SY24641/SY24642/SY24647

High-Side or Low-Side Bidirectional, High-Accuracy, Current-Sense Amplifier

General Description

The SY24641, SY24642 and SY24647 fixed-gain, high-precision, high-side or low-side, current-sense amplifiers with voltage output are suitable for bidirectional (charge /discharge) or unidirectional current measurements. The SY24641 provides 50V/V output gain, the SY24642 provides 100V/V output gain and the SY24647 provides 200V/V output gain.

The SY24641/2/7 use a low-offset, zero-drift architecture and operate across the -0.3V to 26V (the SY24647 operate across the -0.1V to 26V) input common-mode voltage range, which is independent of supply voltage. The precision input offset voltage (V_{OS}) allows the devices to measure the low-voltage drop very accurately.

The SY24641/2/7 are designed to operate from a 3V to 5.5V supply and draw just 80μA (typ) quiescent current.

The devices are provided in an SOT363 package and are specified over the extended industrial temperature range of -40°C to 125°C.

Features

- Voltage-Output, Current-sense Monitor
- -0.3V–26V Common-Mode Operation Range
- 100μA (Maximum) Quiescent Current
- High Accuracy: ±0.5% Gain Error (Maximum)
- Gain: 50V/V (SY24641), 100V/V (SY24642), 200V/V (SY24647)
- Amplifier Output Referenced to V_{REF} input
- Shunt Maximum Input Voltage Range:
  - SY24641:
    - -40mV to 40mV (V_{CC}=5V, REF=2.5V)
    - 1mV to 90mV (V_{CC}=5V, REF=0V)
  - SY24642:
    - -20mV to 20mV (V_{CC}=5V, REF=2.5V)
    - 1mV to 45mV (V_{CC}=5V, REF=0V)
  - SY24647:
    - -10mV to 10mV (V_{CC}=5V, REF=2.5V)
    - 1mV to 24mV (V_{CC}=5V, REF=0V)
- Low Offset Voltage(Maximum):
  - ±100μV (SY24641),
  - ±50μV (SY24642)
  - ±35μV (SY24647)
- 0.5μV/°C Offset Drift (Maximum)
- 10ppm/°C Gain Drift (Maximum)
- Package: SOT363

Applications

- Notebook PCs
- Smartphones
- Micro-inverters
- Battery Chargers
- Power Management
- Telecom Equipment

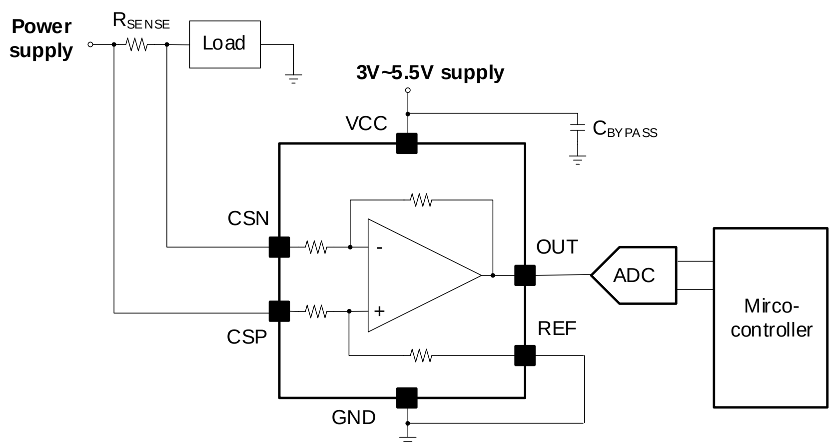


Figure 1. Typical Application

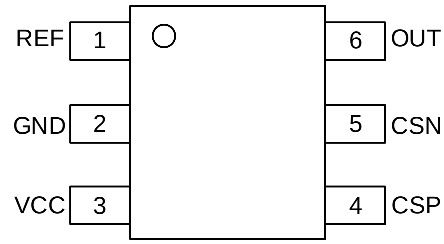
Figure 1 shows the basic connections of the SY24641/2/7. The two-input pin CSN and CSP should be connected to the shunt resistor as closely as possible to minimize any resistance in series with the sense resistor. A bypass capacitor must be connected to the power supply for stability.

Ordering Information

Ordering Part Number	Package type	Top Mark
SY24641AHT	SOT363 RoHS Compliant and Halogen Free	**n***xyz*
SY24642AHT	SOT363 RoHS Compliant and Halogen Free	***q****xyz*
SY24647AHT	SOT363 RoHS Compliant and Halogen Free	***h****xyz*

x = year code, y = week code, z = lot number code

Pinout (Top View)



(SOT363)

Pin Description

Pin No	Pin Name	Pin Description
1	REF	Reference voltage input, 0V to V_{CC}.
2	GND	Ground.
3	V_{CC}	Power supply, 3V to 5.5V.
4	CSP	Connect to supply side of shunt resistor.
5	CSN	Connect to load side of shunt resistor.
6	OUT	Amplifier Output.

Block Diagram

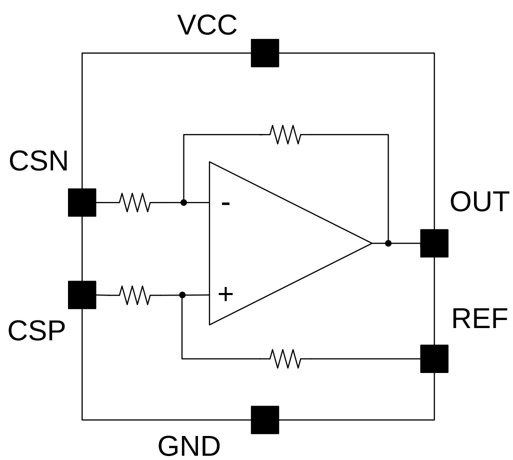


Figure 2. Block Diagram

Absolute Maximum Ratings

Parameter (Note 1)	Min	Max	Unit
V_{CC}	-0.3	6	V
CSP, CSN (Common-Mode)	-0.3	29	
CSP, CSN (Differential)	-29	29	
REF	-0.3	V_{CC}	
OUT	-0.3	V_{CC}	
Junction Temperature, Operating	-40	150	°C
Storage Temperature	-65	150	
ESD: HBM (Human Body Model)	± 4000		V
ESD: CDM (Charged Device Model)	± 1000		V

Thermal Information

Parameter (Note 2)	Min	Max	Unit
θ_{JA} Junction-to-Ambient Thermal Resistance		321	°C/W
θ_{JC} Junction-to-Case Thermal Resistance		60	
P_D Power Dissipation T_A = 25°C		0.31	W

Recommended Operating Conditions

Parameter (Note 3)		Min	Max	Unit
CSP, CSN (Differential)	SY24641	-40	40	mV
	SY24642	-20	20	mV
	SY24647	-10	10	mV
V_{CC}		3	5.5	V
REF		GND	V_{CC}	
Junction Temperature Range		-40	125	°C

Electrical Characteristics

T_A = 25°C, V_{CC} = 5V, V_{SENSE} = CSP - CSN = 0mV, CSP = 12V, and V_{REF} = 2.5V, unless otherwise noted. (Note 4)

Parameter		Symbol	Test condition		Min	Typ	Max	Unit
Input	Common-Mode Input	V_{CM}	SY24641/2, T_A = -40°C to 125°C		-0.3		26	V
			SY24647, T_A = -40°C to 125°C		-0.1		26	
	Common-Mode Rejection Ratio	CMRR	CSP = CSN = 0V to 26V, V_{SENSE} = 0mV	SY24641		116		dB
				SY24642		125		
				SY24647		125		
			CSP = CSN = 0V to 26V, V_{SENSE} = 0mV, T_A = -40°C to 125°C	SY24641	100	116		
				SY24642	105	125		
				SY24647	110	125		
	Offset Voltage, RTI (Note 5)	V_{OS}	V_{SENSE} = 0 mV	SY24641		±5	±100	μV
				SY24642		±1	±50	
				SY24647		±0.5	±35	
	Offset Voltage vs Temperature	dV_{OS}/dT	T_A = -40°C to 125°C			0.1	0.5	μV/°C
	Offset Voltage vs Power Supply	PSR	V_{CC} = 3V to 5.5V, CSP = 12V, V_{SENSE} = 0mV	SY24641		±0.1	±8	μV/V
				SY24642		±0.1	±6	
				SY24647		±0.1	±5	
	Input Bias Current	I_B	V_{SENSE} = 0mV		30	38	45	μA
	Input Offset Current	I_{OS}	V_{SENSE} = 0mV			±0.02		μA
Output	Gain			SY24641		50		V/V
				SY24642		100		
				SY24647		200		
	Gain Error		V_{SENSE} = -40 to 40 mV	SY24641		±0.02%	±0.5%	
			V_{SENSE} = -20 to 20 mV,	SY24642				
			V_{SENSE} = -10 to 10 mV,	SY24647				
			V_{SENSE} = -40 to 40 mV, T_A = -40°C to 125°C	SY24641		±0.02%	±0.5%	
			V_{SENSE} = -20 to 20 mV, T_A = -40°C to 125°C	SY24642				
			V_{SENSE} = -10 to 10 mV, T_A = -40°C to 125°C	SY24647				
	Gain Error vs Temperature		T_A = -40°C to 125°C			3	10	ppm/°C
	Nonlinearity Error					±0.01%		
	Maximum Capacitive Load		No sustained oscillation			1		nF
Voltage Output	Output-Voltage Swing to V_{CC} Power-Supply Rail		R_{LOAD} = 10kΩ to GND			(V_{CC}) -0.05	(V_{CC})-0.2	V
			R_{LOAD} = 10kΩ to GND, T_A = -40°C to 125°C				(V_{CC})-0.2	
	Output Voltage Swing to GND		R_{LOAD} = 10kΩ to GND			(V_{GND})+0.005	(V_{GND})+0.05	V
			R_{LOAD} = 10kΩ to GND, T_A = -40°C to 125°C				(V_{GND})+0.05	
Frequency Response	Bandwidth	BW	C_{LOAD} = 10pF	SY24641		60		kHz
				SY24642		28		
				SY24647		14		
	Slew Rate	SR				0.4		V/μs
Power Supply	Operation Voltage	V_{CC}			3		5.5	V
	Quiescent Current	I_Q	V_{SENSE} = 0mV			80	100	μA
			V_{SENSE} = 0mV, T_A = -40°C to 125°C				100	μA

Note 1: Stresses beyond the “Absolute Maximum Ratings” may cause permanent damage to the device. These are stress ratings only. Functional operation of the device at these or any other conditions beyond those indicated in the operational sections of the specification is not implied. Exposure to absolute maximum rating conditions for extended periods may affect device reliability.

Note 2: Package thermal resistance is measured in the natural convection at T_A = 25˚C on an 8.5cm×8.5cm four-layer Silergy Evaluation Board.

Note 3: The device is not guaranteed to function outside its operating conditions.

Note 4: Production testing is performed at 25˚C; limits at -40°C to +125°C are guaranteed by design, test, or statistical correlation.

Note 5: RTI = Referred to Input.

Application Information

The SY24641/2/7 are fixed-gain, zero-drift current-sense amplifiers that monitor current by amplifying the differential voltage across an external shunt resistor to create an output voltage.

The SY24641/2 feature a -0.3V to 26V input common-mode range and SY24647 feature a -0.1V to 26V input common-mode range, independent of supply voltage. This ability allows the current to be monitored during short-circuit conditions, while also enabling high-side current sensing above the supply voltage. These devices are intended to operate as analog front ends (AFEs) for analog-to-digital converters (ADCs) or microcontrollers that require high common-mode signal translation to low-side referenced inputs. They are commonly used for overcurrent detection, voltage feedback control loops, or power monitoring.

REF Input

SY24641/2/7 will measure the voltage developed across a current-sense resistor. The transfer function of SY24641/2/7 is:

$$OUT = Gain \times V_{SENSE} + V_{REF}$$

Where $V_{SENSE} = V_{CSP} - V_{CSN}$.

This ability makes the SY24641/2/7 suitable for unidirectional and bidirectional current sensing.

Note that the linear output range of the SY24641/2/7 is 0.05V to V_{CC} - 0.2V, which means that the output can become will saturate low with a small input signal when the REF pin is connected to ground, and the output can become saturated high with a small input signal when the REF pin is connected to V_{CC}. In order to achieve a linear response, ensure that the output voltage is between 0.05V and V_{CC} - 0.2V.

For unidirectional current-sense applications, the REF pin can be connected to ground directly, as shown in Figure 3. When the input signal increases, the output voltage will increase. When very low input currents need to be measured, the REF pin needs to be biased to a convenient value above 50 mV to bring the output into the linear range of the device.

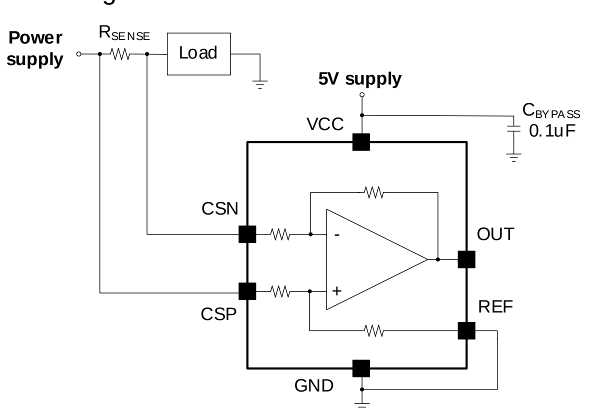


Figure 3. Unidirectional Current-sense Application

For bidirectional current-sense applications, the REF pin can be connected to a reference voltage (for example 0.5 × V_{CC}), as shown in Figure 4. The output rises linearly above the reference voltage for positive differential input signals and falls linearly below the reference voltage for negative differential input signals.

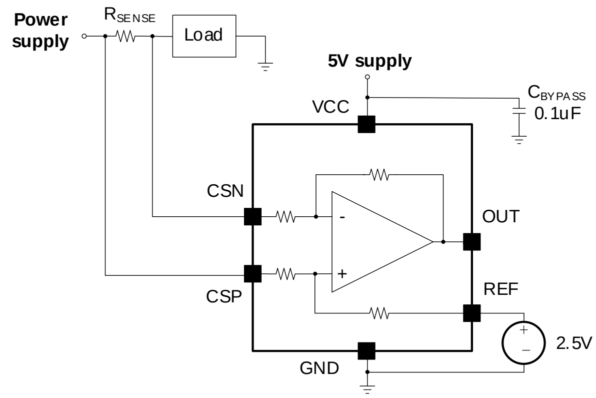


Figure 4. Bidirectional Current-sense Application

Like any differential amplifier, the common-mode rejection ratio of the SY24641/2/7 is affected by the impedance present at the REF input. This problem will not exist when the REF pin is connected directly to most reference or power supplies. When using a resistor-divider from the power supply or a reference voltage, the REF pin must be buffered by an operational amplifier as shown in Figure 5.

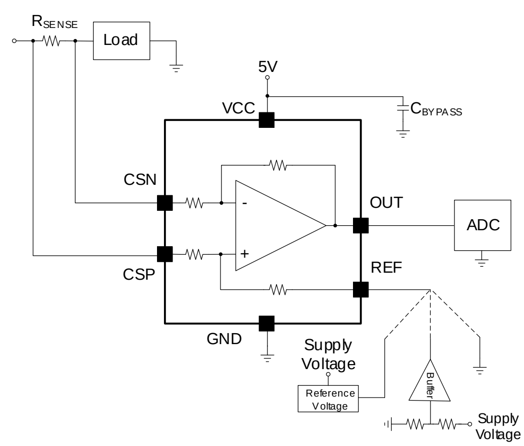


Figure 5. REF Pin Drive

In a system that uses a differential-input ADC or two separate single-ended input ADCs, the differential voltage of the OUT pin and the REF pin of the SY24641/2/7 can be directly connected. This detection method can eliminate the influence of the external impedance on the REF input, where the REF pin can be driven directly with a resistor divider without going through the buffer, as shown in Figure 6.

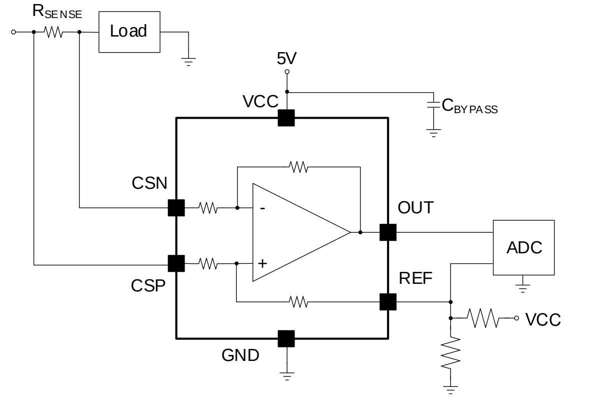


Figure 6. Sensing the SY24641/2/7 to cancel the effects of impedance on the REF input

Input Filtering

To reduce the influence of noise on the sensed power rail and improve the system signal-to-noise ratio (SNR), It's recommended to place a RC filter at the inputs pins, as shown in Figure 7.

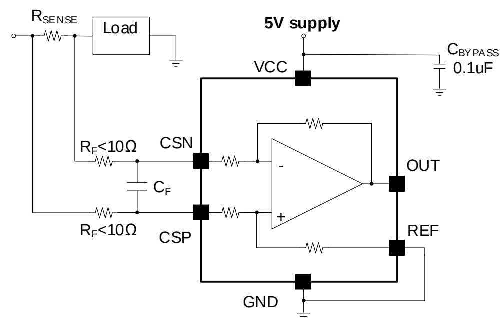


Figure 7. Filter at input pins

Adding external series resistors creates additional errors in the measurement, and using a low value for the resistors is recommended. When differential voltages are applied between the input pins of the SY24641/2/7, there is a mismatch in the input bias currents, which results in an internal bias network. When additional external series filter resistors are added to the circuit, a mismatch in the bias currents results in a mismatch of the voltage drop across the filter resistors. This mismatch produces a differential-error voltage that is subtracted from the voltage generated at the shunt resistor, making the voltage generated across the shunt resistor different from the voltage at the input pin of the device. Without additional series resistance, the mismatch of input bias current has little effect on device operation. To reduce the impact on accuracy, the value of these series resistors should be less than 10Ω.

The amount of error that these external filter resistors add to the measurement can be calculated as follows:

$$GainError = \left(\frac{20000}{12.76 \times R_F + 20000} - 1\right) \times 100\% \quad \text{(for SY24641)}$$

$$GainError = \left(\frac{10000}{6.88 \times R_F + 10000} - 1\right) \times 100\% \quad \text{(for SY24642)}$$

$$GainError = \left(\frac{1000}{0.79 \times R_F + 1000} - 1\right) \times 100\% \quad \text{(for SY24647)}$$

For example, using a R_F = 10Ω for external series resistance will result in a gain error of -0.63% (SY24641) / -0.68% (SY24642) / -0.78% (SY24647).

Selecting R_{SENSE}

The design of the current-sense resistor R_{SENSE} is dependent on the measured current, the maximum current-sense voltage range between CSP and CSN, the reference voltage V_{REF}, and the supply voltage V_{CC}.

For unidirectional current applications, assuming the measured current range is 0–I_{maxP}, because the maximum current-sense voltage range of the CSP pin and the CSN pin is 1mV–90mV (for SY24641), 1mV–45mV (for SY24642) or 1mV–24mV (for SY24647), the maximum current-sense resistor R_{max1} for the input limit is 90mV/I_{maxP} (for SY24641), 45mV/I_{maxP} (for SY24642) or 24mV/I_{maxP} (for SY24647).

Because the output voltage at pin OUT is clamped between GND and V_{CC} - 0.2V, the maximum current-sense resistor R_{max2} for the output limit is (V_{CC} - 0.2V - V_{REF})/(50xI_{maxP}) (for SY24641), (V_{CC} - 0.2V - V_{REF})/(100xI_{maxP}) (for SY24642) or (V_{CC} - 0.2V - V_{REF})/(200xI_{maxP}) (for SY24647).

Choose the smaller value of R_{max1} and R_{max2} to be the maximum available current-sense resistor value

Unidirectional Application R_{SENSE} Design

Parameter		Range
Measured current range		0A–I_{maxP}
Maximum current-sense voltage range	SY24641	1mV – 90mV
	SY24642	1mV – 45mV
	SY24647	1mV – 24mV
Maximum sensing resistor for input limit	SY24641	R_{max1} = 90mV / I_{maxP}
	SY24642	R_{max1} = 45mV / I_{maxP}
	SY24647	R_{max1} = 24mV / I_{maxP}
Maximum OUT pin output range		GND–V_{CC} - 0.2V
Maximum sensing resistor for output limit	SY24641	R_{max2} = (V_{CC} - 0.2V - V_{REF}) / (50 × I_{maxP})
	SY24642	R_{max2} = (V_{CC} - 0.2V - V_{REF}) / (100 × I_{maxP})
	SY24647	R_{max2} = (V_{CC} - 0.2V - V_{REF}) / (200 × I_{maxP})
Maximum available current-sense resistor		$R_{SENSE,max}$ = MIN[R_{max1}, R_{max2}]

For bidirectional current applications, assuming the measured current range is from $-I_{maxN}$ to I_{maxP}, the maximum current-sense resistor R_{max1} for the input limit is the smaller value of $40mV/I_{maxN}$ and $40mV/I_{maxP}$ (for SY24641), or the smaller value of $20mV/I_{maxN}$ and $20mV/I_{maxP}$ (for SY24642), $10mV/I_{maxN}$ and $10mV/I_{maxP}$ (for SY24647).

Because the output voltage at the OUT pin is clamped between GND and V_{CC} - 0.2V, the maximum current-sense resistor R_{max2} for the output limit is the smaller value of $V_{REF}/(50xI_{maxN})$ and $(V_{CC} - 0.2V - V_{REF})/(50xI_{maxP})$ (for SY24641) or the smaller value of $V_{REF}/(100xI_{maxN})$, $(V_{CC} - 0.2V - V_{REF})/(100xI_{maxP})$ (for SY24642) and $(V_{CC} - 0.2V - V_{REF})/(200xI_{maxP})$ (for SY24647).

Choose the smaller value of R_{max1} and R_{max2} as the maximum available current-sense resistor value.

Bidirectional Application R_{SENSE} Design

Parameter		Range
Measured current range		$-I_{maxN}$–I_{maxP}
Maximum current-sense voltage range	SY24641	-40mV – 40mV
	SY24642	-20mV – 20mV
	SY24647	-10mV – 10mV
Maximum sensing resistor for input limit	SY24641	R_{max1} = MIN[$40mV/I_{maxN}$, $40mV/I_{maxP}$]
	SY24642	R_{max1} = MIN[$20mV/I_{maxN}$, $20mV/I_{maxP}$]
	SY24647	R_{max1} = MIN[$10mV/I_{maxN}$, $10mV/I_{maxP}$]
Maximum OUT pin output range		GND–V_{CC} - 0.2V
Maximum sensing resistor for output limit	SY24641	R_{max2} = MIN[V_{REF} / (50 × I_{maxN}), (V_{CC} - 0.2V - V_{REF}) / (50 × I_{maxP})]
	SY24642	R_{max2} = MIN[V_{REF} / (100 × I_{maxN}), (V_{CC} - 0.2V - V_{REF}) / (100 × I_{maxP})]
	SY24647	R_{max2} = MIN[V_{REF} / (200 × I_{maxN}), (V_{CC} - 0.2V - V_{REF}) / (200 × I_{maxP})]
Maximum available current-sense resistor		$R_{SENSE,max}$ = MIN[R_{max1}, R_{max2}]

SY24641 I_{SENSE} and R_{SENSE} Design Recommendations

Unidirectional Application (V_{REF} = 0V)			Bidirectional Application (V_{REF} = 0.5 × V_{CC})		
I_{SENSE} Range	Recommended R_{SENSE}		I_{SENSE} Range	Recommended R_{SENSE}	
	V_{CC} = 5V	V_{CC} = 3.3V		V_{CC} = 5V	V_{CC} = 3.3V
0A–1A	90mΩ	60mΩ	-1A–1A	40mΩ	25mΩ
0A–2A	45mΩ	30mΩ	-2A–2A	20mΩ	14mΩ
0A–3A	30mΩ	20mΩ	-4A–4A	10mΩ	7mΩ
0A–5A	18mΩ	12mΩ	-5A–5A	8mΩ	5mΩ
0A–10A	9mΩ	6mΩ	-10A–10A	4mΩ	2.5mΩ

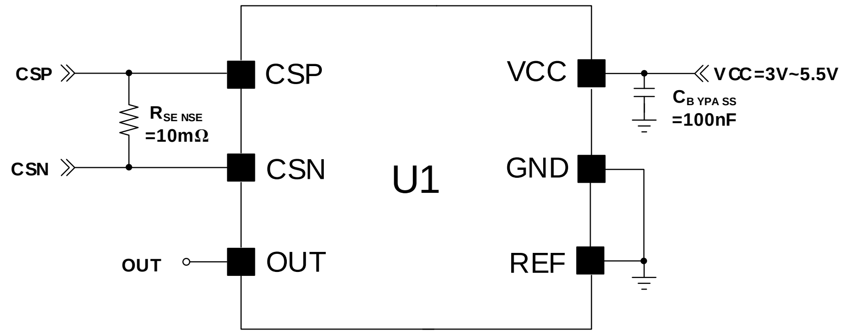
SY24642 I_{SENSE} and R_{SENSE} Design Recommendations

Unidirectional Application (V_{REF} = 0V)			Bidirectional Application (V_{REF} = 0.5 × V_{CC})		
I_{SENSE} Range	Recommended R_{SENSE}		I_{SENSE} Range	Recommended R_{SENSE}	
	V_{CC} = 5V	V_{CC} = 3.3V		V_{CC} = 5V	V_{CC} = 3.3V
0A–1A	45mΩ	30mΩ	-1A–1A	20mΩ	14mΩ
0A–2A	22.5mΩ	15mΩ	-2A–2A	10mΩ	7mΩ
0A–3A	15mΩ	10mΩ	-4A–4A	5mΩ	3.5mΩ
0A–5A	9mΩ	6mΩ	-5A–5A	4mΩ	2.5mΩ
0A–10A	4.5mΩ	3mΩ	-10A–10A	2mΩ	1.4mΩ

SY24647 I_{SENSE} and R_{SENSE} Design Recommendations

Unidirectional Application (V_{REF} = 0V)			Bidirectional Application (V_{REF} = 0.5 × V_{CC})		
I_{SENSE} Range	Recommended R_{SENSE}		I_{SENSE} Range	Recommended R_{SENSE}	
	V_{CC} = 5V	V_{CC} = 3.3V		V_{CC} = 5V	V_{CC} = 3.3V
0A–1A	20mΩ	15mΩ	-1A–1A	10mΩ	7mΩ
0A–2A	10mΩ	7mΩ	-2A–2A	5mΩ	3mΩ
0A–3A	7mΩ	5mΩ	-4A–4A	2.5mΩ	1.5mΩ
0A–5A	4mΩ	3mΩ	-5A–5A	2mΩ	1.4mΩ
0A–10A	2mΩ	1.5mΩ	-10A–10A	1mΩ	0.7mΩ

Application Schematic



BOM List

Reference Designator	Description	Part Number	Manufacturer
C_{BYPASS}	100nF/50V/X7R, 0603	GCJ188R71H104KA12D	muRata
R_{SENSE}	10mΩ/1W, 2512, 1%	RL2512FK-070R01L	YAGEO

Layout Design

For optimal design, follow these PCB layout considerations:

- Use a Kelvin connection to connect the input pins to the current-sense resistor R_{SENSE}. Due to the low resistance values of R_{SENSE}, poor PCB routing often leads to additional parasitic resistance between input pins, resulting in additional errors that cannot be ignored. The Kelvin connection technique ensures that only R_{SENSE} impedance is detected between the input pins. Minimize the loop area formed by these connections.
- Use a 0.1μF MLCC bypass capacitor, placed as close as possible to V_{CC} and GND.

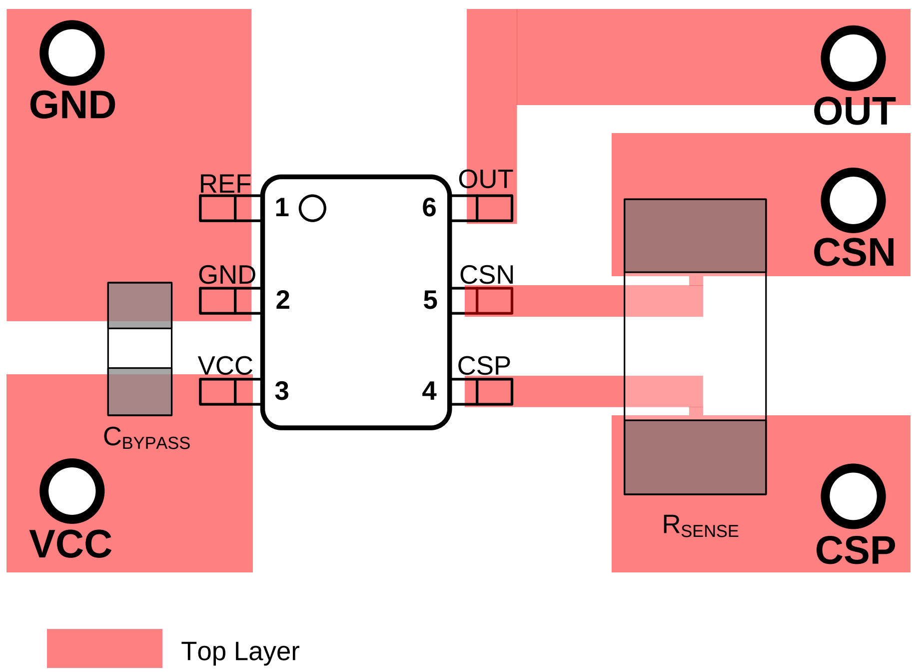
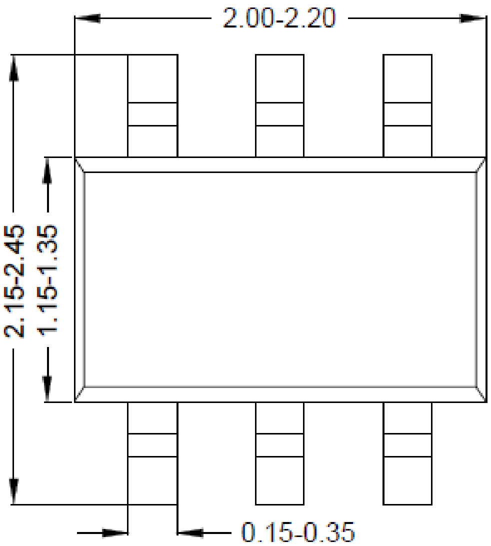
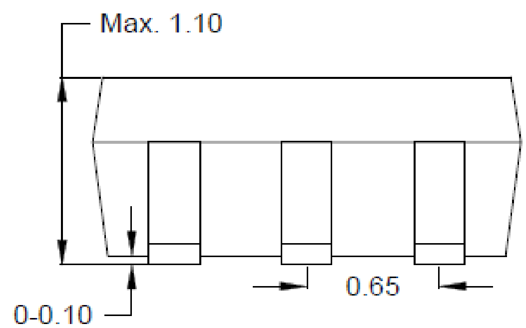


Figure 8. Recommended Layout

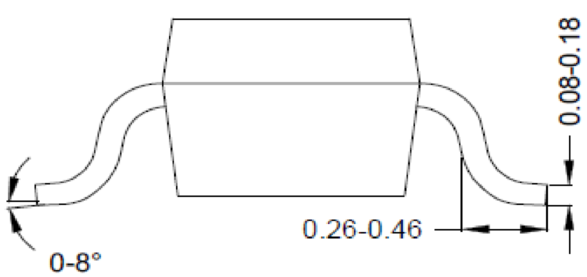
SOT363 Package Outline Drawing



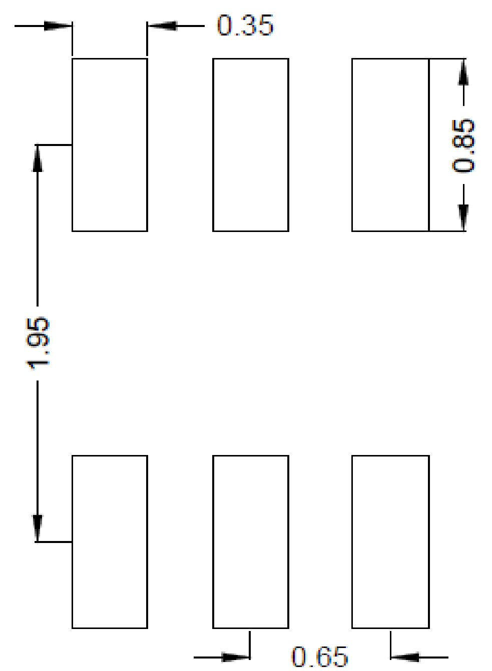
Top view



Side view A



Side view B

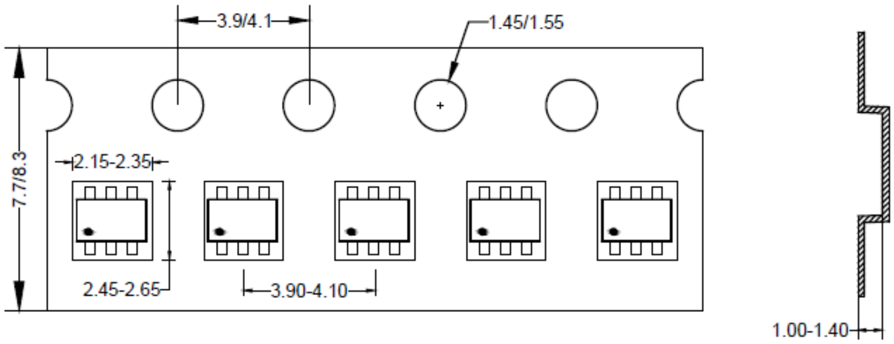


Recommended PCB layout (Reference only)

Note: *All dimensions are in millimeters and exclude mold flash and metal burr.*

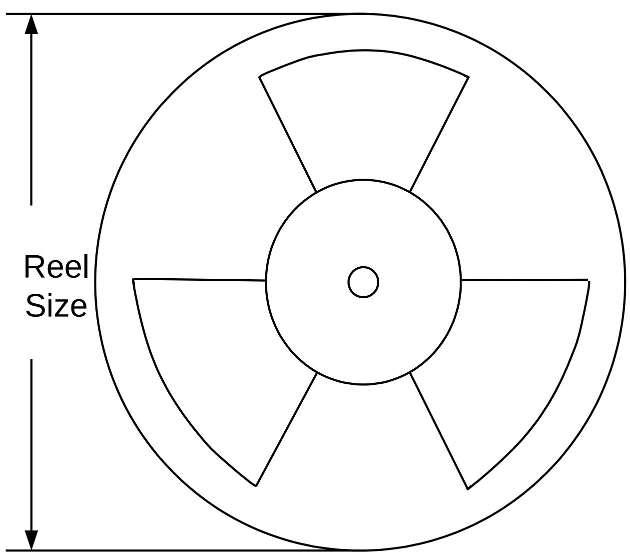
Taping and Reel Specification

Package Orientation



Feeding direction

Carrier Tape and Reel Specification for Packages



Package types	Tape width (mm)	Pocket pitch(mm)	Reel size (Inch)	Trailer length(mm)	Leader length (mm)	Qty per reel
SOT363	8	4	7"	280	160	3000

Others: NA

Revision History

The revision history provided is for informational purpose only and is believed to be accurate, however, not warranted. Please make sure that you have the latest revision.

Date	Revision	Change
Dec. 10, 2021	Revision 0.9	Initial Release.
Dec. 10, 2022	Revision 1.0	Production Release.

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