700V BUCK CONVERTER WITH SMALL INDUCTOR

Description

The AL17052 is a universal AC high-voltage input step-down converter that provides accurate 5V output and outstanding dynamic performance and load regulation without requiring an opto-coupler over line and load regulation. Typical applications are power supplies for offline low-power IoT (Internet of Things) devices that support WPAN (wireless personal area network) connectivity.

To support always-on requirements of IoT connectivity, the AL17052 features ultra-low standby operation power of 10mW. It also features high conversion efficiency 60% from rectified mains voltage to 5V for 50mA output and 50% at 10mA light loading during IoT system in idle and sleep mode.

With integration of embedded 700V high-voltage MOS switches, the AL17052 is designed with high degree of integration, which requires supporting less electronic components to form minimum e-BOM (bill-of-material) with small form factor package and PCB space.

The AL17052 has rich protection features to enhance the system safety and reliability. It has overtemperature protection, VCC undervoltage lock function, overcurrent protection, overload protection.

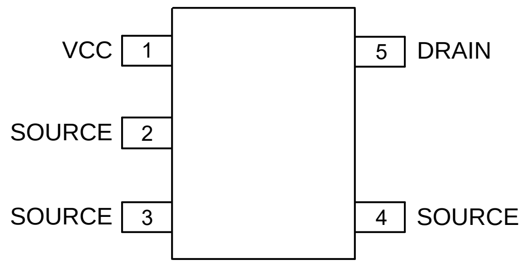
The AL17052 is available in the SOT25 package.

Features

- Small Inductor (330µH) Operation
- Ultra-Fast Startup, < 8ms
- Internal MOSFET up to 700V
- Fixed Option for Output 5V
- No-Load Operation Power Less than 10mW
- High Efficiency 60% at 50mA Output
- High Light-Load Efficiency 50% at 10mA Output
- Universal 85 to 300V_{AC} Input Range
- Supports Low Component-Count Buck Topologies
- Auto-Restart for Overcurrent and Overload Faults
- Excellent Load and Line Regulation
- Fast Transient Response
- Constant Voltage (CV) Control
- Undervoltage Lockout (UVLO) Protection for Input Voltage
- Overcurrent Protection
- Overload Protection
- Overtemperature Protection (OTP)
- **Totally Lead-Free & Fully RoHS Compliant (Notes 1 & 2)**
- **Halogen and Antimony Free. "Green" Device (Note 3)**
- **For automotive applications requiring specific change control (i.e. parts qualified to AEC-Q100/101/104/200, PPAP capable, and manufactured in IATF 16949 certified facilities), please contact us or your local Diodes representative.**
  https://www.diodes.com/quality/product-definitions/

Pin Assignments

(Top View)



SOT25

Applications

- Home appliance applications
- IoT applications
- Industrial controls
- Low standby power applications

Notes: 1. No purposely added lead. Fully EU Directive 2002/95/EC (RoHS), 2011/65/EU (RoHS 2) & 2015/863/EU (RoHS 3) compliant.
2. See https://www.diodes.com/quality/lead-free/ for more information about Diodes Incorporated's definitions of Halogen- and Antimony-free, "Green" and Lead-free.
3. Halogen- and Antimony-free "Green" products are defined as those which contain <900ppm bromine, <900ppm chlorine (<1500ppm total Br + Cl) and <1000ppm antimony compounds.

Typical Applications Circuit

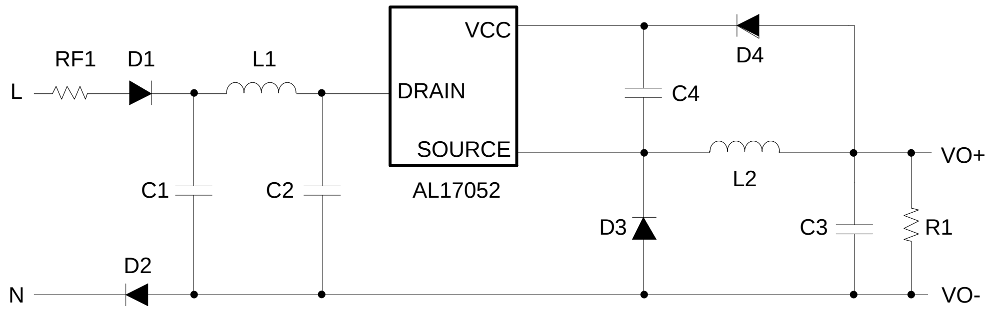
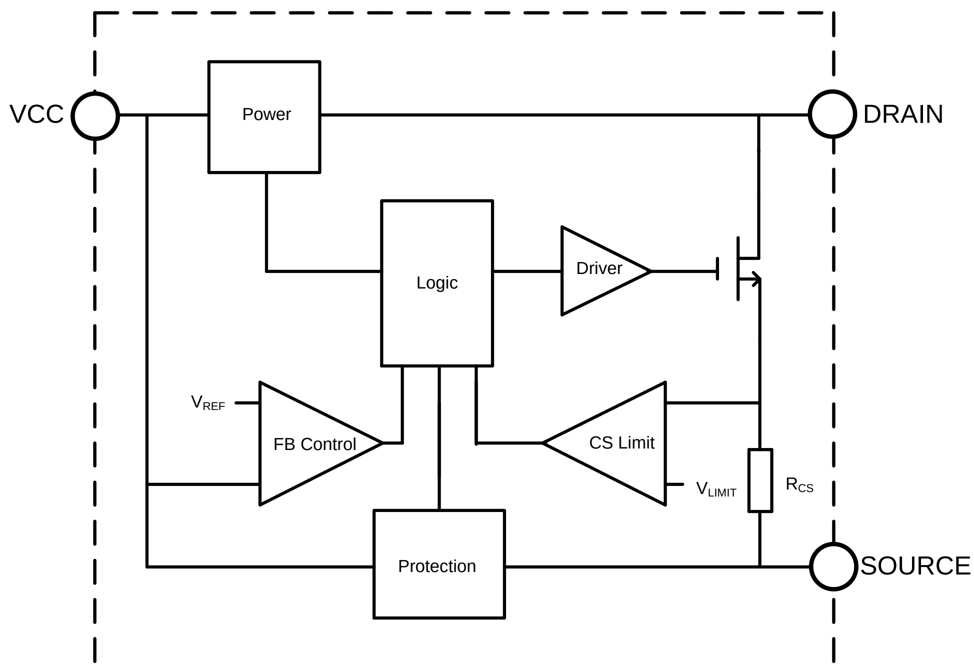


Figure 1. Typical Offline Buck Constant Voltage Output Application Circuit

Pin Descriptions

Pin Number	Pin Name	Function
1	VCC	Control Circuit Power Supply.
2, 3, 4	SOURCE	Internal power MOSFET Source. Ground reference for device.
5	DRAIN	Internal power MOSFET Drain. High voltage current source input.

Functional Block Diagram



Absolute Maximum Ratings (Note 4)

Symbol	Parameter	Rating	Unit
V_{DSS}	Drain to SOURCE (Note 5)	-0.7 to 700	V
VCC	VCC to SOURCE	-0.7 to 6.5	V
P_D	Continuous Power Dissipation (T_A = +25°C) SOT25	0.625	W
T_J	Operating Junction Temperature	+150	°C
T_{STG}	Storage Temperature	-65 to +150	°C
T_{LEAD}	Lead Temperature (Soldering, 10 sec)	+300	°C
$θ_{JA}$	$θ_{JA}$ Thermal Resistance (Junction to Ambient) SOT25 (Note 6)	125	°C/W
$θ_{JC}$	$θ_{JA}$ Thermal Resistance (Junction to Case) SOT25 (Note 6)	37	°C/W
ESD	ESD (Human Body Model)	2000	V
	ESD (Charged Device Model)	2000	V

Note 4: Stresses greater than those listed under *Absolute Maximum Ratings* can cause permanent damage to the device. These are stress ratings only and functional operation of the device at these or any other condition beyond those indicated under *Recommended Operating Conditions* is not implied. Exposure to *Absolute Maximum Ratings* for extended periods can affect device reliability.

Note 5: Device has passed qualification test in condition of V_{DSS} = 560V, V_{CC} = 5V.

Note 6: Device mounted on 2″ × 2″ FR-4 substrate PCB, 2oz copper, with minimum recommended pad layout.

Recommended Operating Conditions

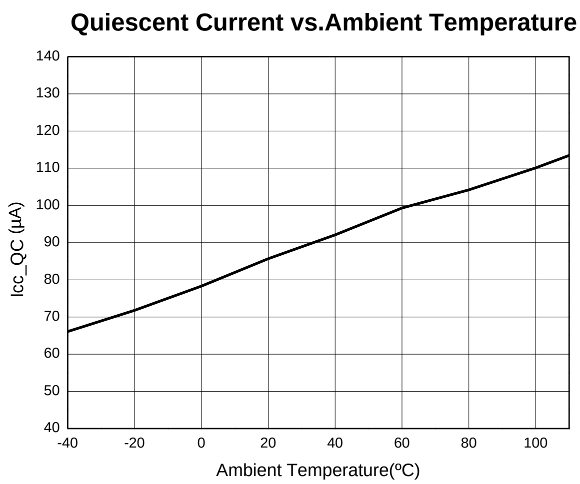
Symbol	Parameter	Min	Max	Unit
T_A	Ambient Temperature	-40	+105	°C
I_{out}	Output Current	—	50	mA

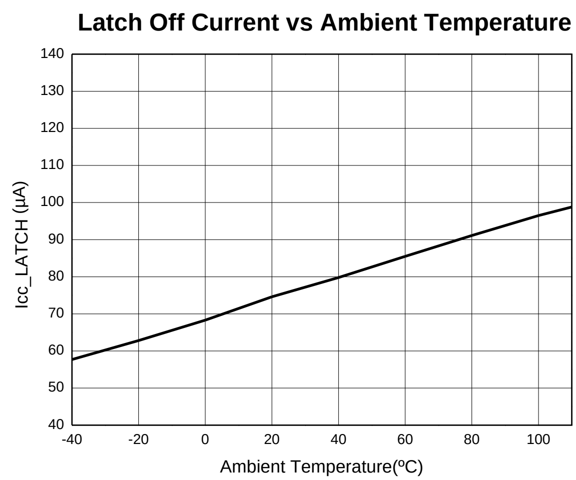
Electrical Characteristics (T_A = +25°C, unless otherwise specified.)

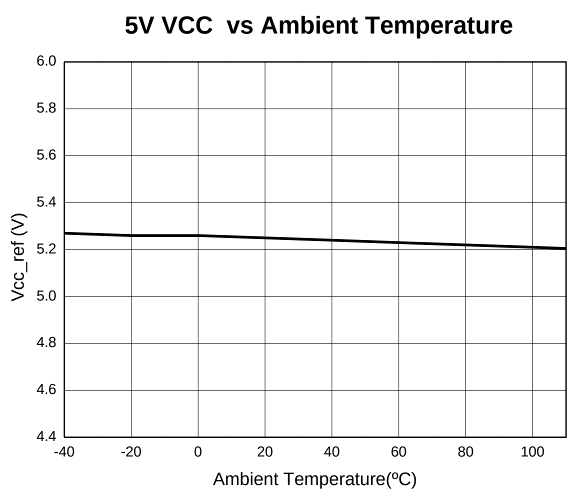
Symbol	Parameter	Condition	Min	Typ	Max	Unit
HV Startup Current Source						
I_{HV}	HV Supply Current	V_{CC} = 2.5V; V_{DRAIN} = 30V	—	0.7	—	mA
I_{LEAK}	Leakage Current of Drain	V_{CC} = 3.6V; V_{DRAIN} = 560V	—	6	—	µA
VCC Voltage Management						
VCC_HV_{OFF}	HV Supply OFF Threshold Voltage	—	2.83	3.20	3.60	V
VCC_HV_{ON}	HV Supply ON Threshold Voltage	—	2.68	3.05	3.39	V
—	HV Supply ON and OFF Hysteresis	—	—	150	—	mV
VCC_{REF}	VCC Reference Voltage for Internal MOSFET Turn On	—	5.22	5.35	5.48	V
VCC_{UVLO}	Min Operating Voltage	—	—	2.7	—	V
I_{CC_FULL}	Operating Current	f_S = 33kHz, D = 35%	—	240	—	µA
I_{CC_QC}	Quiescent Current with No Switching	—	—	88	—	µA
I_{CC_LATCH}	Latch Off Current	—	—	80	—	µA
Internal MOSFET						
V_{DS}	Breakdown Voltage	—	700	—	—	V
$R_{DS(ON)}$	ON Resistance	—	—	40	—	Ω
Internal Current Sense						
I_{PK_MAX}	Peak Current	—	—	140	—	mA
I_{PK_MIN}	Minimum Peak Current	—	—	60	—	mA
t_{LEB}	Leading Edge Blanking	—	—	100	—	ns
t_{MINOFF}	Minimum Off Time	—	—	7	—	µs
Thermal Shutdown						
T_{SD}	Thermal Shutdown Threshold (Note 7)	—	—	+150	—	°C
T_{HYS}	Hysteresis for Recover after OTP (Note 7)	—	—	+50	—	°C

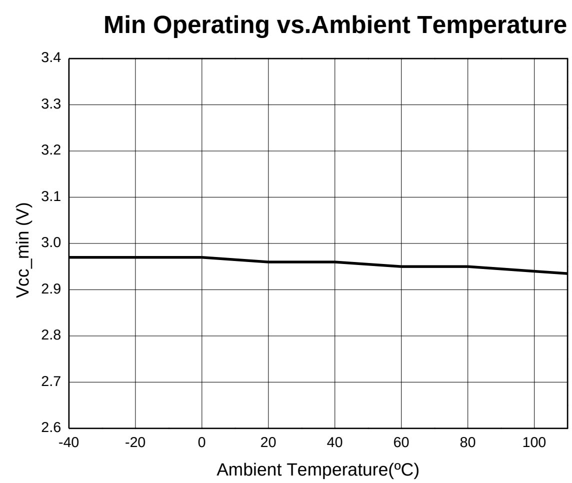
Note: 7. These parameters, although guaranteed by design, are not 100% tested in production.

Performance Characteristics

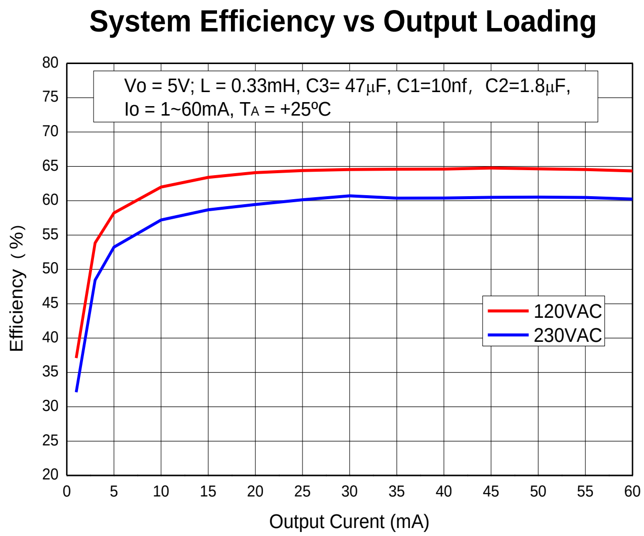


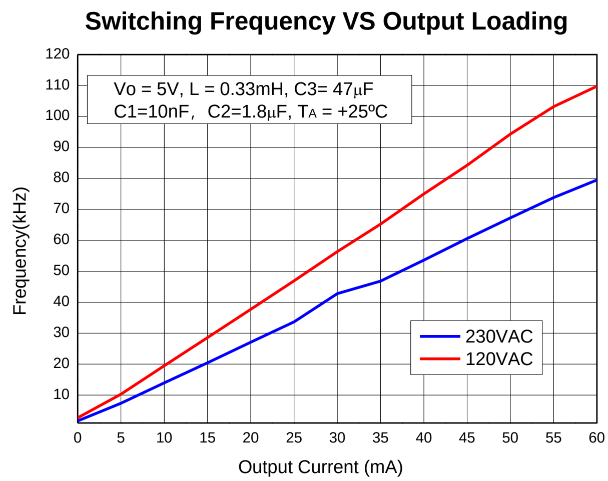


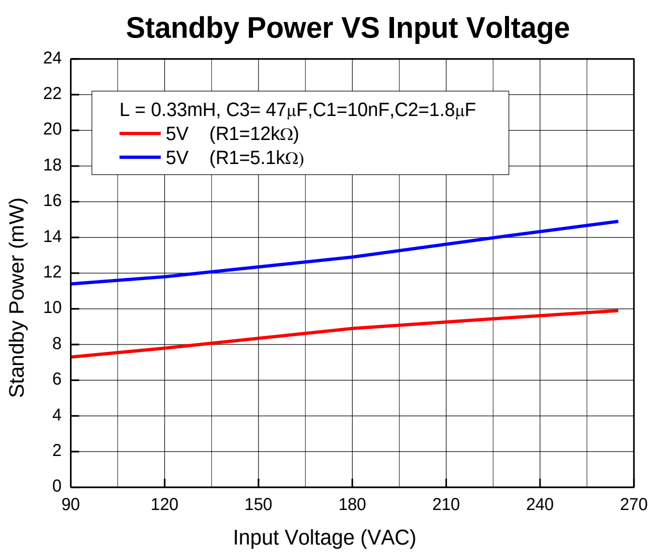


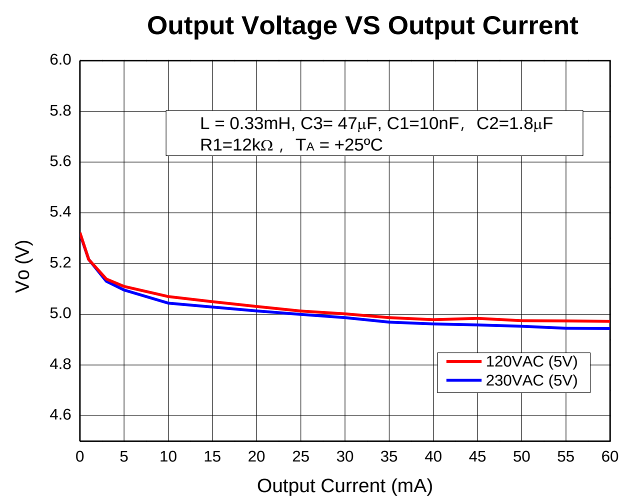


Performance Characteristics (continued) (T_A = +25°C, unless otherwise specified.)









Function Description

Overall Introduction

The AL17052 is a universal AC input step-down regulator. Max peak current limitation and driving frequency vary as the load change can get excellent efficiency performance at light load and improve the overall efficiency of system. Working with a single winding inductor and integrating a 700V MOSFET internal can make it use fewer external components and create a low BOM cost solution. Figure 1 shows a typical application example of a buck power supply.

Converter Operation

Startup and Undervoltage Lockout

The IC control voltage VCC is charged by internal high-voltage regulator. When the VCC voltage is charged to VCC_HV_{OFF}, IC starts to generate switching signal and meanwhile the internal high-voltage regulator is turned off to improve system efficiency. When the VCC voltage drops below VCC_HV_{ON}, the internal high-voltage regulator turns on again to charge the external VCC capacitor. When the voltage on VCC drops below VCC_{UVLO}, the IC stops operating; then the internal high-voltage regulator charges the VCC capacitor. Figure 2 shows the typical waveform with VCC.

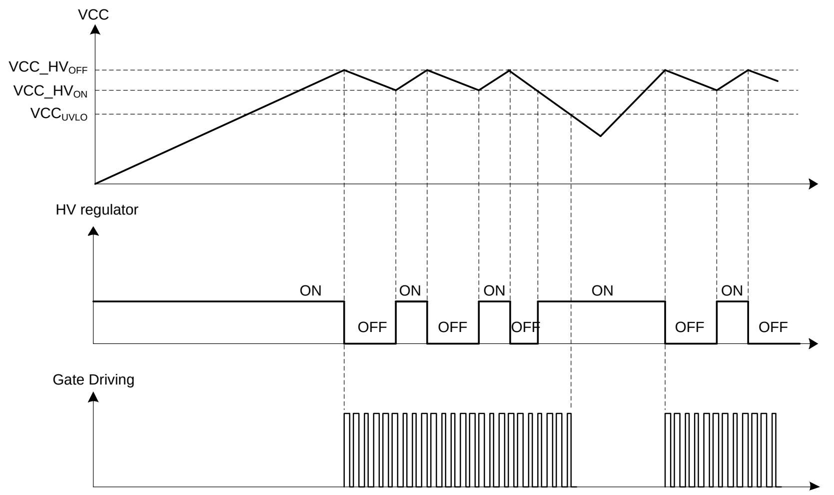


Figure 2. VCC Waveform and HV Regulator ON/OFF Status

Constant Voltage Operation

The AL17052 is a step-down regulator with a 700V MOSFET integrated. It can be used in buck circuit as shown in the typical application circuit.

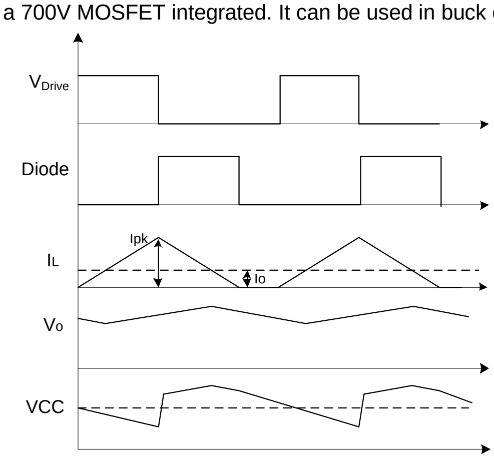


Figure 3. Operation Timing in DCM Mode

The peak current limit and the initial inductance current value altogether with the input voltage determine the ON period time. When the inductor current reaches peak current limit, the internal integrated MOSFET turns OFF. The inductor current charges the VCC capacitor (C_4) and the output capacitor (C_3) via the freewheeling diode D_4 and D_3 respectively. The VCC capacitor voltage is the mapping of the output voltage. The output voltage can be controlled by sampling the voltage of internal feedback which is derived from the voltage of VCC capacitor.

Function Description (continued)

In the OFF stage of internal MOSFET, when the inductor current drops below the output current, the VCC capacitor voltage begins to decrease. When the voltage of internal feedback falls below the reference voltage (2.5V), a new switching cycle begins. Figure 3 shows the detailed operation timing diagram under discontinuous conduction mode (DCM).

Frequency and Peak Current

To maintain high efficiency under different load condition, the AL17052 adjusts the switching frequency automatically. Since the AL17052 should be set to work in DCM mode under full load, the switching frequency can be obtained as:

$$f_s = \frac{2(V_{in} - V_O)}{L \cdot I_{pk}^2} \cdot \frac{I_O V_O}{V_{in}} \quad (1)$$

Generally, the peak current of the inductor (I_{PK}) is constant 140mA, but if the output load decreases to a light loading, the chip will decrease the peak current limit to 60mA to improve load transient.

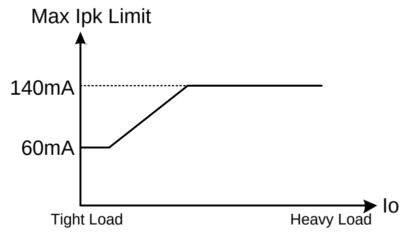


Figure 4. Maximum I_{PK} Limit Modulations with Output Load

If t_{OFF} is lower than 200µs, peak inductor current will be kept at 140mA typical.

If t_{OFF} is higher than 200µs, peak inductor current is calculated from following formula:

$$I_{peak} = \text{Max}\,[140\text{mA} - (t_{OFF} - 200\mu s) \times 0.47\text{mA}/\mu s\,, 60\text{mA}] \quad (2)$$

As the load decreases, the switching frequency decreases and the MOSFET OFF time t_{OFF} increases, leading to the decrease of peak current. In no-load condition, in which only a dummy load is retained, the frequency and the peak current are both minimized. This helps to reduce the no-load power consumption.

Soft-Start Control

The AL17052 implements a minimum OFF time control. In normal condition, the minimum OFF time limit is 7µs.

In the startup process, the output voltage is not established and more demagnetizing time is needed. Therefore, the soft-start technique is adopted. During the startup process, the minimum MOSFET OFF time varies with three stages, and it gradually drops from 4 times of t_{MINOFF}, to 2 times of t_{MINOFF}, and then to t_{MINOFF}. Each stage contains 32 switching cycles and the startup process will end if the desired output voltage is reached.

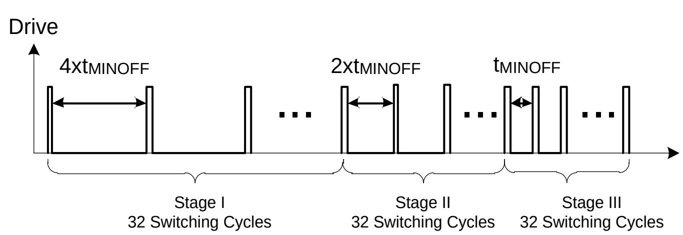


Figure 5. t_{OFF} Control in Soft-Start Sequence

EA Compensation

To improve load regulation and load transient performance, the AL17052 is designed with an error amplifier (EA) compensation function.

The compensation is related to the load condition. With an increasing load, the compensation value increases and the reference voltage of the internal feedback comparator is slightly pulled down. A faster change in the load will lead to a greater compensation step, and then the output voltage will be regulated back to the desired voltage faster. This compensation will precisely maintain the output voltage.

Function Description (continued)

Leading-Edge Blanking

A narrow spike on the leading edge of the current waveform can usually be observed when the power MOSFET is turned on. A 100ns leading-edge blank is built-in to prevent the false-triggering caused by the turn-on spike. During this period, the current limit comparator is disabled and the gate driver cannot be switched off.

Protection

Overcurrent Protection (SCP)

The AL17052 enters overcurrent protection mode once the peak current of inductor exceeds the overcurrent protection threshold (200mA). In this operation mode, the AL17052 increases t_{MINOFF} to 4 times typical value to let inductor discharge for more time. The AL17052 will resume operation when the fault is removed.

Overload Protection (OLP)

With the increase of output load, the peak current and the switching frequency increase. If the AL17052 operates in minimum t_{OFF} status, the internal OLP counter starts counting the switching cycle. OLP is triggered if the OLP counter reaches 8192. In OLP mode, device stops switching, and the VCC voltage starts to decrease. When VCC voltage drops to VCC_{UVLO}, then the internal high-voltage regulator recharges VCC. After 512 cycles for internal high-voltage regulator on/off, the AL17052 starts recover to output switching and then check if the overload condition is removed.

Thermal Shutdown (TSD)

The AL17052 integrates an internal thermal shutdown protection function. If the IC junction temperature rises above TJ_{STOP} (typical value: +150°C), the thermal shutdown (TSD) protection is triggered and the internal MOSFET stops switching. To recover the switching of internal MOSFET, the IC junction temperature has to fall by a hysteresis of 30°C below the TJ_{STOP}. During TSD protection, VCC drops to $VCC_{RESTART}$ (typical value 2.4V), and then the internal high-voltage regulator recharges VCC.

Application and Implementation

The AL17052 is a universal high-voltage step-down regulator. Figure 1 shows a typical application for reference. The application can be used in a wide variety of home appliances and industrial control devices, or any other application where mains isolation is not required.

Input Stage

The input stage consists of RF_1, D_1, D_2, C_1, C_2 and L_1. Resistor RF_1 is a fusible resistor. RF_1 limits the inrush current, and also provides protection in case any component failure causes a short circuit. Value for its resistance is generally selected between 4.7Ω to 15Ω. A half-wave rectifier is implemented with the diode D_1. It is a general purpose 1A/1000V diode. D_2 is added for improving common-mode conducted EMI (electromagnetic interference) noise performance and can be removed if not needed. Component C_1, L_1, C_2 forms a Pi EMI filter; capacitor C_1 and C_2 also act as storage capacitors for the high-voltage input DC voltage.

When use half-wave rectifier, select a 2.2µF as input capacitor for the universal input condition. When use full-wave rectifier, choose 1µF capacitor. To avoid thermal shutdown, capacitance selection must avoid the minimum DC voltage below 70V. And if passing surge test is needed for the converter, adjusting input capacitance can help to meet different surge test requirements.

Inductor

The AL17052 should be set to work in DCM mode under full load. In DCM buck converter, the inductor peak-to-peak current ripple is the peak current, and it should be bigger than double of the output current.

$$\Delta I_L = I_{pk} > 2 \times I_{out} \quad (3)$$

Therefore, the available output current with the AL17052 should be less than half of the peak current limit, generally limited to 60mA.

In DCM mode, the peak current limit and the inductor determine the internal MOSFET turn-on time (t_{on}). And t_{on} can be given by Equation 4.

$$t_{on} = \frac{L \cdot I_{pk}}{V_{in} - V_o} \quad (4)$$

To guarantee normal operation, t_{on} must be bigger than t_{LEB} with margin.

The buck converter reaches maximum power when the off-time equals the minimum off time (t_{MINOFF}). Thus the maximum output power can be calculated as:

$$P_{omax} = \frac{1}{2} L \cdot I_{pk}^2 \cdot \frac{1}{t_{MINOFF}} \quad (5)$$

Since the on-time is generally far smaller than the off-time, the above approximation can be reasonable for estimation.

Function Description (continued)

To design an inductor, the desired maximum output power is given according to the output specification. The desired peak current is also estimated, generally between 80mA and 140mA. Since t_{MINOFF} is 20μs, a minimum inductance can be calculated with Equation 5. The inductance should be checked with Equation 1, Equation 3, and Equation 4, and it should be adjusted to ensure that the on-time limitation is satisfied and the desired peak current under full load is met. Some inductance margin is also needed for tolerance.

With the inductance and its peak current value, a standard off-the-shelf inductor can be used to reduce cost.

Freewheeling Diode

The maximum reverse voltage that the diode would experience during normal operation is given by the following equation.

$$V_{D-MAX} = \sqrt{2} \times V_{INAC-MAX} \quad (6)$$

For a universal AC input application, the 265V_{AC}, thus $V_{D\text{-}MAX}$ value is 375V. Considering a margin of 20%, a 600V diode is a general selection.

A fast recovery diode is required for the buck application. Since the AL17052 works in DCM under full load, slower diode can be used, but the reverse-recovery time should be kept less than 100ns. If even slower diode is to be chosen, special review is needed.

The forward voltage drop difference caused by D_3 and D_4 cannot be neglected. Since the diode forward voltage is positively related with the current flows through it and the current through D_3 is much higher than D_4, VD_3 is higher than VD_4.

Output Capacitor

The output capacitor maintains the DC output voltage, and the value impacts the output ripple. Since the AL17052 works in DCM mode, the output voltage ripple can be estimated as:

$$V_{out\_ripple} = \frac{I_{out}}{f_s C_{out}} \cdot \left(\frac{I_{pk} - I_{out}}{I_{pk}}\right) + I_{pk} \cdot R_{ESR} \quad (7)$$

Where f_S is the switching frequency, and R_{ESR} is ESR of output capacitor. For a typical application, the capacitor value can range from 47μF to hundreds of μF. If the total ripple is higher than the requirement, increasing the capacitance and reducing the ESR can help.

Dummy Load

The output requires a dummy load to maintain the load regulation under no-load condition. This can ensure sufficient inductor energy to charge the sample-and-hold capacitor to detect the output voltage. Most applications can use a 1 to 3mA dummy load and the dummy load can be adjusted according to the regulation. Increasing the dummy load adversely affects the efficiency and no-load consumption.

VCC Capacitor

The VCC capacitor provides a sample-and-hold function. The VCC capacitor discharges slew should be a litter than output capacitor discharge for output load in PWM OFF time. It can make VCC voltage always follow output voltage variation, but the VCC capacitor cannot be too small. VCC voltage will drop too fast and may mis-trigger OLP function in tight output load condition. In hence the capacitance selection should conform to the following equation:

$$0.5 \cdot \frac{I_{CC\_QC}}{I_O} \cdot C_3 < C_4 < \frac{I_{CC\_QC}}{I_O} \cdot C_3 \quad (8)$$

Layout Guidelines

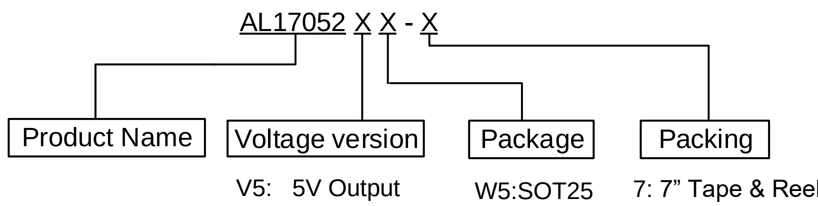
PCB layout is important to achieve reliable operation, good EMI, and thermal performance. Follow these guidelines to optimize performance:

- Minimize the loop area formed by the input capacitor, IC part, freewheeling diode, inductor and output capacitor.
- Place the power inductor far away from the input filter.
- Connect the exposed pad with the DRAIN pin to a large copper area to improve thermal performance.

Design Tools (https://www.diodes.com/design/tools/)

- Evaluation Board User Guides
- Spice Models (PSPICE Digital Simulation)
- Design Calculators

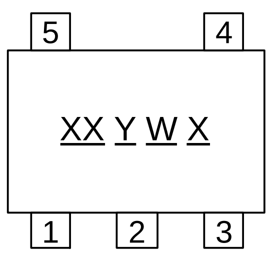
Ordering Information



Part Number	Package	Package Code	Marking ID	Packing	
				Qty.	Carrier
AL17052V5W5-7	SOT25	W5	BP	3000	7" Tape & Reel

Marking Information

(Top View)



XX : Marking ID
Y : Year 0 to 9
W : Week : A to Z : 1 to 26 week;
a to z : 27 to 52 week; z represents 52 and 53 week
X : Internal Code

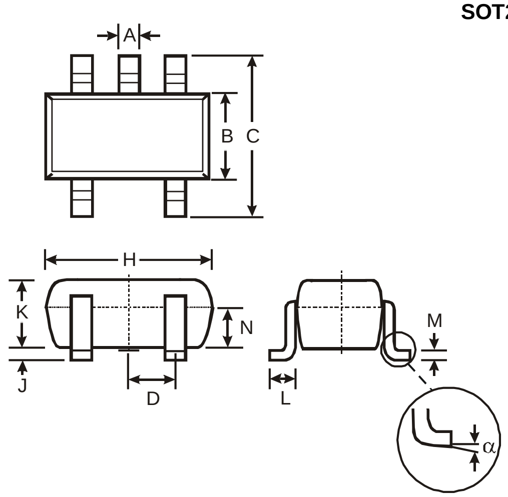
Mechanical Data

- Moisture Sensitivity: Level 1 per JESD22-A113
- Terminals: Finish - Matte Tin Plated Leads, Solderable per M2003 JESD22-B102 e3
- Weight: 0.015 grams (Approximate)

Package Outline Dimensions

Please see http://www.diodes.com/package-outlines.html for the latest version.

SOT25

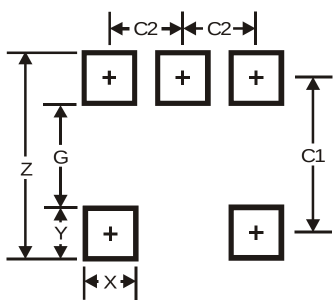


SOT25			
Dim	**Min**	**Max**	**Typ**
A	0.35	0.50	0.38
B	1.50	1.70	1.60
C	2.70	3.00	2.80
D	-	-	0.95
H	2.90	3.10	3.00
J	0.013	0.10	0.05
K	1.00	1.30	1.10
L	0.35	0.55	0.40
M	0.10	0.20	0.15
N	0.70	0.80	0.75
α	0°	8°	-
All Dimensions in mm			

Suggested Pad Layout (Note 8 and Note 9)

Please see http://www.diodes.com/package-outlines.html for the latest version.

SOT25

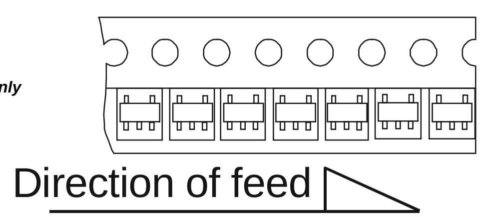


Dimensions	Value (in mm)
Z	3.20
G	1.60
X	0.55
Y	0.80
C1	2.40
C2	0.95

Note 8: The suggested land pattern dimensions have been provided for reference only, as actual pad layouts may vary depending on application. These dimensions may be modified based on user equipment capability or fabrication criteria. A more robust pattern may be desired for wave soldering and is calculated by adding 0.2 mm to the "Z" dimension. For further information, please reference document IPC-7351A, Naming Convention for Standard SMT Land Patterns, and for International grid details, please see document IEC, Publication 97.

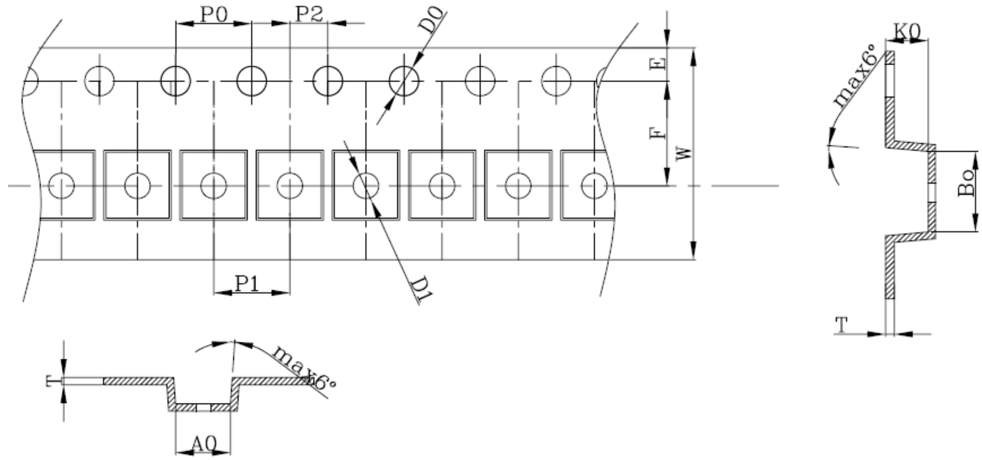
Note 9: For high-voltage applications, the appropriate industry sector guidelines should be considered with regards to creepage and clearance distances between device Terminals and PCB tracking.

Device Tape Orientation

Tape Width	Tape Orientation
8mm	***Note 10: Analogue Only*** 

Note 10: Tape and package drawings are not to scale and are shown for device tape orientation only.

Embossed Carrier Tape Specification

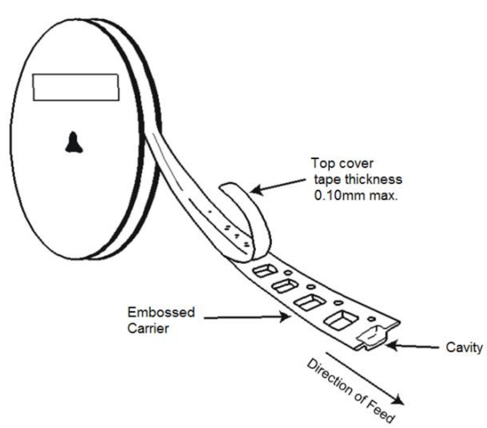


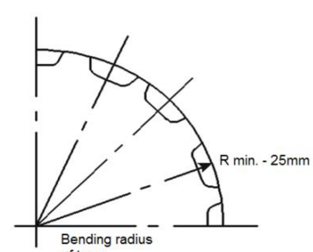
First Source

Tape Width (W)	Dimension	Value (mm)	Dimension	Value (mm)	Dimension	Value (mm)
8mm	**A0**	3.25 ± 0.1	**P1**	4.0 ± 0.1	**F**	3.5 ± 0.05
	B0	3.15 ± 0.1	**P2**	2 ± 0.05	**D0**	1.55 ± 0.05
	K0	1.5 ± 0.1	**T**	0.2 ± 0.02	**D1**	1.1 ± 0.1
	P0	4.0 ± 0.1	**E**	1.75 ± 0.1	**W**	8/+0.3/-0.1
	A0 B0 K0	Determined by component size. The clearance between the component and the cavity must comply to the rotational and lateral movement requirement provided in figures in the *Maximum Component Movement in Tape Pocket* section.				

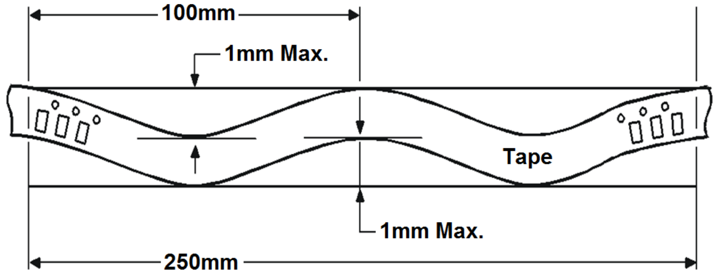
Second Source

Tape Width (W)	Dimension	Value (mm)	Dimension	Value (mm)	Dimension	Value (mm)
8mm	**A0**	3.23 ± 0.1	**P1**	4.0 ± 0.1	**F**	3.5 ± 0.05
	B0	3.17 ± 0.1	**P2**	2 ± 0.05	**D0**	1.50 + 0.1
	K0	1.37 ± 0.1	**T**	0.23 ± 0.02	**D1**	1.0 + 0.25
	P0	4.0 ± 0.1	**E**	1.75 ± 0.1	**W**	8/+0.3/-0.1
	A0 B0 K0	Determined by component size. The clearance between the component and the cavity must comply to the rotational and lateral movement requirement provided in figures in the *Maximum Component Movement in Tape Pocket* section.				





Embossed Carrier Tape Specification (continued)



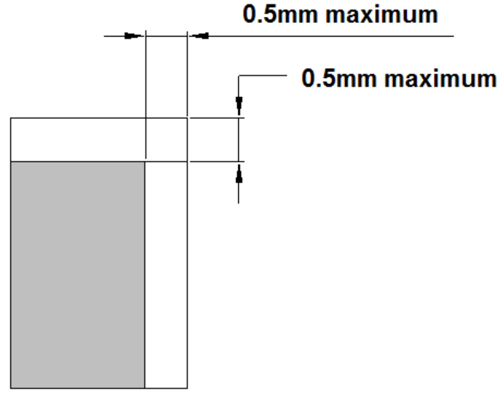
Camber (Top View)

Allowable camber to be 1mm/100mm tape, non-cumulative

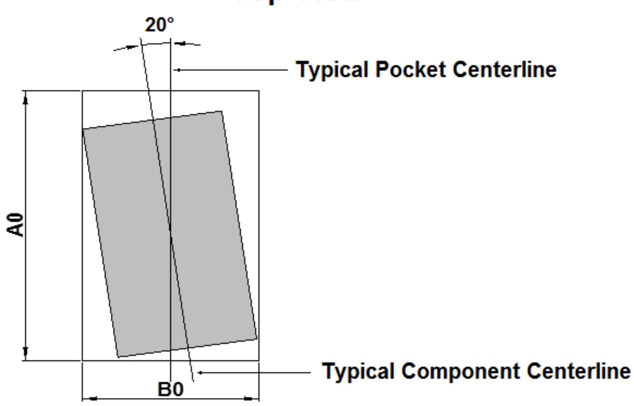
Maximum Component Movement in Tape Pocket

Component Lateral Movement

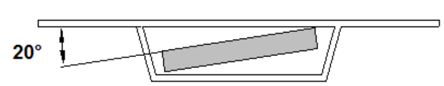
8mm Tape



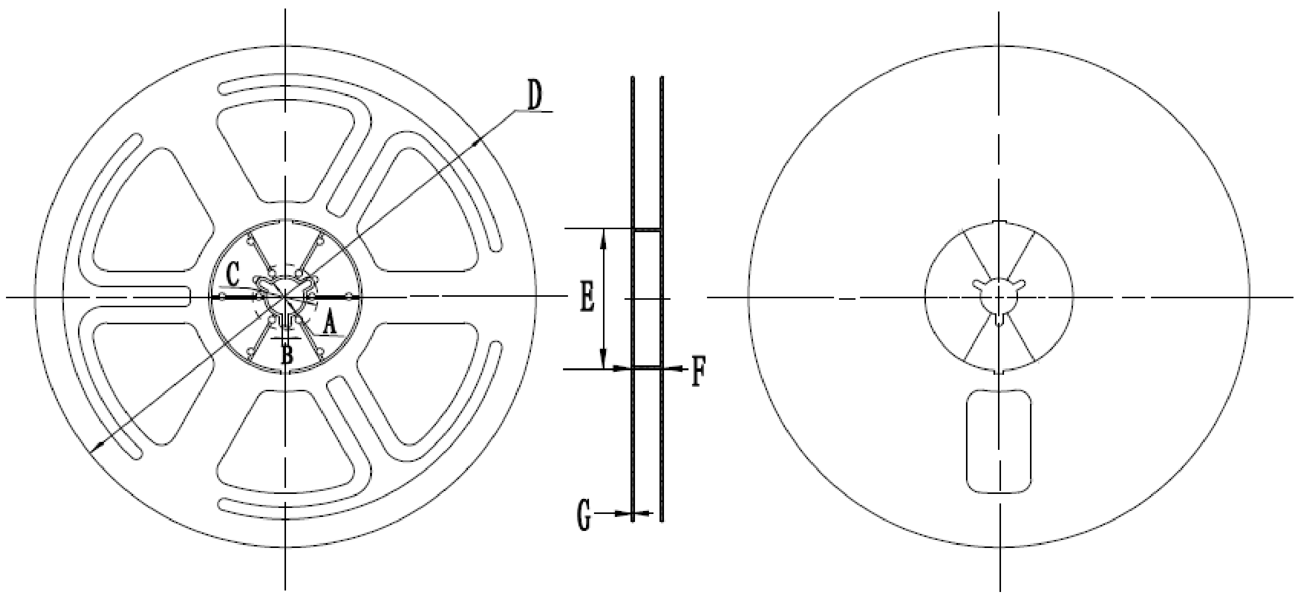
Maximum Component Rotation Top View



Maximum Component Rotation Side View

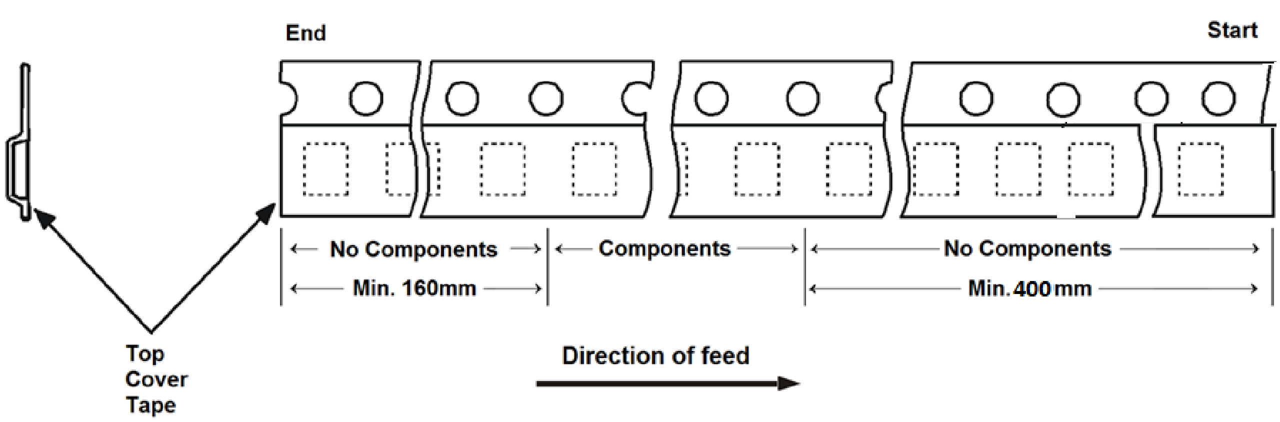


Surface Mount Reel Specifications



Tape Width	Reel Size	A (mm)	B (mm)	C (mm)	D (mm)	E (mm)	F (mm)	G (mm)
8mm	7”	12.8 to 13.5	≥ 1.6	≥ 20.2	Φ178 ± 2	54 to 54.5	8.4 to 9.9	1.4 ± 0.3

Tape Leader and Trailer Specifications (Note 11 and Note 12)



Note 11: There shall be a leader of at least 400mm empty carrier tape sealed with cover tape.
Note 12: There shall be a trailer of at least 160mm of empty carrier tape sealed with cover tape. The entire carrier tape must release from the reel hub as the last portion of the tape unwinds from the reel without damage to the carrier tape and the remaining components in the cavities.

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