SGM6011
1.4MHz, 2A Synchronous Step-Down Converter

GENERAL DESCRIPTION

The SGM6011 is a high efficiency monolithic synchronous step-down regulator using 1.4MHz constant frequency, current mode architecture. The device is available in an adjustable version. It is ideal for portable equipment requiring very high current up to 2A from single-cell Li-ion batteries.

The SGM6011 also can run at 100% duty cycle for low dropout operation, extending battery life in portable systems while light load operation provides very low output ripple for noise sensitive applications. It can supply up to 2A output load current from a 2.5V to 5.5V input voltage and the output voltage can be regulated as low as 1.2V. The high switching frequency (1.4MHz) minimizes the size of external components while keeping switching losses low. The internal slope compensation setting allows the device to operate with smaller inductor values to optimize size and provide efficient operation.

The SGM6011 is available in Green TDFN-3×3-10L package and is rated over the -40℃ to +85℃ temperature range.

FEATURES

- **Forced Continuous PWM Mode Operation**
- **High Efficiency: Up to 95%**
- **2.5V to 5.5V Input Voltage Range**
- **1.4MHz Constant Frequency Operation**
- **2A Output Current**
- **100% Duty Cycle for Lowest Dropout**
- **Less than 2μA Shutdown Current**
- **Low $R_{DS(ON)}$ Internal Switches: 0.135Ω**
- **Allows Use of Ceramic Capacitors**
- **Current Mode Control for Excellent Line and Load Transient Response**
- **Internal Soft-Start Protection**
- **Short Circuit and Thermal Protection**
- **-40℃ to +85℃ Operating Temperature Range**
- **Available in Green TDFN-3×3-10L Package**

APPLICATIONS

PDA, Pocket PC and Smart Phones
USB Powered Modems
CPUs and DSPs
PC Cards and Notebooks
Cellular Phones
Digital Cameras
DSP Core Supplies
Portable Instruments

PACKAGE/ORDERING INFORMATION

MODEL	V_{OUT} (V)	PACKAGE DESCRIPTION	SPECIFIED TEMPERATURE RANGE	ORDERING NUMBER	PACKAGE MARKING	PACKING OPTION
SGM6011	3.3	TDFN-3×3-10L	-40℃ to +85℃	SGM6011-3.3YD10G/TR	SGM C6011D XXXXX	Tape and Reel, 3000
	Adjustable	TDFN-3×3-10L	-40℃ to +85℃	SGM6011-ADJYD10G/TR	SGM D6011D XXXXX	Tape and Reel, 3000

NOTE: XXXXX = Date Code and Vendor Code.

Green (RoHS & HSF): SG Micro Corp defines "Green" to mean Pb-Free (RoHS compatible) and free of halogen substances. If you have additional comments or questions, please contact your SGMICRO representative directly.

ABSOLUTE MAXIMUM RATINGS

Input Supply Voltage.. -0.3V to 6V
EN Voltage.. -0.3V to V_{IN} + 0.3V
FB/OUT, SW Voltages................................ -0.3V to V_{IN} + 0.3V
Power Dissipation, P_D @ T_A = +25℃
TDFN-3×3-10L.. 2.2W
Package Thermal Resistance
TDFN-3×3-10L, θ_{JA}...45℃/W
Operating Temperature Range...........................-40℃ to +85℃
Junction Temperature..150℃
Storage Temperature Range............................-65℃ to +150℃
Lead Temperature (Soldering, 10s)..................................260℃
ESD Susceptibility
HBM.. 3000V
MM.. 200V

OVERSTRESS CAUTION

Stresses beyond those listed may cause permanent damage to the device. Functional operation of the device at these or any other conditions beyond those indicated in the operational section of the specification is not implied. Exposure to absolute maximum rating conditions for extended periods may affect reliability.

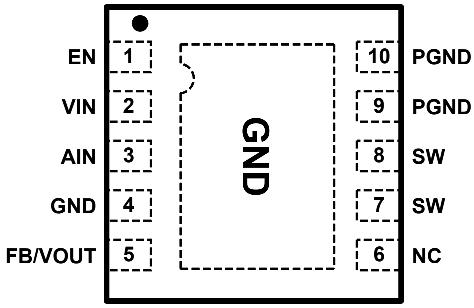
ESD SENSITIVITY CAUTION

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.

DISCLAIMER

SG Micro Corp reserves the right to make any change in circuit design, specification or other related things if necessary without notice at any time.

PIN CONFIGURATION (TOP VIEW)



TDFN-3×3-10L

PIN DESCRIPTION

PIN	NAME	FUNCTION
1	EN	Enable. Pulling EN to ground forces the device into shutdown mode. Pulling EN to IN enables the device. EN should not be left floating and must be terminated.
2	VIN	Supply Voltage Input. Must be closely decoupled to GND, with a 22μF or greater ceramic capacitor.
3	AIN	Analog Supply Input. Provides bias for internal circuitry.
4	GND	Analog Ground.
5	FB	Feedback Pin for Adjustable Version. Receives the feedback voltage from an external resistive divider across the output. The internal voltage divider is disabled for adjustable version.
	VOUT	Output Pin for Fixed Version. Receives the output voltage, which can be connected to the VOUT directly.
6	NC	No Internal Connection.
7, 8	SW	Switching Node Pin. Connect the output inductor to this pin.
9, 10	PGND	Power Ground.
Exposed Pad	GND	Analog Ground Exposed Pad. Must be connected to GND plane.

ELECTRICAL CHARACTERISTICS

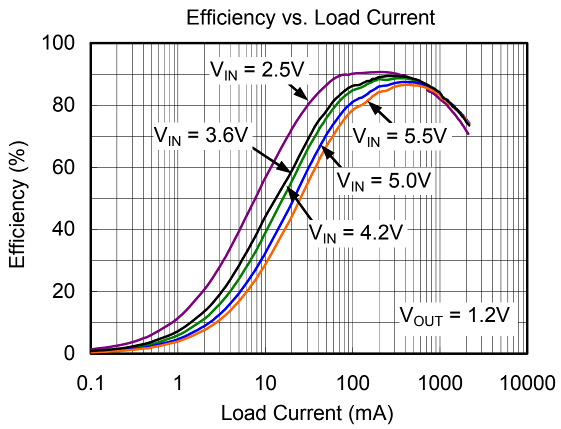
(V_{IN} = 3.6V, T_A = -40℃ to +85℃, unless otherwise noted.)

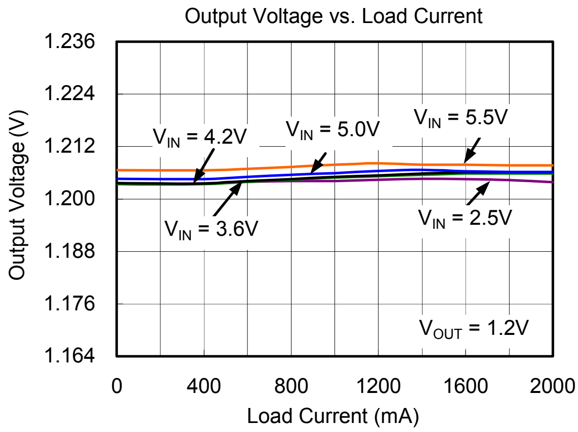
PARAMETER		SYMBOL	CONDITIONS	MIN	TYP	MAX	UNITS
Input Voltage Range		V_{IN}		2.5		5.5	V
Regulated Output Voltage		V_{OUT}		1.2		V_{IN} (1)	V
Input DC Bias Current	PWM Mode	I_Q	V_{FB} = 0.58V		300	450	μA
	Shutdown		V_{IN} = 5.5V, V_{EN} = 0V		0.01	2	
Feedback Input Bias Current		I_{FB}	V_{FB} = 0.65V		0.001	1	μA
Regulated Feedback Voltage		V_{FB}	V_{IN} = 2.5V to 5.5V, T_A = +25℃	0.587	0.6	0.616	V
			V_{IN} = 2.5V to 5.5V, T_A = -40℃ to +85℃	0.583	0.6	0.619	
Line Regulation			V_{IN} = 2.5V to 5.5V, I_{LOAD} = 50mA		0.1	0.6	%/V
Load Regulation			I_{LOAD} = 200mA to 2000mA		0.07		%/A
Output Voltage Accuracy			V_{IN} = 2.5V to 5.5V, I_{LOAD} = 50mA	-3.5		+3.5	%
Oscillator Frequency		f_{OSC}			1.4		MHz
Startup Time		t_S	From Enable to Output Regulation		500		μs
Over-Temperature Shutdown Threshold		t_{SD}			150		℃
Over-Temperature Shutdown Hysteresis		t_{HYS}			15		℃
Peak Switch Current		I_{PK}			2.7		A
$R_{DS(ON)}$ of P-Channel FET		$R_{DS(ON)}$	V_{IN} = 3.6V		135		mΩ
$R_{DS(ON)}$ of N-Channel FET			V_{IN} = 3.6V		115		
EN Threshold	Logic-High Voltage	V_{EN_H}	V_{EN} Rising	1.5			V
	Logic-Low Voltage	V_{EN_L}	V_{EN} Falling			0.4	
Enable Leakage Current		I_{EN}	V_{EN} = 0V or V_{IN}		0.01	1	μA

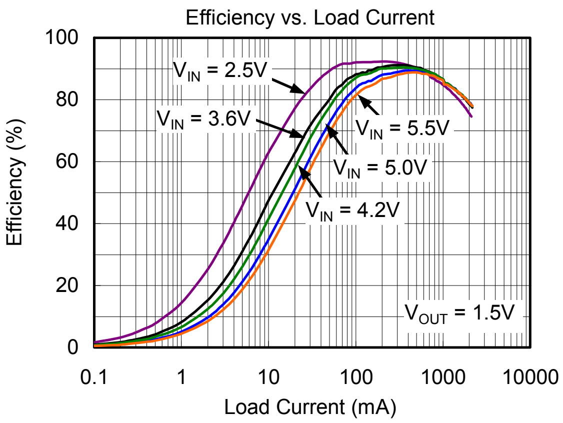
NOTE:
1. The maximum output voltage is 4.4V.

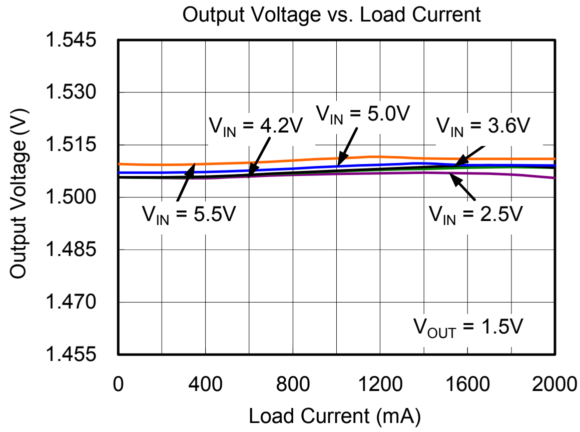
TYPICAL PERFORMANCE CHARACTERISTICS

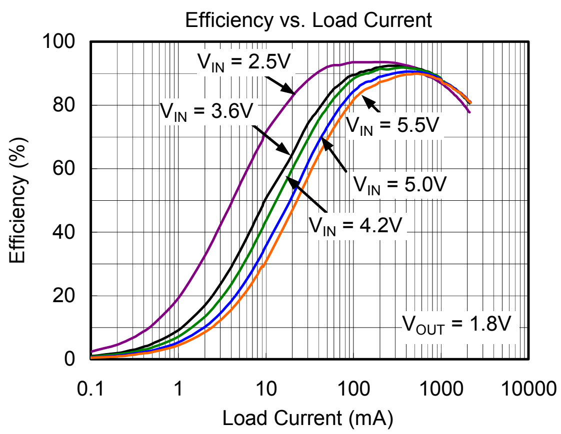
T_A = 25°C, L = 2.2μH, C_{IN} = C_{OUT} = 22μF, unless otherwise noted.

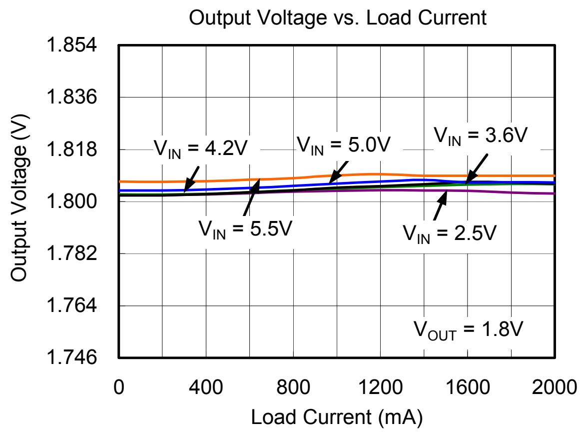












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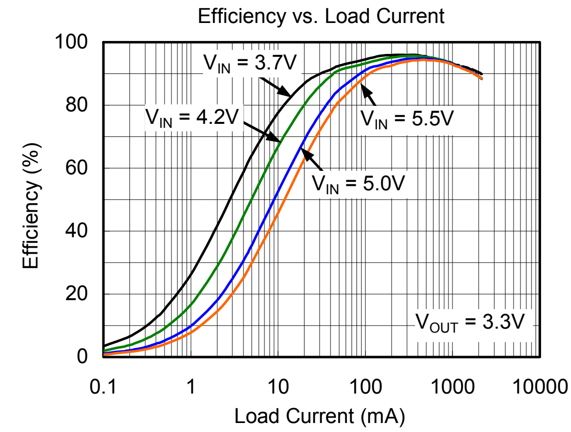
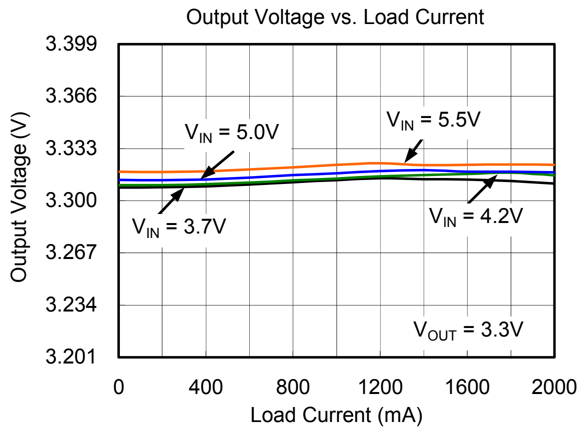
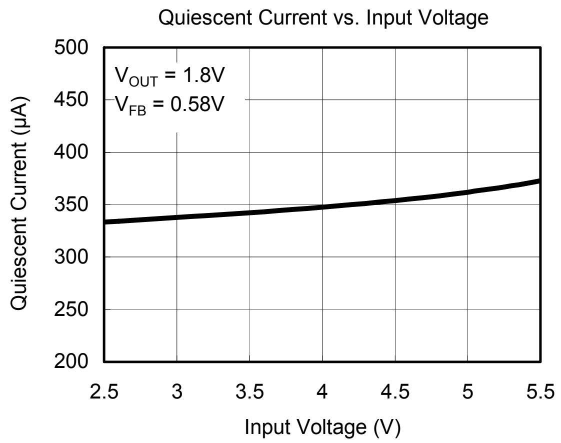
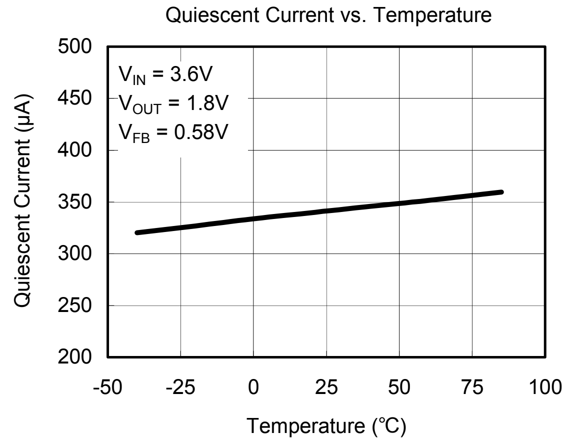
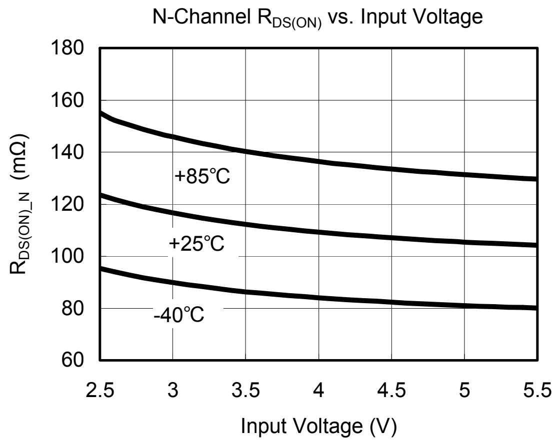
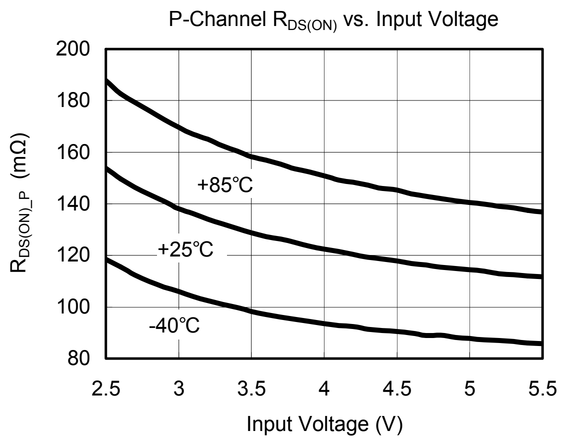








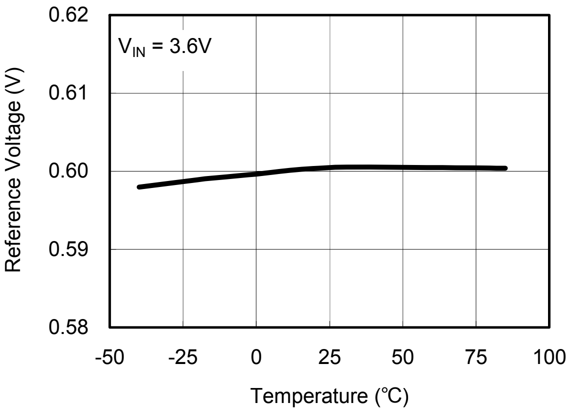




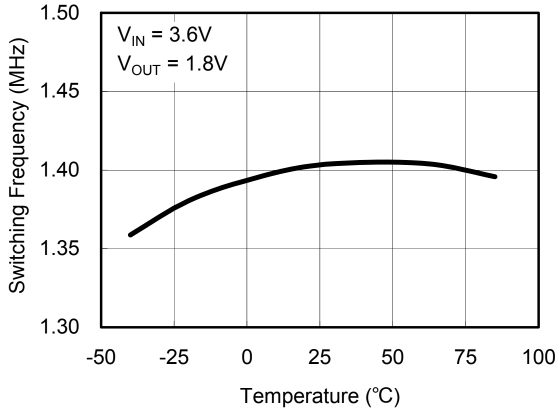
TYPICAL PERFORMANCE CHARACTERISTICS

T_A = 25°C, L = 2.2μH, C_{IN} = C_{OUT} = 22μF, unless otherwise noted.

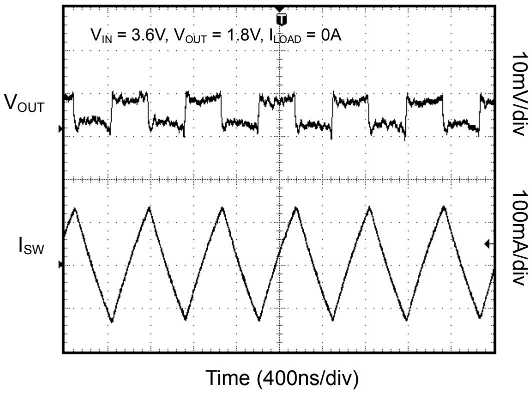
Reference Voltage vs. Temperature



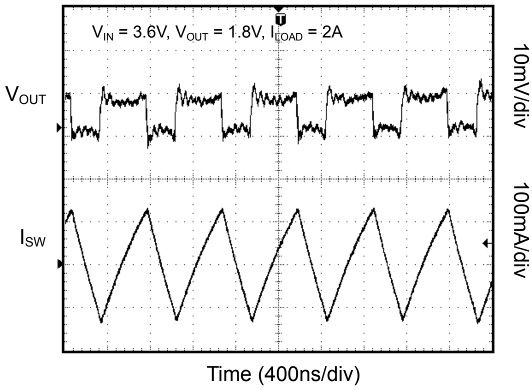
Switching Frequency vs. Temperature



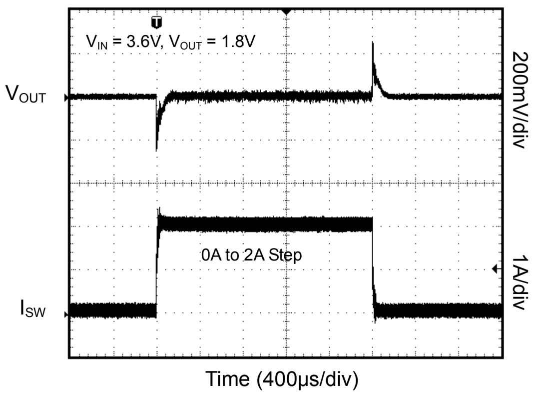
Output Ripple



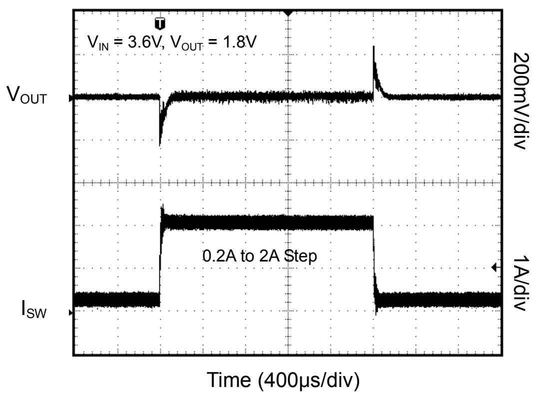
Output Ripple



Load-Transient Response



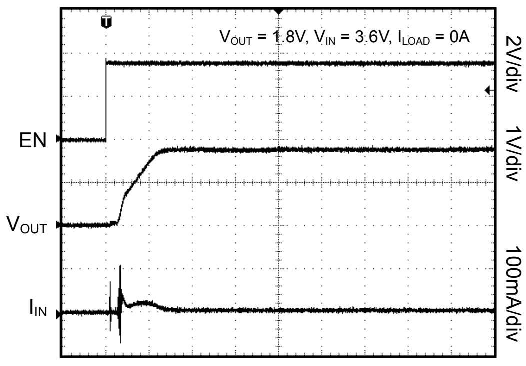
Load-Transient Response



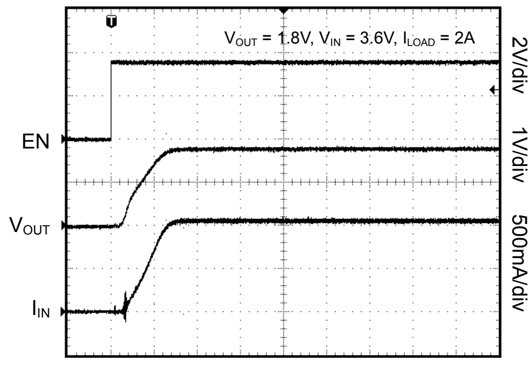
TYPICAL PERFORMANCE CHARACTERISTICS

T_A = 25°C, L = 2.2μH, C_{IN} = C_{OUT} = 22μF, unless otherwise noted.

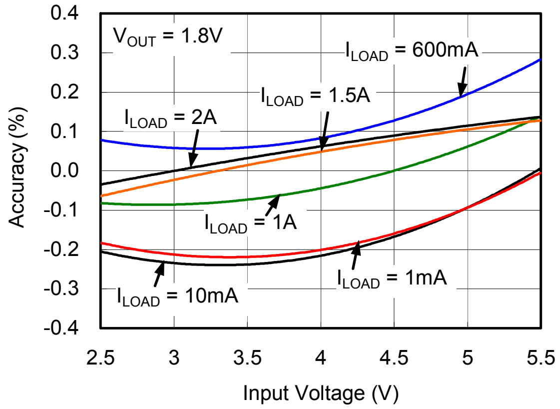
Start Up



Start Up



Line Regulation



TYPICAL APPLICATION CIRCUITS

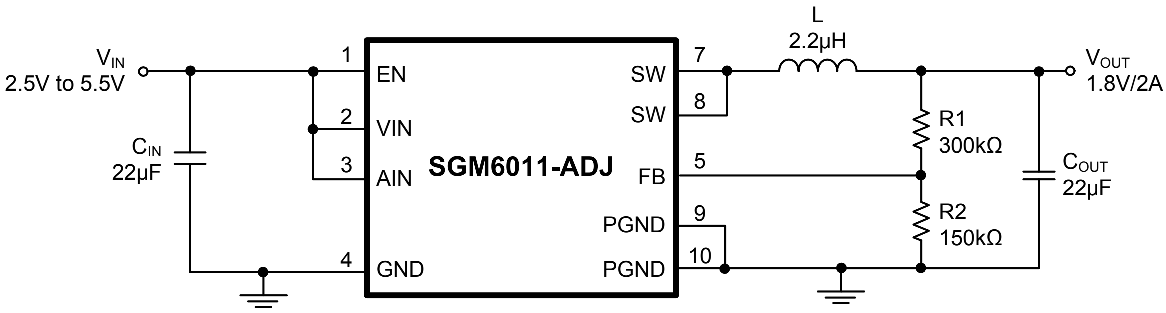


Figure 1. Basic Application Circuit for the Adjustable Output Version

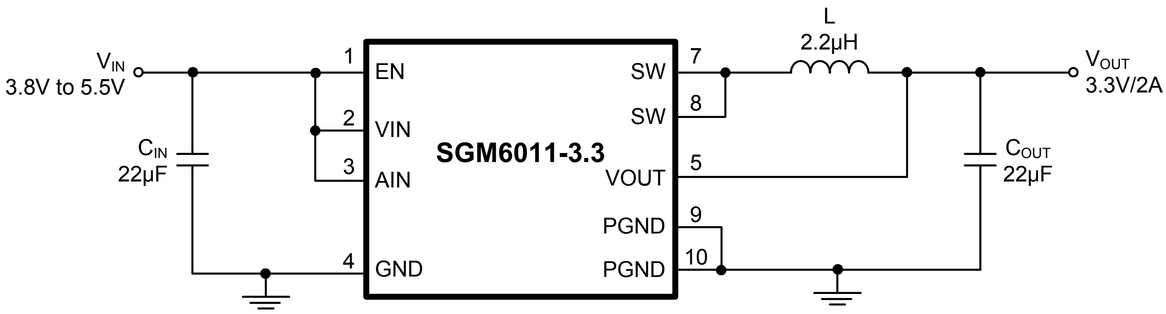


Figure 2. Basic Application Circuit for the Fixed Output Version

APPLICATION INFORMATION

Setting the Output Voltage

For applications requiring an adjustable output voltage, the SGM6011 can be externally programmed. Resistors R1 and R2 in typical application circuit program the output voltage to be equal to or higher than 1.2V. To limit the bias current required for the external feedback resistor string while maintaining good noise immunity, the minimum suggested value for R2 is 41kΩ. Although a larger value will further reduce quiescent current, it will also increase the impedance of the feedback node, making it more sensitive to external noise and interference. Table 1 summarizes the resistor values for typical output voltages.

The external resistors set the output voltage according to the following equation:

$$V_{OUT} = 0.6V \times \left(1 + \frac{R1}{R2}\right) \qquad R1 = \left(\frac{V_{OUT}}{0.6V} - 1\right) \times R2$$

Table 1 shows the resistor selection for different output voltage settings.

Table 1. Standard 1% Resistors Substituted for Calculated Values

V_{OUT} (V)	R1 (kΩ)	R2 (kΩ)
1.2	150	150
1.8	300	150
3.3	450	100

When the battery input voltage decreases near the value of the output voltage, the SGM6011 allows the main switch to remain on for more than one switching cycle and increases the duty cycle until it reaches 100%. The duty cycle D of a step-down converter is defined as:

$$D = t_{ON} \cdot f_{OSC} \cdot 100\% \approx \frac{V_{OUT}}{V_{IN}} \cdot 100\%$$

where t_{ON} is the main switch on-time and f_{OSC} is the oscillator frequency. The minimum on-time is typically 90ns; therefore, the minimum duty cycle is equal to 100 × 90ns × f_{OSC}(Hz).

Inductor Selection

For most designs, the SGM6011 operates with inductor values of 1μH to 4.7μH. Small value inductors can be derived from the following equation:

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

where ΔI_L is inductor ripple current. Large value inductors lower ripple current and small value inductors result in high ripple current. Choose inductor ripple current approximately 30% of the maximum load current 2A, or ΔI_L = 600mA. For output voltages above 2.0V, when light-load efficiency is important, the minimum recommended inductor is 2.2μH.

Manufacturer's specifications list both the inductor DC current rating, which is a thermal limitation, and the peak current rating, which is determined by the saturation characteristics. The inductor should not show any appreciable saturation under normal load conditions. Some inductors may meet the peak and average current ratings yet result in excessive losses due to a high DCR.

Always consider the losses associated with the DCR and its effect on the total converter efficiency when selecting an inductor. For optimum voltage-positioning load transients, choose an inductor with DC series resistance in the 20mΩ to 100mΩ range. For higher efficiency at heavy loads (above 200mA), or best load regulation (but some transient overshoot), the resistance should be kept below 100mΩ. The DC current rating of the inductor should be at least equal to the maximum load current plus half the ripple current to prevent core saturation (2A + 600mA).

Slope Compensation

The SGM6011 step-down converter uses peak current mode control with slope compensation for stability when duty cycles are greater than 50%. The slope compensation is set to maintain stability with lower value inductors which provide better overall efficiency. The output inductor value must be selected so the inductor current down slope meets the internal slope compensation requirements.

APPLICATION INFORMATION

As an example, the value of the slope compensation is set to 1.5A/μs which is large enough to guarantee stability when using a 2.2μH inductor for all output voltage levels from 1.2V to 4.4V. The worst case external current slope (m) using the 2.2μH inductor is when V_{OUT} = 4.4V and is:

$$m = \frac{V_{OUT}}{L} = \frac{4.4}{2.2} = 2\text{A/μs}$$

To keep the power supply stable when the duty cycle is above 50%, the internal slope compensation (m_a) should be:

$$m_a \geq \frac{1}{2}m = \frac{1}{2} \times \frac{V_{OUT}}{L} = 1\text{A/μs}$$

Therefore, to guarantee current loop stability, the slope of the compensation ramp must be greater than one-half of the down slope of the current waveform. So the internal slope compensated value of 1.5A/μs will guarantee stability using a 2.2μH inductor value for all output voltages from 1.2V to 4.4V.

Input Capacitor Selection

The input capacitor reduces the surge current drawn from the input and switching noise from the device. The input capacitor impedance at the switching frequency should be less than the input source impedance to prevent high frequency switching current passing to the input. The calculated value varies with input voltage and is a maximum when V_{IN} is double the output voltage.

$$C_{IN} = \frac{\frac{V_{OUT}}{V_{IN}} \cdot \left(1 - \frac{V_{OUT}}{V_{IN}}\right)}{\left(\frac{V_{PP}}{I_{LOAD}} - ESR\right) \cdot f_{OSC}}$$

$$C_{IN(MIM)} = \frac{1}{\left(\frac{V_{PP}}{I_{LOAD}} - ESR\right) \cdot 4 \cdot f_{OSC}}$$

A low ESR input capacitor sized for maximum RMS current must be used. Ceramic capacitors with X5R or X7R dielectrics are highly recommended because of their low ESR and small temperature coefficients. A 22μF ceramic capacitor for most applications is sufficient. A large value may be used for improved input voltage filtering. The maximum input capacitor RMS current is:

$$I_{RMS} = I_{LOAD} \cdot \sqrt{\frac{V_{OUT}}{V_{IN}} \cdot \left(1 - \frac{V_{OUT}}{V_{IN}}\right)}$$

The input capacitor RMS ripple current varies with the input and output voltage and will always be less than or equal to half of the total DC load current:

$$I_{RMS(MAX)} = \frac{1}{2} \cdot I_{LOAD}$$

A laboratory test set-up typically consists of two long wires running from the bench power supply to the evaluation board input voltage pins. The inductance of these wires, along with the low-ESR ceramic input capacitor, can create a high Q network that may affect converter performance. This problem often becomes apparent in the form of excessive ringing in the output voltage during load transients. Errors in the loop phase and gain measurements can also result.

Since the inductance of a short PCB trace feeding the input voltage is significantly lower than the power leads from the bench power supply, most applications do not exhibit this problem.

In applications where the input power source lead inductance cannot be reduced to a level that does not affect the converter performance, a high ESR tantalum or aluminum electrolytic capacitor should be placed in parallel with the low ESR, ESL bypass ceramic capacitor. This dampens the high Q network and stabilizes the system.

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Output Capacitor Selection

The function of output capacitance is to store energy to attempt to maintain a constant voltage. The energy is stored in the capacitor's electric field due to the voltage applied. The value of output capacitance is generally selected to limit output voltage ripple to the level required by the specification. Since the ripple current in the output inductor is usually determined by L, V_{OUT} and V_{IN}, the series impedance of the capacitor primarily determines the output voltage ripple. The three elements of the capacitor that contribute to its impedance (and output voltage ripple) are equivalent series resistance (ESR), equivalent series inductance (ESL), and capacitance (C).

The output voltage droop due to a load transient is dominated by the capacitance of the ceramic output capacitor. During a step increase in load current, the ceramic output capacitor alone supplies the load current until the loop responds. Within three switching cycles, the loop responds and the inductor current increases to match the load current demand. The relationship of the output voltage droop during the three switching cycles to the output capacitance can be estimated by:

$$C_{OUT} = \frac{3 \cdot \Delta I_{LOAD}}{V_{DROP} \cdot f_{OSC}}$$

In many practical designs, to get the required ESR, a capacitor with much more capacitance than is needed must be selected. The ESR of the C_{OUT} needed to limit the ripple to ΔV_{OUT}, V peak-to-peak is:

$$ESR \le \frac{\Delta V_{OUT}}{\Delta I_L}$$

Ripple current flowing through a capacitor's ESR causes power dissipation in the capacitor. This power dissipation causes a temperature increase internal to the capacitor. Excessive temperature can seriously shorten the expected life of a capacitor. Capacitors have ripple current ratings that are dependent on ambient temperature and should not be exceeded. The output capacitor ripple current is the inductor current, I_L, minus the output current. The RMS value of the ripple current flowing in the output capacitance is given by:

$$I_{RMS} = \Delta I_L \cdot \frac{\sqrt{3}}{6} = \Delta I_L \cdot 0.289$$

ESL can be a problem by causing ringing in the low megahertz region but can be controlled by choosing low ESL capacitors, limiting lead length (PCB and capacitor), and replacing one large device with several smaller ones connected in parallel.

In conclusion, in order to meet the requirement of small output voltage ripple and regulation loop stability, ceramic capacitors with X5R or X7R dielectrics are recommended due to their low ESR and high ripple current ratings. The output ripple V_{OUT} is determined by:

$$\Delta V_{OUT} \le \frac{V_{OUT} \cdot (V_{IN} - V_{OUT})}{V_{IN} \cdot L \cdot f_{OSC}} \cdot \left(ESR + \frac{1}{8 \cdot f_{OSC} \cdot C_{OUT}} \right)$$

A 22μF ceramic capacitor can satisfy most applications.

Thermal Calculations

There are three types of losses associated with the SGM6011 step-down converter: switching losses, conduction losses, and quiescent current losses. Conduction losses are associated with the $R_{DS(ON)}$ characteristics of the power output switching devices. Switching losses are dominated by the gate charge of the power output switching devices. At full load, a simplified form of the losses is given by:

$$P_{TOTAL} = \frac{I_{LOAD}{}^2 \cdot \left[R_{DSON(HS)} \cdot V_{OUT} + R_{DSON(LS)} \cdot (V_{IN}\text{-}V_{OUT})\right]}{V_{IN}} + (t_{SW} \cdot F \cdot I_{LOAD} + I_Q) \cdot V_{IN}$$

I_Q is the step-down converter quiescent current. The t_{SW} is used to estimate the full load step-down converter switching losses.

For the condition where the step-down converter is in dropout at 100% duty cycle, the total device dissipation reduces to:

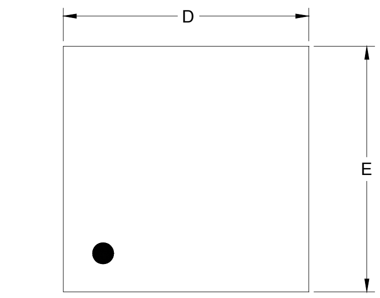
$$P_{TOTAL} = I_{LOAD}{}^2 \cdot R_{DSON(HS)} + I_Q \cdot V_{IN}$$

Since $R_{DS(ON)}$, quiescent current, and switching losses all vary with input voltage, the total losses should be investigated over the complete input voltage range. Given the total losses, the maximum junction temperature can be derived from the θ_{JA} for the TDFN-3×3-10L package which is 45℃/W.

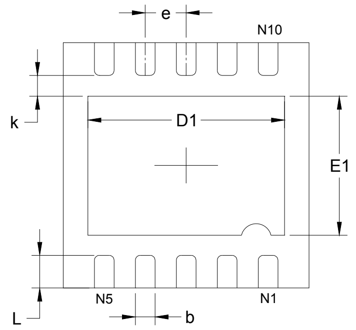
$$T_{J(MAX)} = P_{TOTAL} \cdot \theta_{JA} + T_{AMB}$$

PACKAGE OUTLINE DIMENSIONS

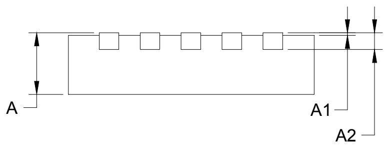
TDFN-3×3-10L



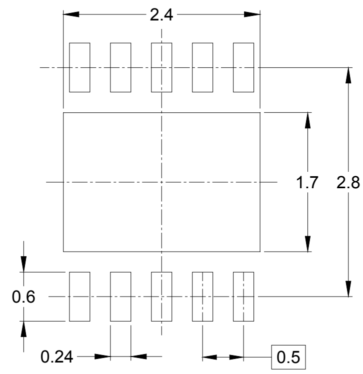
TOP VIEW



BOTTOM VIEW



SIDE VIEW

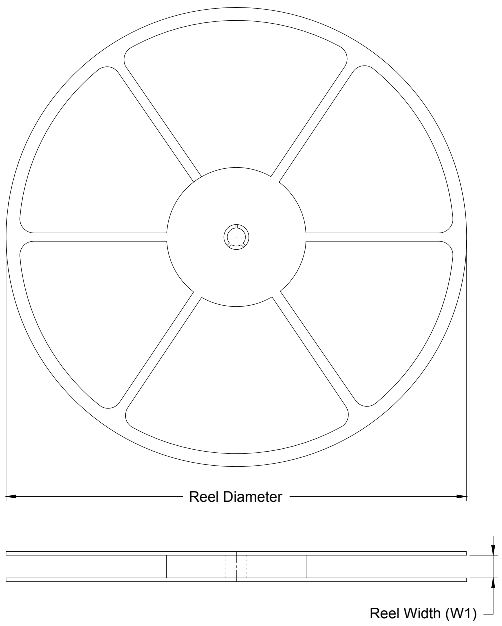


RECOMMENDED LAND PATTERN (Unit: mm)

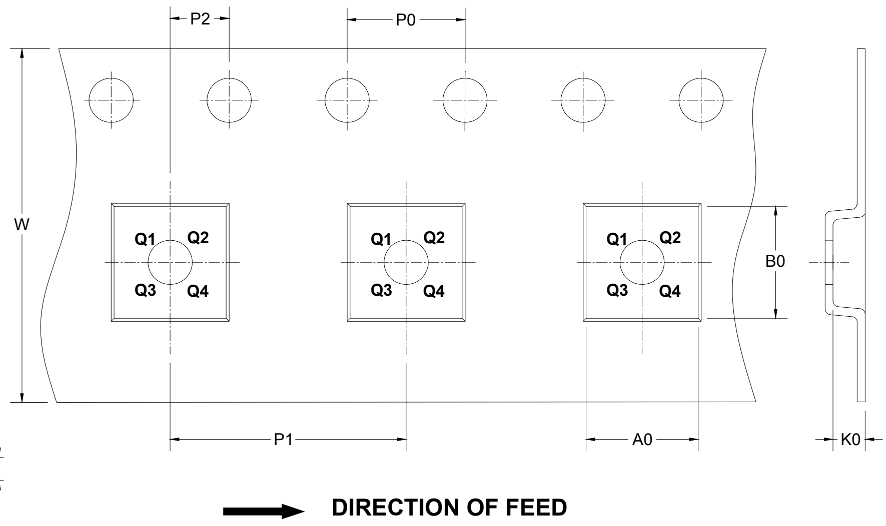
Symbol	Dimensions In Millimeters		Dimensions In Inches	
	MIN	MAX	MIN	MAX
A	0.700	0.800	0.028	0.031
A1	0.000	0.050	0.000	0.002
A2	0.203 REF		0.008 REF	
D	2.900	3.100	0.114	0.122
D1	2.300	2.600	0.091	0.103
E	2.900	3.100	0.114	0.122
E1	1.500	1.800	0.059	0.071
k	0.200 MIN		0.008 MIN	
b	0.180	0.300	0.007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

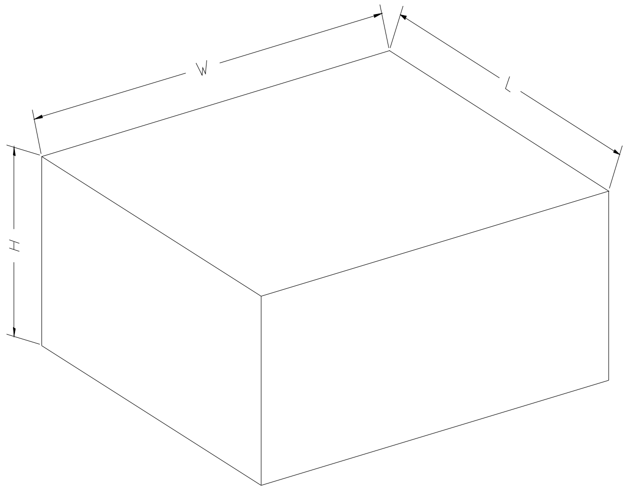


NOTE: The picture is only for reference. Please make the object as the standard.

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