes is important for E/E components/parts due to the effect temperature has on electrical operating characteristics that may cause performance to drift out of operating tolerances. In addition, a thermal condition to be noted and avoided is the situation where high power operation causes rapid temperature increases of materials that may become brittle when cold, thereby causing excessive structural damage, due to thermal expansion stresses.

Applicability. All components.

Procedure. A generic low temperature evaluation procedure, which may be adjusted to suit the needs of a specific component or application, is defined in Table 5.

Table 5: Low Temperature Evaluation Procedure

Step	Low Temperature Evaluation Procedure Tasks
1	Stabilize the instrumented component, in its housing/packaging, in an OFF state, at its lowest required operating temperature (typically -40 °C) for at least 30 minutes. Allow enough time for the temperature change rate to decrease to no more than 1 °C per 5 minutes (0.2 °C per minute).
2	Record all thermal measurements prior to activating the component.
3	Activate the component to an ON state at its **minimum** supply voltage to simulate cold starting conditions, with the component operating under light/no-load input/output conditions. Verify that the component starts up and the input/output functions operate correctly. Record the rate of temperature increase (in °C/minute) and the maximum internal temperature (in °C) at a rate of at least three (3) times per minute. Continue recording until the temperature is stabilized. Allow enough time for the temperature change rate to decrease to no more than 1 °C per 5 minutes (0.2 °C per minute).
4	Stabilize the instrumented component, in its housing/packaging, in an OFF state, at its lowest required operating temperature (typically -40 °C) for at least 30 minutes. Allow enough time for the temperature change rate to decrease to no more than 1 °C per 5 minutes (0.2 °C per minute).
5	Record all thermal measurements prior to activating the component.
6	Activate the component to an ON state at its minimum supply voltage to simulate cold starting conditions. Immediately activate input/output functions in accordance with the Electrical Loading Conditions identified in 4.2.1.2 Electrical Loading Conditions. Verify that the component starts up and the input/output functions operate correctly. Record the rate of temperature increase (in °C/minute) and the maximum internal temperature (in °C) at a minimum rate of at least three (3) times per minute. Continue recording until the temperature is stabilized. Allow enough time for the temperature change rate to decrease to no more than 1 °C per 5 minutes (0.2 °C per minute).
7	Document the following: • The active input/outputs and the currents and voltages of their loads. • The supply voltage and current to the component (compare the current draw to expected or specified conditions to ensure the thermal evaluation is relevant to the application). • The total power being dissipated by the component based on the calculations from the proceeding measurements. • The final thermal equilibrium temperature measurements and the time required to reach them. • Any additional comments or observations.
8	Repeat Step 4 thru Step 7 with the supply voltage set to the **nominal** voltage.
9	Repeat Step 4 thru Step 7 with the supply voltage set to the **maximum** voltage.

Criteria. Verify that the measured temperatures of the parts on the circuit board are within their operating temperature range. The temperature rise in parts (rate of increase and total temperature increase) shall not exceed its physical capabilities of the materials/parts. As a default, any situation where temperatures rise by approximately 30 °C per minute or more, or result in a total internal temperature increase of 50 °C or more, are to be noted and further investigated for ways to avoid the situation. Verify that there are no material or functional degradations.

4.3.1.2 High Temperature Evaluation.

Purpose. This procedure is to measure the temperature of parts on a circuit board to verify that they are within their operating temperature range when exposed to high temperature environments and various electrical loading conditions. Also, this procedure measures the temperature rise in parts (rate of increase and total temperature increase) to verify that the physical capability of the materials/parts are not exceeded when exposed to high temperature environments and various electrical loading conditions.

Background. Circuit performance and functional operation at high temperature extremes are important for E/E components/parts due to the effect temperature has on electrical operating characteristics that may cause performance to drift out of operating tolerances. For components that dissipate enough power to significantly self-heat, thermal performance characteristics, such as the maximum internal part temperatures and their rate of temperature increase, are especially important because:

- Self-heating above the environmental temperatures further contributes to electrical performance thermal drift.
- Self-heating further increases the thermal stress within components and may lead to premature failure, such as plastic, solders, and wiring insulation may weaken and excessively creep or yield.
- The additional thermal expansion/contraction cyclical stress may strain materials into premature fatigue.

Applicability. All components.

Procedure. A generic high temperature evaluation procedure, which may be adjusted to suit the needs of a specific component or application, is defined in Table 6.

Table 6: High Temperature Evaluation Procedure

Step	High Temperature Evaluation Procedure Tasks
1	Stabilize the instrumented component, in its housing/packaging, in an OFF state, at its highest required operating temperature (typically +85 °C for interior components, +105 °C for under hood components, or +125 °C for engine-mounted components, or as specified). Stabilizing time shall be at least 30 minutes. Allow enough time for the temperature change rate to decrease to no more than 1 °C per 5 minutes (0.2 °C per minute).
2	Record all thermal measurements prior to activating the component.
3	Activate the component to an ON state at its **minimum** supply voltage to simulate hot starting conditions, with the component operating under light/no-load input/output conditions. Verify that the component starts up and the input/output functions operate correctly. Record the rate of temperature increase (in °C/minute) and the maximum internal temperature (in °C) at a rate of at least three (3) times per minute. Continue recording until the temperature is stabilized. Allow enough time for the temperature change rate to decrease to no more than 1 °C per 5 minutes (0.2 °C per minute).
4	Stabilize the instrumented component, in its housing/packaging, in an OFF state, at its highest required operating temperature (typically +85 °C for interior components, +105 °C for under hood components, or +125 °C for engine-mounted components, or as specified). Stabilizing time shall be at least 30 minutes. Allow enough time for the temperature change rate to decrease to no more than 1 °C per 5 minutes (0.2 °C per minute).
5	Record all thermal measurements prior to activating the component.
6	Activate the component to an ON state at its minimum supply voltage to simulate hot starting conditions. Immediately activate input/output functions in accordance with the Electrical Loading Conditions identified in 4.2.1.2 Electrical Loading Conditions. Verify that the component starts up and the input/output functions operate correctly. Record the rate of temperature increase (in °C/minute) and the maximum internal temperature (in °C) at a rate of at least three (3) times per minute. Continue recording until the temperature is stabilized. Allow enough time for the temperature change rate to decrease to no more than 1 °C per 5 minutes (0.2 °C per minute).
7	Document the following: • The active input/outputs and the currents and voltages of their loads.

Step	High Temperature Evaluation Procedure Tasks
	• The supply voltage and current to the component (compare the current draw to expected or specified conditions to ensure the thermal evaluation is relevant to the application). • The total power being dissipated by the component based on the calculations from the proceeding measurements. • The final thermal equilibrium temperature measurements and the time required to reach them. • Any additional comments or observations.
8	Repeat Step 4 thru Step 7 with the supply voltage set to the **nominal** voltage.
9	Repeat Step 4 thru Step 7 with the supply voltage set to the **maximum** voltage.

Criteria. Verify that the measured temperatures of the parts on the circuit board are within their operating temperature range. The temperature rise in parts (rate of increase and total temperature increase) shall not exceed its physical capabilities of the materials. As a default, any situation where temperatures rise by approximately 30 °C per minute or more, or result in a total internal temperature increase of 50 °C or more, are to be noted and further investigated for ways to avoid the situation. Verify that there are no material or functional degradations.

4.3.1.3 Room Temperature Thermal Equilibrium Evaluation.

Purpose. This procedure is for determining worst-case self-heating performance at room temperature in order to obtain data for performing or evaluating computational thermal models.

Background. This procedure is useful to evaluate the amount of self-heating in a component or when heat dissipation is expected to raise the temperature of a part on the circuit board by 10 °C or more above the environmental temperature.

Applicability: Components with self-heating.

Procedure. A generic room temperature evaluation procedure, which may be adjusted to suit the needs of a specific component or application, is defined in Table 7.

Table 7: Room Temperature Thermal Equilibrium Evaluation Procedure

Step	Room Temperature Thermal Evaluation Procedure Tasks
1	Stabilize the instrumented component, in its housing/packaging, in an OFF state for at least 30 minutes at room temperature (typically +23 °C). Allow enough time for the temperature change rate to decrease to no more than 1 °C per 5 minutes (0.2 °C per minute).
2	Record all thermal measurements prior to activating the component.
3	Activate the component to an ON state at its maximum supply voltage, operating under high loading conditions identified in 4.2.1.2 Electrical Loading Conditions. Verify that the component starts up and the input/output functions operate correctly. Record the rate of temperature increase (in °C/minute) and the maximum internal temperature (in °C) at a rate of at least three (3) times per minute. Continue recording until the temperature is stabilized. Allow enough time for the temperature change rate to decrease to no more than 1 °C per 5 minutes (0.2 °C per minute).
4	Document the following: • The active input/outputs and the currents and voltages of their loads. • The supply voltage and current to the component (compare the current draw to expected or specified conditions to ensure the thermal evaluation is relevant to the application). • The total power being dissipated by the component based on the calculations from the proceeding measurements.

Step	Room Temperature Thermal Evaluation Procedure Tasks
	• The final thermal equilibrium temperature measurements and the time required to reach them. • Any additional comments or observations.

Criteria. Document the results to be used in the computational thermal models.

4.3.1.4 Occupant Accessible Control Surface Temperature Evaluation.

Purpose. This procedure is used to evaluate occupant accessible control surface temperatures (switches, knobs, or buttons) to ensure that the contact surfaces do not get too hot to touch by vehicle occupants. Control surface temperatures are generally evaluated at room temperature for rise in temperature, but can be performed at any other specified temperature.

Background. This procedure is useful to evaluate the amount of self-heating in any component that may be accessible to vehicle occupants.

Applicability: Any component that is directly accessible to vehicle occupants (switches, knobs, or buttons).

Procedure. A generic room temperature evaluation procedure, which may be adjusted to suit the needs of a specific component or application, is defined in Table 8.

Table 8: Occupant Accessible Control Surface Temperature Evaluation Procedure

Step	Occupant Accessible Control Surface Temperature Evaluation Procedure Tasks
1	Stabilize the instrumented component, in its housing/packaging, in an OFF state for at least 30 minutes at room temperature (typically +23 °C). Allow enough time for the temperature change rate to decrease to no more than 1 °C per 5 minutes (0.2 °C per minute).
2	Record all thermal measurements prior to activating the component.
3	Activate the component to an ON state at its maximum supply voltage, operating under high loading conditions identified in 4.2.1.2 Electrical Loading Conditions, including the effects of backlighting or other internal lighting. Verify that the component starts up and the input/output functions operate correctly. For control surfaces (switches, knobs, or buttons) that could be touched by vehicle occupants, record the maximum temperature (in °C) at a rate of at least three (3) times per minute. Continue recording until the temperature is stabilized. Allow enough time for the temperature change rate to decrease to no more than 1 °C per 5 minutes (0.2 °C per minute).
4	Document the following: • The supply voltage and current to the component (compare the current draw to expected or specified conditions to ensure the thermal evaluation is relevant to the application). • The total power being dissipated by the component based on the calculations from the proceeding measurements. • The thermal equilibrium temperature measurements as measured on the occupant accessible control surfaces (switches, knobs, or buttons) and the time required to reach them. • Any additional comments or observations.

Criteria. Ensure that the control surface temperatures (switches, knobs, or buttons) that could be touched by vehicle occupants do not exceed 44 °C as measured at room temperature (if not otherwise specified).

4.3.1.5 Peak Temperature Evaluation with Worst-Case Loading.

Purpose. This procedure is to measure the temperature of parts on a circuit board to verify that they are within their operating temperature range when exposed to peak temperature environments and worst-case electrical loading conditions. Also, this procedure measures the temperature rise in parts (rate of increase and total temperature increase) to verify that the physical capability of the materials/parts are not exceeded when exposed to high temperature environments and worst-case electrical loading conditions. This procedure can also be used to support computational thermal models.

Background. This procedure is intended as a maximum stress-proof test for parts on a circuit board that can significantly self-heat. This is intended to evaluate the ability of E/E parts to operate for short periods under severe hot conditions and worst-case loads without enduring imminent overstress damage or failure. This procedure is useful when heat dissipation is expected to raise the part's temperature by 10 °C or more in a maximum operating temperature environment.

This can be used to simulate maximum load and temperature environments that can occur for a limited duration, depending on the component application. For example, this may be applicable to an under hood Bussed Electrical Center (BEC), Engine Control Module (ECM), or any other under hood component that may be subjected to heat dissipating conditions, i.e., soak-back while it is still operating after the engine is shut off. An additional scenario is a hot restart with extended idle, following a hot soak in a hot climate. This may also simulate vehicle remote starting conditions of a closed vehicle in a hot climate for components located within the passenger compartment or the trunk. The load condition is not suitable for use as a long-term durability or wear out evaluation.

Applicability. This test is intended for self-heating parts on a circuit board or parts affected by adjacent parts or other components that generate heat.

Procedure. A generic worst-case peak temperature evaluation procedure, which may be adjusted to suit the needs of a specific component or application, is defined in the following table. This loading condition simulates the component operating under maximum supply voltage conditions (16.0 V if not specified), with all outputs active under maximum current load conditions. Account for all heat sources, i.e., environmental and heat from other components, along with the operating and/or electrical power loading conditions, that produce the heating effects on the component. Reference Table 9.

Table 9: Peak Temperature Evaluation with Worst-Case Loading

Step	Peak Temperature Evaluation With Worst-Case Loading
1	Stabilize the instrumented component, in its housing/packaging, in an OFF state, at its highest required excursion temperature (typically +85 °C for interior components, +120 °C for under hood components, or +140 °C for engine-mounted components, or as specified). Stabilizing time shall be for at least 30 minutes. Allow enough time for the temperature change rate to decrease to no more than 1 °C per 5 minutes (0.2 °C per minute).
2	Record all thermal measurements prior to activating the component.
3	Activate the component to an ON state, operating under maximum supply voltage conditions (16.0 V if not specified). Immediately activate input/output functions, or all outputs under worst-case loading conditions, depending on the focus of the evaluation, as described in Worst-Case Loading Conditions under 4.2.1.2 Electrical Loading Conditions. Verify that the component starts up and the input/output functions operate correctly. Record temperatures at a rate of at least three (3) times per minute throughout the procedure. Unless otherwise specified, the duration of the procedure shall be at least 30 minutes, or three (3) sequential remote start-to-shutdown time-out cycles, whichever is the longest.
4	Document the following: • The active input/outputs and the currents and voltages of their loads. • The supply voltage and current to the component (compare the current draw to expected or specified conditions to ensure the thermal evaluation is relevant to the application). • The total power being dissipated by the component based on the calculations from the proceeding measurements. • The final thermal equilibrium temperature measurements and the time required to reach them. • Any additional comments or observations.

Criteria. Verify that the measured temperature of the parts on the circuit board are within their operating temperature range and will not experience excessive internal temperatures that will over-stress the component's parts or materials to the point of imminent faults or failure, e.g., exceeding the electrical operating ranges for internal parts, exceeding a material's Glass Transition temperature (Tg) or melting point, etc. Parts shall not exceed a limit of 90% of their Maximum Rated Temperatures, unless otherwise specified.

The temperature rise in parts (rate of increase and total temperature increase) shall not exceed the physical capabilities of the materials. Verify that there are no material or functional degradations.

Document the results to be used in the computational thermal models.

4.3.1.6 IR Evaluation of Short Circuits.

Purpose. This procedure uses Infrared Thermography to measure and visualize the thermal response of the component as it endures short circuit conditions (see Figure 3), in order to determine if the design can endure short circuit conditions without permanent degradation.

Background. In electrical components, unintentional short circuits are usually caused when a wire's insulation breaks down due to wear, environmental effects, pinching, or chafing, or when another conducting material is introduced, allowing charge to flow along a different path than the one intended. Short circuits could also occur at the PCB level due to electromigration, dendritic growth, design issues, material selection, construction, soldering issues, etc. A short circuit condition could result in unintentionally high current flow in the circuit which can cause a rapid buildup of heat resulting in thermal damage to the circuit or areas adjacent to it.

Applicability. Apply a short circuit condition to Battery or to Ground to any input or output to the component under test. Short circuit tests to supply and ground lines are typically excluded.

Procedure. The generic IR short circuit thermal evaluation procedure defined in Table 10 may be used or modified to measure the desired objective.

Note: This could be a destructive test for circuits that do not contain electronic short circuit protection.

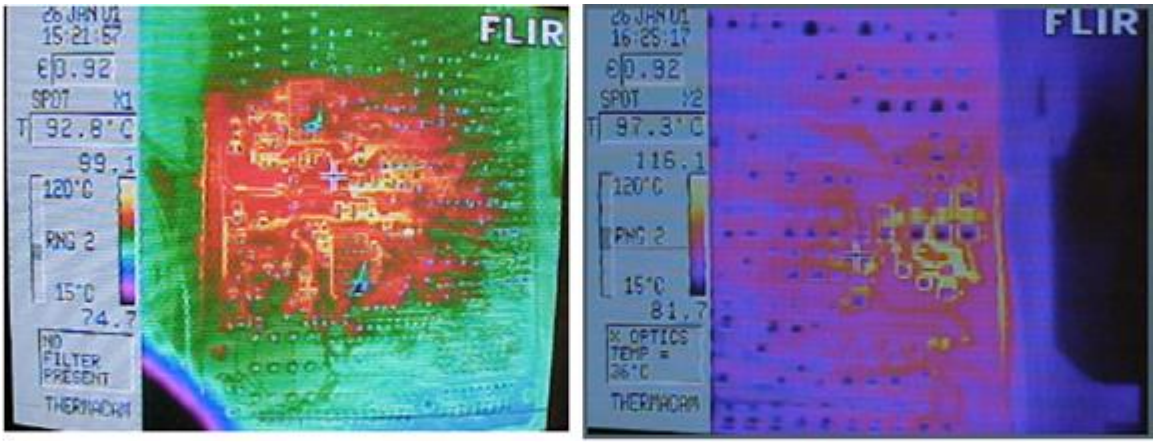

Figure 3: Infrared Thermographs of Circuit Board Trace Heating during a Short Circuit Condition

Table 10: IR Short Circuit Thermal Evaluation Procedure

Step	IR Short Circuit Thermal Evaluation Procedure Tasks
1	Configure and set up the component as appropriate for the evaluation's objections. The component shall be connected to real or simulated inputs and loads to allow operation in accordance with the component's CTS requirements. Instrumentation to measure key voltages and currents shall be used to determine the dissipated power of the component.
2	After calibrating the IR camera, stabilize the inactivated component to the required temperature. Use a minimum 30 minute thermal soak period.

Step	IR Short Circuit Thermal Evaluation Procedure Tasks
3	Set the power supply to the required maximum supply voltage (16.0 V if not defined). Activate the IR camera recording or image capture system, then turn ON the component and apply the desired operating and load conditions.
4	Apply the first of the required short circuit conditions as defined by the PDT.
5	As the component self-heats, use the IR camera to observe and document the self-heating thermal pattern due to the short circuit condition.
6	Identify and measure the responding temperatures and document the peak thermal stress sites, parts, and design features.
7	If a circuit is equipped with a short circuit protection feature, the temperature should stabilize as expected while the protection feature is activated. For a circuit that is not equipped with a short circuit protection feature, the temperature may continually increase until an open circuit exists.
8	Document key IR outputs (using video footage, triggered image capture still photos, etc.) of the component's thermal responses. Measure and document the shorting current and any unexpected responses of the component.
9	Allow the short circuit condition to continue until the component has achieved thermal equilibrium. Allow enough time for the temperature change rate to decrease to no more than 1 °C per 5 minutes (0.2 °C per minute).
10	Document the following: • All measurements in accordance with the goals of the evaluation. • Correlation of the measurements to IR still photos or video recordings. • The number, size, location, and temperatures of the hot spots observed for each short circuit condition. • The supply voltage, short circuit current and any other required electrical measurements. • The test time when thermal equilibrium was achieved. • Any additional comments or observations.
11	Remove the short circuit condition and allow the component to cool. Then apply the next short circuit condition as defined by the PDT. Repeat the process until all the required short circuit conditions have been evaluated.

Criteria. Verify that the measured temperature of the parts on the circuit board is within each part's operating temperature range. The temperature rise in parts (rate of increase and total temperature increase) shall not exceed its physical capabilities of the materials. Verify that there are no material or functional degradations.

4.3.2 Instructions Specific to IR Evaluations. The following test activities are specific to infrared imaging thermal evaluations:

- Ensure that the IR camera is calibrated prior to temperature measurements.
- Activate the IR camera recording or image capture system prior to turning ON the component or applying the desired operating and load conditions.
- As the component self-heats, use the IR camera to observe and document the self-heating thermal pattern. All sides of interest of the component shall be measured. For a printed circuit board, both sides may need to be measured.
- Document key IR outputs (using video footage, triggered image capture still photos, etc.) of the component's thermal responses. Record the test time of each change in the component's electrical loading to correlate

the loading conditions to the thermal images. Include the number, size, location, and temperatures of the hot spots observed.

5 Data

5.1 Calculations. Not applicable.

5.2 Interpretation of Results.

5.2.1 General Acceptance Criteria. The criteria described for each evaluation in 4.3 shall be applied. CTS-defined criteria shall be applied as applicable and appropriate to the component.

For designs that have parts or materials that are exposed to temperatures that approach or exceed the part's or material's stability limits, this can lead to accelerated aging due to excessive rates of material breakdown, resulting in premature wear out failure mechanisms. Large hot-cold temperature differences may also cause thermal expansion/contraction fatigue. The thermal stress data obtained can be used for separate durability analysis or tests.

For designs that do not meet the evaluation criteria or the CTS, additional investigations that are appropriate for determining suitable corrective actions shall be followed. GM Engineering will decide as to the necessity of corrective action. Examples of effective additional investigations and corrective actions include:

a. Investigate methods to reduce the environmental temperatures that the component must endure. Examples: Relocate the component to a less stressful part of the vehicle, use a heat shield and/or insulation, circulate cooler air around the component, etc.
b. Investigate means of reducing the self-heating effect of the component. Examples: Reduce the power that the component must handle, use a more efficient circuit, disburse or separate heat-generating devices, use a more efficient heat transfer mechanism such as a heat sink or thermal via, or implement a cooling system, etc.
c. Investigate means to make the component more robust so that it can handle higher temperatures. Examples: Select a component or material with a higher temperature rating, or, to make a component more robust, add more material to compensate for its reduced strength at higher temperatures. These approaches are intended to improve the part or material strength in order to withstand the stress of higher temperatures.
d. In situations where material degradation is accelerated due to temperatures approaching or exceeding material temperature limits which can result in long-term durability concerns and if the 3 previously listed corrective actions cannot be employed, then more extensive durability evaluations shall be required. These may include: Physics of Failure-based Computer Aided Engineering (CAE) durability simulations of the affected material or component, more extensive durability testing, etc.

Refer to Table B1, Design Guidelines to Improve Thermal Performance, in Appendix B.

5.2.2 IR-specific Acceptance Criteria. The criteria described for each evaluation in 4.3 also apply for infrared thermal evaluations.

If the thermographic image is being compared to a thermal analysis or simulation, good correlation is achieved when the measured peak temperatures are within 10% of the predicted peak values of the simulation. There should also be a good general match between the location and size of the hot spots.

Any unexpected or excessive hot spot(s) shall be investigated to identify the heat source, related power level, and possibility of a faulty component or a sneak circuit. The accuracy of the thermal analysis and its underlining assumptions shall also be evaluated.

Any hot spots that exceeded or were too close to thermal limits shall be evaluated for ways to reduce or improve local heat transfer or reduce power. Refer to Table B1, Design Guidelines to Improve Thermal Performance, in Appendix B. The thermal extreme data can also be used in other evaluations to determine the effects of parametric drift of electrical parts and the resulting impact on the circuit's electrical operation.

5.2.3 Analysis/Simulation Correlation. Compare measurements to the requirements and any relevant circuit analysis/simulation results, such as CAE simulation, manual thermal performance calculations, etc. Any deviation from the CTS requirements or the expectations or requirements of the circuit design shall be investigated for potential improvements or corrective actions. Any situations of marginal performance shall be noted and investigated for susceptibility to fault or failure under variation or drift conditions. Examples include: Part-to-part variation due to parameter tolerance sensitivity or performance drift due to variation within the required operating voltage range. Evaluate the results per the acceptance criteria referenced in 5.2.1 and modify the design if necessary.

5.3 Test Documentation. Thermal Evaluation Report. All evaluation data measurements and performance results in accordance with the criteria shall be included in a Thermal Evaluation Report. All non-compliances shall be documented in the report. Also, this report documents the evaluation objectives and procedures that were selected by the PDT and performed on the component, including the GMW8288 Thermal Evaluations Worksheet (CG3811). The test responsible engineer shall present a summary of the report to the GM PDT. A complete copy of the report shall be delivered to the GM DRE and a copy shall be included and maintained as part of the component's Validation documentation.

6 Safety

This Engineering Standard may involve safety requirements for hazardous materials, the method of operations and equipment. This standard does not propose to address all the safety issues associated with its use. It is the responsibility of the user of this standard to ensure compliance with all appropriate safety and health practices. This would include any specific training that may be required. The safety and health standards include site specific rules and procedures, company rules and procedures, and Government Standards. Contact shall be made with the appropriate site Safety and Health personnel for further direction and guidance in these matters.

7 Notes

7.1 Glossary.

Failure Mechanism: The physical or chemical cause of a failure that occurs.

Failure Mode: The means by which a failure of fault condition is perceived or detected. In other words, this is the realization of a failure. Failure mode evaluation is relative to the human observer.

Glass Transition Temperature (Tg): The temperature where polymers change from a hard and relatively solid or brittle condition to a viscous or soft rubbery condition. Above the Tg, many material properties undergo significant changes that can degrade structural integrity and durability by mechanisms such as delamination, trace/board separation, and large increases in the Coefficient of Thermal Expansion (CTE) rate which accelerates fatigue aging, etc.

Overstress: A classification of failure mechanisms where the strength of a material, part, or component is relatively rapidly overwhelmed by the stress of the mechanical, electrical, thermal, or other type of applied load or combination of loads. This can result in issues such as fracturing, shearing, buckling, and melting.

Physics of Failure: The root-cause of why, where, and how materials fail under the action of different stresses. The physics of failure approach is often considered up front in the design process to simulate life and reliability of the component through modeling of materials, molecular structures, technology, and scientific failure mechanisms. This approach provides details about various degradation mechanisms and improves understanding of the root cause(s) of a failure.

Wear Out: A classification of failure mechanisms where the strength of a material, part, or component is gradually degraded by the effects of continuous or cyclical exposure to stress loading conditions. The stress loads typically cause degradation by means of material loss or a breakdown of structural bonds. Eventually failure or fault conditions occur as weakened materials are unable to bear the load or drift out of operating requirements or tolerances. The rate of degradation is determined by intensity, duration, and frequency of the stress exposure. Wear out is also known as stress aging or material damage accumulation. Examples are: Fatigue and corrosion.

7.2 Acronyms, Abbreviations, and Symbols.

ASNT	American Society of Nondestructive Testing
BEC	Bussed Electrical Center
CAE	Computer Aided Engineering
CTE	Coefficient of Thermal Expansion
CTSs	Component Technical Specifications
CVE	Component Validation Engineer

DRE Design Release Engineer
E/E Electrical/Electronic
ECM Engine Control Module
ENV SME Environmental Subject Matter Expert
FET Field Effect Transistor
GDM Global Document Management
GM General Motors
IC Integrated Circuit
IGBT Insulated Gate Bipolar Transistor
IR Infrared
PCB Printed Circuit Board
PDT Product Development Team
PWM Pulse Width Modulated
SSTSs Subsystem Technical Specifications
TC Thermocouple
Tg Glass Transition Temperature
UV Ultraviolet

8 Coding System

This standard shall be referenced in other documents, drawings, etc., as follows:

Test to GMW8288

9 Release and Revisions

This standard was originated in September 2001. It was first approved in March 2002. It was first published in June 2002.

Issue	Publication Date	Description (Organization)
1	JUN 2002	Initial publication.
2	JUL 2012	Update of entire document for clarification and migrated to latest GMW template. (EMC/ENV - GMW8288 Global Workgroup)
3	MAR 2014	Removed Appendix B Thermal Evaluations Worksheet and replaced it with CG3811. Renumbered the remaining appendices. (Electrical EMC/ENV)
4	SEP 2020	Revised to current template. (Electrical - Electrical Hardware and Program Execution)

Appendix A

Table A1: Electrical Loading Conditions

Item	Load Type	Loading Description/Evaluation Issues
1	Continuous Duty and Steady State Loads	Medium to large loads that are continuously on, with a constant load for over 5 minutes, typically contribute significantly to component self-heating. The electrical and thermal efficiency of the drive circuit controlling the load is a key factor. Components used in several different vehicles may have different load sizes or different load combinations in each vehicle or loads may vary with option combinations. It is recommended that individual circuit thermal evaluation be performed using the worst-case "realistic" steady state load combination. See item 3 of this table for simultaneous loading. If the heat produced by worst-case loading is excessive, efforts to develop a more efficient circuit or improve the heat transfer characteristics of the component shall be considered. These types of loads are typically driven by solid state/silicon technology such as power transistors, Field Effect Transistors (FET), etc.
2	Loads Controlled by Electro-Mechanical Relays and Switches	Continuous duty and steady state loads turned on by integral electro-mechanical switches or relays are less likely to produce significant amounts of heat than loads activated by solid state power transistors, FETs, etc. (unless the contacts and the wires or traces leading to the contacts are undersized for the load or are of poor quality, i.e., high contact resistance). Therefore, the loading conditions of these components typically merit less attention than loads switched by solid state/silicon technology. However, the power needed to activate the relay (either internal or external) shall be considered especially if the relay has a relatively high inrush current in relation to the circuit design and is controlled by a solid-state device.
3	Simultaneous Loading	An accurate thermal evaluation of self-heating parts requires determining simultaneous loading conditions appropriate for the component. The simultaneous use of multiple loads by a power driver circuit will increase the total power and amount of heat to be dissipated, especially when parts in power driver circuits are tightly packed, concentrating large amounts of power in a small area. This produces higher temperatures for the same loads than designs that spread out the parts in power driver circuits. The easiest evaluation approach is to simply perform the evaluation with every load simultaneously on, at maximum power consumption, while at maximum temperature. For many components, especially heavily loaded under hood components, this approach may be essential. For lightly loaded components, this "worst-case approach" would have value only as a short term "peak stress" proof test to confirm that the component can handle maximum demand if needed. For many lightly loaded components, maximum simultaneous loading would not be relevant as a long-term reliability or durability life test. For the use of high non-realistic duty-cycles of high to maximum loading conditions could add unnecessary product cost and mass to components that have acceptable thermal performance. If it is not possible to anticipate realistic loading combinations, the following list is provided to standardize thermal testing around a few concurrent loading conditions defined by the percentage of peak power of any set of loads. The PDT may choose from the following list to define the simultaneous loading configurations most appropriate for the component under test. If neither the Worst-Case, Heavy, or

		Moderate Loading percentages defined apply to the application, the PDT may develop an application-specific loading profile for the evaluation. a. **Worst-Case Loading:** All continuous loads (continuous duty and steady state and dynamic) turned on simultaneously. b. **Heavy Loading:** 85% of peak steady state power (voltage and current) of continuous loads, on simultaneously. c. **Moderate Loading:** 70% of peak power of any combination of continuous loads, on simultaneously. d. **Application-Specific Loading:** Custom configuration to be defined by the PDT.
4	Continuous Dynamic and Cyclical Loads	Dynamic loads vary during operation. For example, Pulse Width Modulated (PWM) controlled dimmable lamps and solenoids. It is recommended that these loads should always be evaluated at the power levels of the highest steady-state current and voltage conditions for the component being evaluated. For example, a controlling component may dissipate maximum power and heat when operating an actuator in a moderate loading condition. However, the actuator will dissipate maximum power and heat when in a full-on state, which reduces the power and heat dissipated in the controlling component. It is also recommended that transient conditions of < 5 s (such as peak in-rush, or surge currents) should not be included in thermal evaluations. These parameters may have relevance to the electrical design of a circuit, but have little thermal consequence, therefore, efforts to simulate them during thermal evaluations are of little benefit.
5	Electric Motor Loads	The electrical load of a motor increases as the mechanical load it drives increases. For example, wiper motors draw more current when wiper blades push heavy snow or operate dry; pump motors draw more current as they move thick cold fluids or pump against a head pressure. Therefore, test setups which use unloaded motors for electrical performance evaluation are non-realistic and unacceptable for the thermal response evaluation of a motor or its control circuit. Thermal evaluations of electric motor circuits shall be performed using either a maximum loaded motor and/or a maximum simulated load for worst-case stress evaluation purposes. In contrast, loads that duplicate steady state voltage and current characteristics of a normally loaded motor are to be used for long-term durability evaluation purposes. Another aspect of motor operation that affects thermal performance is the high current load resulting from a stalled motor. This can produce a very hot thermal response for both the motor and an E/E control component. The recommended thermal evaluation for a stalled motor is 15 minutes of operation with the motor stalled at nominal voltage conditions. This should occur when the component's other inputs and outputs are operating in a moderate to heavily loaded state. Unless otherwise specified, it is recommended that only one stalled motor load be evaluated at a time.
6	Short Duration Transients Loads	Short duration, infrequent, and non-cyclical loads such as power door locks and windows, which last < 30 s, typically have little thermal consequence. Therefore, efforts to incorporate them into accumulative thermal evaluations are of little benefit and are not recommended, unless otherwise specified in the component's CTS.
7	Temperature Varying Loads	Many loads, particularly resistive loads, vary with temperature. Example: If a relay draws a maximum current of 200 mA when it is cold, this may be specified as the peak current to be provided to the relay by a solid-state device. However, when hot, only 150 mA, (75% of its cold load) is drawn. With a 14.5 V supply voltage, the voltage drop through the load driver is 2.0 V (which is 12.5 V to the relays). Therefore, during hot conditions, 150 mA through the load driver produces 0.3 W of dissipated heat. If the hot evaluation of the component were to be incorrectly

		performed (by using a 200 mA load), then 0.4 W (1/3 more power) would be produced. Such "over test" errors could be multiplied by multiple outputs in a component, e.g., if the same error occurred for a component with ten such relays driven by the component, the total power would be 4.0 W instead of 3.0 W. This could drive a significant, but non-relevant, temperature increase, which could lead to inappropriate design changes and costs such as adding a heat sink to deal with the heat. The error of "under testing" could also occur for components that increase voltage drop or current flow with temperature. Also, because loads may be located in a different part of a vehicle than its control component, it cannot be assumed that the controller and the load are always experiencing the same environmental temperature. Therefore, a relevant thermal evaluation depends on selecting conditions appropriate to the ways electrical parameters vary with the temperature range of the load and/or the component. If temperature variation information is not defined, it shall be determined/developed by the GM DRE and the PDT and incorporated into the thermal evaluation.
8	Short Circuit Conditions	This loading condition requires Infrared Thermography to measure and visualize the thermal response of the component as it endures short circuit conditions. This can be used to determine if the design can endure short circuit conditions without permanent degradation.

Appendix B

Table B1: Design Guidelines to Improve Thermal Performance

Item	Design Guidelines
	To ensure long-term durability/reliability, it is required that components or materials do not repetitively reach temperatures that exceed operational or material degradation limits, as this may disrupt performance or cause imminent component failure. It is the supplier's responsibility to determine the operational and degradation temperature limits of the parts and materials that the supplier chooses to incorporate into the component. Parts or materials that approach or exceeds 85% of the limit temperature for more than 15% of the operating life shall be further evaluated for excessive reliability/durability degradation. Key issues to be considered are the high thermal stresses when hot and the potential for fatigue from large thermal-mechanical stress cycles over time. Examples of excessive temperature scenarios that can occur for automotive E/E parts are listed as Item a thru c following. Care should be taken to choose appropriate materials and parts during the design phase of the component.
a	Exceeding the maximum junction temperature of a solid-state component. This may result in operation beyond the specified temperature limit, thus leading to a disruption of the part's operation or may permanently weaken or fail the part.
b	Exceeding the maximum storage or operating temperature of an electrolytic capacitor. This may result in thermal expansion that may cause the internal dielectric fluid to burst its seals and leak out. This initially causes a transitional capacitance value change that eventually ends with the capacitor totally failing to an open or short circuit condition.
c	Exceeding the Glass Transition Temperature (Tg) of most plastics, epoxies and other polymers. This reduces the material's strength and can lead to permanent degradation of the material. Also, the material thermal expansion characteristics increase which can increase stress damage to adjacent materials or parts. Examples: If a copper circuit trace or pad exceeds the Tg of its fiberglass circuit board, the copper-board bond can be structurally weakened, leading to a separation failure. If self-heating causes plastic materials to exceed the Tg value of the plastic, structural weakness may result.

Appendix C: Introduction to IR Thermal Imaging

Infrared (IR) Thermography is a non-contact procedure for rapidly determining the intensity and location of thermal (heat) energy being radiated from an entire surface of an object. This occurs by converting invisible infrared heat energy into a color-coded visible image (see Figure C1) that is correlated to a reference temperature. In E/E components/parts, heat is generated and conducted as a function of:

a. The power dissipated in the circuit.

b. The ambient temperature conditions.

c. The thermal conductivity and emissivity of the components/part's materials.

Therefore, IR Thermography can also be used to assess issues related to current flow and material integrity, as well as identify hot spots. Hot spots, which appear as bright colors in the infrared spectrum, are sites of higher thermal energy (heat stress) concentration. Hot spots have a higher potential for being the location of issues that may affect performance, produce a thermal overstress failure, or cause premature wear out from thermally accelerated material degradation. Thermography also provides the ability to detect: Thermal overstress design issues, faulty or failed components, inadvertent current leakage, and performance changes caused by other overstress or wear out aging mechanisms.

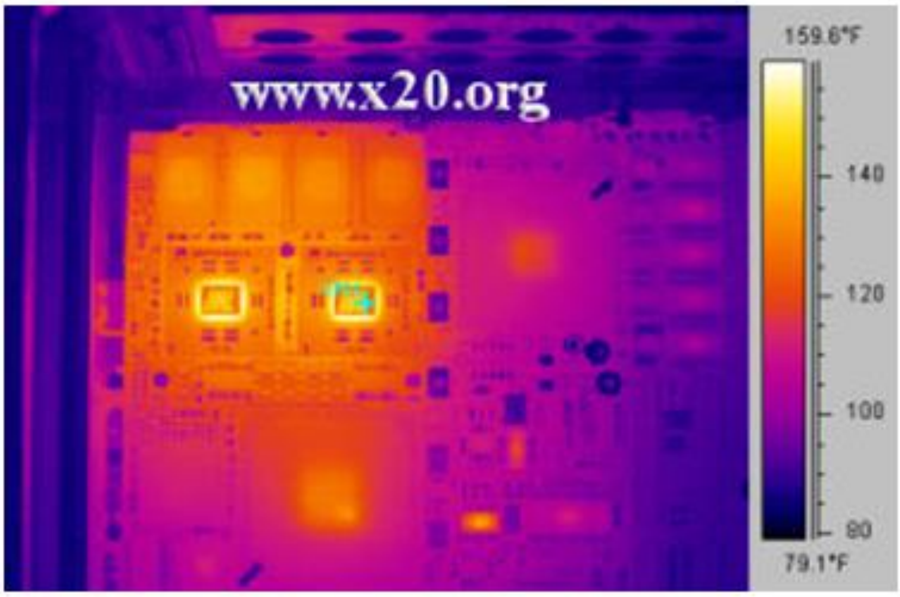

Figure C1: Infrared Thermographic Image of a Circuit Board

Note the location of peak temperatures (bright) hot spots around the high-power heat generating parts on the circuit board, e.g., voltage regulator, power transistors, output driver integrated circuits, etc.

Note the thermal stress gradients from the hottest (light colors) to the coolest (dark color) sections of the circuit board.