MIL-PRF-38534 CERTIFIED

# RADIATION HARDENED HIGH CURRENT ULTRA LOW DROPOUT ADJUSTABLE POSITIVE LINEAR REGULATOR

# 5951RH

M.S.KENNEDY CORP.

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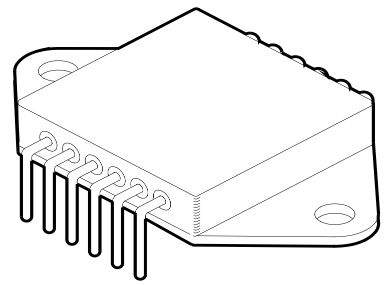
## FEATURES:

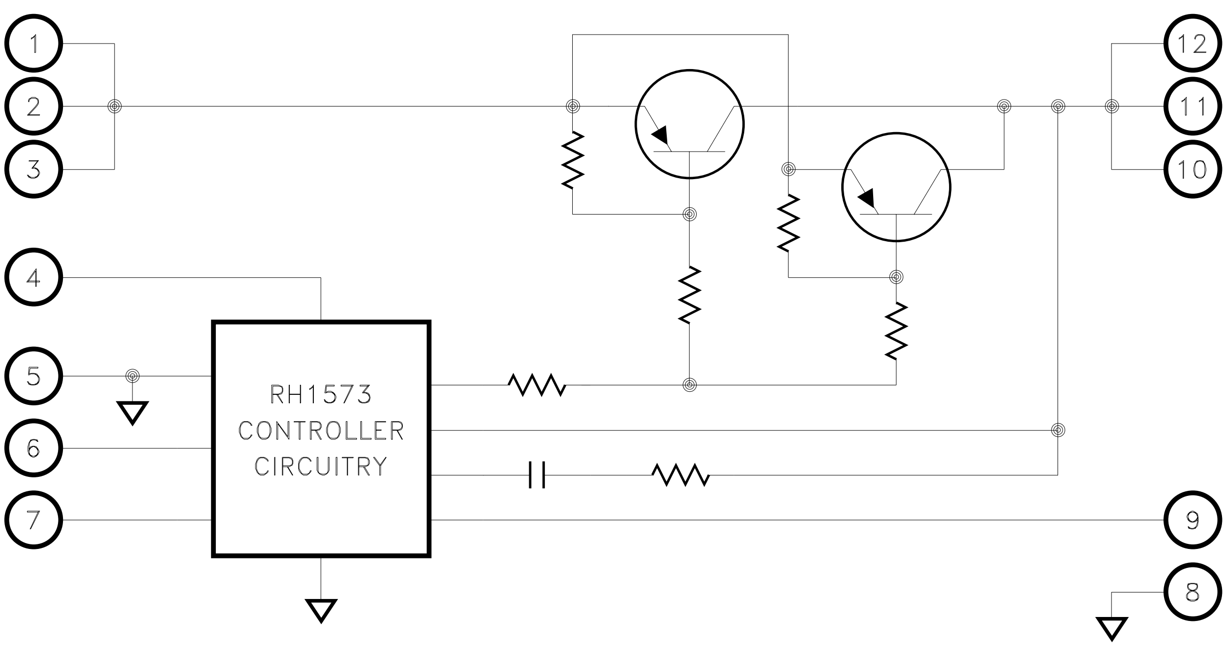


- Manufactured using LINEAR TECHNOLOGY Space Qualified RH1573 Die
- Total Dose Tested to TBDK RAD (Method 1019.7 Condition A)
- Ultra Low Dropout for Reduced Power Consumption
- External Shutdown/Reset Function
- Latching Overload Protection
- Adjustable Output Using Two External Resistors
- Output Current Limit
- Surface Mount Package Available with Lead Forming
- Low Input Voltage for Maximum Efficiency
- Up to 10A Output Current
- Contact MSK for MIL-PRF-38534 Qualification and Appendix G (Radiation) Status

## DESCRIPTION:

The MSK 5951RH is a radiation hardened adjustable linear regulator capable of delivering up to 10 amps of output current. The typical dropout is only 0.11 volts at 2 amps. An external shutdown/reset function is ideal for power supply sequencing. This device also has latching overload protection that requires no external current sense resistor. The MSK 5951RH is radiation hardened and specifically designed for many space/satellite applications. The device is packaged in a hermetically sealed, space efficient 12 pin power dual in line package that has high thermal conductivity for efficient device cooling..

## EQUIVALENT SCHEMATIC




## TYPICAL APPLICATIONS

- Satellite System Power Supplies
- Switching Power Supply Post Regulators
- Constant Voltage/Current Regulators
- Microprocessor Power Supplies

## PIN-OUT INFORMATION

| | | | |
|---|---|---|---|
| 1 | VINA | 12 | VOUTC |
| 2 | VINB | 11 | VOUTB |
| 3 | VINC | 10 | VOUTA |
| 4 | VBIAS | 9 | FB |
| 5 | GND1 | 8 | GND2 |
| 6 | SHUTDOWN | 7 | LATCH |

## ABSOLUTE MAXIMUM RATINGS ⑧

| | | |
|---|---|---|
| $+V_{BIAS}$ | Bias Supply Voltage | 10.0V |
| $+V_{IN}$ | Supply Voltage | 10.0V |
| $I_{OUT}$ | Output Current ⑦ | 10A |
| $T_C$ | Case Operating Temperature Range | |
| | MSK5951K/H/E RH | -55°C to +125°C |
| | MSK5951RH | -40°C to +85°C |
| $T_{ST}$ | Storage Temperature Range | -65°C to +150°C |
| $T_{LD}$ | Lead Temperature Range (10 Seconds) | 300°C |
| $P_D$ | Power Dissipation | See SOA Curve |
| $T_C$ | Junction Temperature | 150°C |

## ELECTRICAL SPECIFICATIONS

| Parameter | Test Conditions ①⑨ | Group A Subgroup | MSK5951K/H/E Min. | MSK5951K/H/E Typ. | MSK5951K/H/E Max. | MSK5951 Min. | MSK5951 Typ. | MSK5951 Max. | Units |
|---|---|---|---|---|---|---|---|---|---|
| Input Voltage Range ② | 10mA ≤ $I_{OUT}$ ≤ 8.0A | 1,2,3 | 2.0 | - | 7.5 | 2.0 | - | 7.5 | V |
| Input Bias Voltage ② | $V_{BIAS}$ ≥ $V_{IN}$ | 1,2,3 | 2.9 | 5.0 | 7.5 | 2.9 | 5.0 | 7.5 | V |
| Feedback Voltage | $I_{OUT}$ = 8.0A R1 = 187Ω | 1 | 1.225 | 1.265 | 1.305 | 1.202 | 1.265 | 1.328 | V |
| | | 2,3 | 1.225 | - | 1.305 | - | - | - | V |
| | Post Radiation | 1 | TBD | - | TBD | TBD | - | TBD | V |
| Feedback Pin Current ② | $V_{FB}$ = 1.265V 10mA ≤ $I_{OUT}$ ≤ 8.0A | 1,2,3 | 0 | - | 5.0 | 0 | - | 5.0 | μA |
| Quiescent Current | $I_{IN}$ + $I_{BIAS}$, $V_{BIAS}$ = $V_{IN}$ = 7.5V Not including $I_{OUT}$ | 1,2,3 | - | 11 | 20 | - | 11 | 20 | mA |
| Bias Current | $V_{BIAS}$ = 7.5V | 1,2,3 | - | 2 | 4 | - | 2 | 4 | mA |
| Line Regulation | $I_{OUT}$ = 10mA 2.8V ≤ $V_{IN}$ ≤ 7.5V | 1 | - | ±0.01 | ±0.50 | - | 0.01 | ±0.60 | %$V_{OUT}$ |
| | R1 = 187Ω | 2,3 | - | - | ±0.50 | - | - | - | %$V_{OUT}$ |
| Load Regulation | 10mA ≤ $I_{OUT}$ ≤ 8.0A | 1 | - | ±0.06 | ±0.80 | - | 0.06 | ±1.0 | %$V_{OUT}$ |
| | R1 = 976 | 2,3 | - | - | ±0.80 | - | - | - | %$V_{OUT}$ |
| Dropout Voltage | Delta FB = 1% $I_{OUT}$ = 7.0A | 1 | - | TBD | TBD | - | TBD | TBD | V |
| | | 2,3 | - | TBD | TBD | - | - | - | V |
| Minimum Output Current ② | 2.8V ≤ $V_{IN}$ ≤ 7.5V | 1 | - | 8 | 10 | - | 8 | 10 | mA |
| | R1 = 187Ω | 2,3 | - | 9 | 10 | - | - | - | mA |
| Output Voltage Range ② | $V_{IN}$ = 7.5V | - | 1.5 | - | 7.0 | 1.5 | - | 7.0 | V |
| Output Current Limit ⑦ | $V_{IN}$ = 2.5V $V_{OUT}$ = 1.5V | 1 | 8.0 | 9.0 | 10.0 | 8.0 | 9.0 | 10.0 | A |
| | | 2,3 | 8.0 | 9.0 | 10.0 | - | - | - | A |
| Shutdown Threshold | $V_{OUT}$ ≤ 0.2V (OFF) | 1 | 1.0 | 1.3 | 1.6 | 1.0 | 1.3 | 1.6 | V |
| | $V_{OUT}$ = Nominal (ON) | 2,3 | 1.0 | 1.3 | 1.6 | - | - | - | V |
| Shutdown Hysteresis | Difference between voltage | 1 | - | 0.02 | 0.2 | - | 0.02 | 0.2 | V |
| | threshold of $V_{SDI}$ (ON) and $V_{SDI}$ (OFF) | 2,3 | - | 0.03 | 0.2 | - | - | - | V |
| Ripple Rejection ② | f = 1KHz to 10KHz | 4 | 20 | - | - | 20 | - | - | dB |
| | 10mA ≤ $I_{OUT}$ ≤ 1.0A 1.0V = $V_{IN}$-$V_{OUT}$ | 5,6 | 20 | - | - | - | - | - | dB |
| Phase Margin ② | $I_{OUT}$ = 450mA | 4,5,6 | 30 | 80 | - | 30 | 80 | - | degrees |
| Gain Margin ② | $I_{OUT}$ = 45OmA | 4,5,6 | 10 | 30 | - | 10 | 30 | - | dB |
| Equivalent Noise Voltage ② | Referred to Feedback Pin | 4,5,6 | - | - | 50 | - | - | 50 | μ$V_{RMS}$ |
| Thermal Resistance ② | Junction to Case @ 125°C Output Devices | - | - | 1.8 | 2.1 | - | 1.8 | 2.5 | °C/W |

## NOTES:

① Unless otherwise specified, $V_{BIAS}$ = $V_{IN}$ = 5.0V, R1 = 1.62K, $V_{SHUTDOWN}$ = 0V and $I_{OUT}$ = 10mA. $I_{OUT}$ is subtracted from $I_Q$ measurement. See typical application circuit.
② Guaranteed by design but not tested. Typical parameters are representative of actual device performance but are for reference only.
③ Industrial grade and "E" suffix devices shall be tested to subgroups 1 and 4 unless otherwise requested.
④ Military grade devices ("H" suffix) shall be 100% tested to subgroups 1,2,3 and 4.
⑤ Subgroup 5 and 6 testing available upon request.
⑥ Subgroup 1,4 $T_C$ = +25°C
Subgroup 2,5 $T_C$ = +125°C
Subgroup 3,6 $T_A$ = -55°C
⑦ Output current limit is tested with a low duty cycle pulse to minimize junction heating and is dependent on the values of $V_{IN}$, $V_{OUT}$ and case temperature. See Typical Performance Curves.
⑧ Continuous operation at or above absolute maximum ratings may adversely effect the device performance and/or life cycle.
⑨ Pre and post irradiation limits, up to 300Krad TID, are identical unless otherwise specified.

## PIN FUNCTIONS

VIN A,B,C - These pins provide the input power connection to the MSK 5951RH. This is the supply that will be regulated to the output. All three pins must be connected for proper operation.

VBIAS - This pin provides power to all internal circuitry including bias, start-up, thermal limit and overcurrent latch. VBIAS voltage range is 2.9V to 7.5V. VBIAS should be kept greater than or equal to VIN.

GND1 - Internally connected to input ground, this pin should be connected externally by the user to the circuit ground and the GND2 pins.

LATCH - The MSK 5951RH LATCH pin is used for both current limit and thermal limit. A capacitor between the LATCH pin and ground sets a time out delay in the event of an over current or short circuit condition. The capacitor is charged to approximately 1.6V from a 7.2µA (nominal) current source. Exceeding the thermal limit will charge the latch capacitor from a larger current source for a near instant shutdown. Once the latch capacitor is charged the device latches off until the latch is reset. Momentarily pull the LATCH pin low, toggle the shutdown pin high then low or cycle the power to reset the latch. Toggling the shutdown pin or cycling the bias power both disable the device during the reset operation (see SHUTDOWN pin description). Pulling the LATCH pin low immediately enables the device for as long as the LATCH pin is held low plus the time delay to re-charge the latch capacitor whether or not the fault has been corrected. Disable the latch feature by tying the LATCH pin low. With the LATCH pin held low the thermal limit feature is disabled and the current limit feature will force the output voltage to droop but remain active if excessive current is drawn.

SHUTDOWN - There are two functions to the SHUTDOWN pin. It may be used to disable the output voltage or to reset the LATCH pin. To activate the shutdown/reset functions the user must apply a voltage greater than 1.3V to the SHUTDOWN pin. The output voltage will turn on when the SHUTDOWN pin is pulled below the threshold voltage. If the SHUTDOWN pin is not used, it should be connected to ground.

FB - The FB pin is the inverting input of the internal error amplifier. The non-inverting input is connected to an internal 1.265V reference. This error amplifier controls the drive to the output transistor to force the FB pin to 1.265V. An external resistor divider is connected to the output, FB pin and ground to set the output voltage.

GND2 - Internally connected to output ground, this pin should be connected externally by the user to the circuit ground and the GND1 pins.

VOUT A,B,C - These are the output pins for the device. All three pins must be connected for proper operation.

## OUTPUT CAPACITOR SELECTION

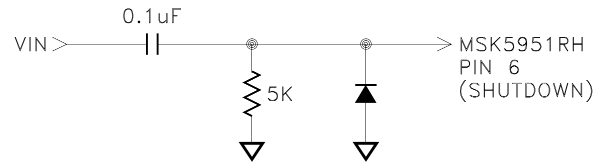
Typically, large bulk capacitance is required at the output of a linear regulator to maintain good load transient response. However, with the MSK 5951RH this is not the case. A 100µF surface mount tantalum capacitor in parallel with a 0.1µF ceramic capacitor from the output to ground should suffice under most conditions. If the user finds that tighter voltage regulation is needed during output transients, more capacitance may be added. If more capacitance is added to the output, the bandwidth may suffer. See typical gain and phase curves.

## POWER SUPPLY BYPASSING

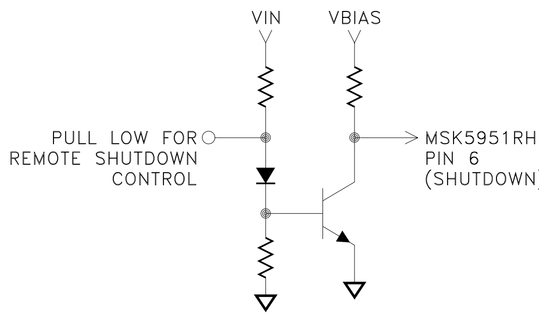
To maximize transient response and minimize power supply transients it is recommended that a 100µF minimum tantalum capacitor is connected between VIN and ground. A 0.1µF ceramic capacitor should also be used for high frequency bypassing.

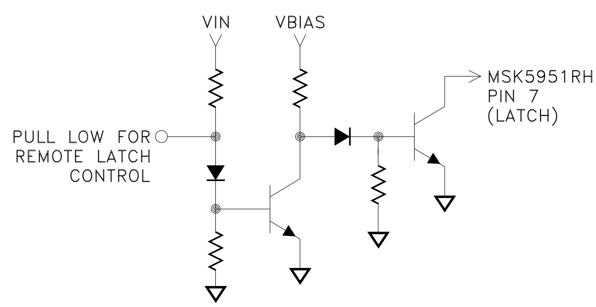
## START UP OPTIONS

The MSK 5951RH starts up and begins regulating immediately when VBIAS and VIN are applied simultaneously. Applying VBIAS before VIN starts the MSK 5951RH up in a disabled or latched state. When starting in a latched state the device output can be enabled either by pulling the latch pin low to drain the latch capacitor or pulsing the shutdown pin high. The shutdown pulse duration is partially dependent upon the size of the latch capacitor and should be characterized for each application; 30uS is typically adequate for a 1uF latch capacitor at 25°C. A momentary high pulse on the shutdown pin can be achieved using the RC circuit below if VIN rises rapidly. The resistor and capacitor must be selected based on the required pulse duration, the rise characteristic of VIN and the shutdown pin threshold (see shutdown pin threshold and current curves).




The shutdown pin can be held high and pulled low after VIN comes up or the latch pin held low and released after VIN comes up to ensure automatic startup when applying VBIAS before VIN. Either of the basic circuits below can be adapted to a variety of applications for automatic start up when VBIAS rises before VIN.




## OVERCURRENT LATCH-OFF/LATCH PIN CAPACITOR SELECTION

As previously mentioned, the LATCH pin provides over current/output short circuit protection with a timed latch-off circuit. Reference the LATCH pin description note. The latch off time out is determined with an external capacitor connected from the LATCH pin to ground. The time-out period is equal to the time it takes to charge this external capacitor from 0V to 1.6V. The latch charging current is provided by an internal current source. This current is a function of bias voltage and temperature (see latch charging current curve). For instance, at 25°C, the latch charging current is 7.2µA at VBIAS = 3V and 8µA at VBIAS = 7V.

In the latch-off mode, some additional current will be drawn from the bias supply. This additional latching current is also a function of bias voltage and temperature (see typical performance curves).

The MSK 5951RH current limit function is directly affected by the input and output voltages. Custom current limit is available; contact the factory for more information.

# APPLICATION NOTES CONT.

## THERMAL LIMITING

The MSK 5951RH control circuitry has a thermal shutdown temperature of approximately 150°C. This thermal shutdown can be used as a protection feature, but for continuous operation, the junction temperature of the pass transistor must be maintained below 150°C. Proper heat sink selection is essential to maintain these conditions. Exceeding the thermal limit activates the latch feature of the MSK 5951RH. See LATCH pin description for instructions to reset the latch or disable the latch feature.

## HEAT SINK SELECTION

To select a heat sink for the MSK 5951RH, the following formula for convective heat flow may be used.

### Governing Equation:

$$T_J = P_D \times (R_{\theta JC} + R_{\theta CS} + R_{\theta SA}) + T_A$$

Where

- $T_J$ = Junction Temperature
- $P_D$ = Total Power Dissipation
- $R_{\theta JC}$ = Junction to Case Thermal Resistance
- $R_{\theta CS}$ = Case to Heat Sink Thermal Resistance
- $R_{\theta SA}$ = Heat Sink to Ambient Thermal Resistance
- $T_A$ = Ambient Temperature

$$\text{Power Dissipation} = (V_{IN} - V_{OUT}) \times I_{OUT}$$

Next, the user must select a maximum junction temperature. The absolute maximum allowable junction temperature is 150°C. The equation may now be rearranged to solve for the required heat sink to ambient thermal resistance ($R_{\theta SA}$).

### Example:

An MSK 5951RH is connected for $V_{IN}$ = +5V and $V_{OUT}$ = +3.3V. $I_{OUT}$ is a continuous 4A DC level. The ambient temperature is +25°C. The maximum desired junction temperature is +125°C.

$R_{\theta JC}$ = 2.1°C/W and $R_{\theta CS}$ = 0.15°C/W for most thermal greases

$$\text{Power Dissipation} = (5V - 3.3V) \times (4A) = 6.8 \text{ Watts}$$

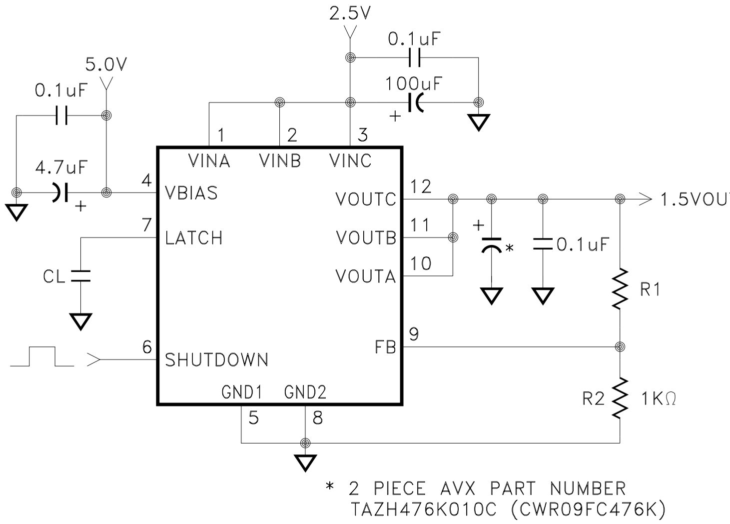
Solve for $R_{\theta SA}$:

$$R_{\theta SA} = \left[\frac{125°C - 25°C}{6.8W}\right] - 2.1°C/W - 0.15°C/W$$

$$= 12.5°C/W$$

In this example, a heat sink with a thermal resistance of no more than 12.5°C/W must be used to maintain a junction temperature of no more than 125°C.

## TYPICAL APPLICATIONS CIRCUIT




$$V_{OUT} = 1.265(1 + R1/R2)$$

## OUTPUT VOLTAGE SELECTION

As noted in the above typical applications circuit, the formula for output voltage selection is

$$V_{OUT} = 1.265\left[1 + \frac{R1}{R2}\right]$$

A good starting point for this output voltage selection is to set R2 = 1K. By rearranging the formula it is simple to calculate the final R1 value.

$$R1 = R2\left[\frac{V_{OUT}}{1.265} - 1\right]$$

Table 1 below lists some of the most probable resistor combinations based on industry standard usage.

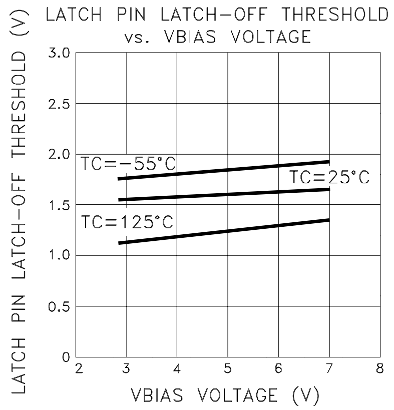
TABLE 1

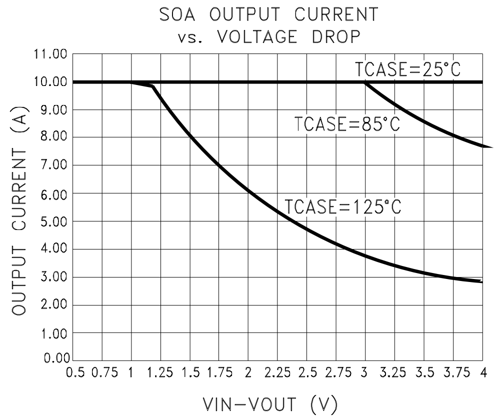
| OUTPUT VOLTAGE (V) | R2 (Ω) | R1 (nearest 1%) (Ω) |
|---|---|---|
| 1.5 | 1K | 187 |
| 1.8 | 1K | 422 |
| 2.0 | 1K | 576 |
| 2.5 | 1K | 976 |
| 2.8 | 1K | 1.21K |
| 3.3 | 1K | 1.62K |
| 4.0 | 1K | 2.15K |
| 5.0 | 1K | 2.94K |

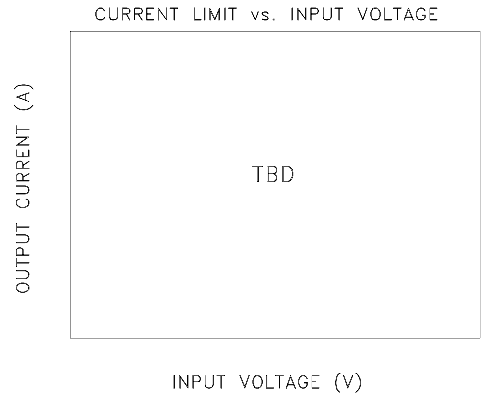
## TOTAL DOSE RADIATION TEST PERFORMANCE

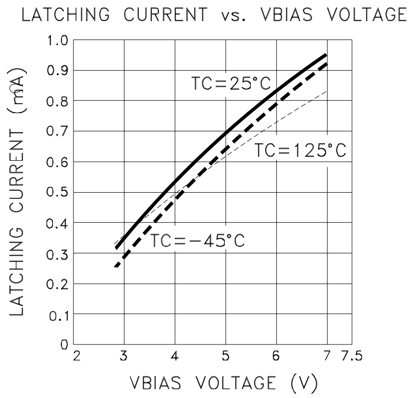
Radiation performance curves for TID testing have been generated for all radiation testing performed by MS Kennedy. These curves show performance trends throughout the TID test process and will be located in the MSK 5951RH radiation test report after TID testing has been performed. The complete radiation test report will be available in the RAD HARD PRODUCTS section on the MSK website.

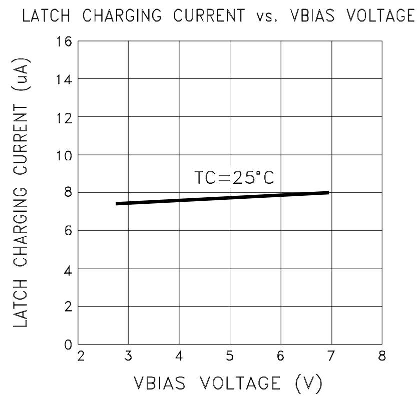
# TYPICAL PERFORMANCE CURVES

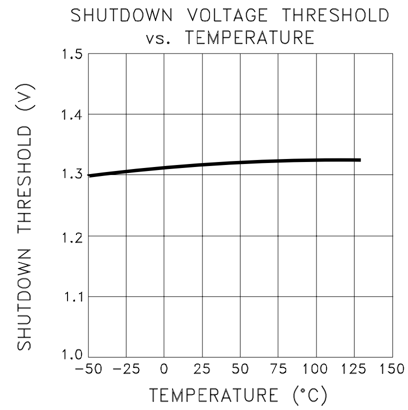


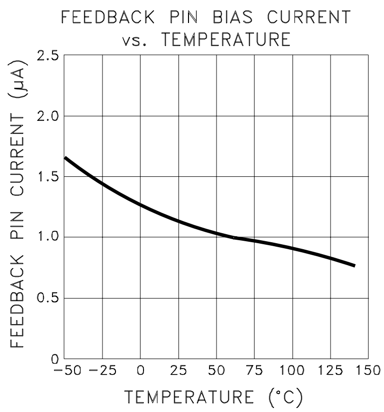



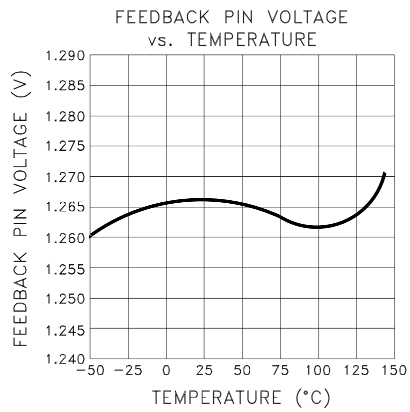



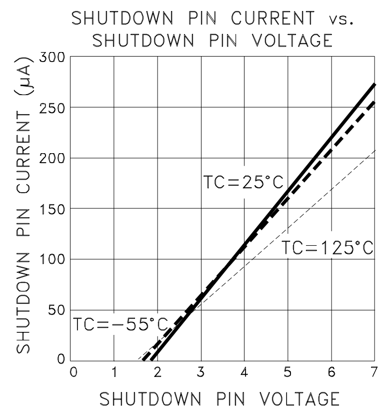



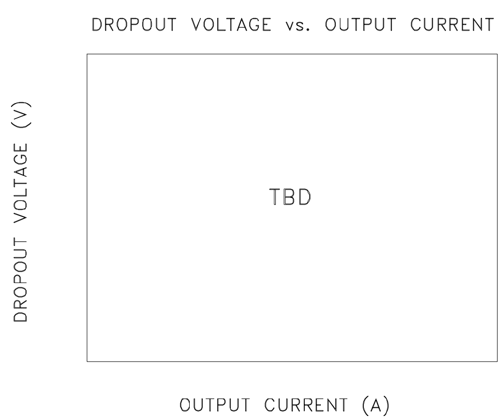



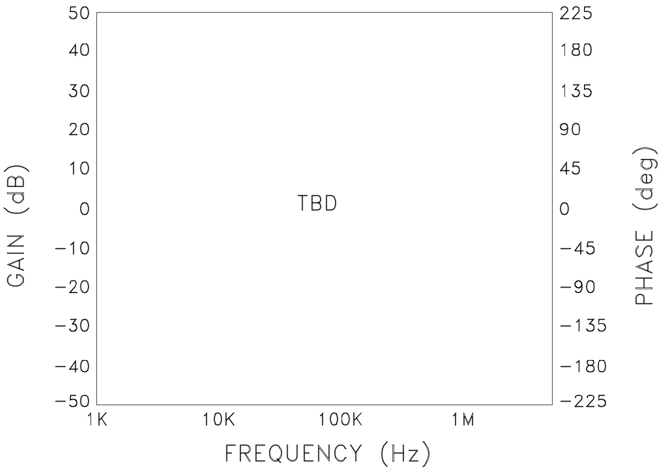



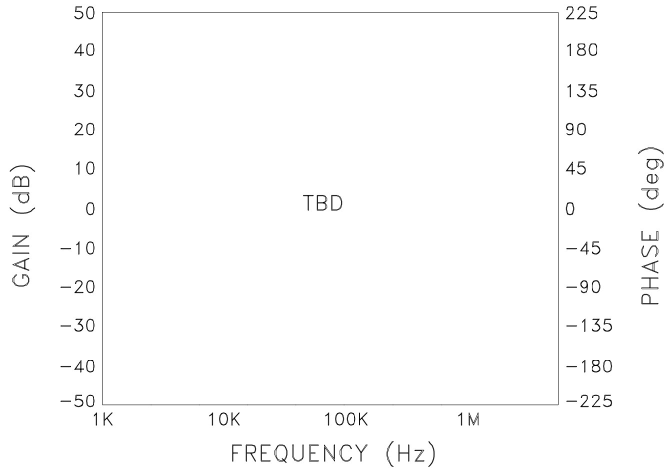



## GAIN AND PHASE RESPONSE
## (SEE TYPICAL APPLICATION CIRCUIT FOR CAPACITIVE LOAD)

MSK5951RH GAIN AND PHASE vs. FREQUENCY




MSK5951RH GAIN AND PHASE vs. FREQUENCY

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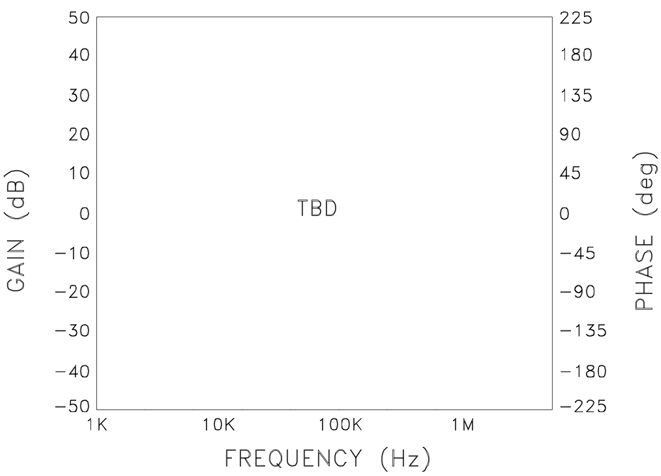


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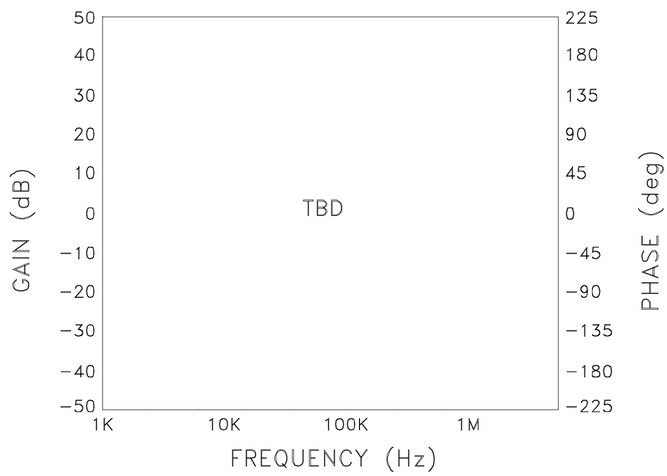


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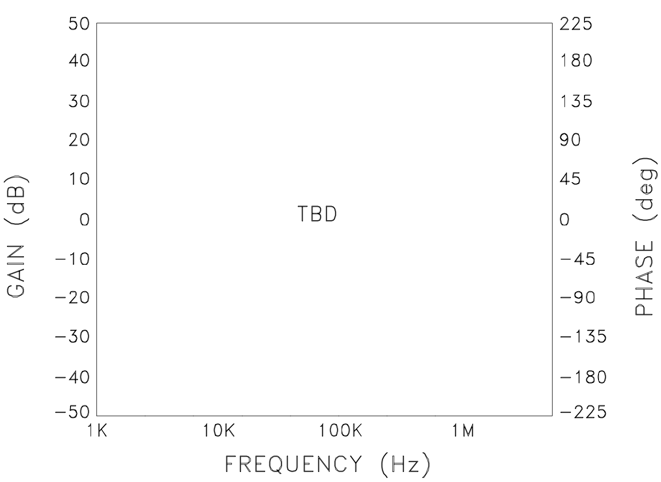
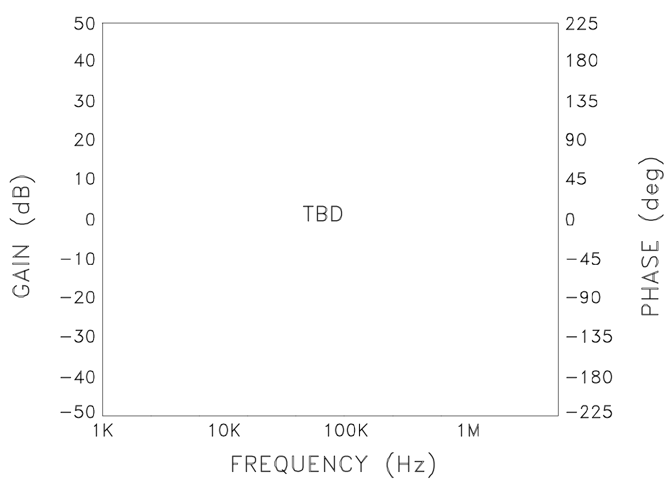
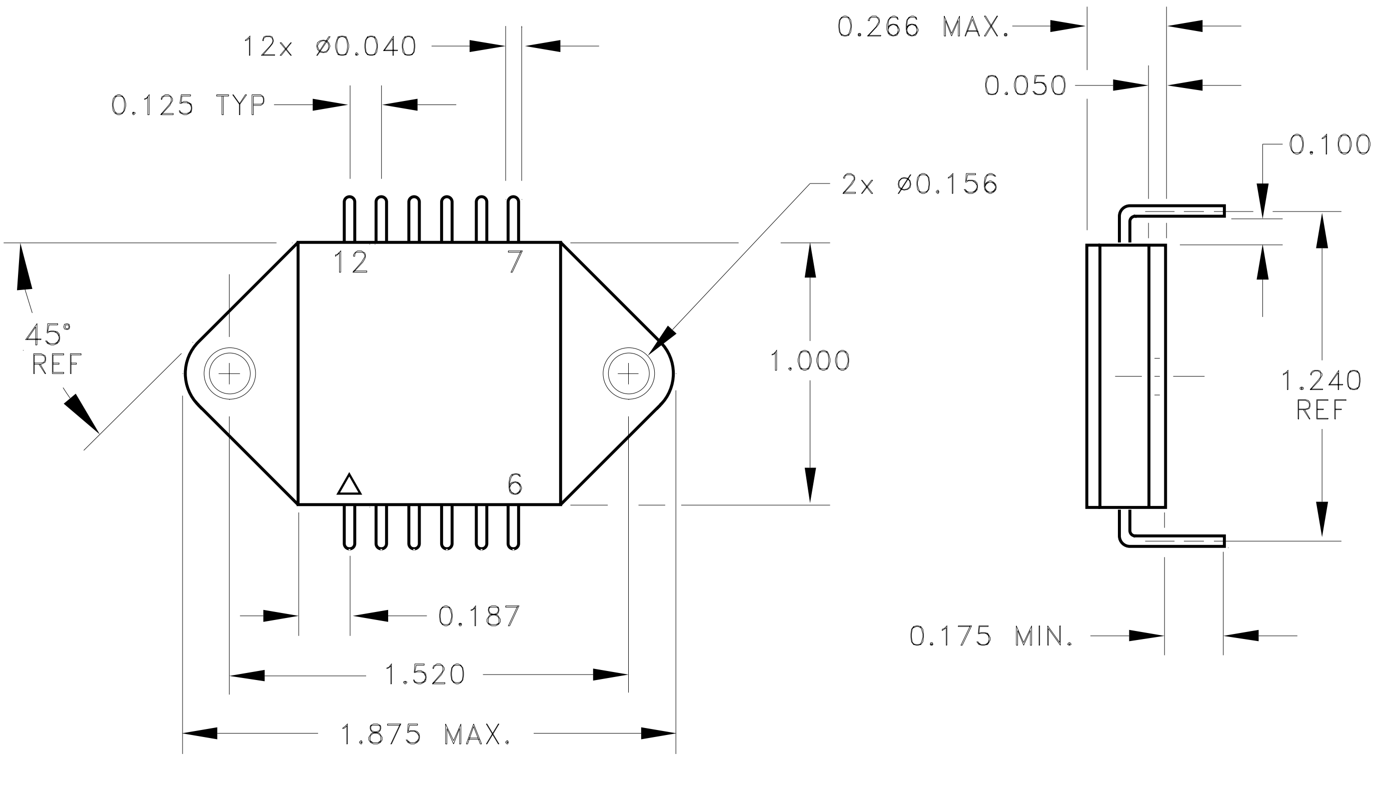



MSK5951RH GAIN AND PHASE vs. FREQUENCY



## MECHANICAL SPECIFICATIONS CONTINUED




WEIGHT = TBD GRAMS TYPICAL

ALL DIMENSIONS ARE ±0.010 INCHES UNLESS OTHERWISE LABELED.
ESD Triangle indicates pin 1.

# ORDERING INFORMATION

| PART NUMBER | SCREENING LEVEL |
|---|---|
| MSK5951RH | INDUSTRIAL |
| MSK5951ERH | EXTENDED RELIABILITY |
| MSK5951HRH | MIL-PRF-38534 CLASS H |
| MSK5951KRH | MIL-PRF-38534 CLASS K |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Contact MSK for MIL-PRF-38534 Class H, Class K and Appendix G (radiation) status.