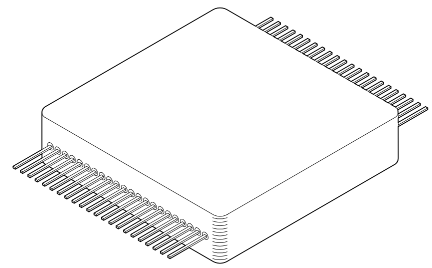
HIGH EFFICIENCY, HIGH VOLTAGE 4 AMP SURFACE MOUNT SWITCHING REGULATORS

5035 SERIES

FEATURES:

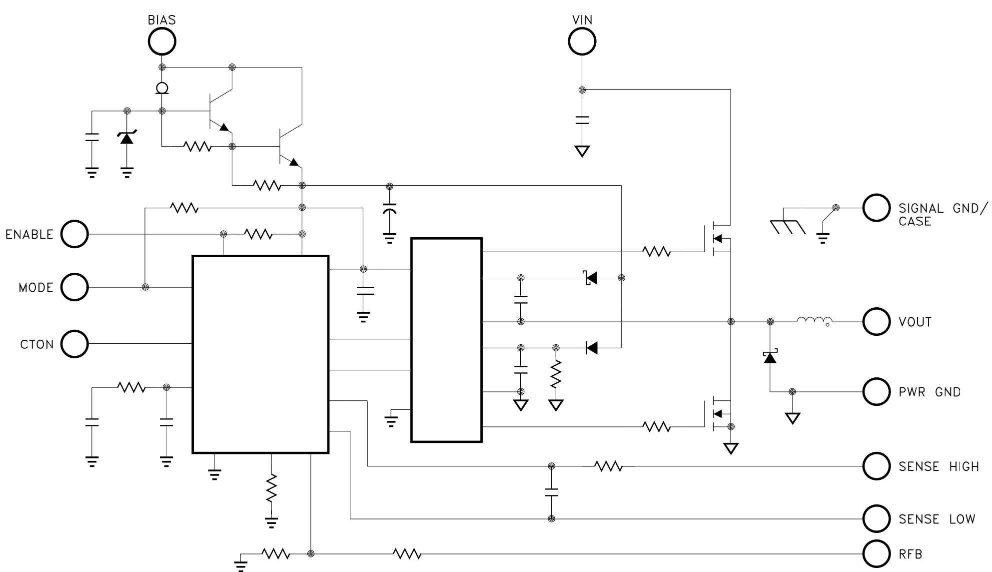
- Up To 88% Efficiency For 5V Version
- 4 Amp Output Current
- 1.2 x VOUT to 80V Input Range with Separate Bias
- 12V to 80V Input Range with UVLO (VBIAS=VIN)
- Preset 2.5V, 3.3V or 5.0V Output Versions
- 300KHz Switching Frequency @ 1 Amp
- User Programmable Soft-Start
- User Programmable Current Limit
- Hermetic Package
- -55°C to +125°C Operating Temperature Range
- Available with Gull Wing Leads
- Contact MSK for MIL-PRF-38534 Qualification Status



DESCRIPTION:

The MSK5035 series are high efficiency, 4 amp, surface mount switching regulators. The output voltage is configured for 2.5V, 3.3V or 5.0V internally with a tolerance of 1% at 1.5 amps. The operating frequency of the MSK5035 is 300KHz. An external "soft start" capacitor allows the user to control how quickly the output comes up to regulation voltage after the application of an input. A low quiescent current and greater than 85% operating efficiency keep the total internal power dissipation of the MSK5035 down to an absolute minimum. The input circuitry has been designed to withstand a very wide range of voltages from less than 12V to as high as 80V. The device is packaged in a hermetic kovar flatpack for high reliability applications and is available screened to MIL-PRF-38534 Class H.

EQUIVALENT SCHEMATIC



TYPICAL APPLICATIONS

- Step-down Switching Regulator
- Microprocessor Power Source
- High Efficiency Low Voltage
- Subsystem Power Supply

PIN-OUT INFORMATION

1	SIGNAL GND/CASE
2	Sense High
3	Sense Low
4	NC
5	RFB
6	NC
7	MODE
8	CTON
9	NC
10	ENABLE
11	VBIAS
12-22	VIN
23-33	PWR GND
34-44	VOUT

ABSOLUTE MAXIMUM RATINGS ⑪

	Input Voltage	+80V
	ENABLE	5V
	MODE	24V
	Output Current	4.0 Amps
	Sense Pin Voltage	40V
	Thermal Resistance (@ 125°C) (Each MOSFET)	15°C/W
T_{ST}	Storage Temperature Range ⑫	-65°C to +150°C
T_{LD}	Lead Temperature Range (10 Seconds)	300°C
T_C	Case Operating Temperature Range	
	MSK5035 Series	-40°C to +85°C
	MSK5035H Series	-55°C to +125°C
T_J	Junction Temperature	+150°C

ELECTRICAL SPECIFICATIONS

Parameter		Test Conditions ①	Group A Subgroup	MSK5035H SERIES			MSK5035 SERIES			Units
				Min.	Typ.	Max.	Min.	Typ.	Max.	
VIN Input Supply Range ⑩			1, 2, 3	Note 10	28	80	Note 10	28	80	V
VBias Input Supply Range ② ⑨			1, 2, 3	12	28	80	12	28	80	V
VBias Current		VIN = 1.5 x (VOUT) VBIAS = 15V IOUT = 2A	1	12	28	-	12	28	-	mA
Under Voltage Lockout		Input Rising	1	7.4	10.2	12.0	7.3	10.2	12.0	V
		Input Falling	1	7.0	9.9	11.7	6.9	9.9	11.7	V
Output Voltage 5045-2.5 ⑧		IOUT = 1.5A	1	2.47	2.5	2.53	2.45	2.5	2.53	V
			2, 3	2.43	2.5	2.56	-	-	-	V
Output Voltage 5045-3.3 ⑧		IOUT = 1.5A	1	3.27	3.3	3.33	3.23	3.3	3.37	V
			2, 3	3.32	3.3	3.38	-	-	-	V
Output Voltage 5045-5.0 ⑧		IOUT = 1.5A	1	4.95	5.0	5.05	4.9	5.0	5.1	V
			2, 3	4.87	5.0	5.13	-	-	-	V
Output Current ②		Within SOA	1	4.0	4.2	-	4.0	4.2	-	A
Load Regulation		0.75A ≤ IOUT ≤ 2.5A	1	-	0.5	1.0	-	0.5	1.0	%
			2, 3	-	0.5	2.0	-	-	-	%
Line Regulation		IOUT = 1.5A 12V ≤ VIN ≤ 40V	1	-	0.5	1.0	-	0.5	1.0	%
			2, 3	-	0.5	2.0	-	-	-	%
Oscillator Frequency ② ⑦		IOUT ≥ 1.5A	4	270	300	330	270	300	330	KHz
Enable Input Voltage ②		Open Circuit Voltage	1	-	12.8	-	-	12.8	-	V
		Rising	1, 2, 3	1.3	1.35	1.4	-	-	1.0	V
Enable Input Current ②		VEN = 0V	1	-	120	200	-	120	200	uA
MODE Input Voltage ②		Open Circuit Voltage	1	-	12.8	-	-	12.8	-	V
		Low	1, 2, 3	-	-	0.5	-	-	0.5	V
MODE Input Current ②		MODE = 0V	1	-	120	200	-	120	200	uA
Disabled Quiescent Current		VEN = 0V	1	-	1	2.5	-	1	2.5	mA
Current Limit Threshold ②		Positive	1	80	100	120	75	100	125	mV
		Negative	1	-	-100	-	-	-100	-	mV
Cton Current ②		Source	1	-	2.0	-	-	2.0	-	uA
Efficiency	5035-2.5	VIN = 16V IOUT = 1.5A	-	-	81	-	-	81	-	%
	5035-3.3	VIN = 16V IOUT = 1.5A	-	-	83	-	-	83	-	%
	5035-5.0	VIN = 16V IOUT = 1.5A	-	-	85	-	-	85	-	%

NOTES:

① VIN = VBIAS = 28V, 5mV ≤ (sense high-sense low) ≤ 75mV, I_L = 0.1A, ENABLE = NC, MODE = NC, R_{SENSE} = 0.01 OHM, C_{OUT} = 5 x 470µF, C_{IN} = 1 x 250µF + 4 x 10µF, C_{TON} = 0.01µF unless otherwise specified.

② Guaranteed by design but not tested. Typical parameters are representative of actual device performance but are for reference only.

③ All output parameters are tested using a low duty cycle pulse to maintain T_J = T_C.

④ Industrial grade devices shall be tested to subgroup 1 unless otherwise specified.

⑤ Military grade devices ('H' suffix) shall be 100% tested to subgroups 1, 2 and 3.

⑥ Subgroup 1 T_A = T_C = +25°C
2 T_A = T_C = +125°C
3 T_A = T_C = -55°C

⑦ Actual switching frequency is load dependent if output current is low and sense resistor is large or zero. Refer to typical performance curves.

⑧ Alternate output voltages are available. Please contact the factory.

⑨ The device can withstand input voltages as high as 80V, but efficiency is best at lower inputs.

⑩ With VBIAS (pin 11) connected to a separate source, VIN Min. is VOUT + $V_{DROPOUT}$; see dropout curves.

⑪ Continuous operation at or above absolute maximum ratings may adversely effect the device performance and/or life cycle.

⑫ Internal solder reflow temperature is 180°C, do not exceed.

INPUT BIAS AND UVLO:

Pin 11 of the MSK5035 provides bias to an internal linear regulator that powers the control circuitry. The VBIAS pin can be connected directly to the input bus for 12V to 80V operation or it can be biased separately with a 12V to 15V source to extend the input range of the device and improve efficiency at high line; refer to the paragraph titled "INPUT VOLTAGE RANGE". VBIAS must be applied simultaneous with or prior to the input voltage. The MSK5035's built in under voltage lockout feature prevents damage to downstream devices in the event of a drop in bias voltage. Under voltage lockout occurs at bias voltages of approximately 10V rising and 9.7V falling. When separating the bias voltage from VIN to extend the input range below the VBIAS UVLO set point, a simple open collector circuit can disable the device at any desired set point for VIN if UVLO is required. The internal bias draws approximately 30mA under normal operation and less than 10mA in Power Save mode with a light load on the output.

INPUT VOLTAGE RANGE

The MSK5035's wide input range of 12V to 80V can be further extended down to VOUT + VDROPOUT by using a separate bias supply; refer to the paragraph titled "LOW VOLTAGE OPERATION". In this configuration very efficient low V to low V conversion can be achieved. At high line voltages the internal linear regulator dissipates more power than at low line. This loss in efficiency can be eliminated with a separate bias supply pushing the high line efficiency up close to the low line performance. Output ripple changes with line voltage; refer to the paragraph titled "OUTPUT INDUCTOR (OPTIONAL)" for more information.

SELECTING RS:

The MSK5035 monitors the inductor current and the average load current by sensing the voltage across RS. Cycle-by-cycle current limiting is controlled with an upper threshold of 100mV ±20mV; the high side MOSFET switch is gated off whenever the upper threshold is exceeded. In BURST and PULSE Skipping Modes, the sychronous rectifier is disabled when the signal falls below 0V. Selection of RS must take these features into consideration.

When operated in the continuous conduction mode peak to peak inductor current is approximated by the equation

$$\left[\frac{(VIN - VOUT) \bullet VOUT}{f \bullet L \bullet VIN}\right]$$

where f=300KHz and L=6.4µH. (If optional output inductance is used L=6.4uH + optional L). The device will operate in continuous conduction as long as IOUT ≥ ½ Ip-p. The maximum and minimum current peaks are equal to IOUT±½ Ip-p. RS translates the current levels into the control signal. Once the current levels are established the designer can size RS for specific applications. Care must be taken when selecting RS because under a short circuit condition the output current will approach the cycle-by-cycle current limit.

For most applications, it may be useful to wire the sense inputs with a twisted pair instead of PCB traces. Low inductance current sense resistors, such as metal film surface mount styles are best.

SOFT START/CTON:

The internal soft-start circuitry allows a gradual increase of the internal current-limit level at start-up for the purpose of reducing input surge currents, and possibly for power-supply sequencing. In Disable mode, the soft-start circuit holds the Cton capacitor discharged to ground. When ENABLE goes high, a 2µA current source charges the Cton capacitor. The resulting linear ramp causes the internal current-limit threshold to increase proportionally from 20mV to 100mV. The output capacitors charge up relatively slowly, depending on the CTON capacitor value. The exact time of the output rise depends on output capacitance and load current and is typically TBD per nanofarad of soft-start capacitance. With no capacitor connected, maximum current limit is reached typically within TBDµS.

POWER DISSIPATION:

In high current applications, it is very important to ensure that both MOSFETS are within their maximum junction temperature at high ambient temperatures. Temperature rise can be calculated based on package thermal resistance and worst case dissipation for each MOSFET. These worst case dissipations occur at minimum voltage for the high side MOSFET and at maximum voltage for the low side MOSFET.

Calculate power dissipation using the following formulas:

$$Pd\ (upper\ FET) = I_{LOAD}^2 \times 0.090\Omega \times DUTY + VIN \times I_{LOAD} \times f \times \left[\frac{VIN \times C_{RSS} + 25ns}{I_{GATE}}\right]$$

$$Pd\ (lower\ FET) = I_{LOAD}^2 \times 0.090\Omega \times (1 - DUTY)$$

$$DUTY = \left[\frac{(VOUT + V_{Q2})}{(VIN - V_{Q1})}\right]$$

Where: VQ1 or VQ2 (on state voltage drop) = $I_{LOAD} \times 0.090\Omega$
C_{RSS} = 65pF
I_{GATE} = 2A

During output short circuit, Q2, the synchronous-rectifier MOSFET, will have an increased duty factor and will see additional stress. This can be calculated by:

$$Q2\ DUTY = 1 - \left[\frac{V_{Q2}}{VIN_{(MAX)} - V_{Q1}}\right]$$

Where: VQ1 or VQ2 = $(120MV/R_{SENSE}) \times 0.090$

INPUT CAPACITOR SELECTION:

The MSK5035 should have an external high frequency ceramic capacitor (0.1uF) between VIN and GND. Connect a low-ESR bulk capacitor directly to the input pin of the MSK5035. Select the bulk input filter capacitor according to input ripple-current requirements and voltage rating, rather than capacitor value. Electrolytic capacitors that have low enough ESR to meet the ripple-current requirement invariably have more than adequate capacitance values. Aluminum-electrolytic capacitors are preferred over tantalum types, which could cause power-up surge-current failure when connecting to robust AC adapters or low-impedance batteries. RMS input ripple current is determined by the input voltage and load current, with the worst possible case occuring at VIN = 2 x VOUT:

$$I_{RMS} = I_{LOAD} \times \sqrt{\frac{VOUT(VIN-VOUT)}{VIN}}$$

OUTPUT CAPACITOR SELECTION:

The output capacitor values are generally determined by the ESR and voltage rating requirements rather than capacitance requirements for stability. Low ESR capacitors that meet the ESR requirement usually have more output capacitance than required for stability. Only specialized low-ESR capacitors intended for switching-regulator applications, such as AVX TPS, Sprague 595D, Sanyo OS-CON, Nichicon PL series or Kemet T510 series should be used.

The output ripple is usually dominated by the ESR of the filter capacitors and can be approximated as IRIPPLE x RESR. Including the capacitive term, the full equation for ripple in the continuous mode is VRIPPLE(p-p)=IRIPPLE x (RESR + 1/(2πfC)). In pulse skipping mode, the inductor current becomes discontinuous with high peaks and widely spaced pulses, so the ripple can be much higher at light load compared to full load. In pulse skipping mode, the output ripple can be calculated as follows:

$$V_{NOISE}(p\text{-}p)= \frac{0.02 \times R_{ESR}}{R_{SENSE}} + \frac{0.0003 \times 6.4\mu H \times [1/VOUT+1/(VIN-VOUT)]}{(R_{SENSE})^2 \times C}$$

ENABLE FUNCTION:

The MSK5035 is enabled by applying a logic level high to the ENABLE pin or leaving it open. A logic level low will disable the device and quiescent input current will reduce to approximately 1mA. The ENABLE threshold voltage is 1.35V. If automatic start up is required, simply make no connection. Maximum ENABLE voltage is +5V. The ENABLE pin has an internal 100K pull up resistor to 10.5V.

CURRENT LIMITING:

Current limiting the MSK5035 is achieved by setting the cycle-by-cycle current limit as described in the section titled SELECTING RS. The designer must set the peak current limit such that the average output current will not exceed the application limits. In a short circuit condition the average output current will approach the peak current limit. RS should be selected such that the average output current will not exceed 4.0 Amps. RS must be small enough to allow for the required load current plus the peak ripple current; 80mV/RS=IOUT+½Ip-p. Load components should be sized to withstand a maximum current of 120mV/RS

OUTPUT INDUCTOR (OPTIONAL):

Placing an output inductor between the package and the sense resistor will reduce output ripple and noise. Output ripple and noise increase as the input to output voltage differential increases. Ouput ripple is also higher when the MSK5035 is operated in BURST or PULSE Skipping Mode. Optional inductance will directly add to the internal inductance of the device and should be included in peak to peak current calculations (see SELECTING RS). Since additional inductance will affect the output response of the regulator, the inductance value must be carefully selected for each application.

RFB:

It is very important that the DC voltage returned to the RFB pin from the output be as noise and oscillation free as possible. This is the feedback voltage that is used to control the final output. Excessive noise or oscillation can interfere with proper feedback leading to an incorrect output voltage. Proper PC board layout techniques can help to achieve a noise free voltage at the RFB pin.

MODE:

The MSK5035 has two user selectable operating modes. Burst mode operates in discontinuous current at light loads. Constant frequency mode operates in continuous current at light loads. The gain and phase response of a switching regulator changes abruptly when the device changes from continuous current to discontinuous current. The regulator will still be stable if properly designed but its response to line and load changes may be slower.

When the Mode pin is pulled below 0.5V Burst mode is enabled. When the device is operating in Burst mode and the load current drops below 15% of the maximum the PWM will allow the output to rise slightly then shut down internal circuitry to conserve power. As the output falls below the set point, the PWM begins switching again. Reverse inductor current is disabled in Burst mode allowing discontinuous inductor current at light loads. Output ripple and noise are slightly elevated in Burst mode.

When the mode pin is pulled above 2.5V the device will operate at a constant PWM frequency mode. In this mode the synchronous rectifier will remain on allowing reverse current in the inductor at light loads. This mode ensures continuous inductor current at light load minimzing output ripple and noise.

***Note*: The mode pin is internally pulled up to approximately 12.8V. If left open circuit the mode pin will be high and the operational mode of the device will be constant PWM frequency.**

LOW VOLTAGE OPERATION:

The MSK5035 is capable of low voltage to low voltage conversion with up to 90% efficiency. A 5V bus can be stepped down to 3.3V or 2.5V with greater efficiency than linear conversion. Using an external bias supply the input voltage can be as low as VOUT plus VDROPOUT; consult the dropout curves for typical dropout voltages. Low line regulation error is easily trimmed with a low value feedback resistor in series with the RFB pin (5). Since the input current of the pin is approximately 123uA the output will increase by approximately 12.3mV per 100 ohms of resistance. The resistor should be selected such that the output voltage does not exceed the nominal output by more than 0.25V under the high input condition. Placing the feedback resistor as close to the device pin as possible helps to maintain noise immunity.

SEQUENCE OF OPERATION:

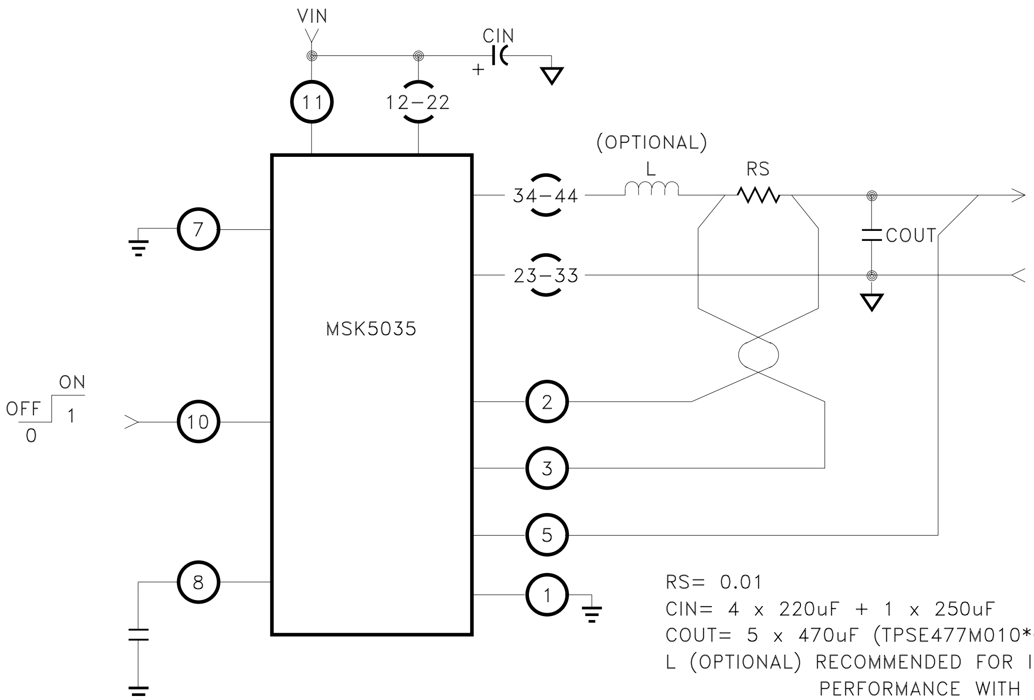
Each pulse from the oscillator sets the internal PWM latch that turns on the high-side MOSFET. As the high-switch turns off, the synchronous rectifier latch is set. 200ns later the low-side MOSFET turns on until the start of the next clock cycle or until the inductor current crosses zero. Under fault conditions the current exceeds the ±100mV current-limit threshold and the high-side switch turns off. Under light load conditions the synchronous rectifier is gated off as the inductor current falls through zero.

TABLE 1

OPERATIONAL CHARACTERISTICS

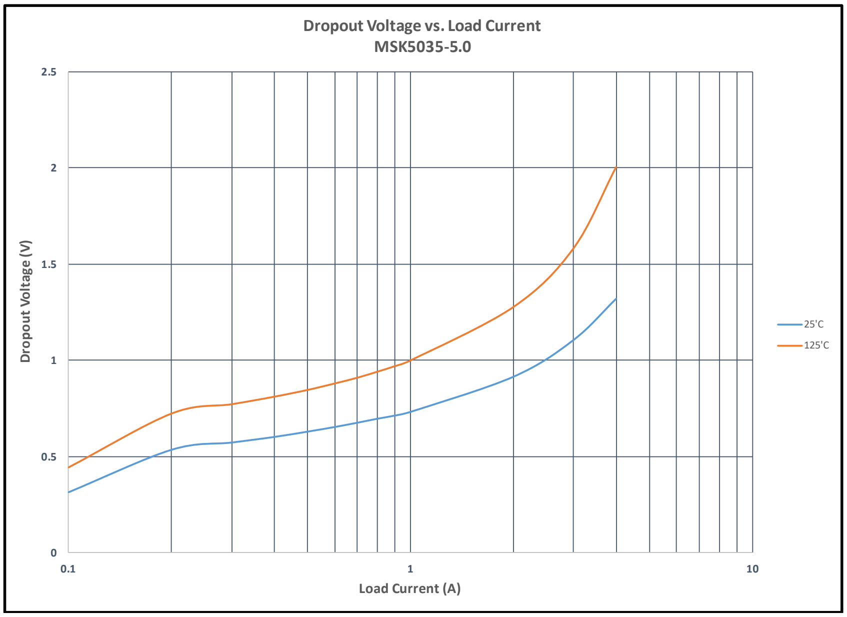
MODE	DESCRIPTION
< 0.5V	BURST MODE, DISCONTINUOUS INDUCTOR CURRENT
> 2.5V	CONSTANT FREQ. PWM MODE, CONTINUOUS INDUCTOR CURRENT

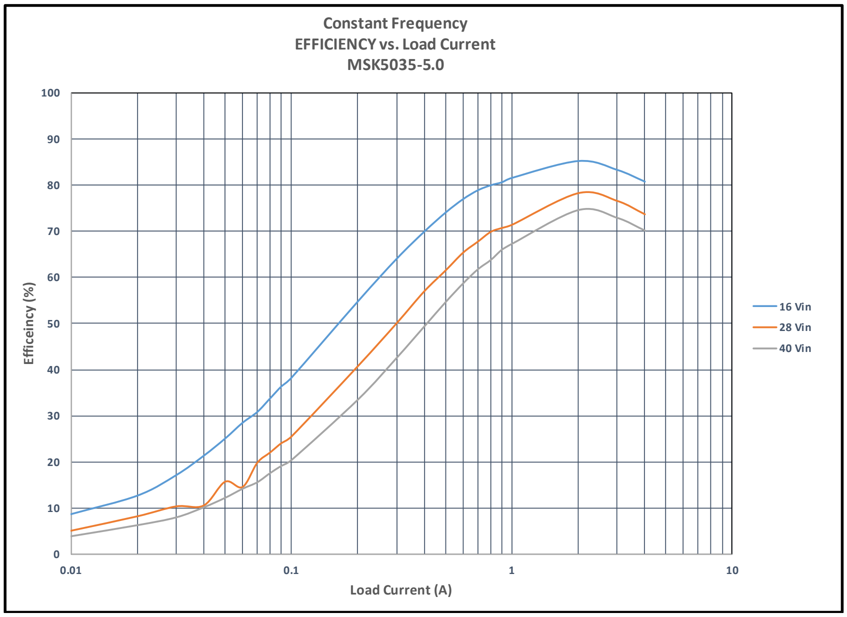
TYPICAL APPLICATION CIRCUIT

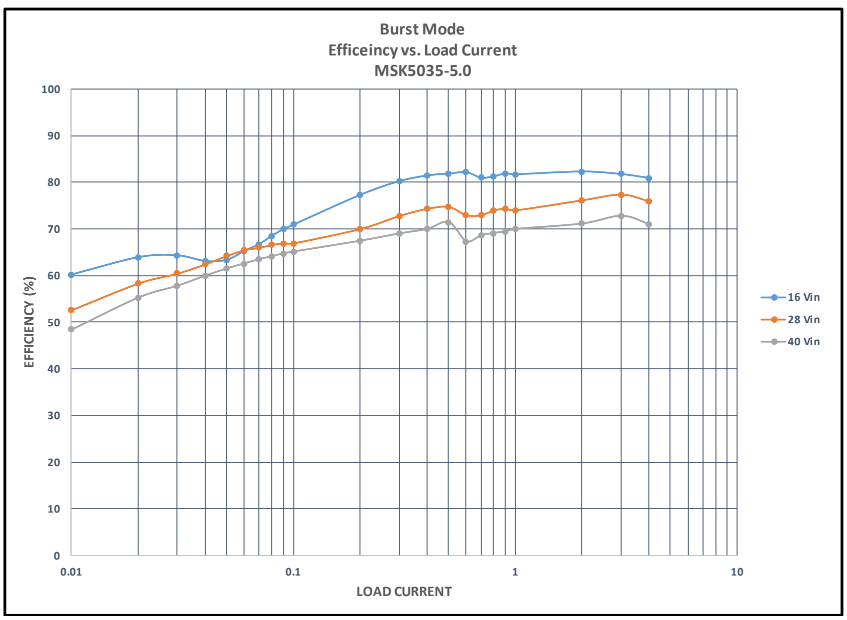


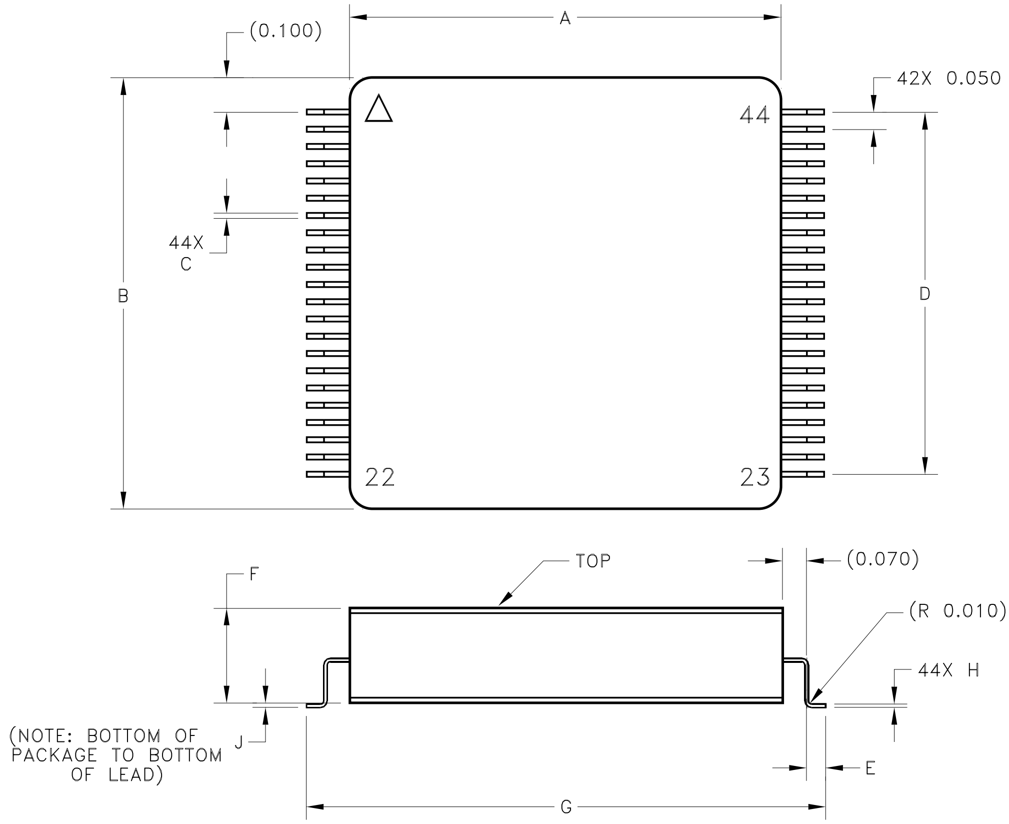
RS= 0.01
CIN= 4 x 220uF + 1 x 250uF
COUT= 5 x 470uF (TPSE477M010*0060 OR SIMILAR) + 1.0uF CERAMIC)
L (OPTIONAL) RECOMMENDED FOR IMPROVED PERFORMANCE WITH HIGH INPUT TO OUTPUT DIFFERENTIAL

TYPICAL PERFORMANCE CURVES









REF	MIN	MAX
A	1.240	1.260
B	1.240	1.260
C	0.013	0.020
D	1.045	1.055
E	0.045	0.065
F	———	0.275
G	1.490	1.510
H	0.008	0.014
J	0.008	0.018

ESD TRIANGLE INDICATES PIN 1
WEIGHT=17 GRAMS TYPICAL

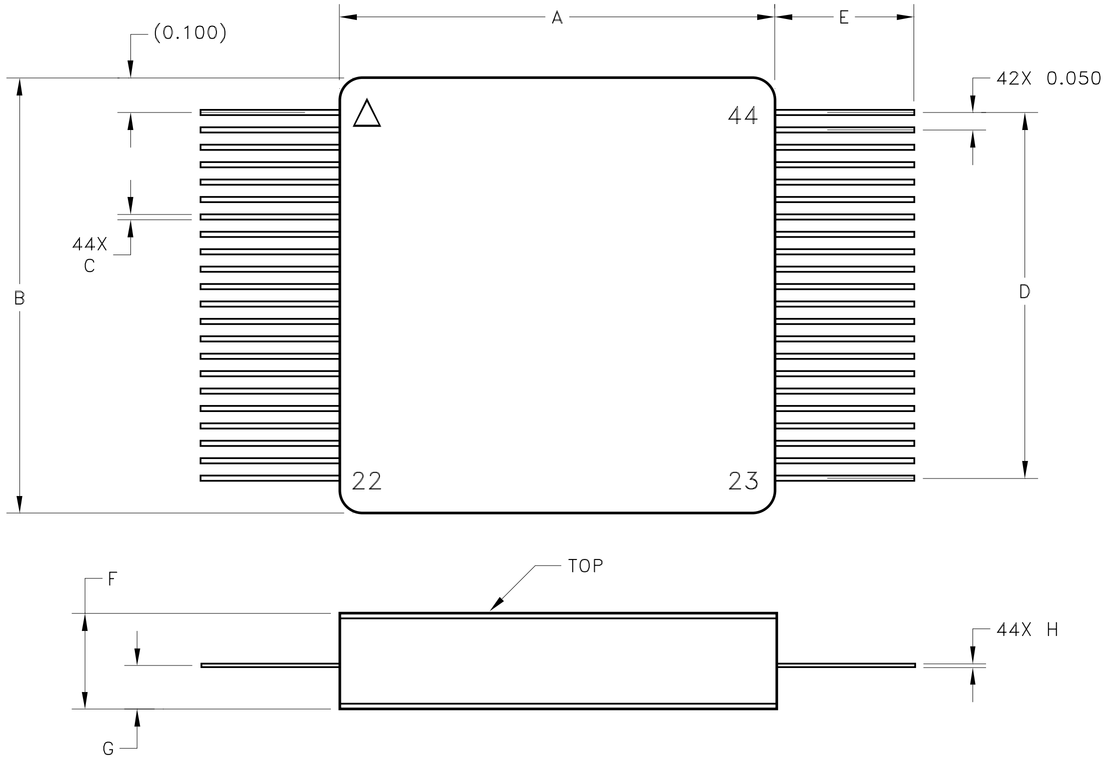
ALL DIMENSIONS ARE SPECIFIED IN INCHES

ORDERING INFORMATION

MSK5035-3.3 H G

- LEAD FORM OPTIONS
  BLANK = STRAIGHT; G = GULL WING
- SCREENING
  BLANK = INDUSTRIAL; H = MIL-PRF-38534 CLASS H
- OUTPUT VOLTAGE
  2.5 = +2.5V; 3.3 = +3.3V; 5.0 = +5.0V
- GENERAL PART NUMBER

The above example is a +3.3V, Military regulator with gull wing leads.



REF	MIN	MAX
A	1.240	1.260
B	1.240	1.260
C	0.013	0.020
D	1.045	1.055
E	0.350	——
F	——	0.275
G	0.115	0.135
H	0.008	0.014

ESD TRIANGLE INDICATES PIN 1
WEIGHT=17 GRAMS TYPICAL

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REVISION HISTORY

REV	STATUS	DATE	DESCRIPTION
A	Preliminary	06/18	Initial Release
B	Preliminary	03/19	Initial Release
C	Released	06/19	Update specifications and remove skip mode operation

ANAREN, MSK Products

www.anaren.com/msk