HFM-6, HFM-7, & HFM-8
OPERATOR'S MANUAL

Version 1.0

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WARNING: **Read instructions carefully and completely before using the HFM. Improper usage could damage the unit. Save this manual for safety and operating instructions, as well as warranty information.**

FORWARD

Thank you for purchasing the Vatell Heat Flux Microsensor (HFM). The HFM is designed to give fast, flexible heat flux measurements with built-in temperature compensation.

To fully appreciate the capabilities of your HFM, please read this Operator's Manual thoroughly. If you have any questions or need any assistance please contact:

Vatell Corporation
P.O. Box 66
Christiansburg, VA 24073

Phone: (540) 961-3576
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Email: mkt@vatell.com

Please indicate model and serial number in all correspondence.

UNPACKING AND INSPECTION

The HFM package should include

1) The Vatell HFM
2) An individual calibration sheet for each HFM
3) This operator’s manual.

The face of the sensor is protected by a rubber cap. Please keep the cap and cover the sensor face with it whenever the HFM is not in use.

If any of these items are missing or damaged, contact Vatell Corporation at the address listed in the Foreword section of this manual.

HFM Operators Manual

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USE OF THE VATELL HEAT FLUX MICROSENSOR

The Vatell Heat Flux Microsensor (HFM) will provide excellent heat flux measurement for a wide variety of applications when used properly. This document will explain the use of the HFM and important factors to take into consideration when making measurements.

Output from the HFM

Two measurements are made with the HFM. The primary output is from a thin-film thermopile heat flux sensor (HFS) that occupies most of the surface area on the sensor face. The HFS signal should not be confused with the output from a thermocouple. The HFS acts like a differential voltage source and should not be grounded. Best results can be obtained by connecting it to a differential amplifier, such as the Vatell AMP-6 or similar amplifier. The second measurement is a temperature value to provide temperature compensation for the HFS. For the HFM-6 and HFM-7 this temperature measurement is obtained from a resistance temperature sensing element (RTS) which consists of a pure platinum thin film deposited in a loop pattern around the outer edge of the sensor face. For the HFM-8 the temperature is from a thin-film thermocouple (TC), which behaves like a regular wire thermocouple although it is independently calibrated as it does not necessarily conform to standard published tables. The functions for both the RTS and TC are linear for most temperatures of interest, although higher order polynomials can be used for specific custom applications.

The calibration sheet lists coefficients *a* through *h* for purposes of accurately determining the heat flux measured by the sensor. They are described below in reverse order:

h = sensitivity of the thermopile to heat flux, in μV/W/cm².
g = temperature correction coefficient for heat flux, in μV/W/cm²/°C.
f = RTS resistance at 0°C in ohms (not used for HFM-8 units) used for zeroing.
e = RTS resistance variation with temperature in ohms/°C (not used for HFM-8 units).
d = Temperature offset value; for the HFM-8 this is the ambient temperature during sensor calibration. The units are in °C.
c = Variation with temperature of the RTS resistance (HFM-6 or HFM-7) or thermocouple voltage (HFM-8) in °C/ohm or °C/mV respectively.
b = Quadratic polynomial term for temperature curve; not used for most applications.
a = Cubic polynomial term for temperature curve; not used for most applications.

While this appears to be complicated, getting a valid heat flux measurement from the HFM is really just three simple steps.

1. Adjust for the ambient temperature value (with coefficients *e* and *f* if applicable).
2. Compute the temperature of the HFM with coefficients *c* and *d*.
3. Compute the heat flux value with coefficients *g* and *h*.

Adjusting for ambient temperature: Since the temperature the sensor is used at may be different from the one at which it is calibrated, an ambient temperature adjustment needs to be made; this is akin to “zeroing” the temperature value. For the HFM-8 coefficient *d* is a default ambient temperature. If the system is zeroed at a known temperature, use that temperature in place of *d*.

For the HFM-6 or HFM-7, how the ambient temperature adjustment is done depends on whether the RTS resistance is being measured directly in ohms or indirectly as a voltage produced by a controlled current source, as is done in Vatell amplifiers. For a direct resistance measurement, just use the resistance value found with an ohmmeter. When the RTS is driven by a current source, the output voltage is usually zeroed at room temperature. The ambient temperature resistance can be found as shown in Equation (1).

$$R_a = e \cdot T_a + f \qquad (1)$$

Where T_a is the ambient temperature in °C.

In summary, the ambient temperature value will be:

- For HFM-8: Either measured room temperature (preferably) or the coefficient *d* from the calibration sheet.
- For HFM-6 or HFM-7: Either the directly measured RTS resistance value (in ohms), or the calculated resistance value R_a from Equation (1).

Compute the current HFM temperature: The temperature function is characterized for each HFM at Vatell, and takes the form:

$$T = c \cdot R + d \qquad (2a)$$

$$T = c \cdot V + d \qquad (2b)$$

Where (2a) is used for HFM-6 and HFM-7 while (2b) is used for HFM-8 with:

T	is the temperature of the HFM (in Celsius).
c & d	are the coefficients of the polynomial, which are given on the Calibration Data Sheet supplied with the sensor.
R	is the resistance of the RTS (in ohms) for the HFM-6 and HFM-7.
V	is the voltage output of the thermocouple (in mV) for the HFM-8.

Note that in most cases coefficients *a* and *b* will be zero and can be ignored. For those unusual cases where *a* and *b* are not zero, refer to Appendix A for dealing with the higher order terms.

For sensors with an RTS, if the resistance *R* is measured directly, that value can be put into equation (2a) to determine the current temperature. If the RTS is being driven with a current source, *R* can be determined from Equation (3).

$$R = \frac{V_{RTS}}{(I_{RTS})(G_{RTS})} + R_a \qquad (3)$$

where:

V_{RTS}	is the voltage output of the RTS amplifier channel (in volts), which may be positive or negative.
I_{RTS}	is the excitation current (in amps) through the RTS used to generate ΔV_{RTS},

equal to $1x10^{-4}$ amps for Vatell amplifiers.

G_{RTS} — is the amplifier gain for the RTS channel. For most Vatell amplifiers, this value is given on the Gain Settings Label on the bottom of the amplifier. If there is no amplifier, this value is just 1.

The resistance value from equation (3) can then be entered into equation (2a) to determine the temperature.

Note that the resistance of the RTS includes the resistance of the wires in the sensor's cable. One should note that during the calibration of the RTS at Vatell, the sensor is always connected to the measuring equipment through a standard 2 meter Vatell amplifier cable, which adds an offset to the resistance of about one ohm to the resistance of the sensor's cable. When using the HFM with a Vatell amplifier, no corrective action is required, as the offset is incorporated into the calibration data. If the Vatell amplifier cable is not used, or if a nonstandard cable length is used, the offset for the cable will be slightly different. In many cases, the difference of an ohm will not seriously impact heat flux measurements, but for the most accurate measurements, this difference in resistance should be applied to the coefficient *f* before computing the temperature.

Compute the heat flux: Once the temperature, *T*, is known, the heat flux can be computed from:

$$q'' = \frac{V_{HFS} / G_{HFS}}{g \cdot T + h} \qquad (4)$$

where:

q'' — is the heat flux (in W/cm^2).

V_{HFS} — is the instantaneous voltage signal from the HFS (in μV) which may be positive or negative.

G_{HFS} — is the amplifier gain for the HFS channel if an amplifier is being used; if not the value of G_{HFS} is 1. For most Vatell amplifiers calibrated value of G_{HFS} is given on the Gain Settings Label on the bottom of the amplifier.

g, h — are coefficients for the relationship between sensitivity and temperature. These are given on the Calibration Data Sheet.

Example 1: Heat flux measurement with an HFM-6 and AMP-6:

The following is an example on using the HFM and the AMP-6 to measure heat flux. For our example, we want to measure the heat flux from a propane torch at a fixed distance from the nozzle. For this purpose the HFM has been mounted in a metal plate to act as a heat sink.

1. First we want to zero all the amplifier outputs to establish a baseline output. To do this, we need to measure the temperature of the sensor before the flame is ignited while the HFM is at room temperature and thermally static. For best measurement practice, allow the amplifier sufficient time to warm up; this takes approximately 8 minutes for Vatell amplifiers. This will prevent possible drift in measurements taken later. Adjust the offset potentiometers for the RTS and HFS outputs so that the voltage output from the amplifier for both channels is zero.

2. To find R_a the resistance can be measured directly across the connector pins of the HFM with an ohmmeter, or it can be computed from the ambient temperature, as shown in step 3.
3. The room temperature is 22 °C, which is our T_a. From the Calibration Data Sheet we find that e = 0.354994 Ω/°C and f = 149.090 Ω. Now with equation (1) we compute

$$R_a = e \cdot T_a + f$$
$$= (0.354994\Omega/^{o}\mathrm{C})(22^{o}\mathrm{C}) + 149.090\Omega$$
$$= 156.9\Omega$$

4. When the flame is ignited, the HFS begins to register a voltage, indicating that the sensor is measuring heat flux. Note that a positive voltage indicates heat flow into the sensor face and a negative voltage indicates heat flow out of the sensor face.
5. After the flame has been adjusted, we take a measurement. The HFS channel reads 0.290 V (290,000 μV) and the RTS channel reads 1.03 V. The gain setting for the HFS and RTS channels are 1000 and 500 respectively. From the Gain Settings Label on the bottom of the AMP-6, we find that these correspond to actual gains of G_{HFS} = 980.6 and G_{RTS} = 495.1. Recall that the excitation current for the Vatell amplifier, I_{RTS}, is $1x10^{-4}$ amps.
6. Next we need to know the current temperature of the sensor, so we measure the RTS resistance either directly with an ohmmeter or using equation (3). For our example

$$R = \frac{V_{RTS}}{(I_{RTS})(G_{RTS})} + R_a$$
$$= \frac{1.03\mathrm{V}}{(1x10^{-4}\mathrm{A})(495.1)} + 156.9\Omega$$
$$= 177.7\Omega$$

7. The temperature can now be computed from equation (2a). Note that for accurate determination of the heat flux, the temperature measurement must be at the face of the sensor. This is why the RTS temperature value has to be used instead of some other temperature reading, such as that of the furnace thermocouple. The coefficients, which can be found on the Calibration Data Sheet, are c = 4.092, and d = -495.566. The temperature is then

$$T = c \cdot R + d$$
$$= (4.092)(177.7) + (-495.566)$$
$$= 231.6\ ^{\circ}\mathrm{C}$$

8. Finally the heat flux, q'', is computed from equation (4), using coefficient values from the Calibration Data Sheet of g = 0.026844 μV/W/cm^2/°C and h = 13.2807 μV/W/cm^2

$$q'' = \frac{V_{HFS}/G_{HFS}}{g \cdot T + h}$$

$$= \frac{290{,}000\mu\text{V}/980.6}{(0.026844\mu\text{V/W/cm}^2/^\circ\text{C})(231.6^\circ\text{C}) + 13.2807\mu\text{V/W/cm}^2}$$

$$= 15.168\text{W/cm}^2$$

Example 2: Heat flux measurement with an HFM-8 and AMP-12:

The following is an example on using the HFM-8 and the AMP-12 to measure heat flux. For our example, we want to measure the heat flux in a furnace that has a thermocouple to monitor its temperature during a slow temperature ramp.

1. First we want to zero all the amplifier outputs to establish a baseline output. To do this, we need to measure the temperature of the sensor before the furnace is turned on while the HFM is at room temperature and thermally static. For best measurement practice, allow the amplifier sufficient time to warm up; this takes approximately 8 minutes for Vatell amplifiers. This will prevent possible drift in measurements taken later. Adjust the offset potentiometers for the TC and HFS outputs so that the voltage output from the amplifier for both channels is zero.
2. The ambient temperature is noted to be 27°C. This measurement will be used in place of the default zeroing temperature given by coefficient *d*.
3. When the furnace is turned on, the HFS begins to register a voltage, indicating that the sensor is measuring heat flux. Note that a positive voltage indicates heat flow into the sensor face and a negative voltage indicates heat flow out of the sensor face.
4. After 1 minute, we take a measurement. The HFS channel reads 0.290 V (290,000 μV) and the TC channel reads 1.03 V. The gain setting for the HFS and TC channels are 1000 and 500 respectively. From the Gain Settings Label on the bottom of the AMP-12, we find that these correspond to actual gains of G_{HFS} = 980.6 and G_{TC} = 495.1.
5. Because we are running the TC output through an amplifier, we need to factor out the amplifier gain to get the TC voltage. For our example

$$V = \frac{V_{TC}}{G_{TC}}$$

$$= \frac{1.03\text{V}}{495.1}$$

$$= 0.00208\text{V} = 2.08\text{mV}$$

6. The temperature can now be computed from equation (2b). Note that for accurate determination of the heat flux, the temperature measurement should be at the face of the sensor. This is why the TC temperature value has to be used instead of some other temperature reading, such as that of the furnace thermocouple. Although the thin-film TC does not measure the temperature right at the face of the sensor, the measurement is spatially close to the surface. Actual surface temperature will differ from the TC measurement depending on the level and duration of the heat flux event. The coefficients, which can be found on the Calibration Data Sheet, are *c* = 14.12145,

and d = 30.34. However, because we have an ambient temperature measurement (27°C), we will use that value in place of d. The temperature is then

$$T = c \cdot R + d$$

$$= (14.12145)(2.08) + (27)$$

$$= 56.3\ °C$$

7. Finally the heat flux, q'', is computed from equation (4), using coefficient values from the Calibration Data Sheet of g = 0.026844 μV/W/cm^2/°C and h = 173.2807 μV/W/cm^2 :

$$q'' = \frac{V_{HFS} / G_{HFS}}{g \cdot T + h}$$

$$= \frac{290{,}000\mu\text{V} / 980.6}{(0.026844\mu\text{V/W/cm}^2/^\circ\text{C})(56.32\,^\circ\text{C}) + 173.2807\mu\text{V/W/cm}^2}$$

$$= 1.692\text{W/cm}^2$$

Note that if we had used coefficient d in place of the ambient temperature measurement, the heat flux value would have been 1.691 W/cm^2, a 0.05% difference in this case.

Modes of Heat Transfer

The HFM can measure heat flux in all three modes of heat transfer, radiative, conductive, and convective, but the nature of the heat transfer may impact measurements and so needs to be taken into consideration.

Radiation Measurements

All heat flux transducers made by Vatell are calibrated using radiant heat sources, because they are the most consistently repeatable. However, the fraction of the radiation absorbed by the transducer is never 100%, and so the *absorbed* heat flux differs from the *incident* heat flux. The relation of incident and absorbed heat flux for a radiation source is given by

$$q''_{in} = \frac{q''_{ab}}{\varepsilon} \tag{5}$$

where

ε is the emissivity

All Vatell heat flux transducers are calibrated in terms of absorbed heat flux, so that for a radiative heat flux measurement, the absorbed heat flux is simply the output voltage divided by the sensitivity of the transducer. Vatell transducers are typically coated with a high temperature black paint, which has an emissivity of 0.95 and a fairly flat spectral response over most wavelengths of interest. Because the emissivity is not unity, to determine the incident radiant heat flux, use equation (5):

Convection Measurements

For convection measurements, there is only an absorbed heat flux value, so the emissivity does not need to be taken into account. Because the thermopile measures the temperature difference between its top and bottom layers regardless of the heat source, the convection measurement is robust even though the calibration is done with a radiant source. That said, because the calibration does not match the application for convective measurements, the accuracy may not be as high in some cases. The standard equation for a convection measurement is given by:

$$q''_{ab} = h\Delta T \qquad (6)$$

where

h	is the heat transfer coefficient.
ΔT	is the temperature difference between the transducer and the fluid.

The heat transfer coefficient is a function of the thermal conductivity of the fluid, and the fluid flow characteristics. Unfortunately fluid flow is extremely complex and difficult to model; consequently the heat transfer coefficient is difficult to determine except in an empirical fashion. Heat flux transducers are commonly used in fact to determine the heat transfer coefficient. By using the heat flux measurement in conjunction with temperature measurements of the fluid and the transducer face to obtain a ΔT, the heat transfer coefficient can be found. This procedure assumes that the heat transfer coefficient for the transducer and the surrounding system are the same. The accuracy of this assumption will vary with different system configurations and materials. In general, the less the transducer alters the system the better.

Conduction Measurements

The same considerations apply to conduction as to convection measurements with regard to the emissivity of the sensor. Exercise caution when doing conduction measurements to prevent damage to the face of the HFM. When in contact with a hard or rough surface, Vatell recommends the use of a buffer like silicon grease or a foil made of gold or Grafoil to achieve good thermal contact without damaging the thin-film sensor. For a conductive heat flux, the governing equation is:

$$q''_{ab} = -k\frac{\delta T}{\delta n} \qquad (7)$$

where

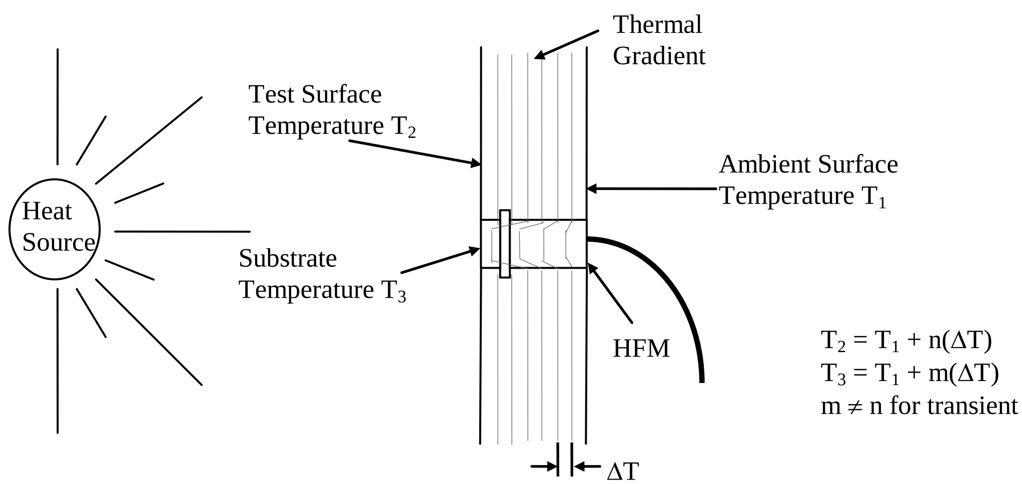
k	is the thermal conductance
$\frac{\delta T}{\delta n}$	is the thermal gradient with n as the unit vector normal to the surface across which the heat flux is being measured.

Measurements with Mixed Modes of Heat Transfer

All three modes of heat transfer can be measured as described above. When radiation is mixed with convection however, there is the question of what fraction of the heat flux needs to be corrected for emissivity, and what fraction does not. Ideally the different modes can be isolated so that the question does not occur; for example, using a radiometer configuration that screens out convection with an optical window to view the radiation from a heat source. Because the HFM has a fast time response, it can often measure the arrival of a radiation pulse before the convective wave hits allowing the two signals to be isolated temporally. If the modes cannot be differentiated experimentally, some intelligent estimates of the relative fractions of the heat flux that each mode contributes must be made. In these cases the emissivity of the HFM should be as high as possible to minimize error.

Sensor Temperature versus Application Temperature

The HFM has a temperature sensor (either RTS or TC) to monitor the temperature of the substrate on which the thermopile has been deposited, in order to account for temperature variations in the HFS signal. The substrate temperature that the HFM temperature sensor measures should not be taken as the transient temperature of the test surface or the heat flux source. This is because the thermal gradient through the test surface and the HFM may not be the same unless the system is in thermal equilibrium. Consequently the HFM temperature sensor will register a transient temperature somewhere between the test surface temperature and the ambient surface temperature, as depicted below.



The HFM temperature sensor can be used to measure the test surface temperature once the system is in thermal equilibrium, provided that the test surface is at a uniform temperature. In such a case the temperature gradient through the HFM and the test surface will be the same because of the high thermal conductivity of the HFM.

Sensor Response Time and Amplifier Gain

The time constant of the uncoated HFM is 17 μs, which give it a 0-95% rise time (R) of 50 μs. For a coated HFM, those numbers are 300 μs and 900 μs respectively. The measured response may be slower than that however, because it is dependent on the bandwidth and gain of the amplifier being used. There is an inherent trade-off between bandwidth and gain. This is usually expressed in the Gain-Bandwidth product

$$F = GB \tag{8}$$

which is a constant for simple amplifiers. Consequently, higher gains result in lower bandwidth. To take full advantage of the speed of the HFM, the bandwidth of the amplifier should be

$$B = \frac{2}{R} = \frac{2}{50x10^{-6}\,\text{s}} = 40\text{kHz}$$

Knowing the minimum bandwidth required for an application, the maximum gain can be computed. For example, to fully utilize the time response of the HFM with an amplifier having a Gain-Bandwidth product of 1 MHz, the maximum gain would be

$$G = \frac{F}{B} = \frac{1\text{MHz}}{40\text{kHz}} = 25$$

For more sophisticated amplifiers, like the Vatell AMP-6 or AMP-10, the Gain-Bandwidth product is not necessarily constant. Refer to the specification sheet to determine bandwidth at any given gain; these values are given for Vatell amplifiers at the end of the amplifier manual. To keep signal noise to a minimum, one should use the smallest bandwidth possible for the required time response and set the gain accordingly.

HFM Calibration

Each HFM is individually calibrated in a multi-step procedure. The first step is to remove hysteresis in the RTS. The hysteresis effect causes the temperature versus resistance curve of the RTS to shift as the sensor is heated and cooled, so that the resistance for a given temperature changes with each temperature cycle. The more a sensor is temperature cycled the less pronounced this shift becomes. For purposes of the HFM, the hysteresis becomes negligible after several temperature cycles, the exact number of which has been empirically determined and is conducted on each sensor before the next calibration step. This cycling is not necessary for the thermocouple on the HFM-8.

The RTS or TC is then characterized in a computer-controlled furnace that maps resistance values to corresponding temperature values. From these data points a curve fit is performed to acquire the coefficients for equation (1). The linear temperature portion of this curve (between 30 °C and 200 °C for low temperature HFMs, and up to 400°C for high temperature HFMs) is used to generate the linear fit for the coefficients for equation (2).

Finally the HFS is calibrated by comparing its output voltage (V_{HFM}) against the output voltage of a standardized reference heat flux gauge (V_{ref}) when each gauge is exposed to the same radiation heat flux source (q''). Both the HFM and the reference gauge are coated with the same high-temperature black paint, which is a high emissivity coating (so that $\varepsilon_{HFM} = \varepsilon_{ref} = 0.95$). The sensitivity of the HFM (S_{HFM}) is calculated from the sensitivity of the reference gauge (S_{ref}) by

$$q'' = (S_{HFM})(V_{HFM}) = (S_{ref})(V_{ref}) \qquad (9)$$

CARE AND MAINTENANCE

Proper care of the HFM will insure good performance throughout its lifetime. Vatell recommends regular calibrations to maintain optimal measurements.

Sensor Face

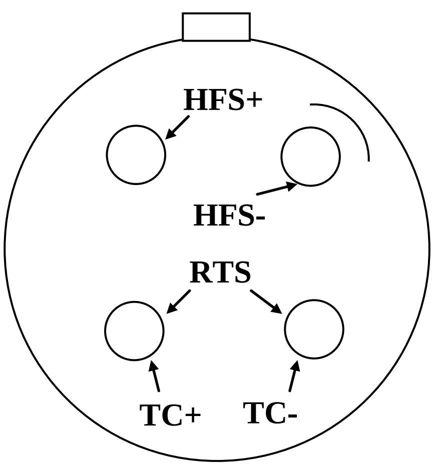
Although the HFM has a protective alumina coating over the surface, it is a thin-film device and as such it should be handled with care. To prevent altering the surface emissivity, the face of the sensor should never be touched (except in the case of a conduction measurement, and then care should be taken not to damage the thin-film). If the face of the sensor needs to be cleaned, use dry compressed air to dust it off. For more extensive cleaning, please return the HFM to Vatell for recoating and recalibration.

Cables

The Teflon cables on the low temperature HFM units and at the connector end of the high temperature units are durable and flexible, with a bend radius equal to the diameter of the cable. They can take a maximum temperature of 200°C. Note that the epoxy in the transition ferrule on the high temperature sensors can only go up to 130°C.

The metal Inconel cables on the high temperature sensors can survive much higher temperatures, up to 600°C, but have limited flexibility, having a bend radius of 2.5 cm. Although the Inconel cables can be straightened and bent again, repeated bending should be kept to a minimum.

In the event that the Lemo connector needs to be removed from the HFM, refer to the following wiring diagram. An HFM will have either an RTS or thermocouple (TC) but not both. The heat flux signal (HFS) and TC both have polarity, but the RTS does not.



Female Lemo (viewed from solder cups in back)

Lemo HFM Color Code Chart
White = HFS+
Black = HFS-
Blue, Green, Red, Yellow = RTS
Purple = TC+
Red = TC-

APPENDIX A

Higher order polynomial temperature curve

For cases in which coefficients *a* and *b* are not zero, substitute equations (2a*) or (2b*) for (2a) or (2b) as appropriate to compute the temperature.

$$T = a \cdot R^3 + b \cdot R^2 + c \cdot R + d \qquad (2a^*)$$

$$T = a \cdot V^3 + b \cdot V^2 + c \cdot V + d \qquad (2b^*)$$

This reflects a higher order polynomial curve fit of the temperature calibration. Because the temperature curve is typically linear, this is only done in unusual circumstances.

HFM SPECIFICATIONS

Thin-film technology allows the HFM series sensor to be the fastest heat flux sensor on the market, with an uncoated response time of 17 microseconds. The thermopile construction measures radiation and convection equally well with a 180° field-of-view. Each HFM also has a temperature measurement for signal compensation.

HFM	**HFM-6D/H**	**HFM-7E/H**	**HFM-7E/L**	**HFM-8E/L**	**HFM-8E/H**
Time Response (μs) uncoated (coated)	17 (300)	17 (300)	17 (300)	17 (300)*	17 (300)*
Minimum Sensitivity (μV/W/cm²)	10	150	150	150	150
Max Face Temperature (°C)**	800	600/400	350	350	600/400
Metallurgy	Pt/Pt-Rh	NiCr/CuNi	NiCr/CuNi	NiCr/CuNi	NiCr/CuNi
Temperature Sensor	Surface RTD	Surface RTD	Surface RTD	Thermocouple in body	Thermocouple in body
Housing material	Nickel	Nickel	Copper & Brass	Copper & Brass	Nickel
Cable	Mineral sheath	Mineral sheath	Teflon coated	Teflon coated	Mineral sheath
Calibration Accuracy	±3%	±3%	±3%	±3%*	±3%*
Repeatability	2%	2%	2%	2%	2%

* Time response to heat flux only, temperature response for thermocouple measurements may lag depending on heat sink conditions. Large lags in temperature response may affect accuracy.
**Max face temperature listed; max cable temperature is 600°C for E/H units and 200°C for others. For HFM-7E/H and HFM-8E/H max face temperature lists short term and continuous use temperature respectively.

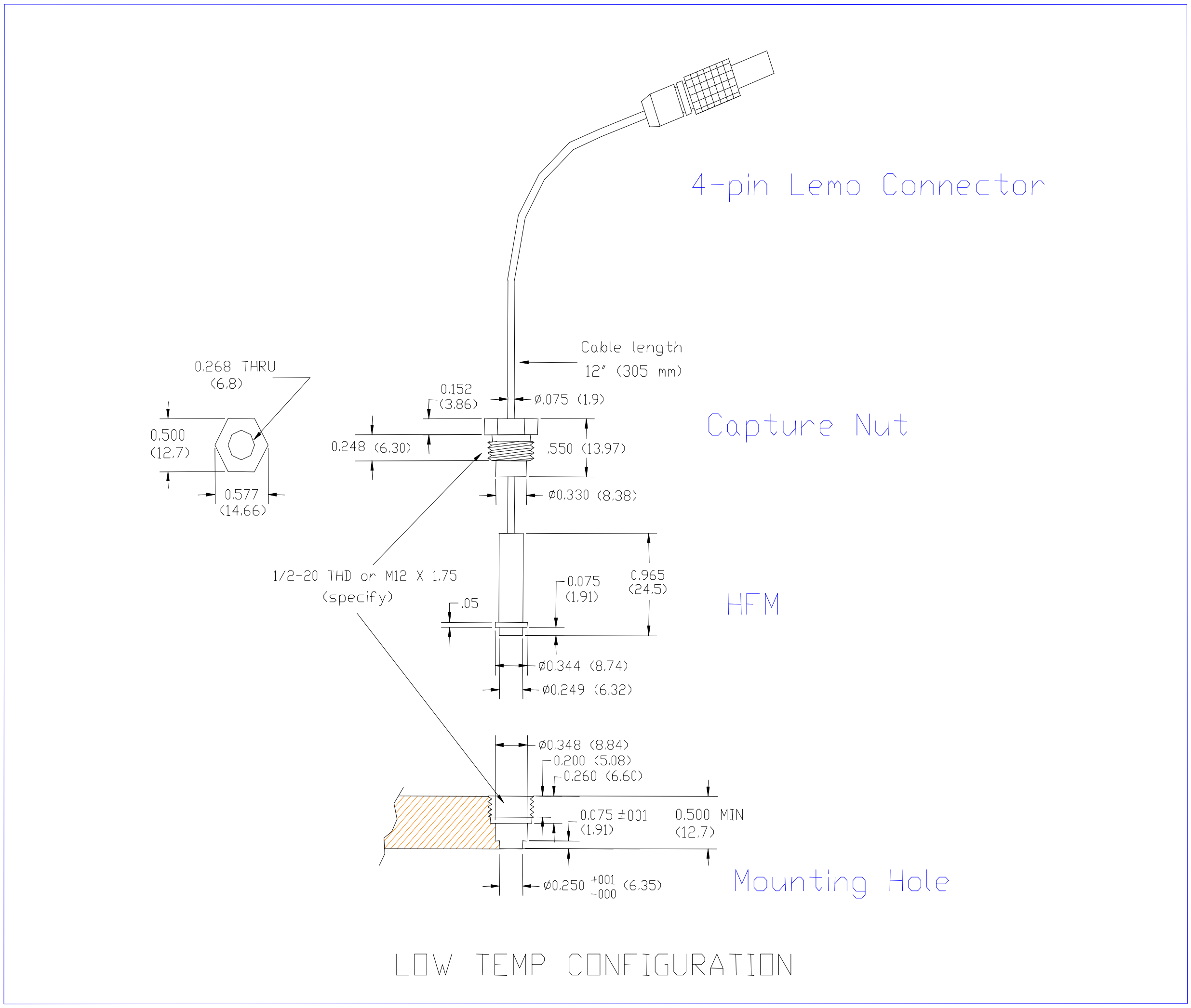
GLOSSARY FOR HEAT TRANSFER

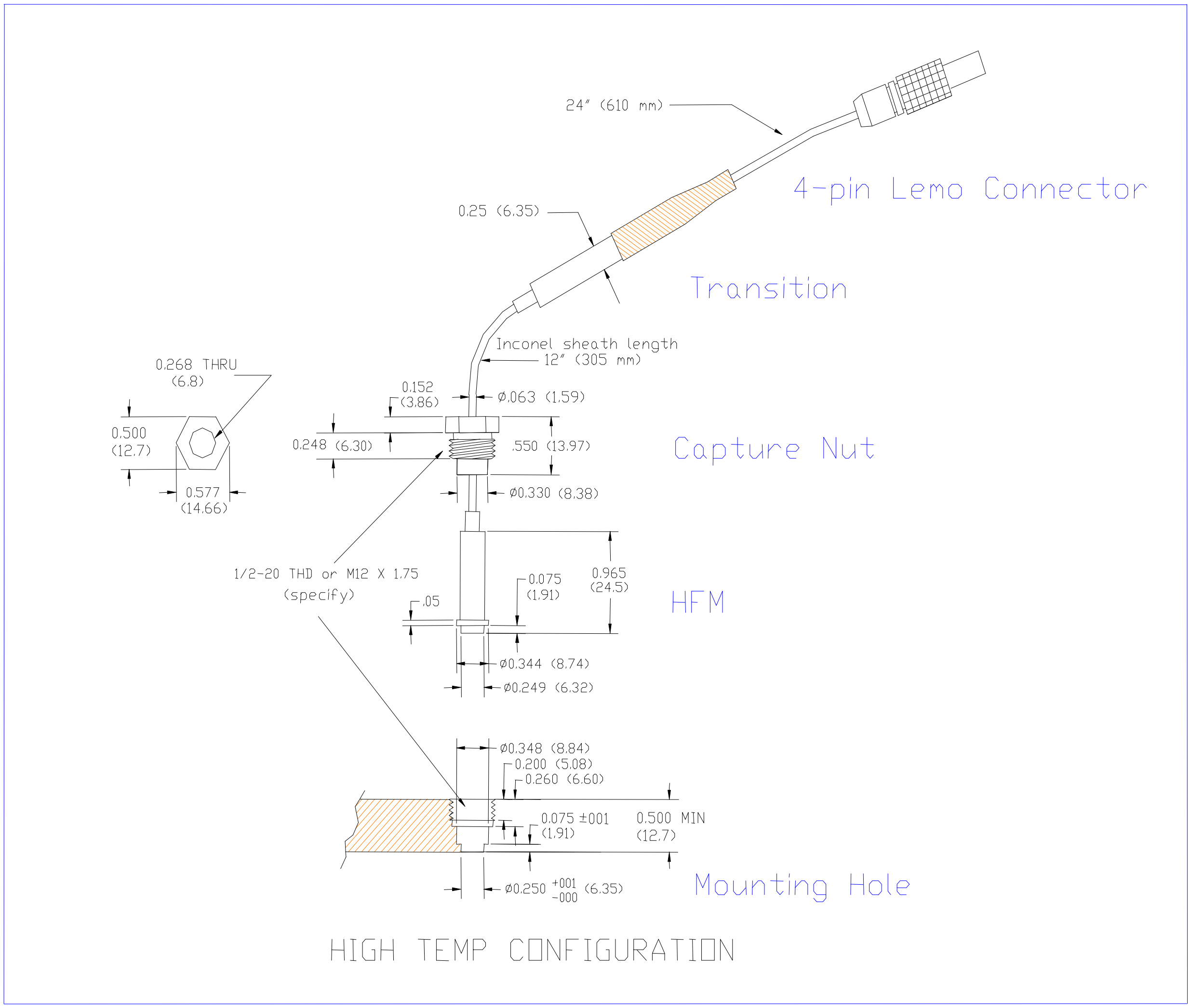
As in any technical discussion, keeping the terminology straight is important. Refer to this glossary if things start to get confusing.

- *Heat* is the amount of energy moved across a thermodynamic barrier, and is measured in Joules (J).
- *Heat transfer* is the rate at which energy moves across the thermodynamic barrier, measured in Watts (W), that is, Joules per second. Heat transfer occurs in three different modes, conduction, convection, and radiation.
- *Heat flux* is the rate of energy transfer per unit area, expressed in W/m^2, W/cm^2, or similar units. Heat flux can be positive or negative, depending on the direction of heat transfer.
- *Temperature* is a fundamental property that indicates the internal energy of matter. Any temperature scale (Celsius, Fahrenheit, *etc.*) may be used as long as the units are kept consistent.
- *Conduction* is a mode of heat transfer through a substance, either solid or fluid, on a molecular level as a result of a temperature gradient being present.
- *Convection* is a mode of heat transfer when there is fluid flow. As in conduction, a temperature gradient must be present, but convection is influenced by fluid flow, which alters the temperature gradient.
- *Radiation* is a mode of heat transfer that occurs via electromagnetic radiation, and does not require any transport medium or material.
- *Emissivity* is the ratio of the actual energy emitted by a real body to that emitted by a blackbody. Emissivity can be considered equal to absorptivity for a gray body; that is a body whose emissivity is independent of wavelength and which reflects radiation in a diffuse manner. Most objects can be reasonably approximated as gray bodies.
- A *thermocouple* is used to measure temperature. It consists of a pair of junctions between two different metals that will produce a voltage proportional to the temperature difference between the junctions of the wires due to the Seebeck effect. Commercially available thermocouples will appear to have only one junction; the second junction is essentially where the two leads are connected to a voltmeter or electronic thermometer. For a thermocouple to give an accurate reading the second junction must be at a reference temperature; frequently this is taken to be room temperature. For more accurate measurements, the second junction is lowered to a known temperature, such as the ice point.
- A *thermopile* is an array of thermocouples. By connecting many thermocouples in series, the temperature sensitivity is increased, because the thermocouple voltages add when linked in series. Like a thermocouple, the thermopile reads the temperature difference between two points. For a heat flux transducer, these two points are the top and bottom layers of the thermopile.

HFM MOUNTING

Mounting torque for the standard capture nut should be 5.5 N-m of torque (50 lbs-in). With a split spacer the torque is only 3.5 N-m (30 lbs-in).




24" (610 mm)
4-pin Lemo Connector
0.25 (6.35)
Transition
Inconel sheath length
12" (305 mm)
0.268 THRU
(6.8)
0.152
(3.86)
Ø.063 (1.59)
0.500
(12.7)
0.248 (6.30)
.550 (13.97)
Capture Nut
0.577
(14.66)
Ø0.330 (8.38)
1/2-20 THD or M12 X 1.75
(specify)
0.075
(1.91)
0.965
(24.5)
.05
HFM
Ø0.344 (8.74)
Ø0.249 (6.32)
Ø0.348 (8.84)
0.200 (5.08)
0.260 (6.60)
0.075 ±001
(1.91)
0.500 MIN
(12.7)
Ø0.250 +001 -000 (6.35)
Mounting Hole
HIGH TEMP CONFIGURATION

WARRANTY

Vatell Corporation warrants that this product will be free from defects in materials and workmanship for a period of 90 days from the date of shipment. If the product proves defective during this warranty period, Vatell Corporation, at its option, either will repair the defective product without charge for parts and labor, or will provide a replacement in exchange for the defective product.

In order to obtain service under this warranty, the customer must notify Vatell Corporation in writing of the defect before the expiration of the warranty period and make arrangements for service. The customer shall be responsible for packaging and shipping of the defective product to Vatell Corporation with shipping charges prepaid. Vatell Corporation will pay for the return of the product to the customer, if the shipment is to a location within the United States of America. The customer is responsible for paying all shipping charges, duties, taxes, and any other charges for products returned to locations outside of the USA.

This warranty shall not apply to any defect, failure or damage caused by improper use or improper or inadequate maintenance and care.

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