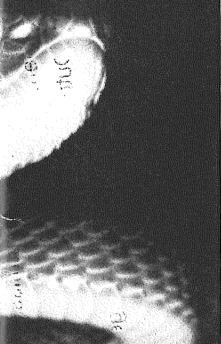
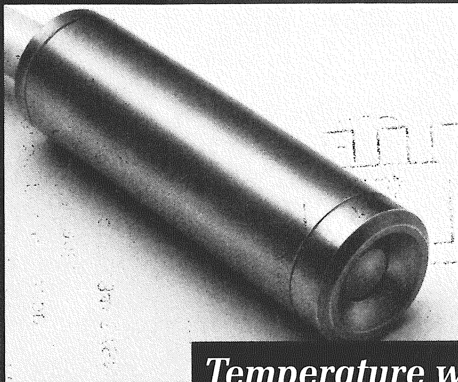
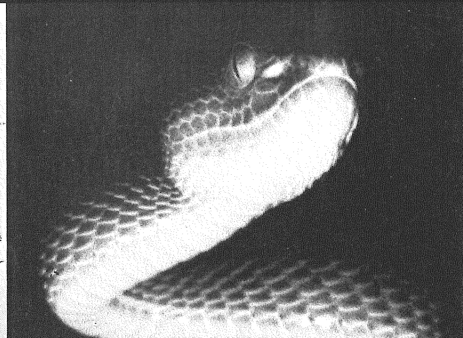
Infrared Thermocouple: IR t/c™ Operating Principles


Temperature with Striking Speed and Accuracy

EXERGEN

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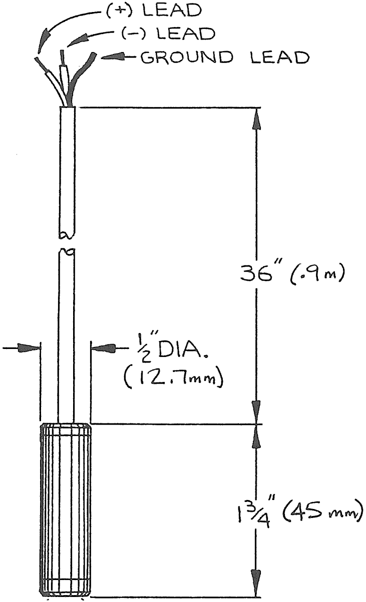


IR t/c Lead Materials

	Positive Lead	Negative Lead
J	Iron	Constantan
K	Chromel	Alumel
E	Chromel	Constantan
T	Copper	Constantan

IR t/c Lead Color Codes

	Positive Lead	Negative Lead	Ground Lead
J	white	red	metallic
K	yellow	red	metallic
E	purple	red	metallic
T	blue	red	metallic

Introduction

The IR t/c™ Infrared Thermocouple is an inexpensive, self-powered measurement instrument which can be substituted directly for standard Type J, K, T, or E thermocouples to make noncontact temperature measurements.

The Infrared Thermocouple should be used whenever:

- The object to be measured is moving.
- Contact will alter the object.
- Contact will compromise a sterile environment (biomedical applications).
- A contact device will be inaccurate.
- A contact device will wear too quickly because of friction or vibration.
- A contact device is too slow.
- A much wider area must be monitored than can be done with contact devices.

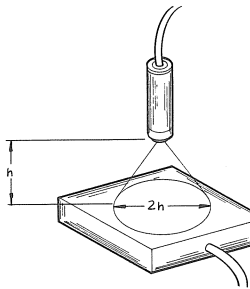
The Infrared Thermocouple combines the latest in infrared technology with an entirely new concept in thermoelectric principles to determine an object's temperature by measuring its emitted infrared radiation.

Easy as 1...2...3!

Use the Infrared Thermocouple just like any thermocouple, keeping in mind that it is an infrared device, with three distinct characteristics:

1. The target must fill the 1:2 field of view.

See also: Field of View



2. The IR t/c works most accurately on high-emissivity surfaces.

Good applications
All non-reflective materials:
Food, paper, plastics, coated metals, stone, clay, glass, liquids, fabrics

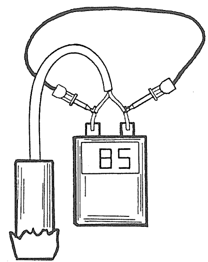
Poor applications
Reflective materials:
Shiny metals

"Maybe" applications:
Dull metals, thin plastics

See also: Emissivity

3. Some controllers will generate an offset.

See also: Controller-Generated Current Offset



5-Step Installation and Check Out Procedure

1. Use on materials with high emissivities.

Examples of high-emissivity materials include food, paper, plastics, coated metals, stone, clay, glass, liquids, fabrics. Dull or corroded metals and thin plastic films should be tested to determine suitability.

See also: *Emissivity*

2. Select optimum location.

Install as close to target as possible, in a clean location with an ambient temperature of 200°F (93°C) or less.

See also: *Field of View*
Dirty Environments
High Ambient

3. Mount securely.

The IR t/c is fully encapsulated and can be clamped firmly.

Do not drill into housing.

4. Connect leads to output device.

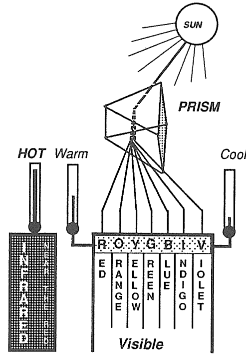
- ❑ IR t/c leads are actual thermocouple leads. By convention, red is always the negative lead.
- ❑ Use IR t/c cables like any thermocouple cable: extension cables and connectors must be of same type as IR t/c to maintain proper thermoelectric circuit.
- ❑ For electrically noisy environments, use shielded extension cables and connect shield to a suitable signal common at output device.
- ❑ Use standard thermocouple practice for splicing, cable lengths, and thermocouple transmitters.

5. Check for response.

Wave hand or hot object in front of IR t/c to check proper connection with readout device.

Principles of Infrared Measurement

In 1665, Sir Isaac Newton became the first to split sunlight into colors with a prism, thus demonstrating the existence of light as radiated energy of differing wavelengths.

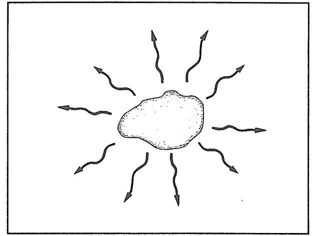


Herschel's Experiment
Year 1800

About 135 years later, another great English astronomer-scientist, William Herschel, measured the heat content at each of the colors of Newton's spectrum. Herschel was shocked to discover that his thermometer registered the greatest heat beyond the red - in an area of the spectrum he could not see. He coined the term "infrared" to describe this heat energy "beyond the red."

One hundred years later, a German scientist by the name of Max Planck solved the problem of quantifying heat radiation, making it possible to apply radiation physics as a tool. The reach this goal, Planck had to resort to probably the most significant "guess" in the history of science! He invented "quanta" to explain heat radiation. This led directly to the creation of quantum physics, arguably the most useful of all physics models of the way the universe works.

An object emits heat directly as a function of its temperature, as determined by the Stefan-Boltzmann equation:



$$e = sT^4$$

where **e** is the total emitted energy by radiation, **T** is the object's temperature on the absolute scale, and **s** is the Stefan-Boltzmann constant. The infrared thermocouple measures this energy and produces a signal proportional to the amount of energy radiating from the object it is looking at, which includes both emitted and reflected energy. Unfortunately, few objects are perfect emitters and reflect, to varying degrees based on their surface properties, radiation from nearby objects. To make good infrared measurements, it is important to understand the proportion of radiation that an object emits as compared to the radiation it reflects. This property is called **emissivity.**

Emissivity

Emissivity is a surface property which determines how well an object's temperature can be measured. Emissivity can be more easily understood if it is realized that infrared has similar properties to visible light.

Is it possible to see a mirror? When the mirror is looked at, all other objects in the room are seen. Is it invisible? No, if it were, the wall would show behind it. So how can it be seen?

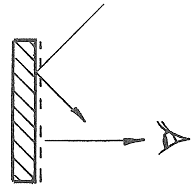
If crayon spots are painted on the mirror, now the mirror can be seen! Of course, it can only be seen where there are spots. Everywhere else still reflects. Thus, light is emitted from the spots and reflected from the non-spots.

Mirrors figure prominently in the discussion of heat radiation and emissivity. Since heat and light radiation behave the same way, we can use what we see with our eyes as examples of what the IR t/c sees.

When you look in the mirror with your eyes, you see only reflection, nothing of the mirror itself. If the mirror is perfect, it has 100% reflectivity. Therefore, it emits nothing because it reflects everything. For this condition, the emissivity is zero.

If we consider an imperfect mirror, the eye then sees mostly reflection, but also some of the imperfections on the mirror surface. If, for example, we saw 90% of the mirror as a perfect reflector and 10% as imperfections, 90% of the mirror would reflect; the remaining 10% would emit. Therefore, the emissivity equals 0.1.

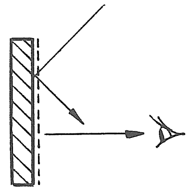
Consider for a moment the exact opposite of a perfect mirror, which is a perfect emitter. The eye looks at the perfect emitter and sees no reflection at all, only the emitting surface. Since 100% of the surface emits, and 0% reflects, the emissivity equals 1.0.



Poor Emitter

Emissivity	=	0.1
Reflectivity	=	<u>0.9</u>
		1.0

And finally consider a good emitter. The eye sees a small amount of reflection interspersed with the large amount emitting. If, for example, 10% of the surface did not emit, and instead reflected, then we would have 10% reflecting and the remaining 90% emitting. Therefore, the emissivity equals 0.9.



Good Emitter

Emissivity = 0.9
Reflectivity = 0.1
1.0

Accordingly, we can state the following as the rule of emissivity:

> **The emissivity of a surface is simply the percentage of a surface that emits. The remaining percentage of the surface reflects.**

Shiny metal surfaces act like mirrors: they reflect more ambient radiation than they emit on their own. The IR t/c is specially designed to accurately measure all but shiny metal surfaces, including all plastics, paper, and coated metal surfaces. Any shiny metal surface will require preparation to make a good measurement.

Painting the surface black (as with the black paint marker included with Exergen's IR t/c Designer' Kit) or covering the surface with tape, substantially reduces the reflection of ambient radiation, allowing the IR t/c to read only the target's emitted radiation. Alternatively, if the surface is wet with a thin layer of liquid, the liquid will be at the same temperature as the surface and will allow high-emissivity measurements. WARNING: Black felt-tip marker will not cover the surface well enough to reduce reflections.

Some applications may require measuring objects which change surface characteristics appreciably, affecting the emissivity, and therefore, the temperature indicated by the IR t/c. Testing under actual operating conditions is recommended to determine suitability.

Some thin plastic films, especially polyethylene and polypropylene are transparent to infrared wavelengths. This means that the IR t/c will "see through" the film and not measure its temperature. The recommended procedure is to simply install the IR t/c in place and monitor results.

Dull metals have emissivities between 0.1 and 0.9. At the higher end, the results will be satisfactory, but at the lower end they will not. Again, the best procedure is to install an IR t/c in place, calibrate, and monitor results. Refer to Calibration section for procedure.

Note: Emissivity calibration for the IR t/c is accomplished with the "span" adjustment of the readout device. No adjustment of the IR t/c is required.

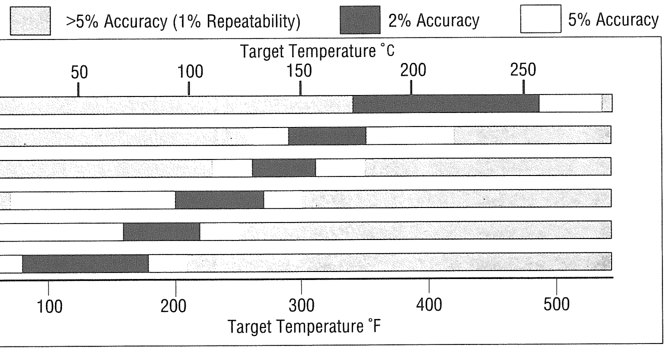
The Operation of the Infrared Thermocouple

Like all thermocouples, the IR t/c generates a signal by utilizing the thermoelectric properties of dissimilar metals. This means the electrical connections to the IR t/c are actual thermocouple wires. Thermocouple wire must be used to extend the cable length, and the IR t/c must be connected to a readout device with cold junction compensation.

Each IR t/c model is optimized for performance in the temperature range indicated in the Temperature Selection Chart as "2% Accuracy." This applies to all IR t/c types (J, K, etc.) and is the recommended selection. Outside the 2% range, the signal output matches a standard thermocouple less precisely (5% accuracy and >5% accuracy) but maintains repeatability. Each can be used for control to temperatures from 0°F (-18°C) to 1200°F (650°C).

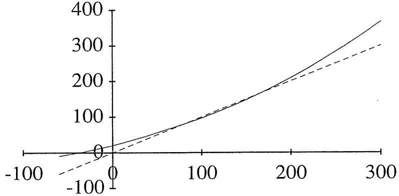
The accuracy specification of the IR t/c refers to how well it matches the equivalent signal produced by a standard thermocouple. The temperature ranges specified are those in which the non-linear signal from the IR t/c matches the relatively linear signal from a t/c, within 2%, 5%, or >5%. Outside of these ranges, the IR t/c retains its repeatability, and the readout device can be calibrated to the IR t/c output.

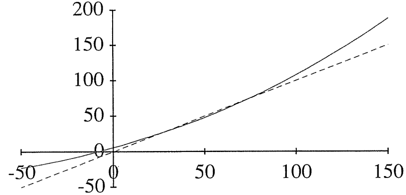
The accompanying charts: J-140, J-180, etc. give typical temperature output (y-axis) relative to actual (x-axis) temperature, and can be used to estimate suitability for application.



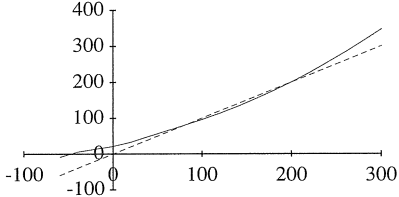
°F °C

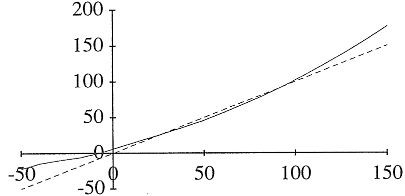
Models: J-140
K-140
E-140
T-140





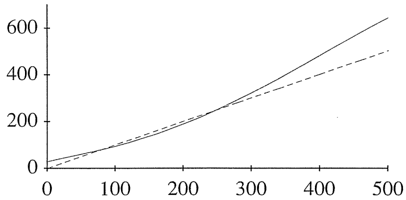
Models: J-180
K-180
E-180
T-180

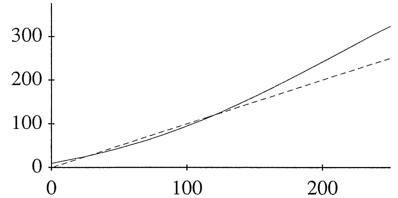




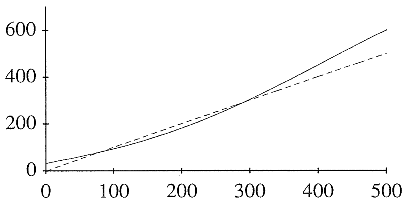
°F °C

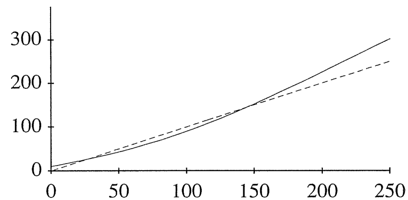
Models: J-240
K-240
E-240
T-240





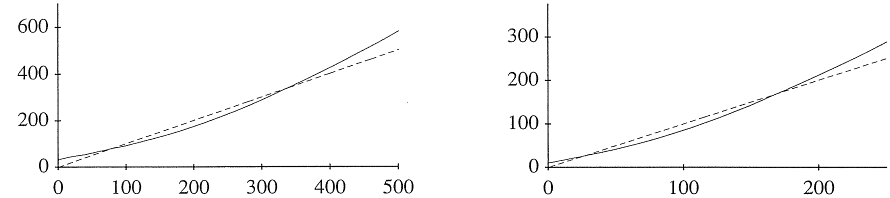
Models: J-280
K-280
E-280
T-280



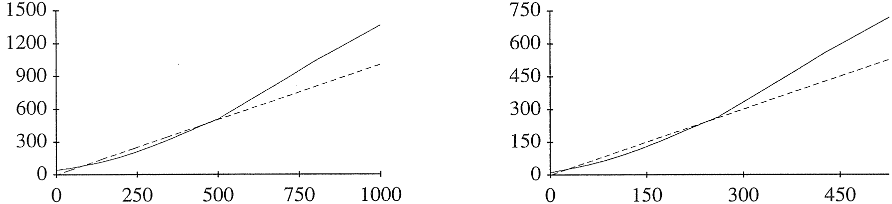


°F °C

Models: J-340 K-340 E-340 T-340



Models: J-440 K-440 E-440 T-440

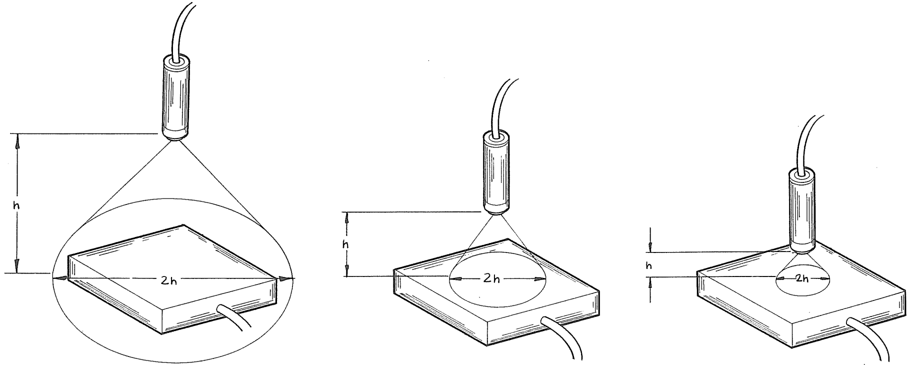


Field of View

The IR t/c has a **field of view** of 1:2. Also referred to as a distance-to-target size ratio, a 1:2 field of view means that the sensor sees a circular area with a diameter equal to two times the distance between the sensor and target. For example, at a 2-inch distance, the sensor sees a 4-inch diameter spot.

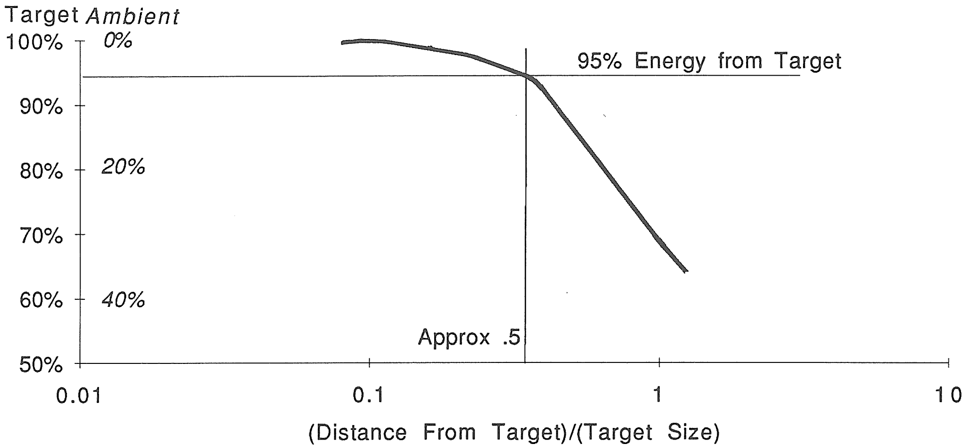
The IR t/c should be mounted as close as possible to the target being measured. This ensures that the target completely fills the field of view. In addition, it minimizes the amount of radiation, emitted by other objects in the room and reflected off the target and into the sensor.

The curve below shows the actual performance. Note that as distance is increased, target signal is replaced by ambient signal, which is exactly analogous to a reduction in emissivity. The best practice is to simply mount the IR t/c as close as practical.



Poor **Good** **Best**

IR t/c Optical Characteristics: Effect of Distance On Temperature Signal



Repeatability

Within the specified accuracy band for each model, the device-to-device repeatability is 2%. The repeatability for a given instrument is 1% of the reading on the readout device.

Because of the fact that an object emits energy as a function of its temperature *to the fourth power*, significant non-linearities can result for temperatures outside the specified range. For applications outside the specified operating ranges, the IR t/c is suitable for recalibration to ensure accuracy at a required setpoint (see Calibration Sections). The IR t/c provides a continuous but unspecified signal up to 1200°F (650°C) with 1% repeatability under normal use. If the IR t/c housing temperature is held constant, repeatability is better than 0.01% of reading.

Response

The time constant for the Infrared Thermocouple is 80 milliseconds, allowing fast temperature measurements to be made. Most controllers and thermocouple readout devices, however, are quite slow, taking readings about once every second. Often the response of the IR t/c appears to be slow because it is connected to a slow readout device.

The fast response of the IR t/c allows it to be connected to an oscilloscope or spectrum analyzer to study the frequency domain of temperature phenomena. While neither an oscilloscope or spectrum analyzer has cold junction compensation for the thermocouple, it is not necessary when working in the frequency domain because cold junction compensation is a DC or extremely low frequency effect.

Effect of Changing Ambient Temperatures

The internal compensation system allows the IR t/c to operate in any ambient temperature between 80 and 200°F (27 to 93°C) and still maintain accuracy equivalent to ASTM specifications for thermocouples. However, as the housing temperature changes, the output of the instrument may vary slightly. Typical variation is 0.02% of the reading per °F change, with a maximum variation for any model of 4°F (2°C) over an ambient change of 20°F (10°C). If greater stability is required, variations in the housing temperature of the IR t/c should be minimized. The IR t/c housing has been designed so that it conducts heat readily, so that the IR t/c can be heatsunk to a machine chassis or some other object which experiences little temperature variation.

Controller-Generated Current Offsets

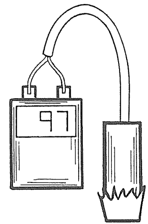
Many thermocouple controllers and read-out devices generate a small amount of leakage current which is usually generated to test for broken thermocouples. The controller can determine that the thermocouple is damaged if an open circuit results.

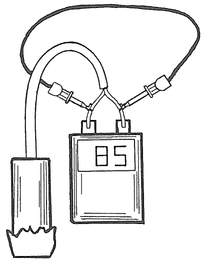
Most thermocouples have small internal resistances, usually well below 100 ohms. The IR t/c, however, has an internal resistance of about 3 Kohms, which can cause a constant offset on the controller's output. For most controllers, the offset is less than 20°F (11°C). A few controllers, however, produce offset errors of 100°F (56°C). In all cases, this offset is constant, and does not affect the operation of the IR t/c, and can be calibrated out with the controller's offset adjustment. An alternative solution is to select a controller with a smaller "leakage" current, normally indicated by a higher input impedance specification.

To understand the controller generated offset, perform the simple bench-check that follows. Once the IR t/c is installed and removal is inconvenient, follow the steps in the on-line calibration procedure to eliminate any controller generated offset.

Bench Calibration

1. Cover the IR t/c with foil and place it next to the readout instrument so both are at the same temperature.
2. Allow the sensor to stabilize for at least 10 minutes before running the test so that it generates no signal.





3. With the IR t/c still connected, short circuit the input terminals and note the display reading.
4. Then remove the short and note the new reading. The difference between the two readings is the offset.

Repeat this procedure as needed to accurately determine the instrument's offset. The offset can be eliminated by recalibrating the instrument to compensate for the offset current.

On-line Calibration and Emissivity Adjustment

To adjust for emissivity, attain greater accuracy, for use outside specified accuracy ranges, or to measure through infrared transmitting windows, the IR t/c installation can be calibrated using a simple three-step procedure.

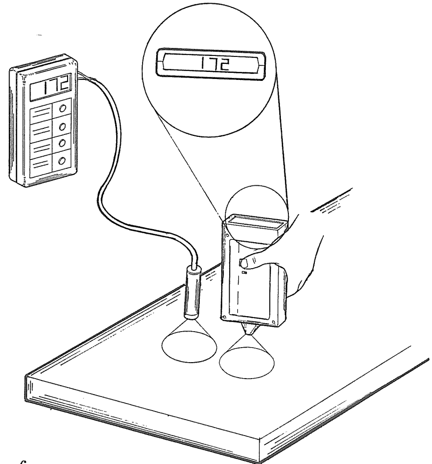
1. **Mount the IR t/c in the desired operating position and connect to the thermocouple readout device.**

   Follow the direction in the INSTALLATION AND CHECK-OUT section and make sure that it is operating correctly.

2. **Adjust the offset.**
   - Cover the IR t/c with foil and allow the reading to stabilize.
   - Measure the temperature of the IR t/c housing with a reliable instrument, and adjust the read-out device offset until it reads the temperature of the IR t/c housing.

3. Set the gain.

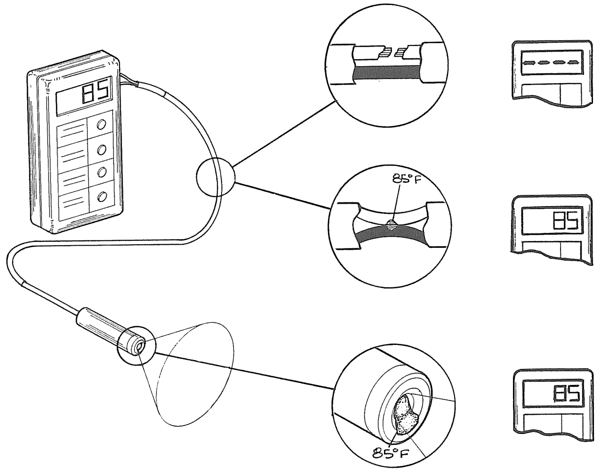
- Using a hand-held infrared instrument (such as the Exergen D501 Microscanner or other reliable means), measure the target temperature, ensuring that the target fills the field of view of the D501.*
- Adjust the span of the readout device so that the indicated temperature is equal to the temperature measured.



***for highest accuracy, and to eliminate emissivity effects, employ AECS feature of D501.*

Failure Modes

The IR t/c has three possible failure modes which should be considered when using the instrument. Prudent design is required to prevent damage and maintain safety.



1. The IR t/c will show an electrical open circuit if a lead is severed either inside or outside the device, thus allowing open circuit detection circuits in controllers to respond.

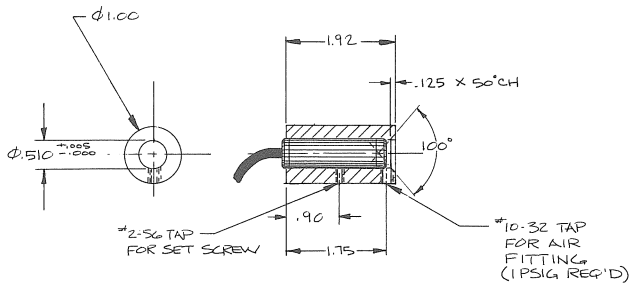
2. A short in the external connecting leads will cause a failure that is undetectable by the controller. The indicated temperature will be that of the short circuit.

3. The IR t/c will produce a signal indicative of the IR t/c housing temperature and not the target temperature if the sensor is blocked or damaged.

Dirty Environments

Just like eyeglasses, which must let light through for the eye to see, the window of the IR t/c must be kept clean to allow infrared radiation to pass through to the infrared sensor inside. Dust, splattering liquids, or condensing moisture can settle on the window and prevent proper operation of the IR t/c.

For applications where excessive dust, debris, or airborne particles are present, use a small amount of air blowing across the window to keep the window clean. A simple collar is illustrated, which holds the IR t/c in position while air is supplied to a fitting near the front end.



High Ambient

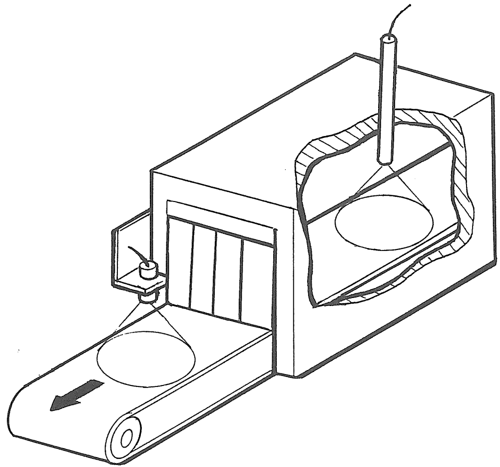
The internal temperature of the IR t/c should not exceed 212°F (100°C). For use in oven applications where the product travels on a conveyor through the chamber, the IR t/c can be mounted at the outlet to monitor the temperature of the product as it emerges from this particular processing step. To mount inside the chamber, the IR t/c must be heatsunk, using a copper tube, for example, to a cooler part of the machinery outside. Alternatively, an air cooling jacket can be employed. Contact Exergen for details.

To test whether the operating environment exceeds the specification of the IR t/c, use the following simple procedure:

High Ambient Temperature Check

- Cover the IR t/c with aluminum foil so that it is "blinded."
- Place the IR t/c in its proper operating position, connect the IR t/c to a readout instrument, and allow it to stabilize.

The reading of the instrument is the ambient temperature of the IR t/c during operating conditions. Be sure that this temperature is below 212°F (100°C).



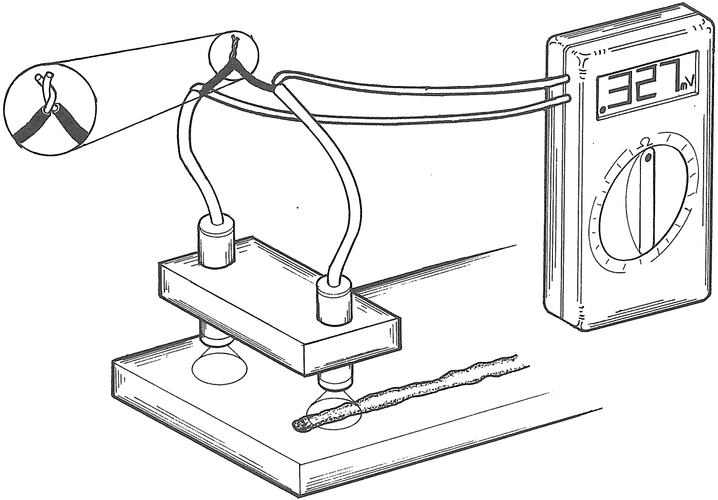
Location options for high ambient

Differential Measurements

Since the IR t/c is truly a thermocouple, complete with thermocouple wire leads, it can be used in series or parallel circuits. For example, several thermocouples can be mounted across a web and wired in parallel to give the average temperature across the web. Also, two infrared thermocouples can be mounted side-by-side and wired differentially to make precise relative measurements. This is a powerful tool in adhesive applications for example, where it is desired to measure the amount of hot melt which is placed on the substrate. If a small bead of hot melt adhesive is being used, small changes in quantity will give small changes in IR t/c output, which could easily be masked by small changes in substrate temperature.

However, if two sensors are used in a differential arrangement, one is used to measure the substrate, while the other measures the applied hot melt. If there is no hot melt, the outputs of each sensor are the same (since they are both looking at the same target) and the resulting output of the differential pair is zero. As hot melt is applied, one IR t/c measures the slightly higher temperature independent of substrate temperature changes, and the differential output is a positive signal. This differential signal is directly a function of the amount of applied adhesive.

This method can be used for many other differential temperature inspection tasks in a similar fashion.



Two IR t/c's wired differentially.

Troubleshooting

- **IR t/c does not respond**
  1. Check wiring for correct connections.
  2. Check electrical resistance of IR t/c to be about 3 Kohms. If short or open circuit is found, replace IR t/c.
  3. Check window for blockage. Clean with alcohol of other common cleaner.

- **IR t/c reads too high**
  1. Check read-out device for offset.
  2. Check rating of IR t/c. Be sure proper model is used for the target temperature and t/c type.

- **IR t/c reads too low**
  1. Check IR t/c model to make sure it is in the proper range.
  2. Check for lens cleanliness. If dirt builds up, provide air jet.

  See also: Dirty Environment.

■ **IR t/c seems inaccurate or erratic**

1. Check to be sure target does not have a shiny metal surface.
   See also: Emissivity.
2. Dull metal will give low readings. Recalibrate for greater accuracy.
   See also: Calibration.
3. Check for high ambient temperature. Provide cooling or heat sinking, if necessary.
   See also: High Ambient.

Specifications

Accuracy
±2% of nominal value (target with emissivity of 0.9, over temperature range shown below)

Repeatability
±1% of reading between 0 and 1200°F (650°C)

Temperature Compensation Range
Complies with ASTM standards over 80 to 200°F (27 to 93°C) range

Ambient Temperature Coefficient
Averages 0.02% of reading per °F over 80 to 200°F (27 to 93°C) range

Operating Ambient Range
0 to 212°F (-18 to 100°C)

Storage Temperature Range
-50 to 250°F (-45 to 121°C)

Output Impedance
3KΩ nominal

Response Time
80 ms

Spectral Response
6.5 to 14 microns

Field of View
90°

Dimensions
1.75"L x 0.5"D (4.45 x 1.27 cm)

Cable
Twisted shielded pair of base thermocouple material in a Teflon jacket; rated to 500°F (260°C)

Housing

303 stainless steel with silicon window, hermetically sealed and suitable for vacuum chamber service. Electrically connected to shield wire and isolated from signal leads.

Model	2% Accuracy Range	5% Accuracy Range
IR t/c-*-140	80-180°F (25-80°C)	50-210°F (10-99°C)
IR t/c-*-180	160-220°F (70-105°C)	50-250°F (10-121°C)
IR t/c-*-240	200-270°F (90-135°C)	70-310°F (21-154°C)
IR t/c-*-280	260-310°F (130-155°C)	230-360°F (110-182°C)
IR t/c-*-340	290-350°F (145-180°C)	260-420°F (127-216°C)
IR t/c-*-440	340-480°F (170-250°C)	340-540°F (171-282°C)

(*indicate J-type, K-type, etc. in model number)

All models can be used between 0 and 1200°F (-18 and 650°C) with 1% repeatability. However, the IR t/c measures infrared radiation which is emitted as a function of the square of the square of an object's temperature, so that outside the specified range the signal is highly non-linear (refer to charts in *The Operation of the Infrared Thermocouple*).

Repair

For Service contact:

Exergen Corporation
1-800-422-3006

One Bridge Street
Newton, MA 02158, USA
(617) 527-6660

In order to avoid processing delays, obtain a Return Materials Authorization (RMA) number from the Exergen Customer Service Department before returning any product for repair. The RMA number should be marked on the outside package of any returned product.

Please have the following information available for the Customer Service Representative:

1. Model of the product.
2. Date of purchase.
3. Description of problem.

Warranty

Exergen warrants this unit to be free of defects in material and workmanship for a period of 15 months from date of purchase. Exergen adds an additional three (3) month grace period to the normal one (1) year product warranty to cover handling and shipping time. This ensures that our customers receive maximum coverage on each product. If the unit should malfunction, it must be returned to the factory for evaluation. Our Customer Service Department will issue a Return Materials Authorization (RMA) number immediately upon phone or written request. Upon examination by Exergen, if the unit is found to be defective, it will be repaired or replaced at no charge. However, this WARRANTY is VOID if the unit shows evidence of having been tampered with or shows evidence of being damaged as a result of excessive corrosion; or current, heat, moisture or vibration; improper specification; misapplication; misuse or other operating conditions outside of Exergen's control.

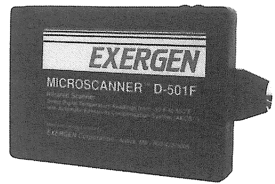
There are no warranties except as stated herein. There are no other warranties, expressed or implied, including but not limited to the implied warranties of merchantability and of fitness for a particular purpose. Exergen Corporation is not responsible for any damages or losses caused to other equipment, whether direct, indirect, incidental, special or consequential, which the purchaser may experience as a result of the installation or use of the product. The buyer's sole remedy for any breach of this agreement by Exergen Corporation or any breach of any Warranty by Exergen Corporation shall not exceed the purchase price paid by the purchaser to Exergen Corporation for the unit or units or equipment directly affected by such breach.

Every precaution for accuracy has been taken in the preparation of this manual, however, Exergen Corporation neither assumes responsibility for any omissions or errors that may appear nor assumes liability for any damages that result from the use of the products in accordance with the information contained in the manual.

D-Series

Portable Instrument for Calibrating IR t/c Installations

Finest surface-temperature-measuring instruments in the world, featuring a patented automatic emissivity compensation system (AECS) for precision and accuracy, and ultra-fast speed, all in a convenient shirt-pocket size. Unique characteristics vary acccording to model, and include temperatures from -100°F to 1600°F (-73°C to 870°C), remote sensors for hard-to-reach areas, 0.1° resolution, 80 msec response time, analog output for datalogging applications, and accessory for accurate measurement of relative humidity.



The D501F is recommended for IR t/c calibration.

About Exergen

Located just outside Boston in Newton, MA, Exergen Corporation manufactures an extensive line of proprietary infrared scanners, thermometers, and controls used in a wide wariety of medical and industrial applications, and is the world leader in thermal infrared instrumentation. All of its products are based on unique technology and are protected by issued or pending patents.

The IR t/c™ infrared thermocouples are manufactured in the USA by Exergen at its plant in Newton, MA.

EXERGEN

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