SGM6010
3A, 2MHz, Synchronous Step-Down Converter

GENERAL DESCRIPTION

The SGM6010 is a high efficiency synchronous, step-down DC/DC converter. Its input voltage range is from 3V to 5.5V and provides an adjustable regulated output voltage from 0.8V to 5V while delivering up to 3A of output current.

The internal synchronous low on-resistance power switches increase efficiency and eliminate the need for an external Schottky diode. The switching frequency is set by an external resistor. The 100% duty cycle provides low dropout operation extending battery life in portable systems. Current mode operation with external compensation allows the transient response to be optimized over a wide range of loads and output capacitors.

The SGM6010 is operated in forced continuous PWM mode which minimizes ripple voltage and reduces the noise and RF interference.

SGM6010 is available in the Green TDFN-3×3-10L package. It is rated over the -40℃ to +85℃ temperature range.

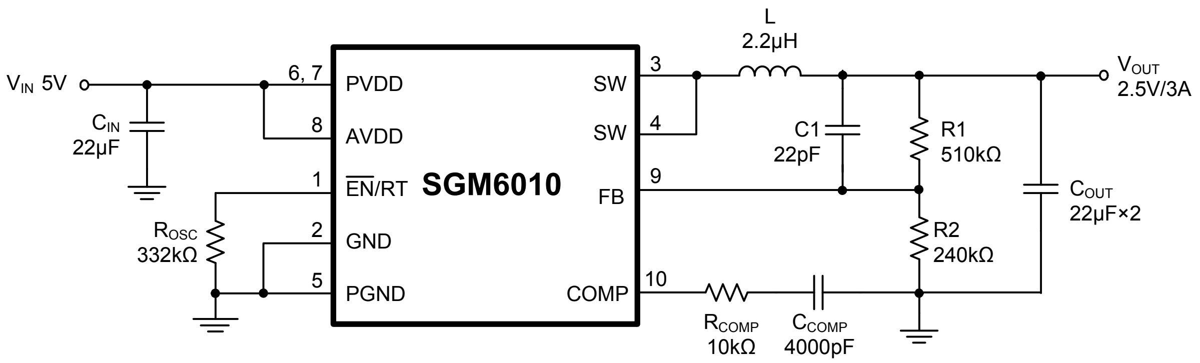
FEATURES

- **High Efficiency: Up to 95%**
- **Low $R_{DS(ON)}$ Internal Switches: 120mΩ**
- **Programmable Frequency: 300kHz to 2MHz**
- **3A Output Current**
- **Input Voltage Range: 3V to 5.5V**
- **0.8V Reference Allows Low Output Voltages**
- **Less than 1μA Shutdown Current**
- **100% Duty Cycle for Lowest Dropout**
- **Forced Continuous PWM Mode Operation**
- **No External Power MOSFETs and Schottky Diode Required**
- **Excellent Line Regulation and Load Transient Response**
- **-40℃ to +85℃ Operating Temperature Range**
- **Available in Green TDFN-3×3-10L Package**

APPLICATIONS

Digital Book Readers
Digital Cameras
Portable Instruments
Wireless and DSL Modems
Battery Powered Equipments
Microprocessor, DSP Power Supplies

TYPICAL APPLICATION



PACKAGE/ORDERING INFORMATION

MODEL	PIN-PACKAGE	SPECIFIED TEMPERATURE RANGE	ORDERING NUMBER	PACKAGE MARKING	PACKAGE OPTION
SGM6010	TDFN-3×3-10L	-40℃ to +85℃	SGM6010YTD10G/TR	SGM 6010D XXXXX	Tape and Reel, 3000

NOTE: **XXXXX** = Date Code and Vendor Code.

ABSOLUTE MAXIMUM RATINGS

Input Supply Voltage... -0.3V to 6V
Other I/O Voltages.......................-0.3V to (AVDD/PVDD + 0.3V)
SW Switch Voltage.................................-0.3V to (PVDD + 0.3V)
Peak SW Sink and Source Current......................................3.6A
Operating Temperature Range............................-40℃ to +85℃
Junction Temperature..150℃
Storage Temperature Range..............................-65℃ to +150℃
Power Dissipation, P_D @ T_A = +25℃
TDFN-3×3-10L.. 2.2W
Package Thermal Resistance
TDFN-3×3-10L, θ_{JA} ....45℃/W
Lead Temperature (Soldering, 10s) ....260℃
ESD Susceptibility
HBM...2000V
MM..200V

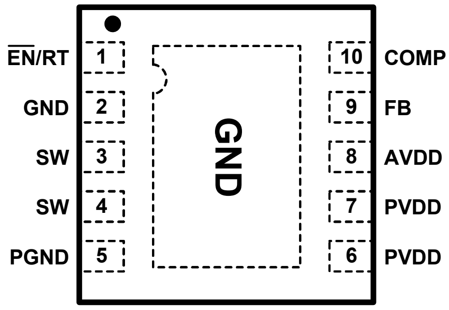
NOTE:
Stresses beyond those listed under "Absolute Maximum Ratings" may cause permanent damage to the device. These are stress ratings only, and functional operation of the device at these or any other conditions beyond those indicated in the operational sections of the specifications is not implied. Exposure to absolute maximum rating conditions for extended periods may affect device reliability.

CAUTION

This integrated circuit can be damaged by ESD if you don't pay attention to ESD protection. SGMICRO recommends that all integrated circuits be handled with appropriate precautions. Failure to observe proper handling and installation procedures can cause damage. ESD damage can range from subtle performance degradation to complete device failure. Precision integrated circuits may be more susceptible to damage because very small parametric changes could cause the device not to meet its published specifications.

SGMICRO reserves the right to make any change in circuit design, specification or other related things if necessary without notice at any time. Please contact SGMICRO sales office to get the latest datasheet.

PIN CONFIGURATION (TOP VIEW)



PIN DESCRIPTION

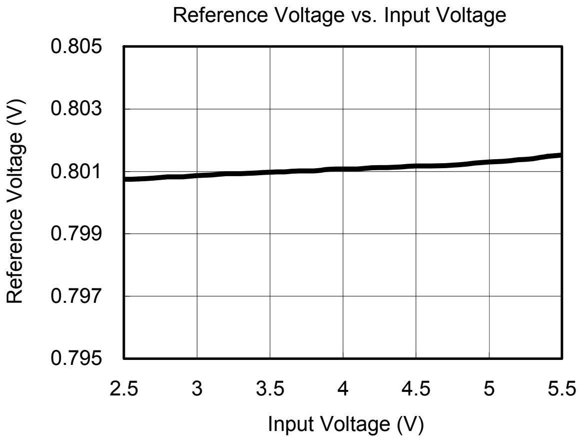
PIN	NAME	FUNCTION
1	$\overline{EN}$ / RT	Oscillator Resistor Input. Connecting a resistor to ground from this pin sets the switching frequency. Forcing this pin to AVDD causes the device to be shutdown.
2	GND	Signal Ground. All small-signal components and compensation components should connect to this ground, which in turn connects to PGND at one point.
3,4	SW	Internal Power MOSFET Switches Output. Connect this pin to the inductor.
5	PGND	Power Ground. Connect this pin close to the negative terminal of C_{IN} and C_{OUT}.
6,7	PVDD	Power Input Supply. Decouple this pin to PGND with a capacitor.
8	AVDD	Analog Signal Power Supply. Decouple this pin to GND with a capacitor. Normally AVDD is equal to PVDD.
9	FB	Feedback Pin. This pin receives the feedback voltage from a resistive divider connected across the output.
10	COMP	Error Amplifier Compensation Point. The current comparator threshold increases with this control voltage. Connect external compensation elements to this pin to stabilize the control loop.
Exposed Pad	—	Power Ground Exposed Pad. Must be connected to GND plane.

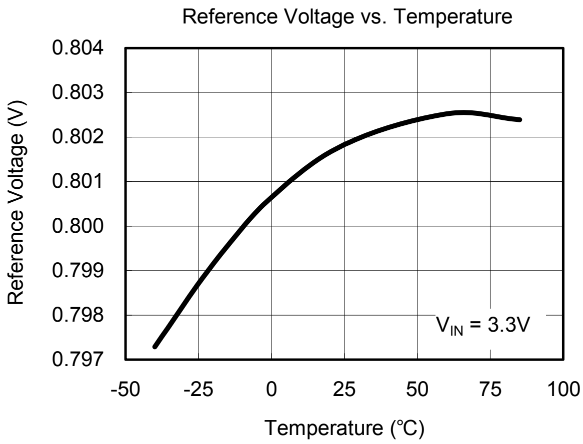
ELECTRICAL CHARACTERISTICS

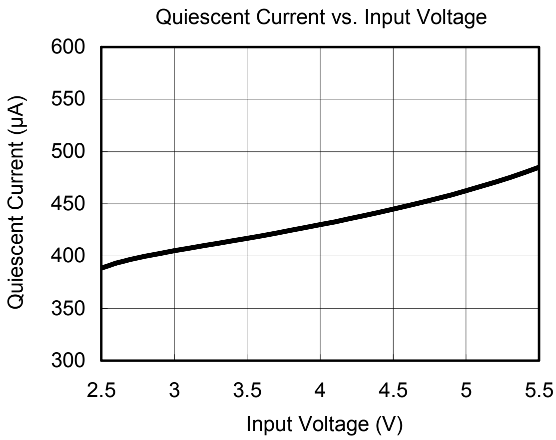
(V_{IN} = 3.3V, T_A = -40℃ to +85℃, typical values are at T_A = +25℃, unless otherwise noted.)

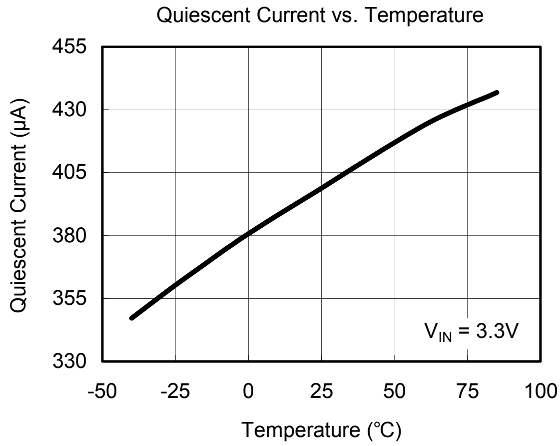
PARAMETER		SYMBOL	CONDITIONS	MIN	TYP	MAX	UNITS
Input Voltage Range		V_{IN}		3		5.5	V
Feedback Reference Voltage		V_{REF}		0.772	0.8	0.828	V
Feedback Input Bias Current		I_{FB}		-0.4	0.1	0.4	μA
Input DC Bias Current	Active Mode	I_S	V_{FB} = 0.78V, R_{OSC} = 332kΩ, Not Switching		410	600	μA
Input DC Bias Current	Shutdown	I_S				2.0	μA
Output Voltage Line Regulation		ΔV_{OUT}	V_{IN} = 2.6V to 5.5V		0.1		%/V
Output Voltage Load Regulation		$V_{LOADREG}$	V_{IN} = 5V, V_{OUT} = 2.5V, I_{LOAD} = 0 to 3A		0.15		%/A
Error Amplifier Transconductance		g_m			800		μs
Current Sense Trans-Resistance		R_{OSC}			0.4		Ω
Oscillator Frequency		f_{OSC}	R_{OSC} = 332kΩ, T_A = 25℃	0.75	1	1.25	MHz
Oscillator Frequency		f_{OSC}	Switching Frequency	0.3		2	MHz
Switch On Resistance, High		R_{PMOS}	I_{SW} = 0.5A, T_A = 25℃		120	210	mΩ
Switch On Resistance, Low		R_{NMOS}	I_{SW} = 0.5A, T_A = 25℃		100	160	mΩ
Peak Current Limit		I_{PK}	T_A = 25℃	3.3	3.5		A
Under-Voltage Lockout Threshold		UVLO	V_{DD} Rising		2.2		V
Under-Voltage Lockout Threshold		UVLO	V_{DD} Failing		2.05		V
Shutdown Threshold					V_{IN} - 0.7	V_{IN} - 0.4	V

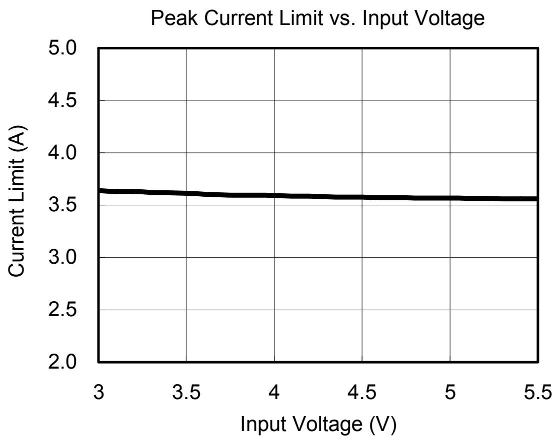
TYPICAL PERFORMANCE CHARACTERISTICS

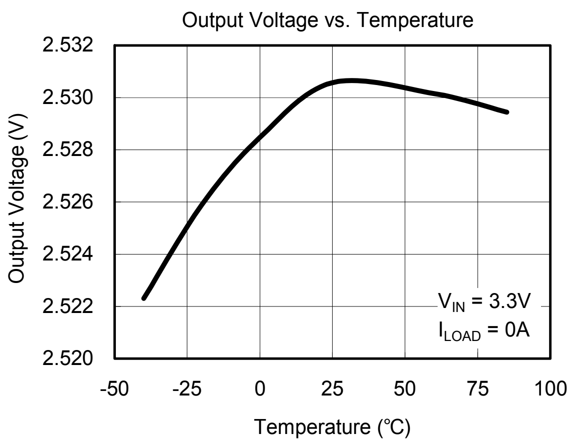






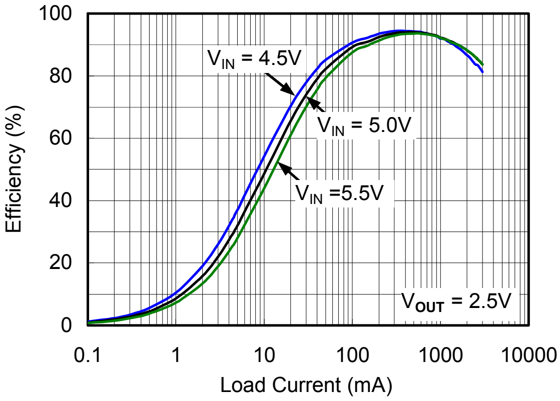




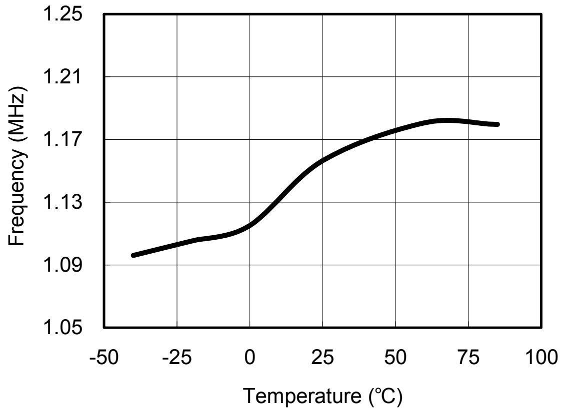


TYPICAL PERFORMANCE CHARACTERISTICS

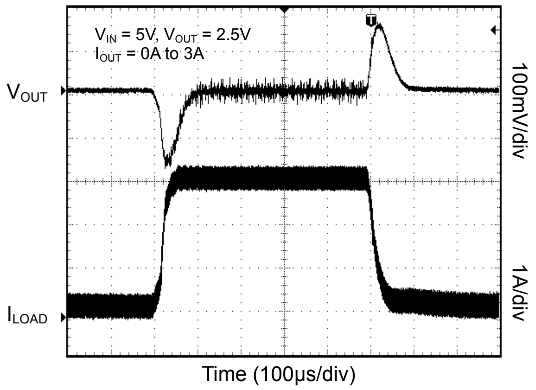
Efficiency vs. Load Current



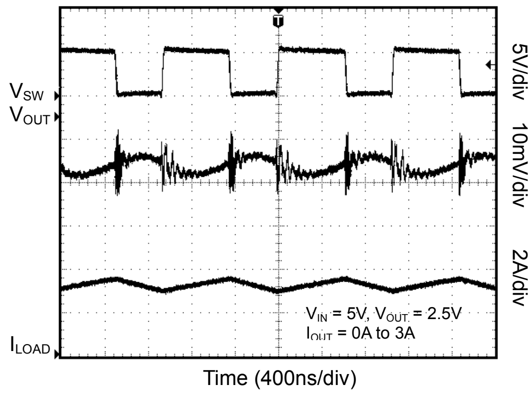
Frequency vs. Temperature



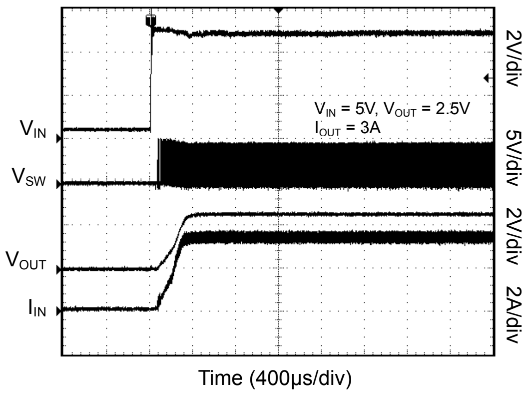
Load Transient Response



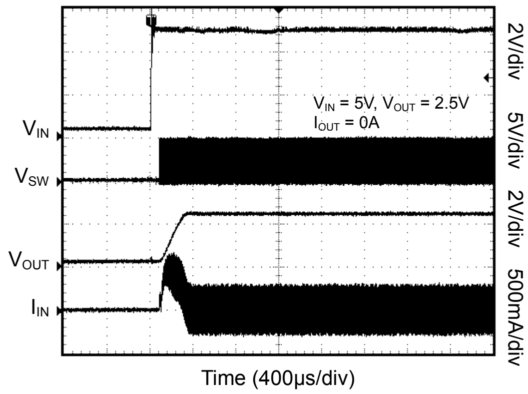
Output Ripple



Start-Up with Heavy Load



Start-Up with No Load



OPERATION

Main Control Loop

The SGM6010 is a monolithic, constant-frequency, current mode step-down DC/DC converter. During normal operation, the internal top power switch (P-Channel MOSFET) is turned on at the beginning of each clock cycle. Current in the inductor increases until the peak inductor current reaches the value defined by the voltage on the COMP pin. The error amplifier adjusts the voltage on the COMP pin by comparing the feedback signal from a resistor divider on the FB pin with an internal 0.8V reference. When the load current increases, it causes a reduction in the feedback voltage relative to the reference. The error amplifier raises the COMP voltage until the average inductor current matches the new load current. When the top power MOSFET shuts off, the synchronous power switch (N-MOSFET) turns on until either the bottom current limit is reached or the beginning of the next clock cycle.

The operating frequency is set by an external resistor connected between the RT pin and ground. The practical switching frequency can range from 300kHz to 2MHz. In an over-voltage condition, the top power MOSFET is turned off and the bottom power MOSFET is switched on until either the over-voltage condition clears or the bottom MOSFET's current limit is reached.

Dropout Operation

When the input supply voltage decreases toward the output voltage, the duty cycle increases toward the maximum on-time. Further reduction of the supply voltage forces the main switch to remain on for more than one cycle eventually reaching 100% duty cycle.

The output voltage will then be determined by the input voltage minus the voltage drop across the internal P-Channel MOSFET and the inductor.

Low Supply Operation

The SGM6010 is designed to operate down to an input supply voltage of 3V. One important consideration at low input supply voltages is that the $R_{DS(ON)}$ of the P-Channel and N-Channel power switches increases. The user should calculate the power dissipation when the SGM6010 is used at 100% duty cycle with low input voltages to ensure that thermal limits are not exceeded.

Slope Compensation and Inductor Peak Current

Slope compensation provides stability in constant frequency architectures by preventing sub-harmonic oscillations at duty cycles greater than 50%. It is accomplished internally by adding a compensating ramp to the inductor current signal. Normally, the maximum inductor peak current is reduced when slope compensation is added. In the SGM6010, however, separated inductor current signals are used to monitor over current condition. This keeps the maximum output current relatively constant regardless of duty cycle.

Short-Circuit Protection

When the output is shorted to ground, the inductor current decays very slowly during a single switching cycle. A current runaway detector is used to monitor inductor current. As current increasing beyond the control of current loop, switching cycles will be skipped to prevent current runaway from occurring.

APPLICATION INFORMATION

The basic SGM6010 application circuit is shown in Typical Application Circuit. External component selection is determined by the maximum load current and begins with the selection of the inductor value and operating frequency followed by C_{IN} and C_{OUT}.

Output Voltage Programming

The output voltage is set by an external resistive divider according to the following equation:

$$V_{OUT} = V_{REF} \times \left(1 + \frac{R1}{R2}\right)$$

where V_{REF} equals to 0.8V typical.

The resistive divider allows the FB pin to sense a fraction of the output voltage as shown in Figure 1.

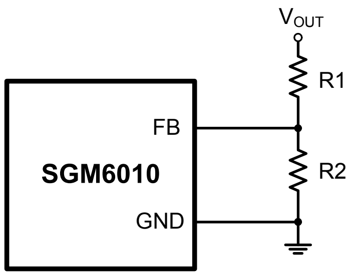


Figure 1. Setting the Output Voltage

Operating Frequency

Selection of the operating frequency is a tradeoff between efficiency and component size. High frequency operation allows the use of smaller inductor and capacitor values. Operation at lower frequency improves efficiency by reducing internal gate charge and switching losses but requires larger inductance and/or capacitance to maintain low output ripple voltage.

The operating frequency of the SGM6010 is determined by an external resistor that is connected between the RT pin and ground. The value of the resistor sets the ramp current that is used to charge and discharge an internal timing capacitor within the oscillator. The R_{OSC} resistor value can be determined by examining the switching frequency vs. R_{OSC} curve. Although frequencies as high as 2MHz are possible, the minimum on-time of the SGM6010 imposes a minimum limit on the operating duty cycle. The minimum on-time is typically 110ns. Therefore, the minimum duty cycle is equal to 100 × 110ns × f_{OSC} (Hz).

Inductor Selection

For a given input and output voltage, the inductor value and operating frequency determine the ripple current. The ripple current ΔI_L increases with higher V_{IN} and decreases with higher inductance.

$$\Delta I_L = \frac{1}{(f_{OSC})(L)} V_{OUT} \left(1 - \frac{V_{OUT}}{V_{IN}}\right)$$

Having a lower ripple current reduces the ESR losses in the output capacitors and the output voltage ripple. Highest efficiency operation is achieved at low frequency with small ripple current. This, however, requires a large inductor. A reasonable starting point for selecting the ripple current is $\Delta I_L = 0.4(I_{MAX})$. The largest ripple current occurs at the highest V_{IN}. To guarantee that the ripple current stays below a specified maximum, the inductor value should be chosen according to the following equation:

$$L = \frac{V_{OUT}}{(f_{OSC})(\Delta I_{L(MAX)})} \left(1 - \frac{V_{OUT}}{V_{IN(MAX)}}\right)$$

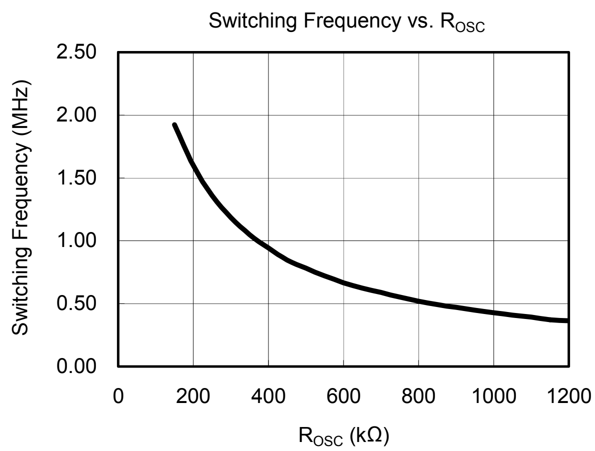


Figure 2

APPLICATION INFORMATION

Inductor Core Selection

Once the value for L is known, the type of inductor must be selected. High efficiency converters generally cannot afford the core loss found in low cost powdered iron cores, forcing the use of more expensive ferrite or mollypermalloy cores. Actual core loss is independent of core size for a fixed inductor value but it is very dependent on the inductance selected. As the inductance increases, core losses decrease. Unfortunately, increased inductance requires more turns of wire and therefore copper losses will increase.

Ferrite designs have very low core losses and are preferred at high switching frequencies, so design goals can concentrate on copper loss and preventing saturation. Ferrite core material saturates “hard”, which means that inductance collapses abruptly when the peak design current is exceeded. This result in an abrupt increase in inductor ripple current and consequent output voltage ripple. Do not allow the core to saturate!

Different core materials and shapes will change the size/current and price/current relationship of an inductor. Toroid or shielded pot cores in ferrite or permalloy materials are small and don't radiate energy but generally cost more than powdered iron core inductors with similar characteristics. The choice of which style inductor to use mainly depends on the price vs. size requirements and any radiated field/EMI requirements.

C_{IN} and C_{OUT} Selection

The input capacitance, C_{IN}, is needed to filter the trapezoidal current at the source of the top MOSFET. To prevent large ripple voltage, a low ESR input capacitor sized for the maximum RMS current should be used. RMS current is given by:

$$I_{RMS} \cong I_{OUTMAX} \frac{V_{OUT}}{V_{IN}} \sqrt{\frac{V_{IN}}{V_{OUT}} - 1}$$

This formula has a maximum at $V_{IN} = 2V_{OUT}$, where $I_{RMS} = I_{OUT}/2$. This simple worst-case condition is commonly used for design because even significant deviations do not offer much relief. Choose a capacitor rated at a higher temperature than required.

Several capacitors may also be paralleled to meet size or height requirements in the design.

The selection of C_{OUT} is determined by the effective series resistance (ESR) that is required to minimize voltage ripple and load step transients, as well as the amount of bulk capacitance that is necessary to ensure that the control loop is stable. Loop stability can be checked by viewing the load transient response as described in a later section. The output ripple, ΔV_{OUT}, is determined by:

$$\Delta V_{OUT} \le \Delta I_L \left(ESR + \frac{1}{8f_{OSC} \times C_{OUT}} \right)$$

The output ripple is highest at maximum input voltage since ΔI_L increases with input voltage. Multiple capacitors placed in parallel may be needed to meet the ESR and RMS current handling requirements. Dry tantalum, special polymer, aluminum electrolytic and ceramic capacitors are all available in surface mount packages. Special polymer capacitors offer very low ESR but have lower capacitance density than other types. Tantalum capacitors have the highest capacitance density but it is important to only use types that have been surge tested for use in switching power supplies. Aluminum electrolytic capacitors have significantly higher ESR but can be used in cost-sensitive applications provided that consideration is given to ripple current ratings and long term reliability. Ceramic capacitors have excellent low ESR characteristics but can have a high voltage coefficient and audible piezoelectric effects. The high Q of ceramic capacitors with trace inductance can also lead to significant ringing.

Using Ceramic Input and Output Capacitors

Higher values, lower cost ceramic capacitors are now becoming available in smaller case sizes. Their high ripple current, high voltage rating and low ESR make them ideal for switching regulator applications. However, care must be taken when ceramic capacitors are used at the input and the output. When a ceramic capacitor is used at the input and the power is supplied by a wall adapter through long wires, a load step at the output can induce ringing at the input, V_{IN}. At best, this ringing can couple to the output and be mistaken as loop instability. At worst, a sudden inrush of current through the long wires can potentially cause a voltage spike at V_{IN}, large enough to damage the part.

APPLICATION INFORMATION

Checking Transient Response

The regulator loop response can be checked by looking at the load transient response. Switching regulators take several cycles to respond to a step in load current. When a load step occurs, V_{OUT} immediately shifts by an amount equal to $\Delta I_{LOAD(ESR)}$, where ESR is the effective series resistance of C_{OUT}. ΔI_{LOAD} also begins to charge or discharge C_{OUT} generating a feedback error signal used by the regulator to return V_{OUT} to its steady-state value. During this recovery time, V_{OUT} can be monitored for overshoot or ringing that would indicate a stability problem. The COMP pin external components and output capacitor shown in Typical Application Circuit will provide adequate compensation for most applications.

Thermal Considerations

In most applications the SGM6010 does not dissipate much heat due to its high efficiency. But, in applications where the SGM6010 is running at high ambient temperature with low supply voltage and high duty cycles, such as in dropout, the heat dissipated may exceed the maximum junction temperature of the part. If the junction temperature reaches approximately 150℃, both power switches will be turned off and the SW node will become high impedance.

To avoid the SGM6010 from exceeding the maximum junction temperature, the user will need to do some thermal analysis. The goal of the thermal analysis is to determine whether the power dissipated exceeds the maximum junction temperature of the part. The temperature rise is given by: $T_R = (P_D)(\theta_{JA})$ where P_D is the power dissipated by the regulator and θ_{JA} is the thermal resistance from the junction of the die to the ambient temperature. The junction temperature, T_J, is given by: $T_J = T_A + T_R$ where T_A is the ambient temperature.

As an example, consider the SGM6010 in dropout at an input voltage of 3.3V, a load current of 2A and an ambient temperature of 85℃. From the typical performance graph of switch resistance, the $R_{DS(ON)}$ of the P-channel switch at 85℃ is approximately 130mΩ. Therefore, power dissipated by the part is:

$$P_D = I_{LOAD}^2 \cdot R_{DS(ON)} = 0.52W$$

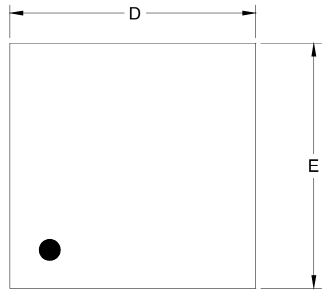
For the TDFN-3×3-10L package, the θ_{JA} is 45℃/W. Thus, the junction temperature of the regulator is:

$$T_J = 85℃ + (0.52)(45) = 108.4℃$$

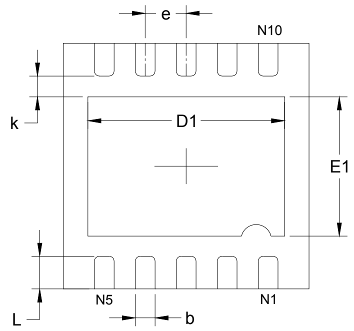
which is below the maximum junction temperature of 150℃. Note that at higher supply voltages, the junction temperature is lower due to reduced switch resistance ($R_{DS(ON)}$).

PACKAGE OUTLINE DIMENSIONS

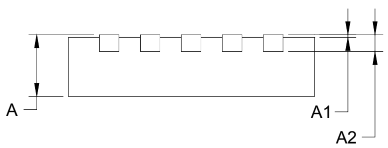
TDFN-3×3-10L



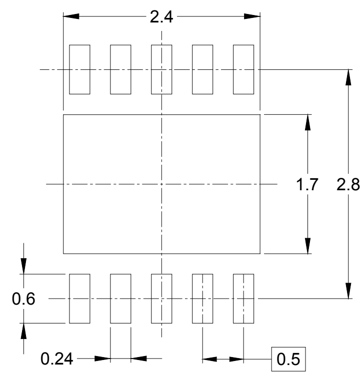
TOP VIEW



BOTTOM VIEW



SIDE VIEW

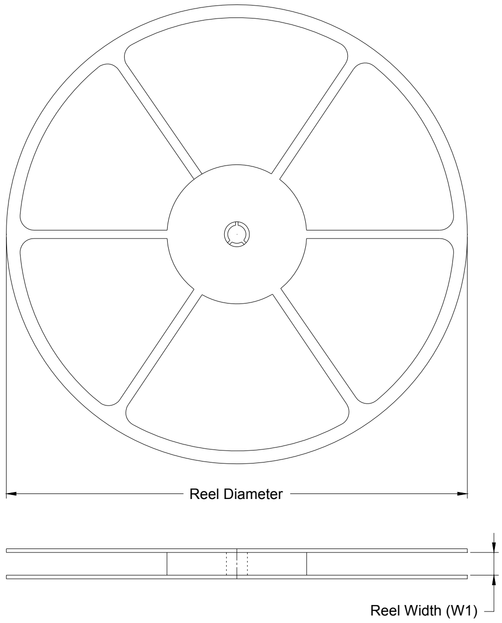


RECOMMENDED LAND PATTERN (Unit: mm)

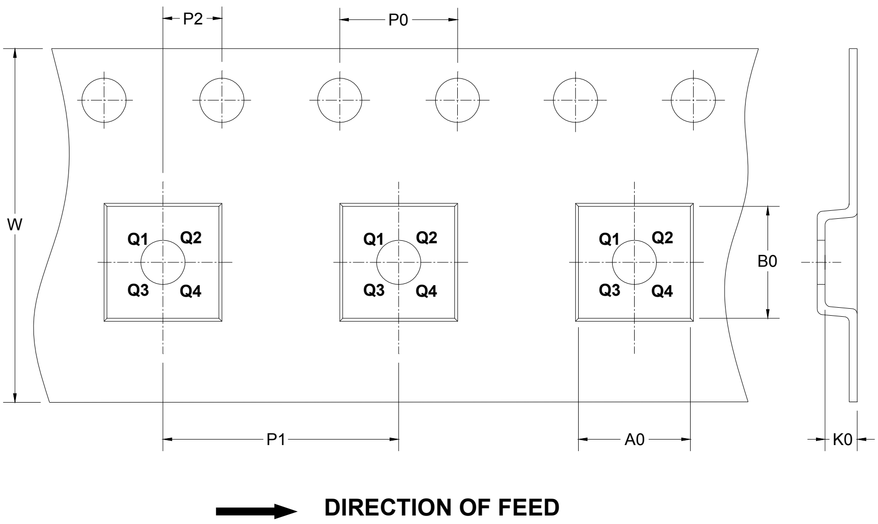
Symbol	Dimensions In Millimeters		Dimensions In Inches	
	MIN	**MAX**	**MIN**	**MAX**
A	0.700	0.800	0.028	0.031
A1	0.000	0.050	0.000	0.002
A2	0.203 REF		0.008 REF	
D	2.900	3.100	0.114	0.122
D1	2.300	2.600	0.091	0.103
E	2.900	3.100	0.114	0.122
E1	1.500	1.800	0.059	0.071
k	0.200 MIN		0.008 MIN	
b	0.180	0.300	0.007	0.012
e	0.500 TYP		0.020 TYP	
L	0.300	0.500	0.012	0.020

TAPE AND REEL INFORMATION

REEL DIMENSIONS



TAPE DIMENSIONS

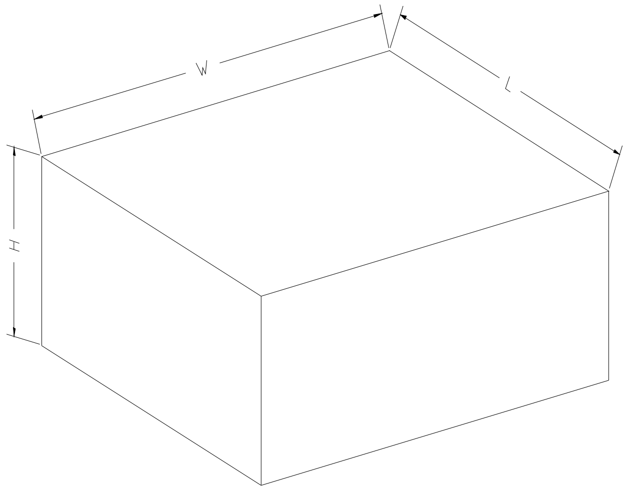


NOTE: The picture is only for reference. Please make the object as the standard.

KEY PARAMETER LIST OF TAPE AND REEL

Package Type	Reel Diameter	Reel Width W1 (mm)	A0 (mm)	B0 (mm)	K0 (mm)	P0 (mm)	P1 (mm)	P2 (mm)	W (mm)	Pin1 Quadrant
TDFN-3×3-10L	13″	12.4	3.35	3.35	1.13	4.00	8.00	2.00	12.00	Q1

CARTON BOX DIMENSIONS



NOTE: The picture is only for reference. Please make the object as the standard.

KEY PARAMETER LIST OF CARTON BOX

Reel Type	Length (mm)	Width (mm)	Height (mm)	Pizza/Carton
13″	386	280	370	5