

Transformer Driver for Isolated Power Supplies

GENERAL DESCRIPTION

The SiLM6201 is a push-pull circuit controller with integrated power MOSFETs. The internal power MOSFETs has a high degree of drive symmetry, thus reducing the magnetic bias of the push-pull topology.

The SiLM6201 has key technologies to improve reliability. It integrates the soft start function, which avoids the impact of high inrush current during startup to damage the device, and ensures normal startup with full load in constant current load mode. The SiLM6201 integrates output short-circuit protection, which has good consistency performance over the full temperature range. It also integrates the over-temperature protection. When the junction temperature is higher than the specified temperature range, the SiLM6201 automatically enters the sleep mode and automatically recovery when the temperature reduces again.

FEATURES

- Absolute maximum input voltage up to 25V
- Integrates MOSFETs
- Symmetrical MOSFETs driver
- Integrates soft-start
- Output short protection
- Thermal shutdown protection
- Package: SOT23-5

APPLICATIONS

- Isolated interface power supply
- Industrial automation
- Process control

TYPICAL APPLICATION CIRCUIT

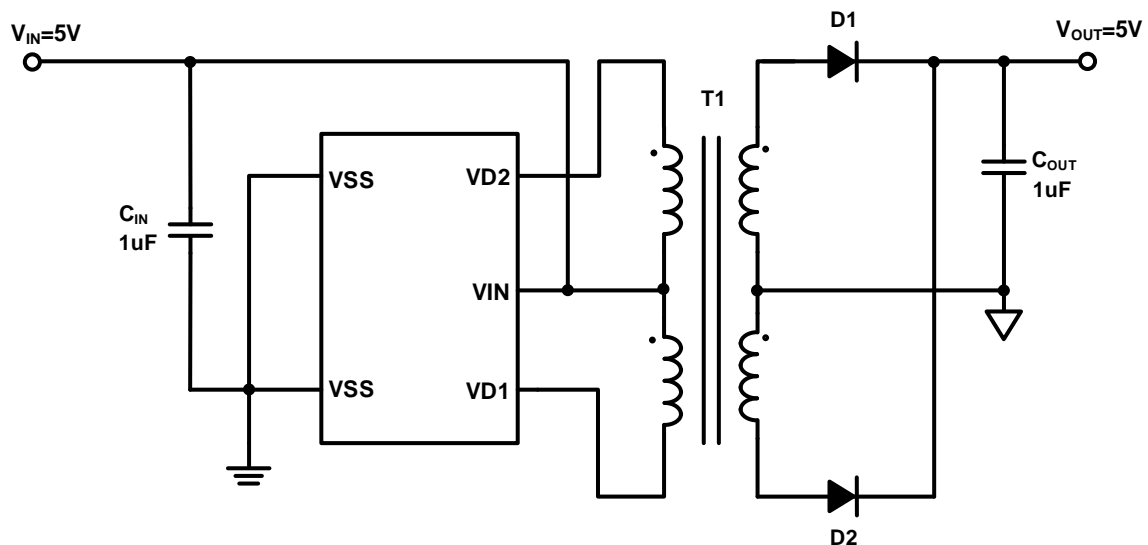
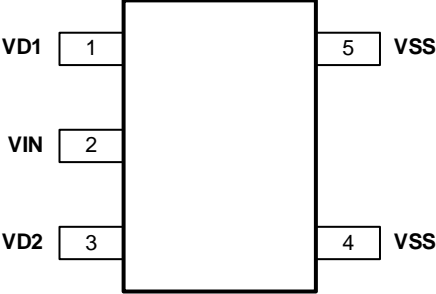


Figure 1. Typical Application Circuit

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PIN CONFIGURATION

Package	Pin Configuration (Top View)
SOT23-5	

PIN FUNCTION DESCRIPTIONS

No.	Pin Name	Function Description
1	VD1	Drain of the internal MOSFET1. Working with the internal MOSFET2 to drive the push-pull transformer. Connect this pin to one end of the transformer primary side.
2	VIN	Power supply input. Connect this pin to the center-tap of the transformer primary side.
3	VD2	Drain of the internal MOSFET2. Working with the internal MOSFET1 to drive the push-pull transformer. Connect this pin to the other end of the transformer primary side.
4, 5	VSS	Device ground.

ORDERING INFORMATION

Operation Temperature Range: -40°C to +125°C

Order Part No.	Package	QTY
SiLM6201BAD-7G	SOT23-5	3000

FUNCTIONAL BLOCK DIAGRAM

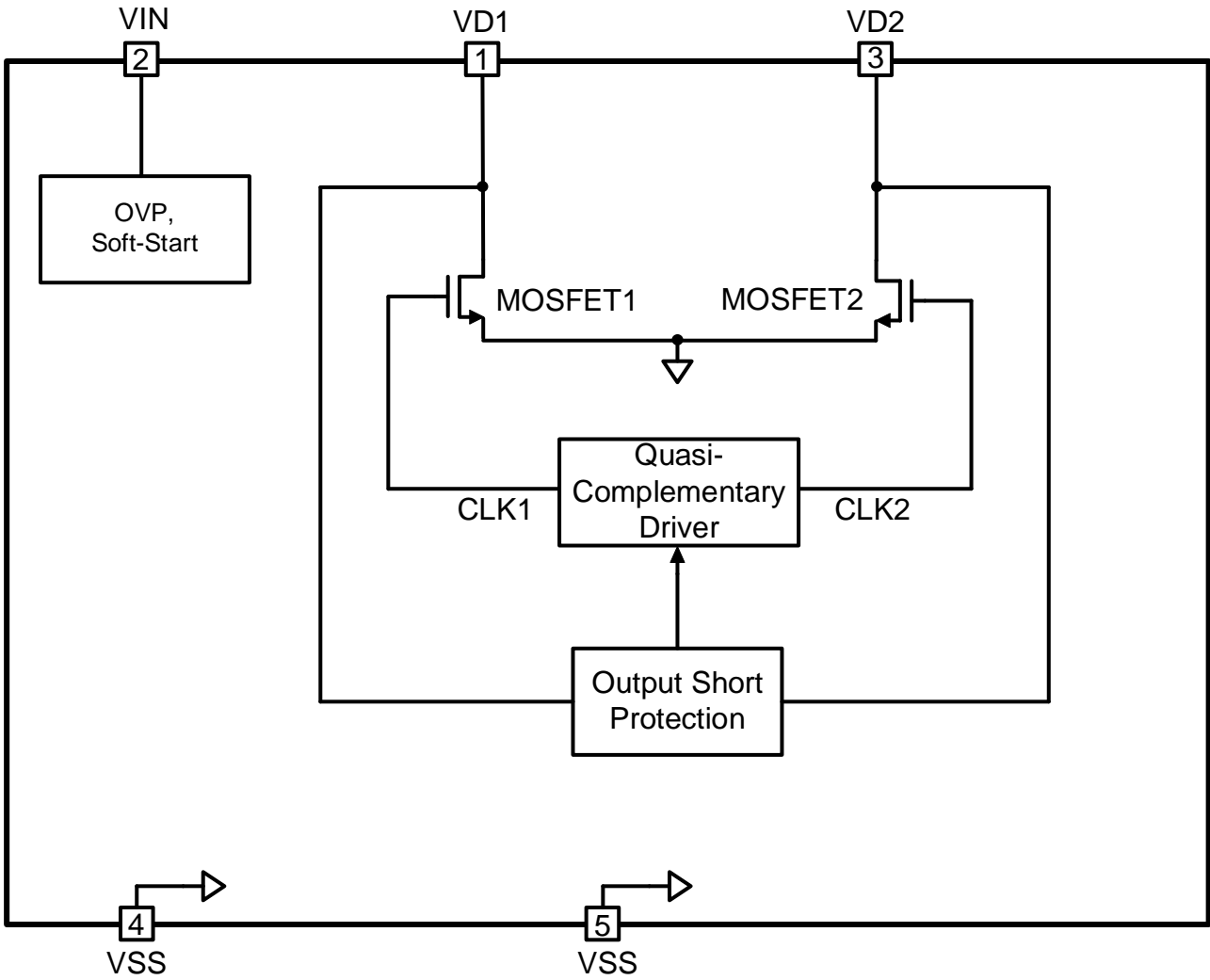


Figure 2. Functional Block Diagram

ABSOLUTE MAXIMUM RATINGS

Symbol	Definition	Rating
V_{IN}	Voltage on VIN	25V
V_{VD1}, V_{VD2}	Voltage on VD1, VD2	30V
I_{VD1}, I_{VD2}	Current on VD1, VD2	300mA
T_J	Junction temperature	-40°C to 150°C
T_S	Storage temperature	-65°C to 150°C
T_L	Lead temperature (soldering, 10 sec)	260°C

ELECTRICAL CHARACTERISTICS

$V_{IN} = 5V$, $T_J = 25^\circ C$ for typical specifications and $T_J = -40^\circ C$ to $+125^\circ C$ for minimum/maximum specifications, unless otherwise specified.

Symbol	Parameter	Condition	Min	Typ	Max	Unit
V_{IN}	Input voltage range		2.9		8	V
I_Q	Quiescent current on V_{IN} , no load	$V_{IN}=3.3V$		1.5	2.1	mA
		$V_{IN}=5V$		2	2.7	mA
$R_{DS(on)_5V}$	MOSFET resistance when $V_{IN}=5V$	$I_{DS}=0.2A$		0.4	0.68	Ω
$R_{DS(on)_4V}$	MOSFET resistance when $V_{IN}=4V$	$I_{DS}=0.2A$		0.42	0.7	Ω
f_{SW}	Switching frequency		250	290	340	kHz
T_{D_OSP}	Delay time during output short protection			120		ms
T_{SLEEP}	Sleep time during output short protection			840		ms
t_r	Rising time during turn on	$V_{IN}=5V$		70		ns
t_f	Falling time during turn off	$V_{IN}=5V$		45		ns
t_{BBM}	Dead-time	$V_{IN}=5V$		85		ns

MEASUREMENT INFORMATION

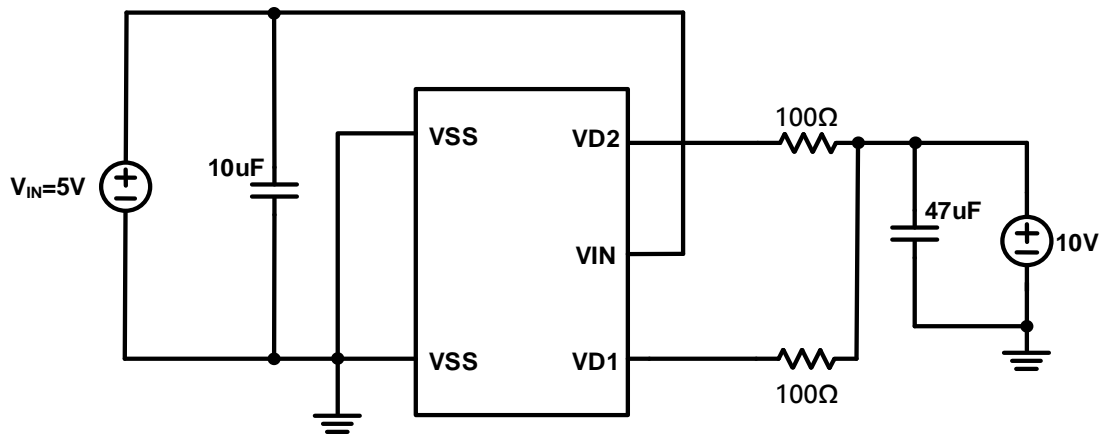


Figure 3. Test Circuit for f_{sw} , t_r , t_f , t_{BBM}

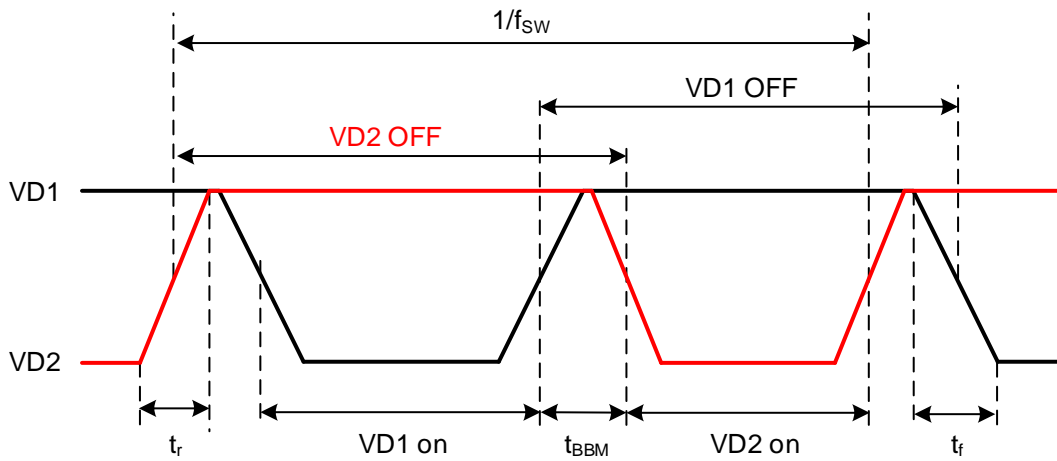


Figure 4. Timing Diagram

OPERATION PRINCIPLE

Push-Pull Converter

Push-pull converter requires transformer with center-taps to transfer power from the primary to the secondary as shown in Figure 5 and Figure 6. The drive waveforms on VD1/VD2 of the power MOSFET Q1/Q2 are shown as in Figure 4. The two MOSFETs are switched on alternately, and the duration of the two switching periods is equal. There is a dead-time, t_{BDM} , between the two switching periods, and two MOSFETs keeps off during the dead-time. That means the driving signal of the two MOSFETs are quasi-complementary in timing. When one MOSFET is turned on, the other is turned off, but there is a small dead-time to ensure that the two MOSFETs are not turned on at the same time and to avoid the current flowing back.

As shown in the highlighted part in red in Figure 5, when Q1 is turned on, the input voltage V_{IN} drives a current through the lower half of the primary side winding of the transformer and Q1 to the ground, while the induced electromotive force of the secondary side winding charges the output capacitor through diode D1.

Similarly, as shown in Figure 6, when Q2 is turned on, the induced electromotive force charges the output capacitor through diode D2. This is repeated repeatedly, and the required power supply is obtained on the secondary side of the power converter.

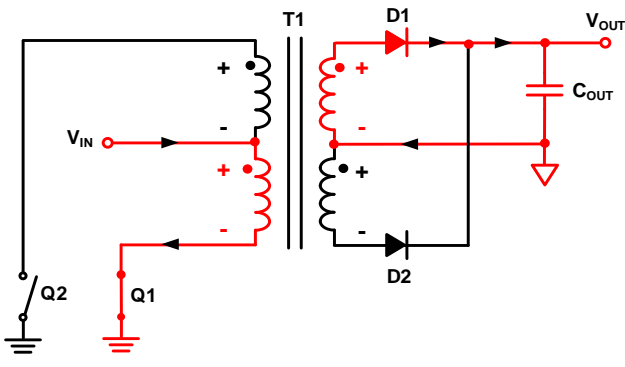


Figure 5. Push-Pull Converter Switching Cycle 1

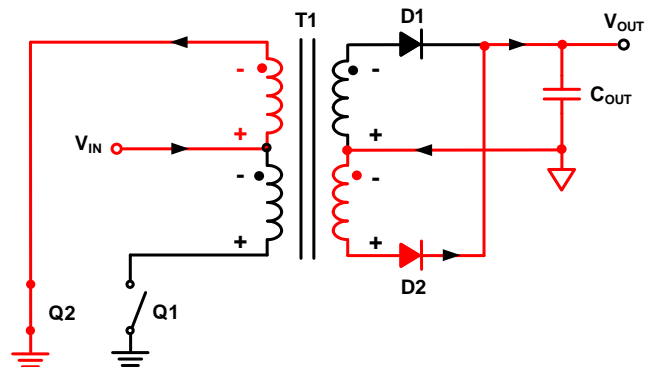


Figure 6. Push-Pull Converter Switching Cycle 2

Core Magnetization

Figure 7 shows the ideal magnetizing curve for a push-pull converter with B as the magnetic flux density and H as the magnetic field strength. When Q1 conducts the magnetic flux is pushed from A to A', and when Q2 conducts the flux is pulled back from A' to A. The difference in flux and thus in flux density is proportional to the product of the primary voltage, V_{LP} , and the time, t_{ON} , it is applied to the primary: $B \approx V_{LP} \times t_{ON}$.

This volt-seconds (V-t) product is important as it determines the core magnetization during each switching cycle. If the V-t products of both phases are not identical, an imbalance in flux density swing results with an offset from the origin of the B-H curve. If balance is not restored, the offset increases with each following cycle and the transformer slowly creeps toward the saturation region. This magnetic flux deviation is usually caused by the unequal on-resistance or switching speed of the two power devices. Although the two power devices are integrated on the same wafer with the advantage of high matching of semiconductor integrated circuit technology and the on-resistance or switching speed is approximately equal, there still be manufacturing errors, so that there is a small deviation of the on-time.

Fortunately, due to the positive temperature coefficient of a MOSFET's on-resistance, the SiLM6201 has a self-correcting effect on V-t imbalance. In the case of a slightly longer on-time, the prolonged current flow through a MOSFET gradually heats the transistor which leads to an increase in $R_{DS(ON)}$. The higher resistance then causes the drain-source voltage, V_{DS} , to rise. As shown in Figure 8, the voltage at the primary is the difference between the constant input voltage, V_{IN} , and the voltage drop across the MOSFET, $V_{LP} = V_{IN} - V_{DS}$, V_{LP} is gradually reduced and V-t balance restored.

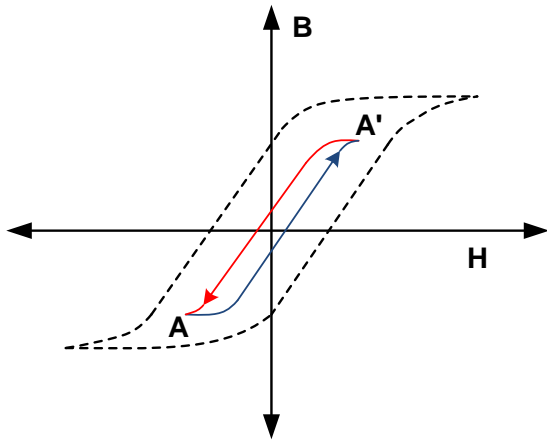


Figure 7. Magnetizing Curve

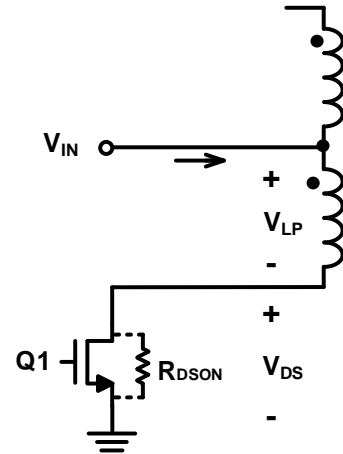


Figure 8. Self-Regulation Through Positive Temperature Coefficient of $R_{DS(on)}$

DEVICE FUNCTIONAL MODES

The SiLM6201 operates in three modes: start-up mode, push-pull steady mode and short circuit protection mode.

In the start-up mode, the SiLM6201 provides sufficient charging time for the output capacitor to avoid being mistaken for short circuit when the output capacitor voltage is too low during startup, which will lead to abnormal startup. The MOSFET is always in the current-limit state in start-up mode. The drive voltage of the MOSFET is limited so the current through the MOSFET is limited at I_{SOFT} which is within the safe range of the device, thus avoiding large inrush current impact and excessive heating.

In push-pull steady mode, the MOSFET is always in full drive state. The MOSFET works in the switching state, and keeps the MOSFET resistance very low, which ensures the efficiency of the converter.

In short circuit protection mode, it stops driving the MOSFET, dissipates the heat generated in start-up mode. It returns to start-up mode again after the sleep time expired.

These three modes can be switched seamlessly. As long as there is an abnormal output short circuit, it will be switched between the start-up mode and short circuit protection mode. When the abnormal condition disappears, it will automatically return to the push-pull steady mode, which fully ensures the reliability of the converter, and doesn't affect the normal operation of the converter.

Start-Up Mode

When the converter powers up, the voltage on the output capacitor is zero and it works in the start-up mode. Figure 9 shows the start-up mode flow chart. The MOSFET is driven in current limit mode and the voltage on the MOSFET (V_{VD1} , V_{VD2}) is monitored.

- If the V_{VD1} or V_{VD2} voltage is above the setting threshold and persists for longer than T_{D_OSP} (120ms typical), the device enters to the short circuit protection mode.
- If the V_{VD1} and V_{VD2} voltage is below the setting threshold, the device enters to the push-pull steady mode.

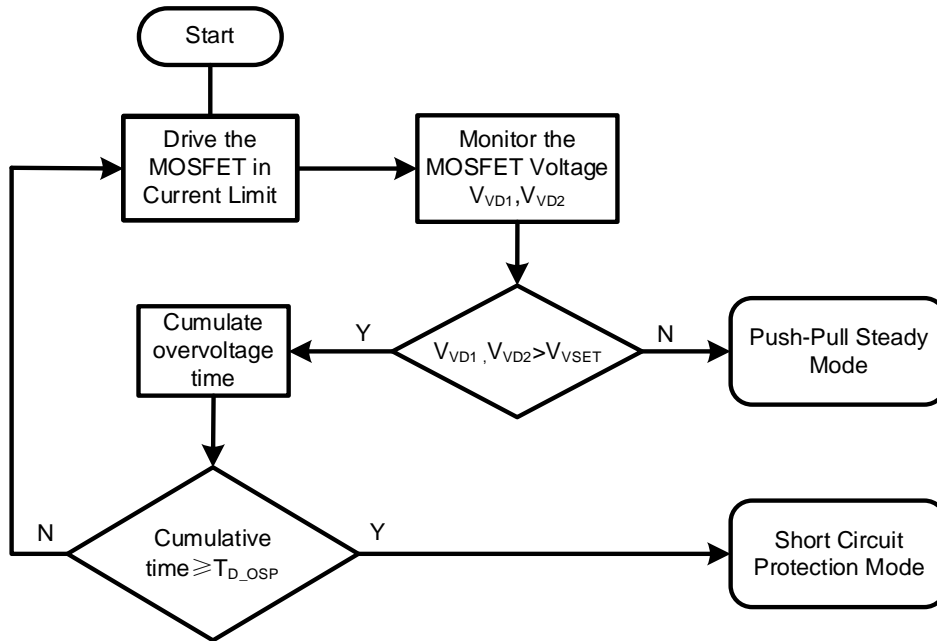


Figure 9. Start-Up Mode Flow Chart

Push-Pull Steady Mode

If there is no short circuit in the output of the converter, the voltage of the output capacitor gradually increases during the continuous cycle charging in the startup mode. When the voltage on the MOSFET (V_{VD1} , V_{VD2}) is below the setting threshold, the converter will enter the push-pull steady mode. Figure 10 shows the push-pull steady mode flow chart. During the push-pull steady mode, the MOSFET is always in full drive state (working in the switching state) which keeps low turn-on resistance and ensures high efficiency of the converter. The V_{VD1} , V_{VD2} are always monitored and if the V_{VD1} or V_{VD2} is higher than the setting threshold, the part will enter to the start-up Mode.

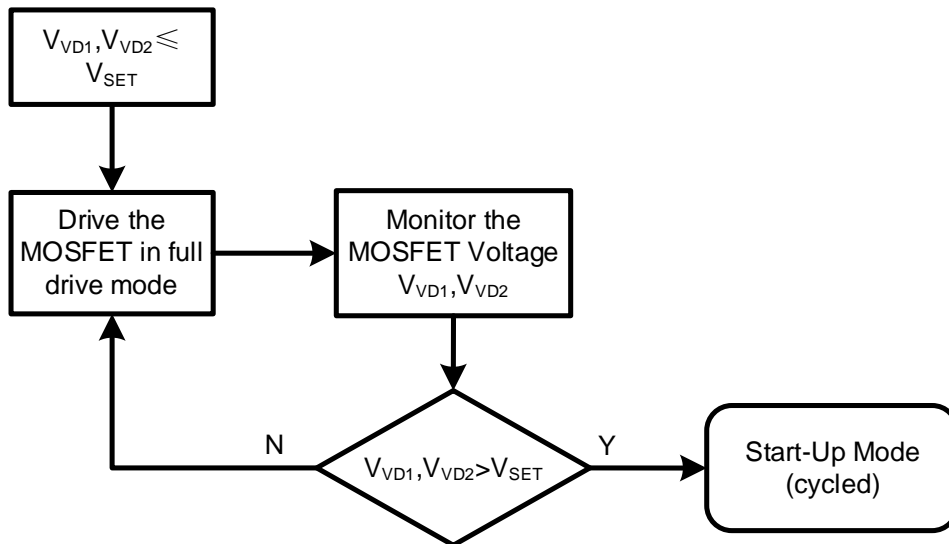


Figure 10. Push-Pull Steady Mode Flow Chart

Short Circuit Protection Mode

When the output of the converter is shorted, the V_{VD1} or V_{VD2} voltage is above the setting threshold and the duration time exceeds T_{D_OSP} (120ms typical), the device enters to the short circuit protection mode. The MOSFETs stop switching and a sleep timer starts counting. Once the sleep timer expired (T_{SLEEP} is 840ms typically), the device returns to the start-up mode. Figure 11 shows the short circuit protection mode flow chart.

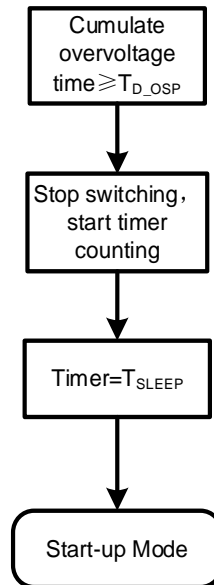


Figure 11. Short Circuit Protection Mode Flow Chart

APPLICATION DESCRIPTION

The typical application of SiLM6201 is shown in Figure 12. The output voltage, output voltage range, output voltage ripple, etc. can be determined by the selection of external components.

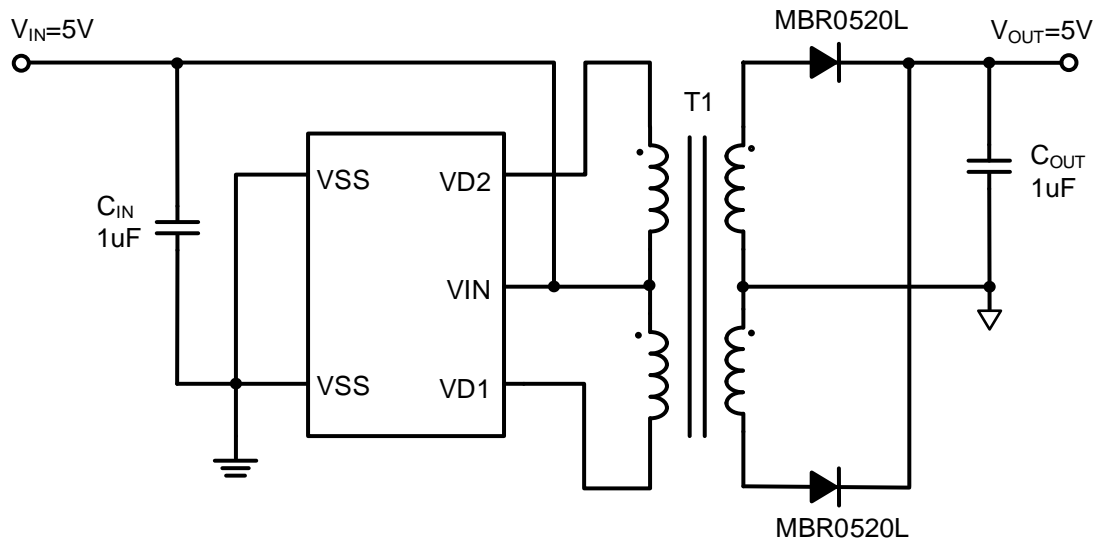


Figure 12. Typical Application Circuit

Transformer Selection

To prevent saturation of the transformer, its V-t product must be greater than the maximum V-t product applied by the SiLM6201. The maximum voltage delivered by the SiLM6201 is the nominal input voltage plus 10%. The maximum time this voltage is applied to the primary is half the period of the lowest frequency at the specified input voltage. Therefore, the transformer’s minimum V-t product is determined through below equation:

$$V_{t_{min}} \geq V_{IN_MAX} \times \frac{T_{MAX}}{2} = \frac{V_{IN_MAX}}{2 \times f_{SW_MIN}}$$

Inserting the numeric values from the data sheet into the equation above yields the minimum V-t products.

$$V_{t_{min}} \geq \frac{3.63V}{2 \times 250kHz} = 7.3V\mu s \text{ for } V_{IN}=3.3V.$$

$$V_{t_{min}} \geq \frac{5.5V}{2 \times 250kHz} = 11V\mu s \text{ for } V_{IN}=5V.$$

Common V-t values for low-power center-tapped transformers range from 22Vμs to 150Vμs with typical footprints of 10 mm x 12 mm. However, transformers specifically designed for PCMCIA applications provide as little as 11Vμs and come with a significantly reduced footprint of 6 mm x 6 mm only.

Beside the V-t and size, other important factors such as isolation voltage, transformer wattage, and turns ratio must be considered before making the final decision.

Turns Ratios Estimation

Assume the rectifier diode and linear regulator (LDO) has been selected, so the maximum voltage drop of the diode, V_{F_MAX} , and the maximum voltage drop of the LDO, V_{DO_MAX} , is known. Also, it has been determined that the transformer chosen must have a V-t product of at least 11Vμs. However, before searching the manufacturer websites for a suitable transformer, the user still needs to know its minimum turns ratio that allows the push-pull converter to operate perfectly over the specified current and temperature range, and still provide enough input voltage to the LDO to maintain stability. With the LDO selected, the minimum input voltage can also be determined.

$$V_{P_MIN} = V_{IN_MIN} - V_{DS_MAX}$$

$$V_{S_MIN} = V_{F_MAX} + V_{DO_MAX} + V_{O_MAX}$$

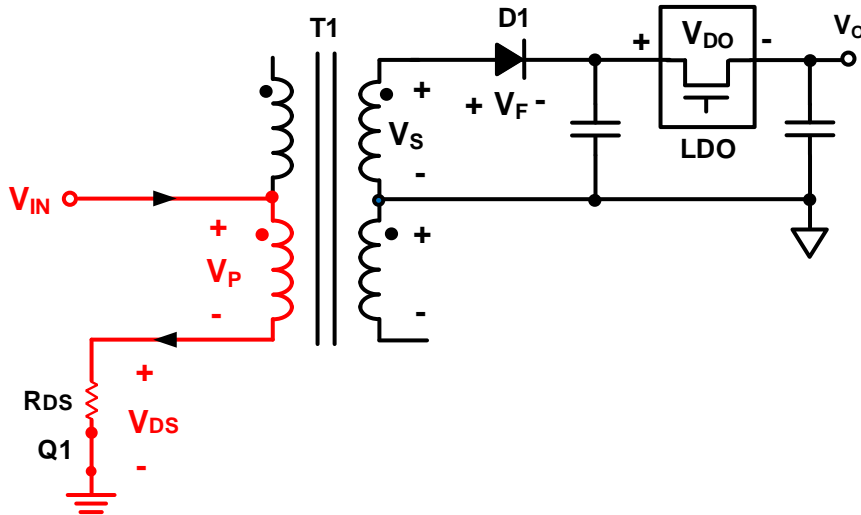


Figure 13. Voltage on Each Node when Q1 Turns On

$$V_{DS_MAX} = R_{DS_MAX} \times I_{D_MAX}, \text{ so } V_{P_MIN} = V_{IN_MIN} - R_{DS_MAX} \times I_{D_MAX}$$

The turn ratio can be obtained by $N_{MIN} = 1.031 \times \frac{V_{S_MIN}}{V_{P_MIN}}$, and a correction factor 1.031 that takes the transformer's typical efficiency of 97% into account.

$$\text{So } N_{MIN} = 1.031 \times \frac{V_{F_MAX} + V_{DO_MAX} + V_{O_MAX}}{V_{IN_MIN} - R_{DS_MAX} \times I_{D_MAX}}$$

For a 3.3V_{IN} to 5V_{OUT} application using MBR0520L as the rectifier diode, and TPS76350 as the 5V LDO, load current of 100mA and operation temperature at 85°C, V_{F_MAX}=0.3V, V_{DO_MAX}=0.2V, V_{O_MAX}=5.175V.

Assuming the 3.3V input supply with a maximum ±2% accuracy, that makes V_{IN_MIN}=3.234V.

According to the SiLM6201 datasheet, R_{DS_MAX}=0.5Ω at I_{D_MAX}=200mA.

Inserting the value above the N_{MIN} equation to calculate a minimum turns ratio of the transformer:

$$N_{MIN} = 1.031 \times \frac{0.3 + 0.2 + 5.175}{3.234 - 0.5 \times 0.2} = 1.87$$

So, a transformer with turns ratio=2 can be selected.

Capacitor Selection

The input bulk capacitor at the center-tap of the primary supports large currents into the primary during the fast-switching transients. For minimum ripple make this capacitor 1μF to 10μF. In a 2-layer PCB design with a dedicated ground plane, place this capacitor close to the primary center-tap to minimize trace inductance. A 100nF capacitor can be placed close to the VIN pin to improve the transient response and noise rejection.

The bulk capacitor at the rectifier output smooths the output voltage. And in most cases, low ESR ceramic capacitors in the 1μF to 10μF range are sufficient to meet the requirements.

Diode Selection

A rectifier diode should always possess low-forward voltage to provide as much voltage to the converter output as possible. When used in high frequency switching applications, such as the SiLM6201 however, the diode must also possess a short recovery time. Schottky diodes meet both requirements and are therefore strongly recommended in push-pull converter designs. A good choice for low-volt applications and ambient temperatures of up to 85°C is the low-cost Schottky rectifier MBR0520L with a typical forward voltage of 275 mV at 100mA forward current. For higher output voltages such as ±10V and above use the MBR0530 which provides a higher DC blocking voltage of 30V.

TYPICAL PERFORMANCE CHARACTERISTICS

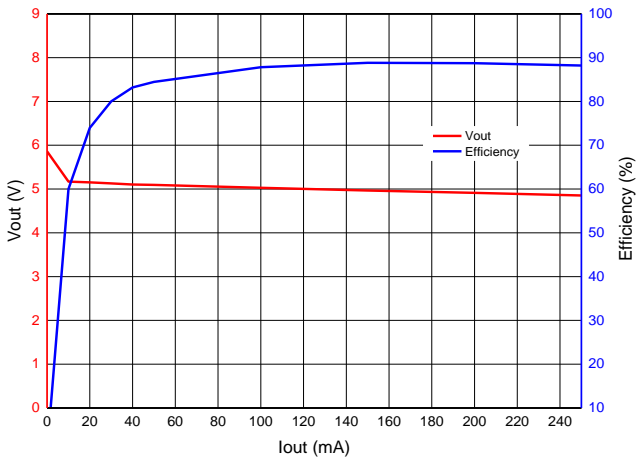


Figure 14. $V_{IN}=5V$, $V_{OUT}=5V$, $T1=Wurth\ 760390012$

Output Voltage/Efficiency vs. Output Current

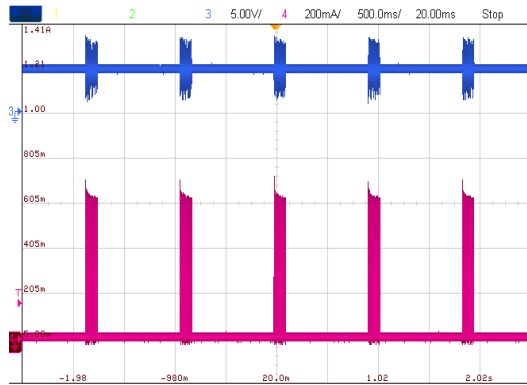


Figure 16. $V_{IN}=5V$, $V_{OUT}=5V$, Output Short

CH3: V_{VD1} , CH4: I_{VD1}

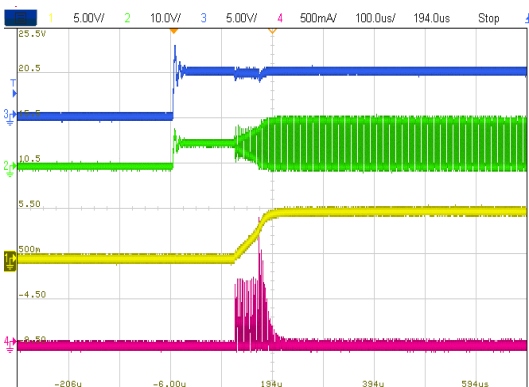


Figure 18. V_{IN} Power Up, $V_{IN}=5V$, $V_{OUT}=5V$

CH1: V_{OUT} , CH2: V_{VD1} , CH3: V_{IN} , CH4: I_{VD1}

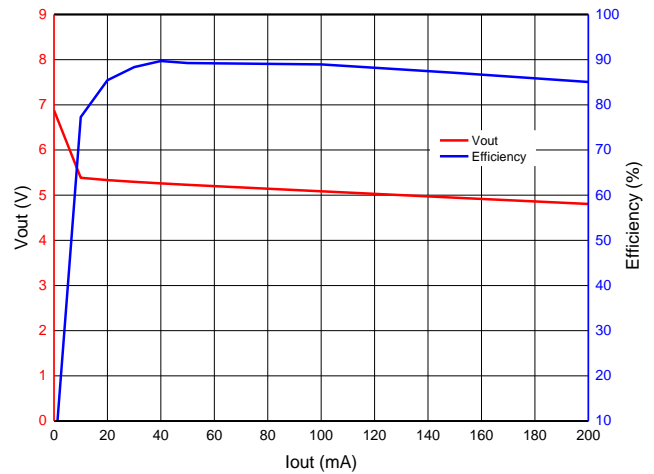


Figure 15. $V_{IN}=3.3V$, $V_{OUT}=5V$, $T1=Wurth\ 760390013$

Output Voltage/Efficiency vs. Output Current

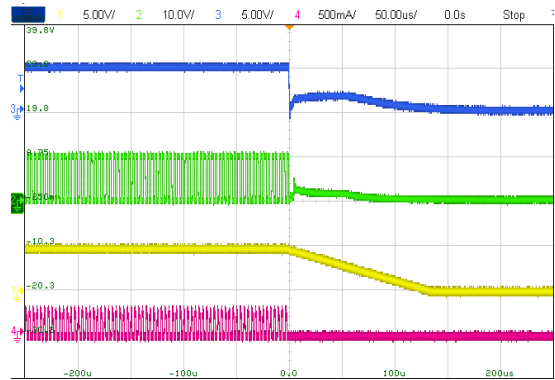
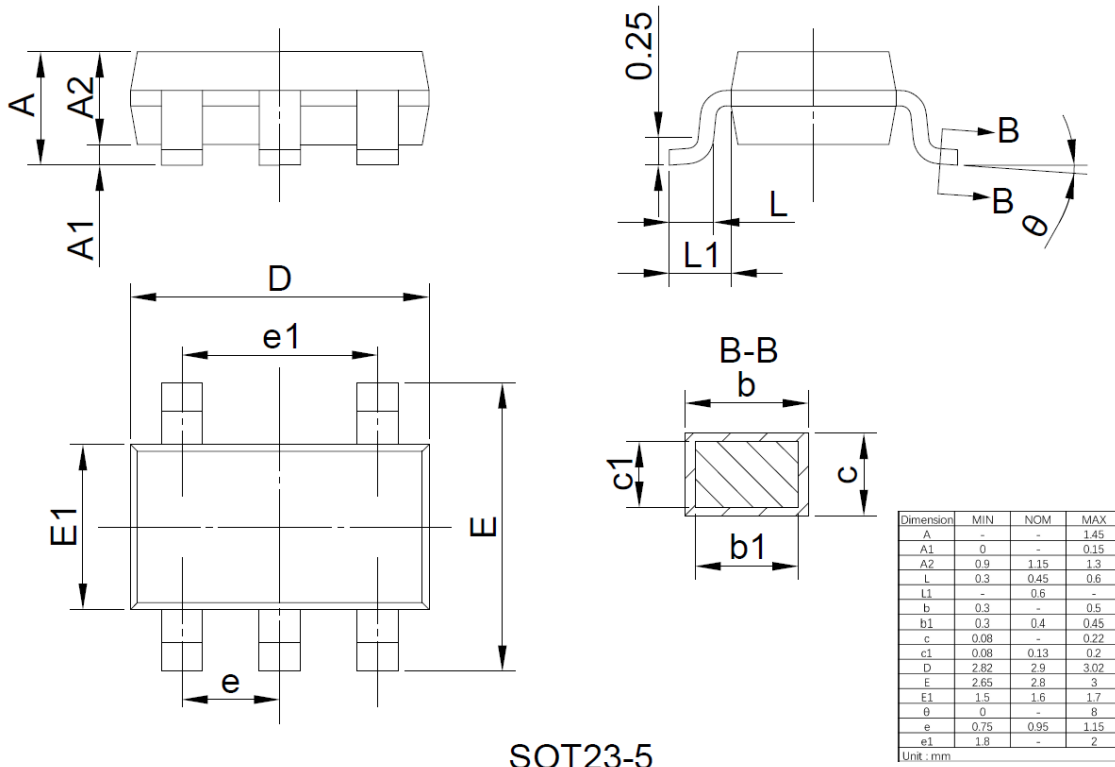


Figure 17. V_{IN} Power Off, $V_{IN}=5V$, $V_{OUT}=5V$

CH1: V_{OUT} , CH2: V_{VD1} , CH3: V_{IN} , CH4: I_{VD1}

PACKAGE CASE OUTLINES



SOT23-5

Figure 19. SOP23-5 Outline Dimensions

REVISION HISTORY

Note: page numbers for previous revisions may differ from page numbers in current version

Page or Item	Subjects (major changes since previous revision)
Rev 1.0 Datasheet, 2024-12-09	
Whole document	Initial release