SC190
Synchronous Buck Converter with Programmable Output

POWER MANAGEMENT

Description

The SC190 is a synchronous step-down converter with integrated power devices and an integrated front-end LDO to minimize input supply ripple. Output voltage is programmable using two control bits, eliminating the need for feedback resistors tied to the output. The device is offered in four distinct variants with each variant providing four fixed output voltage options to choose from.

The front-end LDO can be bypassed externally to maximize efficiency. A second LDO is switched in place of the switching regulator for low current operation to further improve efficiency and reduce noise.

The SC190's flexible clocking scheme allows it to be synchronized to an external oscillator or controlled by the internal oscillator. The 1MHz switching frequency allows the use of small inductors and capacitors.

The internal MOSFET switches provide peak current greater than 500mA to achieve a DC output of at least 300mA. Shutdown current is typically 0.1µA.

The SC190 has four different variants with four voltage settings each. It is designed for single-cell Li-ion battery applications, but also performs well in fixed 3.3V and 5V applications.

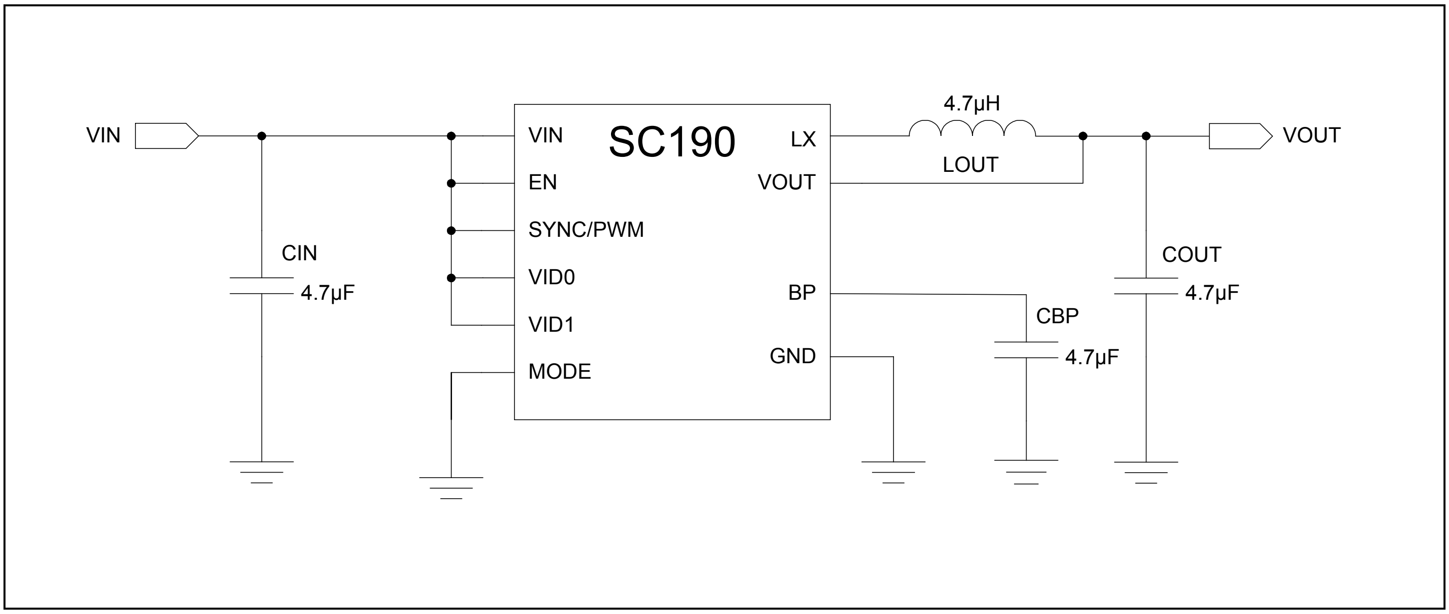
Features

- Less than 1mV Supply Ripple
- Output Voltage Regulated by Either the Switching Regulator or Linear Regulator
- Dynamic Handover Between Linear and Switching Regulator for Maximum Efficiency
- 2.7V to 5.5V Input Range
- 300mA Guaranteed Output Current
- Fixed Frequency 1MHz Operation or 750kHz to 1.5MHz Clocked Operation
- No Schottky Diode Required
- Up to 95% Efficiency (VIN=BP)
- Over-current Protection
- Over-voltage Protection
- Over-temperature Protection
- Soft Start
- MLP-10, 3 x 3mm Lead-frame, Lead-free Package
- Low Output Noise < 100µVrms

Applications

- Cell Phones
- Cordless Phones
- Notebook and Subnotebook Computers
- PDAs and Mobile Communicators
- WLAN Peripherals
- 1 Li-Ion or 3 NiMH/NiCd Powered Devices

Typical Application Circuit



Absolute Maximum Ratings

Exceeding the specifications below may result in permanent damage to the device or device malfunction. Operation outside of the parameters specified in the Electrical Characteristics section is not implied.

Parameter	Symbol	Maximum	Units
VIN Input	V_{IN}	-0.3 to 7	V
Logic Inputs (SYNC/PWM, EN, MODE, VID0, and VID1)	V_N	-0.3 to 7	V
LX Voltage	V_{LX}	-1 to BP +1	V
VOUT Voltage	V_{OUT}	-0.3 to VIN + 0.3	V
BP Voltage	V_{BP}	VIN -0.3 to VIN + 0.3	V
Thermal Impedance Junction to Ambient	θ_{JA}	*31	°C/W
VOUT Short Circuit to GND	t_{SC}	Continuous	s
BP Current	I_{BP}	0.8	A
LX Current	I_{LX}	+1.2	A
Storage Temperature	T_S	-65 to +150	°C
Junction Temperature	T_{JC}	+150	°C
Peak IR Reflow Temperature	T_{LEAD}	260	°C

* Tied to PCB with 1 square inch, 2 ounce copper.

Electrical Characteristics

Unless otherwise noted: V_{IN} = 3.6V, SYNC/PWM = V_{IN}, MODE = GND, EN = V_{IN}, T_A = -40 to 85°C. Typical values are at T_A = +25°C. This device is ESD sensitive. Use of standard ESD handling precautions is required.

Parameter	Symbol	Conditions	Min	Typ	Max	Units
Input Voltage Range	V_{IN}	$V_{IN} = V_{BP}$	2.7		5.5	V
		$V_{IN} \neq V_{BP}$	2.9		5.5	V
Input Voltage Ripple	$V_{IN\ PK-PK}$	C_{IN}, C_{BP} = 10µF		1		mV
Line Regulation	$V_{LINEREG}$	190A, B and D: see note (1)	-0.3		0.3	%/V
		190C: see note (2)	-0.5		0.5	%/V
Load Regulation	$V_{LOADREG}$	I_{OUT} = 5mA to 300mA		0.002		%/mA
P-Channel On Resistance	R_{DSP}	I_{LX} = 100mA		0.3		Ω
N-Channel On Resistance	R_{DSN}	I_{LX} = 100mA		0.2		Ω
Start Up Time	T_{START}	I_{OUT} = 150mA		1.25		ms

Electrical Characteristics (Cont.)

Unless otherwise noted: V_{IN} = 3.6V, SYNC/PWM = V_{IN}, MODE = GND, EN = V_{IN}, T_A = -40 to 85°C. Typical values are at T_A = +25°C. This device is ESD sensitive. Use of standard ESD handling precautions is required.

Parameter	Symbol	Conditions	Min	Typ	Max	Units
VOUT Accuracy	V_{OUT}	I_{OUT} = 150mA	-3		3	%
		MODE = V_{IN}, I_{OUT} = 1mA	3		3	%
		I_{OUT} = 150mA, T_A = +25°C	-1.5		1.5	%
		MODE = V_{IN}, I_{OUT} = 1mA, T_A = +25°C	-1.5		1.5	%
Back-end LDO Load Regulation (BELDO)	$VOUT_{LOADREG}$	I_{OUT}= 100µA to 5mA MODE = V_{IN}	-0.1		0.1	%/mA
Back-end LDO Line Regulation (BELDO)	$VOUT_{LINEREG}$	V_{IN} = 2.7V to 5.5V MODE = V_{IN}	-0.3		0.3	%/V
Back-end LDO Current Limit (BELDO)	$I_{out\ LIMLDO}$	MODE = V_{IN}	20	40	60	mA
Front-end LDO (FELDO)	V_{BP}	I_{BP} = 180mA(3)		300	325	mV
P-Channel Current Limit	$I_{LIM(P)}$		500	630	860	mA
N-Channel Current Limit	$I_{LIM(N}$		-270	-420	-520	mA
Quiescent Current	I_Q	MODE = V_{IN}, I_{OUT} = 100µA(4)		10	15	µA
Shutdown Current	I_{SD}	EN = 0		0.1	1	µA
LX Leakage Current PMOS	I_{LXP}	V_{IN} = 5.5V, LX = 0V, EN = 0		0.1	1	µA
LX Leakage Current NMOS	I_{LXN}	V_{IN} = 5.5V, LX = 5.5V, EN = 0	-20	0.1		µA
Output Voltage Noise	e_n	C_{OUT} = 4.7µF, V_{OUT} = 1V, I_{OUT} = 1mA, 100Hz < f < 100kHz		93		$µV_{RMS}$
Oscillator Frequency	f_{OSC}		0.87	1.0	1.12	MHz
SYNC Frequency (upper)	f_{SYNCU}			1.5		MHz
SYNC Frequency (lower)	f_{SYNCL}				750	kHz

Electrical Characteristics (Cont.)

Unless otherwise noted: V_{IN} = 3.6V, SYNC/PWM = V_{IN}, MODE = GND, EN = V_{IN}, T_A = -40 to 85°C. Typical values are at T_A = +25°C. This device is ESD sensitive. Use of standard ESD handling precautions is required.

Parameter	Symbol	Conditions	Min	Typ	Max	Units
UVLO Threshold (lower)	V_{UVL}		2.4	2.5	2.6	V
UVLO Hysteresis	V_{UVLHYS}			50		mV
Thermal Shutdown	T_{HI}			145		˚C
Thermal Shutdown Hysteresis	T_{HYSR}			10		˚C
Logic Input High	VIH	EN, SYNC/PWM, MODE, VID0, VID1	1.6			V
Logic Input Low	VIL	EN, SYNC/PWM, MODE, VID0, VID1			0.6	V
Logic Input Current High	I_{IH}	EN, SYNC/PWM, MODE, VID0, VID1	-2	0.1	2	µA
Logic Input Current Low	I_{IL}	EN, SYNC/PWM, MODE, VID0, VID1	-2	0.1	2	µA

Notes:

(1) Line regulation is tested with 2.7V < VIN < 5.5V and the following output voltage settings:

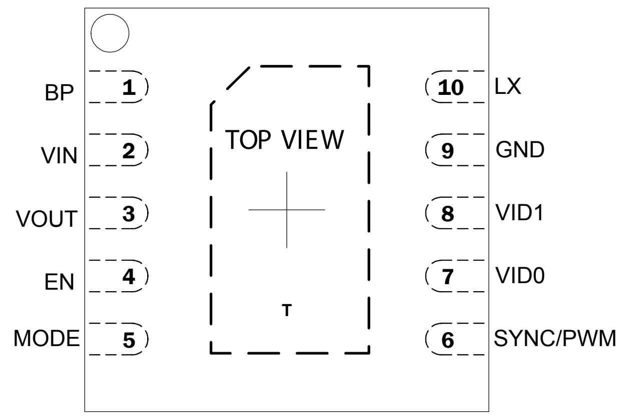
- SC190A - 1.8V
- SC190B - 1.8V
- SC190D - 1.4V

(2) Line regulation is tested with 3.7V < VIN < 5.5V and VOUT = 2.6V for the SC190C version. The input voltage range is reduced due to the higher output voltage settings of the SC190C. This also forces the specification range to grow wider because it is expressed as a percentage of the input voltage range.

(3) Tested at I_{BP} = 180mA. Equivalent to I_{OUT} = 300mA at V_{OUT} = 1.8V.

(4) $I_Q = I_{IN} - I_{OUT}$.

Pin Configuration



MLP10: 3X3 10 LEAD

Ordering Information

Device	Package
SC190AIMLTRT[1]	MLP 3X3-10
SC190BIMLTRT[1]	
SC190CIMLTRT[1]	
SC190DIMLTRT[1]	
SC190AEVB	Evaluation Board[2]
SC190BEVB	
SC190CEVB	
SC190DEVB	

(1) Lead-free packaging only. This product is fully WEEE and RoHS compliant. Available on tape and reel only. A reel contains 3000 devices.

(2) Part specific evaluation boards - consult factory for availability.

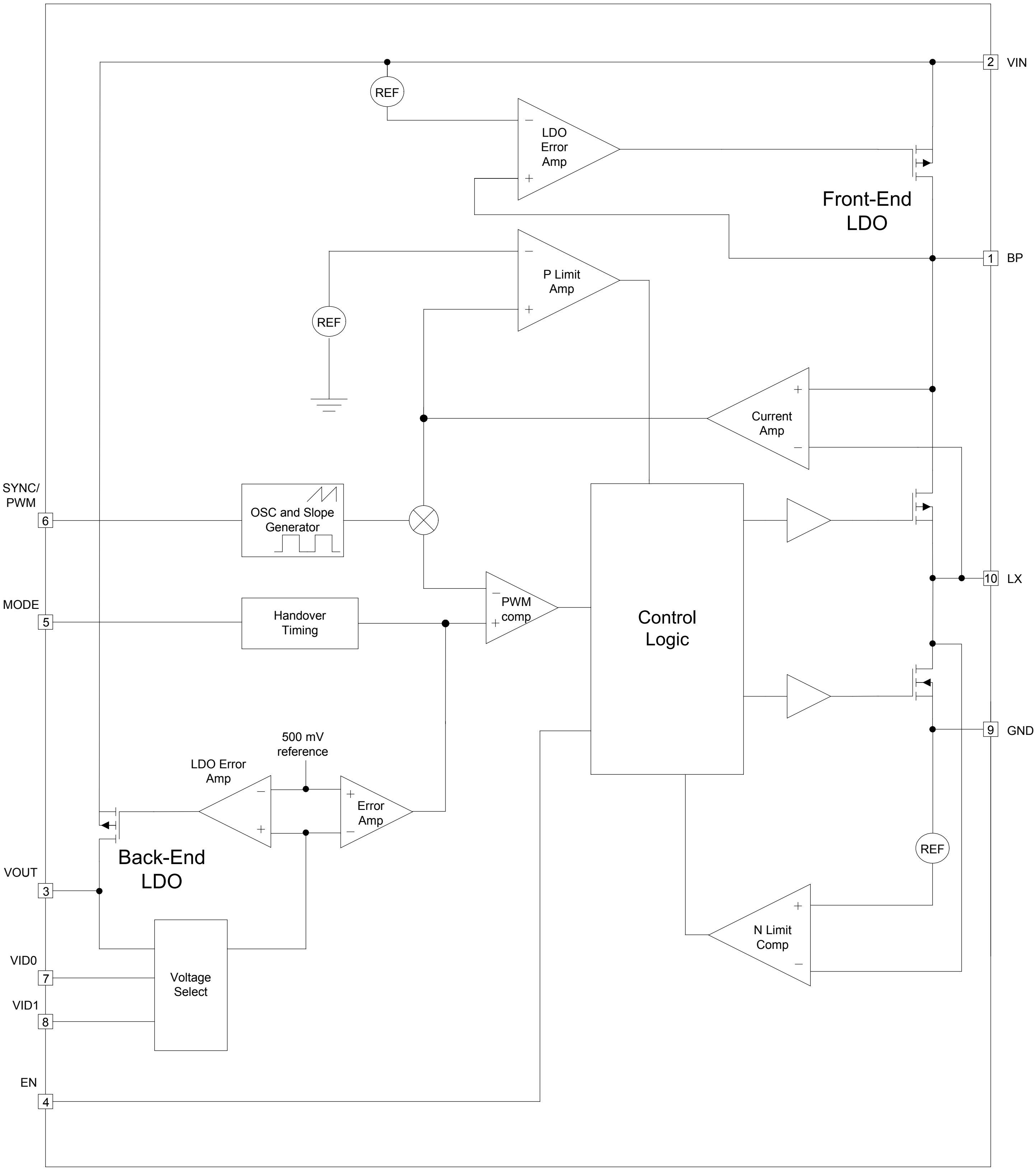
Programmable Output Voltage

VID1	VID0	SC190A	SC190B	SC190C	SC190D
0	0	1.8V	1.2V	2.5V	1.3V
0	1	1.85V	1.5V	2.8V	1.35V
1	0	1.75V	1.0V	2.6V	1.375V
1	1	1.9V	1.8V	2.7V	1.4V

Pin Descriptions

Pin #	Pin Name	Pin Function
1	BP	Regulated output, with respect to VIN, of the front-end LDO. A decoupling capacitor is connected to this pin. This input goes directly to the internal MOSFET switch.
2	VIN	Input power supply voltage
3	VOUT	Regulated output voltage and feedback for SC190.
4	EN	Enable (digital input): high input enables the SC190, a low disables and reduces quiescent current to 0.1µA. In shutdown, LX becomes high impedance.
5	MODE	Mode select pin (digital input): MODE = VIN - linear regulator mode; MODE = GND - switcher mode.
6	SYNC/PWM	Oscillator synchronization input. Tie to VIN for forced continuous mode or external clock for frequency synchronization.
7	VID0	Logic level Bit 0 used in conjunction with VID1 to set the output voltage.
8	VID1	Logic level Bit 1 used in conjunction with VID0 to set the output voltage.
9	GND	Ground.
10	LX	Inductor connection to the switching FETs.
T	Thermal	Pad for heatsinking purposes. Not connected internally. Connects to ground plane using multiple vias.

Block Diagram



Applications Information

SC190 Detailed Description

The SC190 is a step-down, pulse-width-modulated (PWM) DC-DC converter with a low dropout (LDO) pre-regulator and a low current LDO regulator for operation in low power modes.

The device has an internal synchronous rectifier and does not require a Schottky diode on the LX pin. The device is designed to operate as a buck converter in PWM mode with a fixed frequency of 1MHz, but at loads below 5mA, the part can be operated as an ultra-low current LDO regulator to minimize supply current.

Programmable Output Voltage

The SC190 has four device variants (SC190A, SC190B, SC190C, SC190D) each with a distinct range of output voltages. The output voltage of each variant has four predetermined values which can be individually selected by the correct programming of the VID0 and VID1 pins. (See “Programmable Output Voltage” table on page 5).

Note that the SC190C has much higher output voltage settings than the other three variants. This device was intended for use with higher input voltages, so some performance over the entire input voltage range cannot be guaranteed.

Switcher Mode with less than 1mV supply ripple

This is a fixed frequency current mode architecture with the input supply for the switching regulator pre-regulated by a front-end LDO regulator. This technique reduces the supply voltage ripple from 20mV, typically seen from a switching converter, to approximately 1mV for the SC190. The supply to the switcher is regulated to the supply voltage minus approximately 300mV.

Current feedback for the switching regulator is through the PMOS current path and it is amplified and summed with the internal slope compensation network and level shift. The voltage feedback loop is through an internal feedback divider. The ON time is determined by comparing the summed current feedback and the output of the error amplifier. The period is set by the onboard oscillator or by an external clock attached to the SYNC/PWM pin.

Efficiency at moderate to high loads can be improved by shorting the VIN to BP pins at the expense of higher input voltage ripple.

Continuous Conduction & Oscillator Synchronization

The SC190 is designed to operate in continuous conduction mode thereby maintaining a fixed frequency. When the SYNC/PWM pin is tied high the part runs under control of the internal oscillator. The part can be synchronized to an external clock by driving a clock signal into the SYNC/PWM pin. The part synchronizes to the rising edge of the clock.

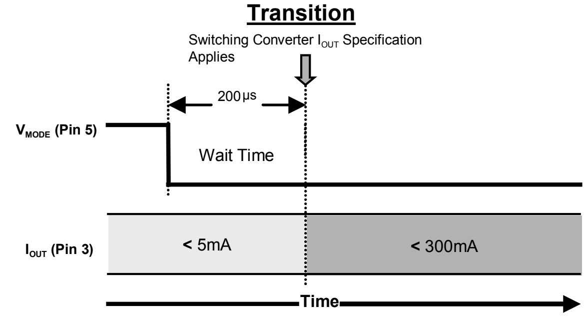
Back End LDO Mode

The SC190 ultra-low current linear regulator regulates the same output as the switching regulator. The linear regulator minimizes the supply current drawn at light loads consuming only 10µA when supporting a 100µA load. The SC190 can swap between switching regulator and linear regulator mode under control of the MODE pin (see “handover” section). In this way the part either operates at a fixed frequency or DC output, thereby never generating load dependant frequencies that are typically seen with lightly loaded switching regulators.

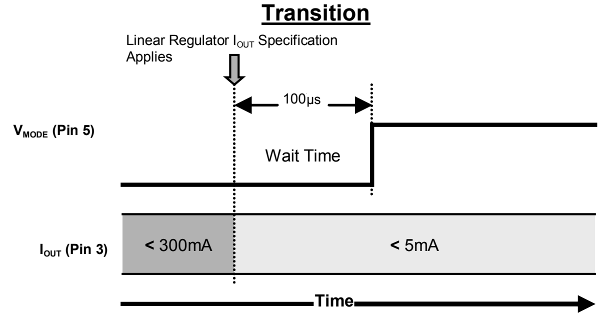
Handover (Switcher Mode to LDO Regulator Mode, LDO Regulator Mode to Switcher Mode)

The device can be switched between Switcher mode and Linear regulator mode and back to Switcher mode without having to disable and re-enable the part. The output maintains regulation during the switch over.

Linear Regulator Mode to Switching Mode Transition



Switching Mode to Linear Regulator Mode Transition



Applications Information

The output load in switcher mode has to be reduced to a load that the LDO regulator can support before switching between the two modes to minimize output voltage deviation. The transition from LDO regulator mode to switcher mode requires the load to be kept at levels the LDO regulator can support for a given time period after the MODE pin has been pulled low (see Timing Diagram on page 7).

Protection Features

The SC190 provides the following protection features:

- Thermal Shutdown
- Current Limit
- Overvoltage Protection
- Soft-Start

Thermal Shutdown

The device has a thermal shutdown feature to protect the device if the junction temperature exceeds 150°C. In thermal shutdown the PWM drive is disabled tri-stating the LX output and the front-end LDO is disabled. The device will not be enabled again until the temperature reduces by 10°C. If during this time the output falls by greater than 60% of its regulation voltage a soft start will be invoked. Thermal shutdown is not active during LDO mode in order to minimize supply current.

Current Limit

The part has a number of current limit functions. The Front-end LDO regulator has a current limit set at approximately 500mA, which will protect the FELDO regulator in the event of a pulsed short circuit.

The PMOS and NMOS power devices of the buck switcher stage are protected by current limit functions.

In the case of a short to ground on the output, the part enters frequency foldback mode which causes the switching frequency to divide by a factor determined by the output voltage, stopping the inductor current "stair stepping."

The back-end LDO regulator has a current limit feature which will limit the maximum output current during LDO regulator mode to 50mA.

Overvoltage Protection

Overvoltage protection is provided on the SC190. In the event of an overvoltage on the output in switcher mode, the drive to the PWM stage is disabled and the part will not resume switching until the output voltage has fallen to below 2% of the regulation voltage.

Soft-Start

The soft-start mode is enabled after every shutdown cycle to limit in-rush current. In conjunction with the frequency foldback this controls the maximum current during the start-up. The switcher's PMOS current limit is stepped from 25%, to 50%, to 75%, and then 100% of its typical value by the internal oscillator. The oscillator frequency is stepped by $^1/_8$, $^1/_4$, $^1/_2$ and 1 under the control of 4 output voltage thresholds causing modulation of the soft-start timer (see Current Limit description in the Protection Features section). As soon as the part reaches regulation, soft-start mode is disabled.

100 Percent Duty Cycle Operation

The SC190C has a 100% duty cycle mode of operation to allow the switcher to regulate the output at low input voltage to high output voltage conditions. As the input supply drops towards the output voltage, the PMOS on-time increases linearly until a point where the PMOS FET is on for 100% of the time. Once the PMOS is on DC the output voltage will track the input voltage minus the voltage drop across the PMOS power device according to the following relationship:

$$V_{out} = V_{in} - I_{out}\,(R_{dsp} + R_{ind})$$

V_{out} = Output Voltage
V_{in} = Input Voltage
I_{out} = Output current
R_{dsp} = PMOS switch ON resistance
R_{ind} = Series resistance of the inductor

Output Filter
The SC190 series of synchronous step-down converters have internal loop compensation. The internal compensation is designed to work with a certain output filter corner frequency defined by the equation:

$$f_C = \frac{1}{2\pi\sqrt{L \bullet C}}$$

The internal compensation is optimized to operate with an output filter, L=4.7μH & COUT = 10μF. When selecting output filter components the LC product should not vary over a wide range.

Table 1: Output Filter combinations

L(μH)	C_{OUT}(μF)
4.7	4.7
4.7	10
10	10

The selection of smaller inductor & capacitor values will move the corner frequency, having an impact on system stability. Due to this issue the practical lower limit for the inductor value is 4.7μH.

Inductor Selection
As previously stated the value of the inductor should be in the range 4.7μH to 10μH. The magnitude of the inductor current ripple is dependant on the inductor value and can be determined by the following equation:

$$\Delta IL = \frac{Vo\left(1 - \frac{Vo}{Vi}\right)}{L \bullet f}$$

This equation demonstrates the relationship between V_{IN},V_{OUT} & I_L. The inductor ripple current decreases with higher inductance & increases with higher V_{IN} or V_{OUT}.

To maximize efficiency the inductor should have a low DCR to minimize the conduction losses. As a minimum requirement the DC current rating of the inductor should be equal to the maximum load current plus half of the inductor current ripple and can be determined by the following equation:

$$ILpk = Iout(max) + \frac{\Delta IL}{2}$$

Alternatively, set the inductor saturation current to be greater than the switch current limit as a maximum limit. I_{SAT} > PMOS. Final inductor selection will depend on various design considerations such as efficiency, EMI, size and cost. Table 2 lists the manufacturers of practical inductor options.

Table 2 - Recommended Inductors

Manufacturer	Part Number	Value (μH)	DCR (Ω)	Rated Current (A)	Saturation Current (A)	Tolerance %	Dimensions (LxWxH mm)
TDK	LDR655312T-4R7W	4.7	0.206	0.9	-	20	6.5 x 5.3 x 1.2
Sumida	CDRH3D16LD	4.7	0.073	0.68	-	30	4 x 4 x 1.8
Taiyo Yuden	LMNP04SB100M	10	0.066	0.9	-	20	5 x 5 x 2
Coilcraft	LPS3015	10	0.044	-	0.65	20	3 x 3 x 1.5
Coilcraft	LP06610-103M	10	0.41	-	0.8	20	6.9 x 3.8 x 1.0

Applications Information (Cont.)

PCB Layout Considerations

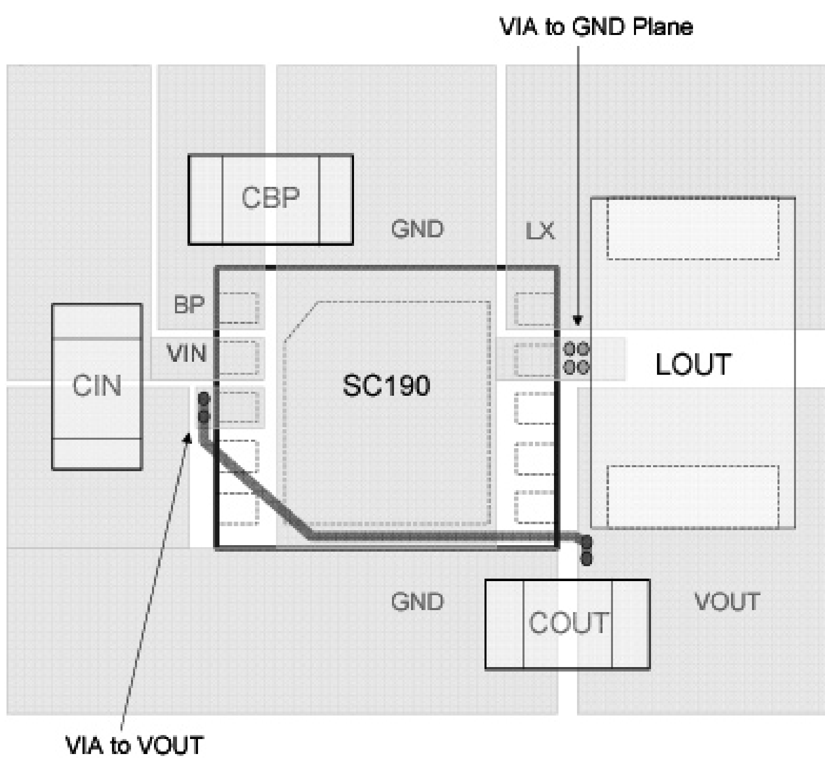
Poor layout can degrade the performance of the DC-DC converter and can be a contributory factor in EMI problems, ground bounce and resistive voltage losses. Poor regulation and instability can result.

A few simple design rules can be implemented to ensure good layout:

1. Place the inductor and filter capacitors as close to the device as possible and use short wide traces between the power components.

2. Route the output voltage feedback path away from inductor and LX node to minimize noise and magnetic interference. Use a ground plane to further reduce noise interference on sensitive circuit nodes.

Suggested Layout



Applications Information (Cont.)

CIN Selection

The source input current to the SC190 buck converter is a DC supply current with a triangular ripple riding on it. To prevent large input voltage ripple a low ESR ceramic capacitor is required. A minimum value of 4.7μF should be used for sufficient input voltage filtering and a 10μF MLCC should be used for optimum input voltage filtering. Input voltage ripple of approximately 1mV can be achieved when C_{IN} = 10μF, and the front-end LDO regulator is active and pre-regulating the input supply to the switching regulator. (See page 12: Input Voltage Ripple graphs).

COUT Selection

A 10μF ceramic capacitor is recommended for the output filter capacitor. Output voltage ripple is dominated by the filter capacitance as shown in the following equation:

$$\text{Vout\_ripple} = \Delta \text{IL(ripple)} \bullet \text{Cout(ESR)}$$

Choose an X7R or X5R ceramic dielectric for low ESR and superior temperature and voltage characteristics. Do not use Y5V capacitors - their temperature coefficients make them impractical for this application.

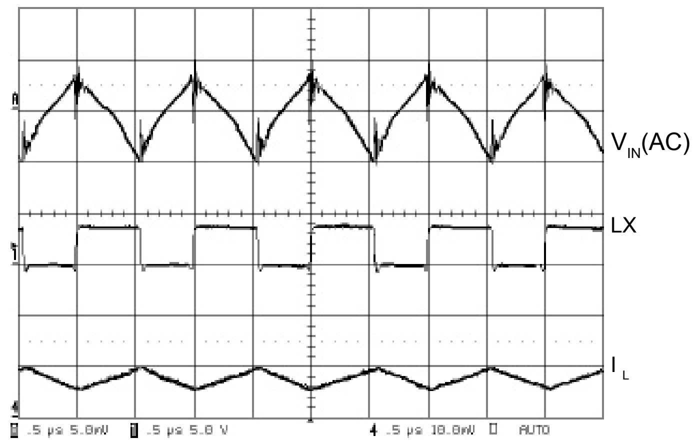
Table 3: Recommended Capacitors

Manufacturer	Part Number	Value (μF)	Rated Voltage (VDC)	Type	Case Size
Murata	GRM188R60J475KE19D	4.7	6.3	X5R	0603
Murata	GRM188R60G106ME47D	10	4	X5R	0603
TDK	C1608X5ROG106M	10	4	X5R	0603

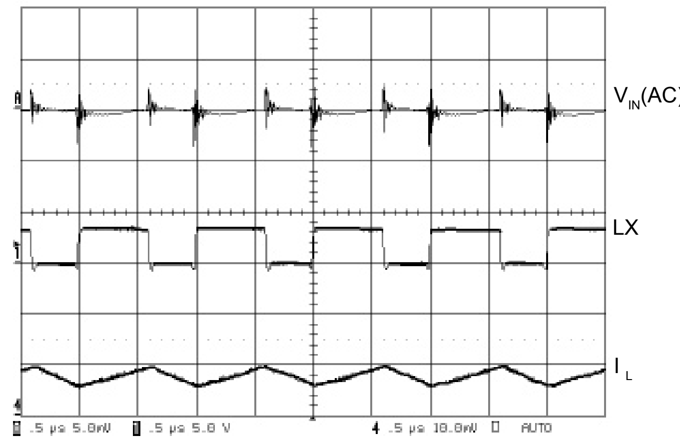
Typical Characteristics

NOTE: Conditions: L = 10µH, Cout = 10µF

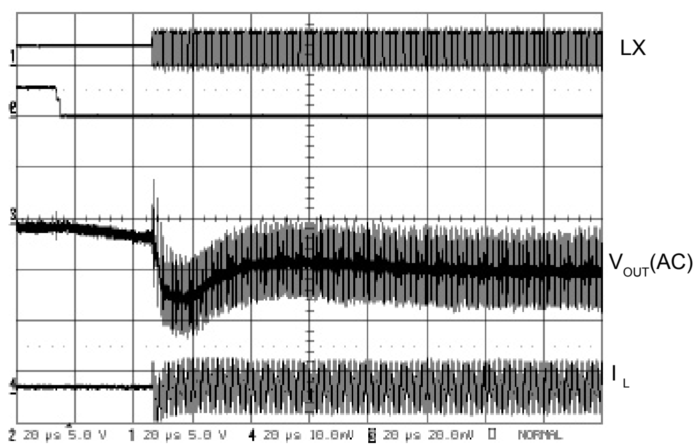
Input Voltage Ripple (FELDO bypassed)



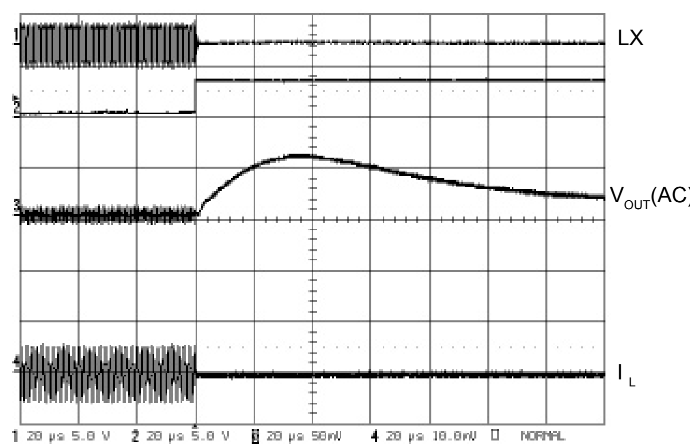
Input Voltage Ripple (FELDO active)



Handover Transition Linear to Switcher

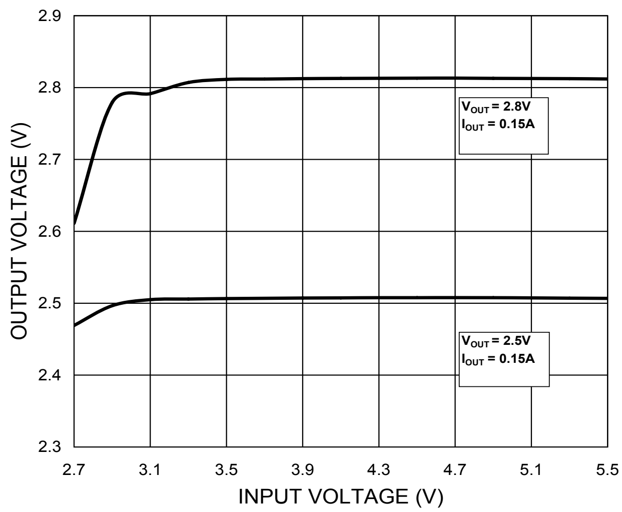


Handover Transition Switcher to Linear

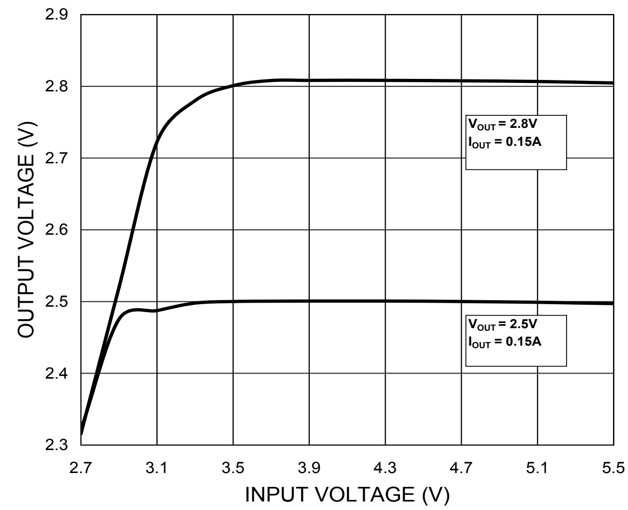


Typical Characteristics (Cont.)

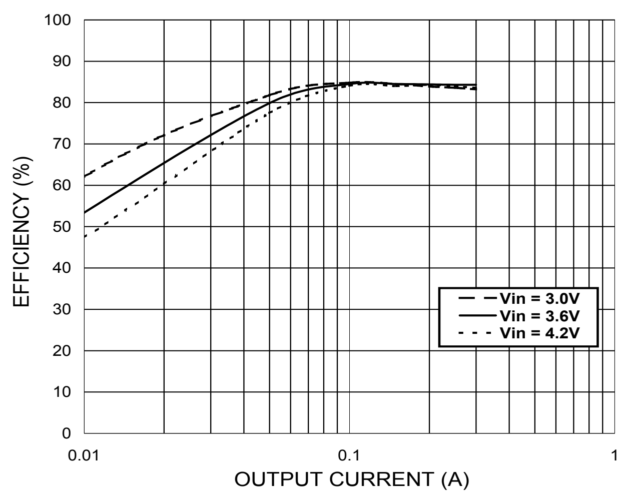
SC190C Line Regulation (FELDO Bypassed)



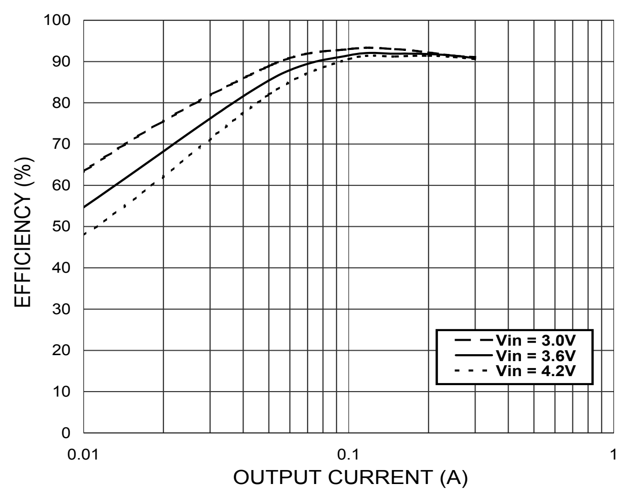
SC190C Line Regulation (FELDO Active)



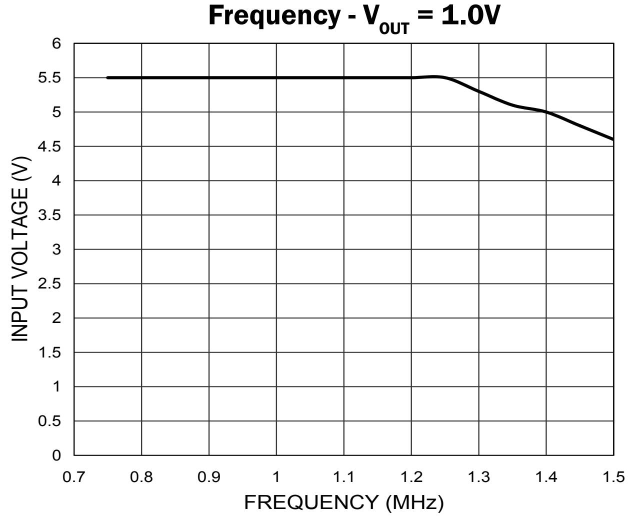
Efficiency vs Load Current (FELDO Active) - V_{OUT} = 1.8V



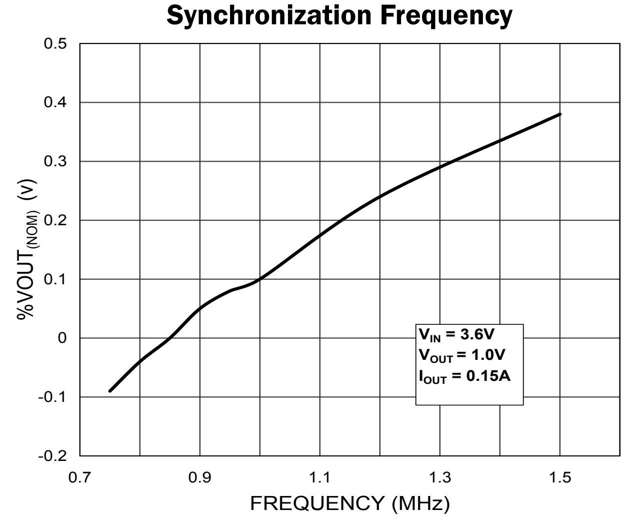
Efficiency vs Load Current (FELDO Bypassed) - V_{OUT} = 1.8V



Maximum Input Voltage vs Synchronization Frequency - V_{OUT} = 1.0V

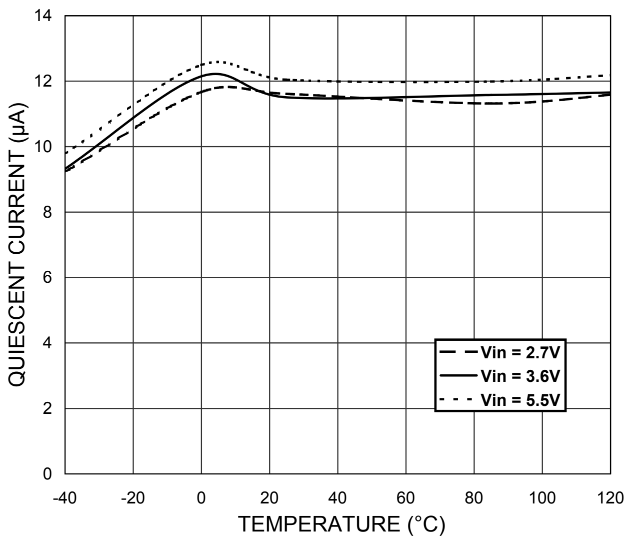


Output Voltage vs Synchronization Frequency

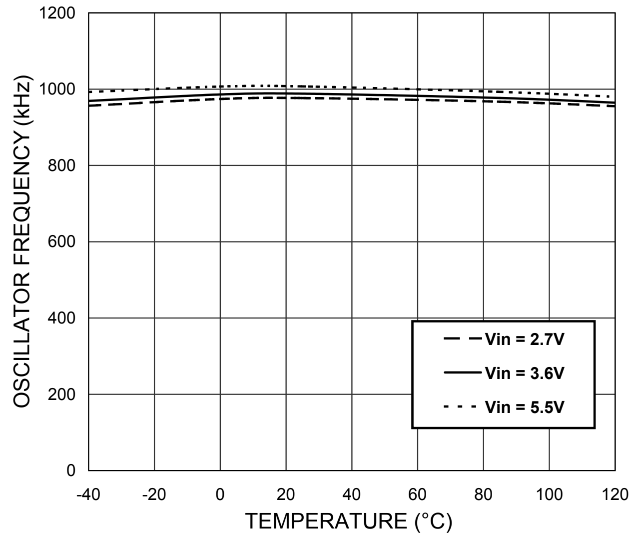


Typical Characteristics (Cont.)

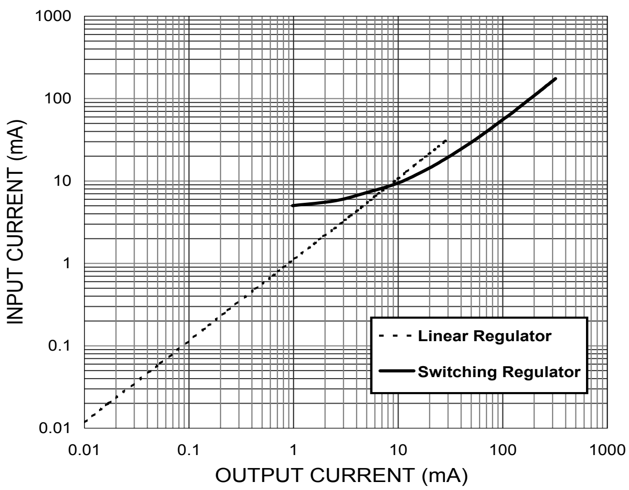
Quiescent Current vs Temperature



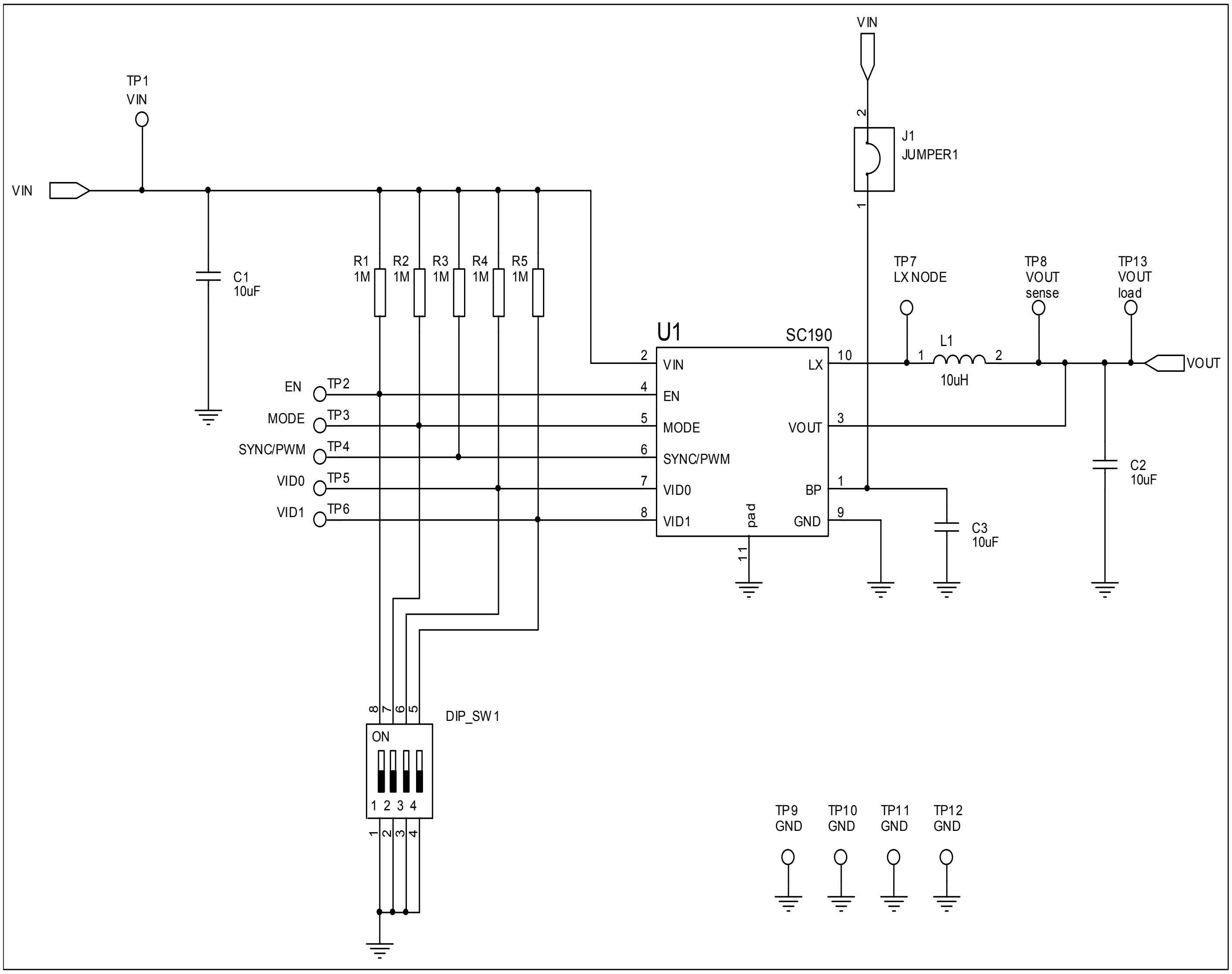
Oscillator Frequency vs Temperature



Input Current vs Output Current

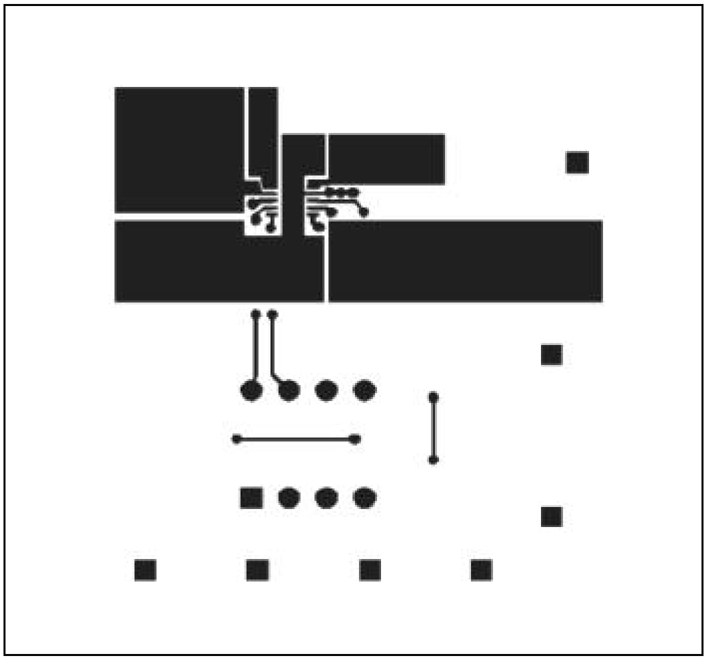


Evaluation Board Schematic

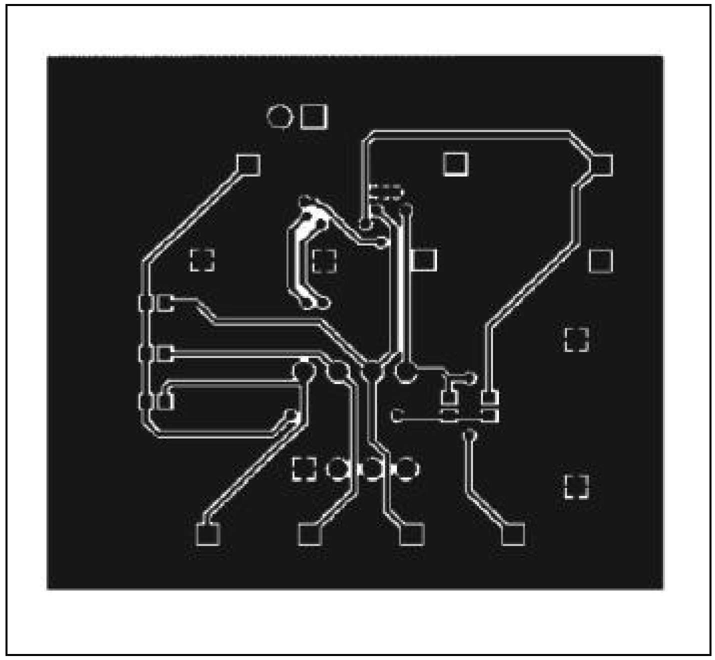


Evaluation Board Gerber Plots

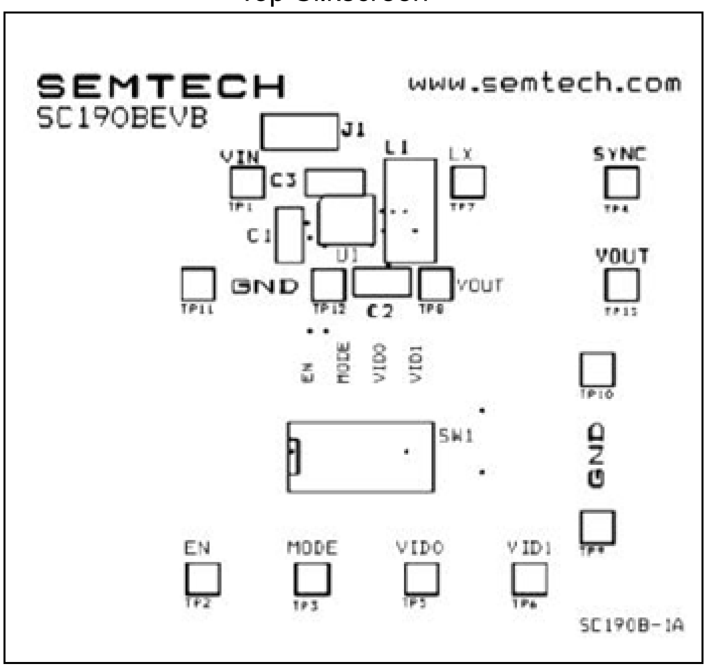
Top Copper



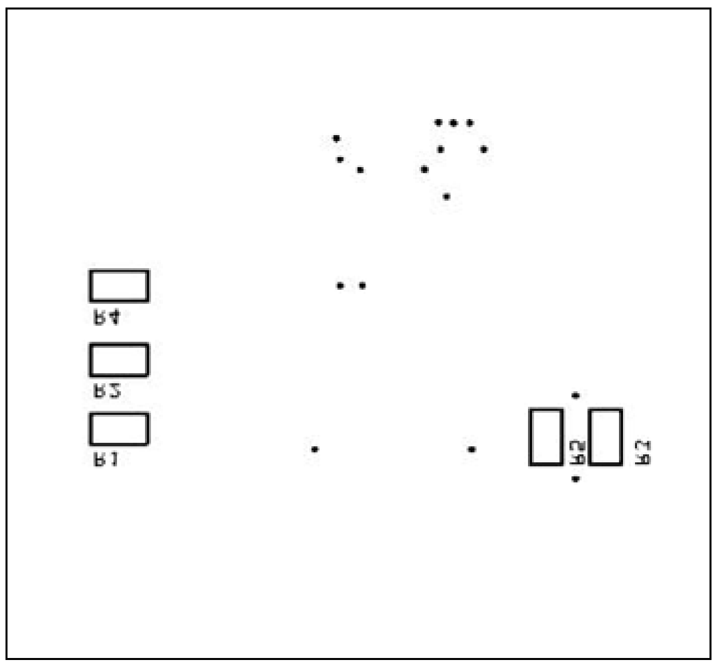
Bottom Copper



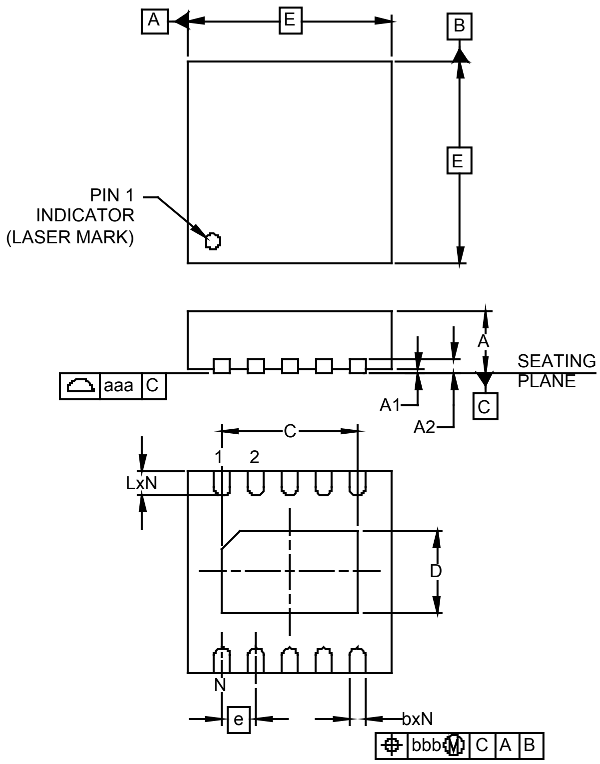
Top Silkscreen



Bottom Silkscreen



Outline Drawing - MLP-10 3x3

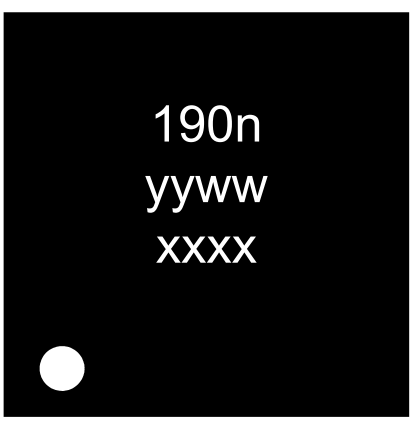


DIM	INCHES MIN	INCHES NOM	INCHES MAX	MILLIMETERS MIN	MILLIMETERS NOM	MILLIMETERS MAX
A	.031	-	.039	0.80	-	1.00
A1	.000	-	.002	0.00	-	0.05
A2	-	(.008)	-	-	(0.20)	-
b	.007	.009	.011	0.18	0.23	0.30
C	.074	.079	.083	1.87	2.02	2.12
D	.042	.048	.052	1.06	1.21	1.31
E	.114	.118	.122	2.90	3.00	3.10
e	.020 BSC			0.50 BSC		
L	.012	.016	.020	0.30	0.40	0.50
N	10			10		
aaa	.003			0.08		
bbb	.004			0.10		

NOTES:

1. CONTROLLING DIMENSIONS ARE IN MILLIMETERS (ANGLES IN DEGREES).
2. COPLANARITY APPLIES TO THE EXPOSED PAD AS WELL AS TERMINALS.

Marking Information



yy = two digit year of manufacture
ww = two digit week of manufacture
xxxx = lot number

"n" can be A, B, C, or D