UM10371

STARplug buck and buck-boost converter demo board (STARbuck)

Rev. 2 — 4 May 2011 **User manual**

Document information

Info	Content
Keywords	STARplug, buck converter, buck/boost converter, white goods, non-isolated SMPS
Abstract	The NXP Semiconductors STARbuck demo board is a flexible, user configurable, non-isolated SMPS application intended for low power loads. STARbuck has a universal mains input and a single positive or negative DC voltage output. This manual describes the STARbuck demo board version 1.0. Refer to the TEA152x data sheet for details on the STARplug device and the STARplug application note AN00055 for general application information.

Revision history

Rev	Date	Description
v.2	20110504	second issue
v.1	20100407	first issue

Contact information

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1. Introduction

WARNING

Lethal voltage and fire ignition hazard

The non-insulated high voltages that are present when operating this product, constitute a risk of electric shock, personal injury, death and/or ignition of fire.

This product is intended for evaluation purposes only. It shall be operated in a designated test area by personnel qualified according to local requirements and labor laws to work with non-insulated mains voltages and high-voltage circuits. This product shall never be operated unattended.

The STARbuck Switched Mode Power Supply (SMPS) demo board has one single non-isolated DC output voltage. The circuit is built around an NXP Semiconductors STARplug IC and the operation mode of the circuit is either buck or buck/boost. The default configuration on the STARbuck demo Printed-Circuit Board (PCB) implements Buck mode operation and produces 5 V (DC) (100 mA maximum) on the output terminals. However, by changing the jumper settings, modifying the component values, or swapping the components, the STARbuck demo board can be adapted easily to meet specific needs with respect to the output voltage and the output current.

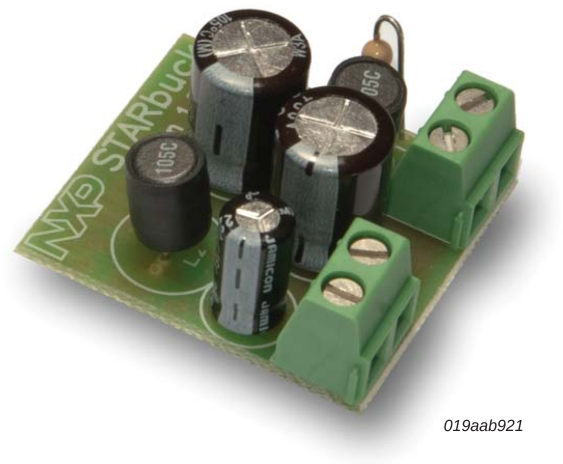

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Fig 1. STARbuck demo board

2. Features

- Universal mains input
- Single DC voltage output
- Non-isolated, AC mains supply Neutral terminal connected to 0 V (GND) DC output terminal
- Produces either a positive polarity in Buck mode or a negative polarity voltage in Buck/boost mode
- No custom-made magnetic components required; uses only standard components

- User configurable output voltage range between 5 V and 36 V
- User configurable maximum output current set using resistor R3:
  - TEA1520T: up to 125 mA; maximum output power < 2.5 W
  - TEA1521T: up to 250 mA; maximum output power < 5 W
  - TEA1522T: up to 500 mA; maximum output power < 10 W
- High efficiency (at higher output voltages only):
  - TEA1520T: 12 V; 1 W; typical efficiency > 75 %
  - TEA1522T: 12 V; 4 W; typical efficiency > 78 %
- Very low standby (no-load) power (at higher output voltages only):
  - TEA1520T: 12 V; 1 W; typical standby power < 40 mW
  - TEA1522T: 12 V; 4 W; typical standby power < 65 mW
- Overload protection
- OverTemperature Protection (OTP)
- Built-in ElectroMagnetic Interference (EMI) filter

3. Technical specifications

Table 1. Input specification

Parameter	Condition	Value	Remark
input voltage		80 to 276 V (AC)	universal mains
input frequency		47 to 63 Hz	-

Table 2. Output specification

Parameter	Condition	Value	Remark
output voltage		5 V	user changeable
output voltage tolerance	at 75 % load	± 5 %	-
output voltage stability	at 5 V output	+15 %/–5 %	over full power range
	at 12 V output	+10 %/–5 %	over full power range

4. Performance data

4.1 Output voltage and no-load power consumption

Table 3 shows the no-load power consumption figures for three implementations of the STARbuck SMPS:

- TEA1520T: 5 V; 100 mA (500 mW); the default implementation on the demo board
- TEA1520T: 12 V; 83 mA (1 W)
- TEA1522T: –12 V; –333 mA (4 W)

Table 3. No-load output voltage and power consumption values

Power supply	Energy start 2.0 requirement	Output voltage (V_{out})	Power consumption (P_i)
5 V, 500 mW STARbuck			
115 V/60 Hz	≤ 300 mW	5.6 V	160 mW
230 V/50 Hz	≤ 300 mW	5.6 V	300 mW
12 V, 1 W STARbuck			
115 V/60 Hz	≤ 300 mW	13.0 V	30 mW
230 V/50 Hz	≤ 300 mW	13.0 V	40 mW
–12 V, 4 W STARbuck			
115 V/60 Hz	≤ 300 mW	–13.0 V	30 mW
230 V/50 Hz	≤ 300 mW	–13.0 V	65 mW

4.2 Efficiency performance data

Table 4 shows the efficiency figures for three implementations of the STARbuck SMPS:

- TEA1520T: 5 V; 100 mA (500 mW); the default implementation on the demo board
- TEA1520T: 12 V, 83 mA (1 W)
- TEA1522T: –12 V, –333 mA (4 W)

Table 4. Efficiency values

Power supply	Energy star requirement	Efficiency (η)				
		average	25 % load	50 % load	75 % load	100 % load
5 V, 500 mW STARbuck						
115 V/60 Hz	31.6 %	50.6 %	39.3 %	50.2 %	55.4 %	57.5 %
230 V/50 Hz	31.6 %	40.1 %	30.7 %	37.5 %	44.0 %	48.4 %
12 V, 1 W STARbuck						
115 V/60 Hz	62.2 %	80.6 %	78.3 %	79.9 %	83.0 %	81.2 %
230 V/50 Hz	62.2 %	75.7 %	69.2 %	74.5 %	79.1 %	80.1 %
–12 V, 4 W STARbuck						
115 V/60 Hz	70.9 %	80.5 %	80.0 %	82.6 %	80.9 %	78.6 %
230 V/50 Hz	70.9 %	78.6 %	74.0 %	78.6 %	80.8 %	80.9 %

Remark: Warm-up time is 15 minutes. Settle time after the load change is 90 s.

4.3 Electro-Magnetic Compatibility (EMC) performance data

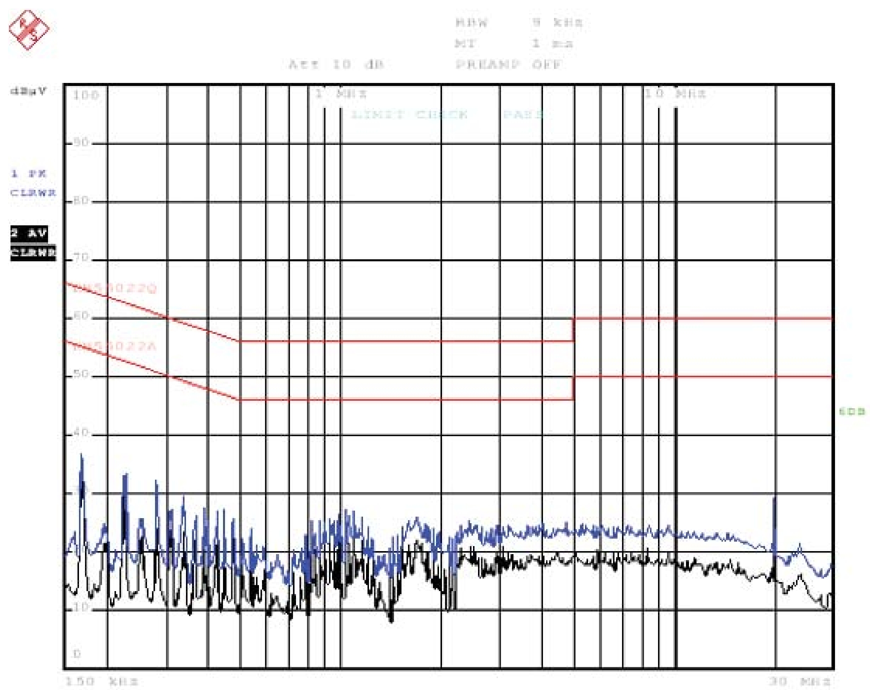

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Fig 2. Conducted EMC test: V_{IN} = 115 V (AC), V_{out} = 5 V, P_o = 500 mW

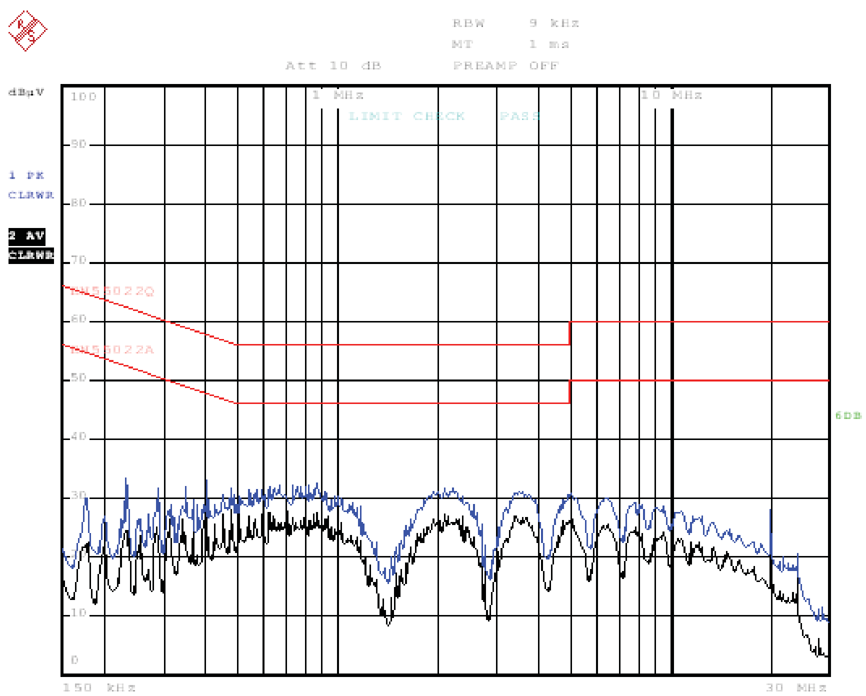

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Fig 3. Conducted EMC test: V_{IN} = 230 V (AC), V_{out} = 5 V, P_o = 500 mW

Both the average and quasi-peak EMC performance of the STARbuck demo board meet the requirements of EN55022.

5. Connection of the demo board

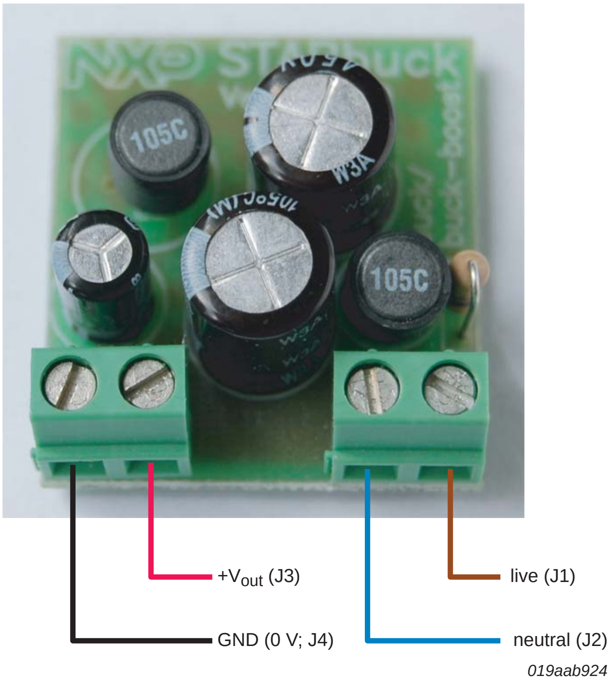

Fig 4. Demo board connections set-up (Buck mode, jumper JP2 mounted)

In Buck mode J2 (neutral) is connected to J4 (GND). The output voltage (+V_{out}) on J3 has a positive polarity with respect to GND.

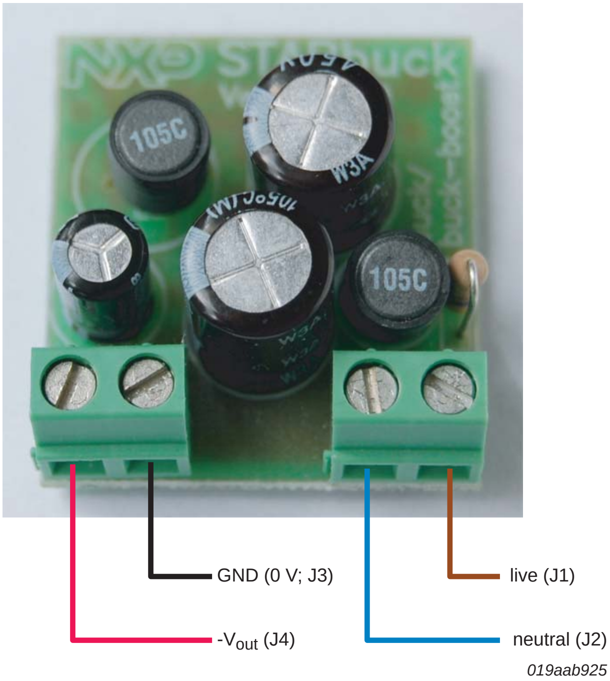

Fig 5. Demo board connections set-up (Buck/boost mode, jumper JP1 mounted)

In Buck/boost mode J2 (neutral) is connected to J3 (GND). The output voltage ($–V_{out}$) on J4 has a negative polarity with respect to GND.

6. Circuit description

The default STARbuck demo board consists of a single-phase half wave rectifier circuit, a filtering section, a switching section, an output section and a feedback section. The full default circuit diagram implemented on the STARbuck demo board PCB is shown in Figure 6.

6.1 Rectification section

The single phase, half wave rectifier consists of a single diode (D1). Capacitor C1 functions as a reservoir capacitor for the rectified input voltage. The inrush current is limited by resistor R1. Connectors J1 (live) and J2 (neutral) connect the input to the electricity utility network. Swapping live and neutral, however, does not have any effect on the operation of the STARbuck converter.

The half wave rectifier circuit allows the neutral terminal to have the same potential level as the GND terminal. This enables the triacs and SCRs to be driven from a logic circuit powered by the STARbuck SMPS. This is for example, a common approach in white goods applications that do not require AC mains supply isolation.

6.2 Filtering section

The filtering section which consists of L1 and C2, effectively reduces the noise and harmonic content that would otherwise be injected from the TEA152x switching electronics into the electricity utility network. This circuit aids in achieving the EMC performance required by EN55022.

6.3 Switching section

The switching section uses a standard NXP Semiconductors STARplug TEA152xT IC in an SO14 package. The operating frequency is set by the combination of R2 and C3. Resistor R3 limits the peak current that can occur in the STARplug internal MOSFET switch and consequently in inductor L2. The current limitation simultaneously prevents the internal MOSFET switch from being overstressed (the maximum switch current is given in Equation 1) and the output current of the SMPS from exceeding the value in Equation 2. In this way a programmable overload protection is built into the application.

$$I_{DS(max)} = \frac{0.5}{R3} \quad (1)$$

$$I_{o(max)} = \frac{0.25}{R3} \quad (2)$$

At low DC output voltages ($V_{out} \leq 10$ V), the STARplug IC must provide its own operating voltage supply (V_{CC}). It does this using the internal JFET current source built into the TEA152x family of ICs by buffering the supply voltage on the V_{CC} pin (pin 1) using a 220 nF capacitor (C7).

Remark: This way of generating the V_{CC} supply voltage has negative consequences for the total efficiency and for the no-load power consumption of the SMPS. However, for low output voltages there is no straightforward solution that is more efficient and economically feasible.

The AUX pin of the IC (pin 8) receives information regarding the magnetization status of the inductor L2 via the two resistors R6 and R7. The resistor was divided in to two parts because of the relatively high voltage that can appear across R6/R7.

6.4 Output section

The output section of the STARbuck application consists of D2, L2, C6 and D3. Jumpers JP1 and JP2 (1206 SMD jumpers) are used to select either the Buck mode or Buck/boost mode as the operating mode. The freewheel diode D2 acts as the lower switch in the buck (or buck/boost) converter. L2 is the primary energy storage element of this application and C6 buffers the output voltage and reduces output voltage ripple.

The Zener diode D3 prevents the output of the SMPS rising too high above the nominal programmed output voltage under low load or no-load conditions. This unwanted voltage increase is a consequence of the switching spikes that occur in the Switching section. This can be effectively countered using a low power Zener diode.

6.5 Feedback section

The feedback section consists of D4, C5, R4, R5 and C4. With diode D4 and capacitor C5, the voltage across C6 (V_{out}) is more or less “copied” and level shifted to the C5 voltage. Resistors R4 and R5 form a voltage divider with an output to the STARplug REG pin (pin 7). The programmed output voltage of the STARbuck SMPS is given in Equation 3.

$$V_{out} = 2.5 \cdot \frac{R4 + R5}{R5} \qquad (3)$$

Capacitor C4 acts as a noise suppressor in the feedback regulation circuit and adds a pole to the feedback loop.

Refer to the *STARplug application note AN00055* for more detailed/accurate information on the operation of STARplug TEA152x and the dimensioning of STARplug circuits.

7. Alternative circuit options

7.1 Buck/boost converter circuit

Instead of implementing a buck converter as shown in Figure 6, a buck/boost converter circuit can be realized by removing jumper JP2 and mounting jumper JP1. Note the required wiring diagram changes (see Section 5). The output voltage has a negative polarity with respect to GND. See the circuit diagram shown in Figure 7 and the component changes in Table 9.

7.2 Buck or buck/boost converter with an output voltage > 10 V

When the output voltage of the buck (or buck/boost) converter is above 10 V, the output voltage can simultaneously be used to supply the internal electronics of the TEA152x IC through its V_{CC} pin. A provision is made on the STARbuck demo board PCB enabling jumper JP3 (1206 SMD jumper) to be mounted so that it connects the feedback voltage across C5 to the IC V_{CC} pin.

When the V_{CC} pin is powered externally, the internal JFET current source stops operating, saving a considerable amount of power. When jumper JP3 is mounted, the capacitors C5 and C7 are operate completely in parallel. This makes it possible to eliminate C7, if the value of C5 is increased.

Table 3 shows that the no-load power consumption drops drastically when compared to the situation where the output voltage is too low to mount JP3 (see Table 3). The efficiency is also increased significantly when this circuit option is implemented.

The circuit diagram shown in Figure 8 and the component changes indicated in Table 10 show a STARbuck application with 12 V output voltage and a maximum output current of 350 mA.

7.3 V_{CC} voltage spike suppression

When the STARplug V_{CC} pin is powered externally harsh environments may induce voltage spikes on the V_{CC} pin via the output section of the STARbuck circuit. A voltage spike above 40 V can damage the STARplug IC. Voltage spikes can be suppressed by mounting a Zener diode (D5) in the position of C7 and replacing JP3 with a small (10 Ω) 1206-sized resistor (R8). See the circuit diagram in Figure 9 and the component changes in Table 11.

7.4 Increased current capability

As described in Section 6.3, both the maximum current through the STARplug's internal MOSFET and the SMPS' maximum output current can be programmed by changing the R3 resistor value. Equation 1 and Equation 2 show the relationships. Care must be taken that the programmed maximum drain-source current ($I_{DS(max)}$) value does not exceed the maximum current capability of the TEA152xT device that is mounted on the PCB.

Table 5 shows the $I_{DS(max)}$ values that are tolerable for the respective TEA152x family members.

Table 5. STARplug IC family members' current capability

STARplug family member	$I_{DS(max)}$	Maximum STARbuck output current (I_o)	Lowest tolerable R3 value
TEA1520T	250 mA	125 mA	2 Ω
TEA1521T	500 mA	250 mA	1 Ω
TEA1522T	1000 mA	500 mA	0.5 Ω

The L2 inductor value and current capability must be adapted to meet the requirements of higher current outputs. Guidelines can be found in the *AN00055 STARplug application note*.

A small output voltage limiting diode (BZX384) in the D3 position is sufficient for low output power STARbuck versions. If such a small Zener diode in the D3 position becomes too hot, the STARbuck PCB has a provision for mounting an SMA-sized Zener diode (e.g. Vishay BZG03) in the same position.

The value of the inrush current reduction resistor must be adapted. Table 6 gives suggested values for various conditions.

Finally, it is suggested to adapt the value of the C1 and C2 reservoir capacitors. See Table 7. The values proposed in Table 6 and Table 7 are not the optimal values for an end application but these values should work fine for the initial evaluation of a STARbuck application.

Remark: It is recommended to carry out the proper calculations for the specific STARbuck implementation for an end application.

Table 6. Suggested R1 inrush current limiting resistor values

Input voltage (V_{IN})	Output power (P_o)				
	1 W	2 W	4 W	7 W	10 W
115 V (AC)	47 Ω	47 Ω	33 Ω	22 Ω	22 Ω
230 V (AC)	47 Ω	47 Ω	47 Ω	33 Ω	33 Ω

Remark: The R1 resistor must be a carbon film type. A metal film resistor could act as a fuse instead of an inrush current limiter.

Table 7. Suggested C1 and C2 reservoir capacitor values

Input voltage (V_{IN})	Output power (P_o)				
	1 W	2 W	4 W	7 W	10 W
115 V (AC)	2.2 μF	2.2 μF	4.7 μF	6.8 μF	10 μF
230 V (AC)	2.2 μF	2.2 μF	2.2 μF	4.7 μF	6.8 μF

7.5 Reduced EMI filtering

Applications that do not require a high level of EMI filtering can eliminate the L1 and C2 components from the STARbuck demo board PCB, further reducing the cost. The L1 inductor must be replaced with a wire bridge. See the circuit diagram shown in Figure 10 and the component changes shown in Table 12.

8. Schematics

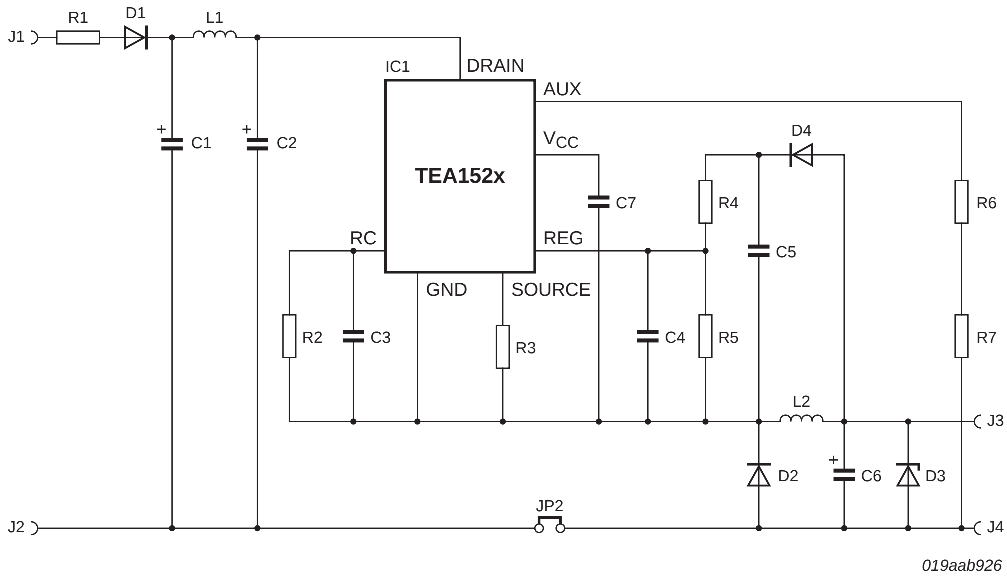

Fig 6. STARbuck with default PCB population (+5 V output, buck)

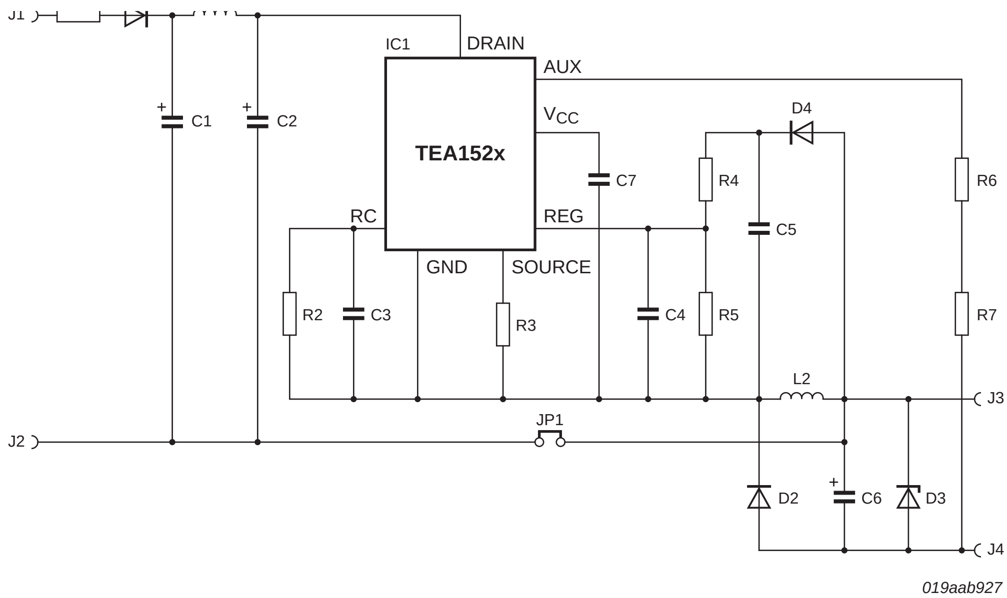

Fig 7. STARbuck in Buck/boost mode (−5 V output, buck/boost)

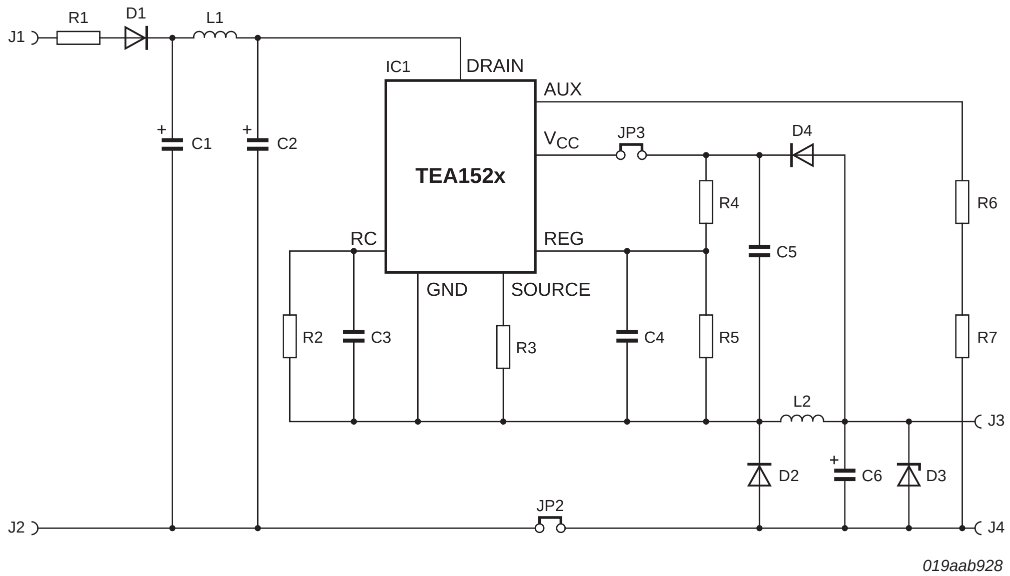

Fig 8. STARbuck with externally powered V_{CC} (12 V output, buck)

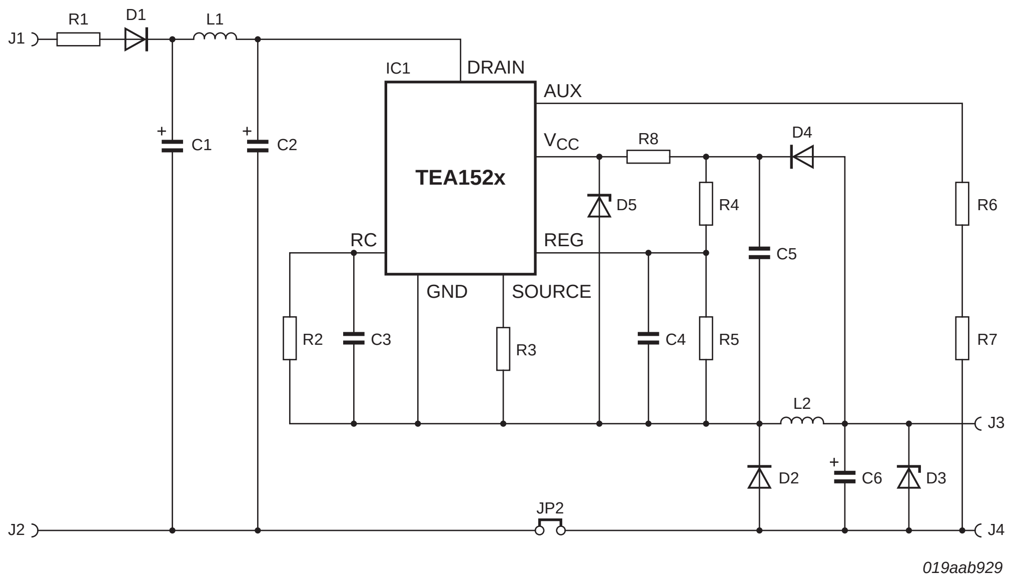

Fig 9. STARbuck V_{CC} spike protection (12 V output, buck)

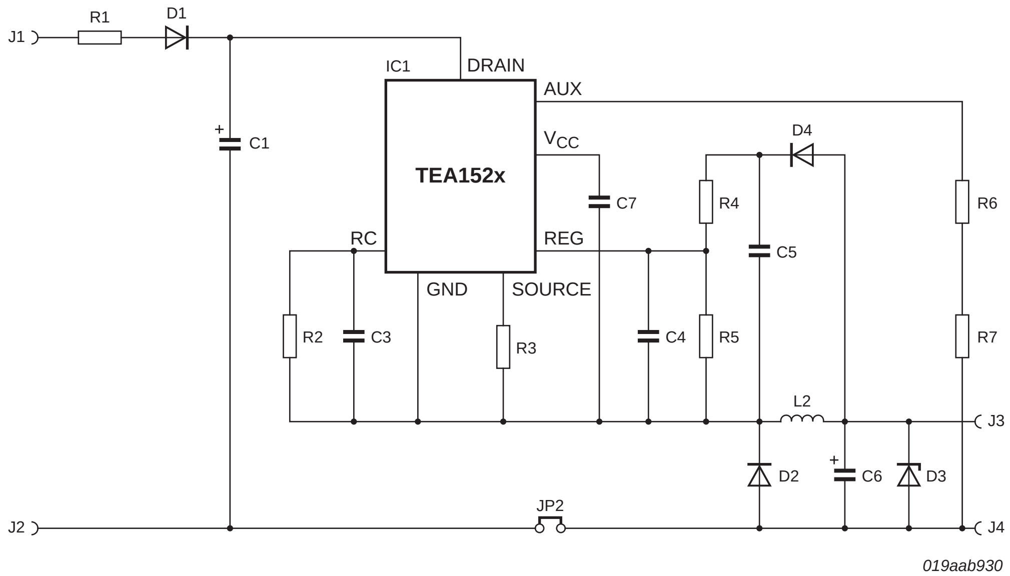

Fig 10. STARbuck with reduced EMI filtering

9. Component lists

Table 8. Default component list

Reference	Component	Package	Remarks
IC1	NXP Semiconductors TEA1520T	SO14	-
D1	Vishay S1M	DO214-AC	-
D2	Vishay FR1J	DO214-AC	-
D3[1]	Vishay BZG03C5V6	DO214-AC	-
D3(A)	NXP BZX384C5V6	SOD323	-
D4	Vishay FR1J	DO214-AC	-
L1	inductor ELC06D, 1 mH	-	e.g. Murata 22R105C
L2	inductor ELC06D, 1 mH	-	e.g. Murata 22R105C
C1	2.2 μF, 400 V, elcap	radial; 2E	maximum diameter 10.5 mm
C2	2.2 μF, 400 V, elcap	radial; 2E	maximum diameter 10.5mm
C3	330 pF, 50 V	0805	-
C4	5.6 nF, 50 V	0805	-
C5	100 nF, 50 V	0805	-
C6	220 μF, 16 V, elcap	radial; 1E	maximum diameter 8 mm
C7	220 nF, 50 V	1206	-
R1	47 Ω, 0.5 W, carbon film	radial; 1E	mounted upright
R2	7.5 kΩ	0805	-
R3	2.2 Ω, 0.25 W	1206	-
R4	5.6 kΩ	0805	-
R5	5.6 kΩ	0805	-
R6	200 kΩ	1206	-
R7	200 kΩ	1206	-
JP1[1]	0 Ω SMD jumper	1206	-
JP2	0 Ω SMD jumper	1206	-
JP3[1]	0 Ω SMD jumper	1206	-
J1/J2	2-pole terminal block	2E pitch	Phoenix: 1729128, Farnell: 304-1440
J3/J4	2-pole terminal block	2E pitch	Phoenix: 1729128, Farnell: 304-1440

[1] Not mounted.

Table 9. Component list modification for buck/boost converter option

Reference	Component	Package	Remarks
JP1	0 Ω SMD jumper	1206	-
JP2[1]	0 Ω SMD jumper	1206	-

[1] Not mounted.

Table 10. Component list modification for externally powered V_{CC}

Reference	Component	Package	Remarks
IC1	NXP Semiconductors TEA1522T	SO14	-
D2	Vishay BYG20J	DO214-AC	-
D3(A)	NXP BZX384C13	SOD323	-
D4	Vishay BYG20J	DO214-AC	-
L2	inductor 390 μH	-	I_i > 400 mA (DC); I_{SAT} > 800 mA
C5	330 nF, 50 V	0805	-
C7[1]	-	1206	-
R3	0.68 Ω, 0.25 W	1206	-
R4	16 kΩ	0805	-
R5	4.3 kΩ	0805	-
JP3	0 Ω SMD jumper	1206	-

[1] Not mounted.

Table 11. Component list modification for externally powered V_{CC} with spike protection

Reference	Component	Package	Remarks
IC1	NXP Semiconductors TEA1522T	SO14	-
D2	Vishay BYG20J	DO214-AC	-
D3(A)	NXP Semiconductors BZX384C13	SOD323	-
D4	Vishay BYG20J	DO214-AC	-
D5	NXP Semiconductors BZX384C27	SOD323	mount in C7 position
L2	inductor 390 μH	-	I_i > 400 mA (DC); I_{SAT} > 800 mA
C5	330 nF, 50 V	0805	-
C7[1]	-	1206	-
R3	0.68 Ω, 0.25 W	1206	-
R4	16 kΩ	0805	-
R5	4.3 kΩ	0805	-
R8	10 Ω	1206	mount in JP3 position
JP3[1]	0 Ω SMD jumper	1206	-

[1] Not mounted.

Table 12. Component list modification for reduced EMI filtering

Reference	Component	Package	Remarks
L1[1]	-	-	-
C2[1]	-	radial; 2E	-
JP4	Wire bridge jumper	-	mount in L1 position

[1] Not mounted.

10. Printed-circuit board

The STARbuck SMPS printed-circuit board is a single-sided board.
Dimensions are 34 × 31 mm. The demo boards are produced on 1.6 mm FR4 with single sided 35 μm copper (1 Oz.). FR2 could also be used as the PCB material.

The PCB can be configured to provide a number of NXP Semiconductors STARbuck SMPS implementations. With the default component population a tiny 5 V/100 mA power supply is created. The same PCB can be used, however, to create a 12 V/350 mA or even a 24 V/400 mA non-isolated SMPS.

The Gerber File set for the production of the PCB is available from NXP Semiconductors. Normally, the bottom silk is not used for PCB production - it is only a component position reference.

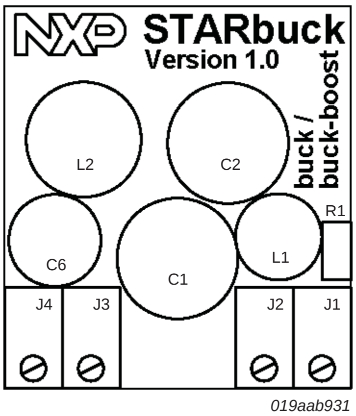

Fig 11. Top silk screen (top view)

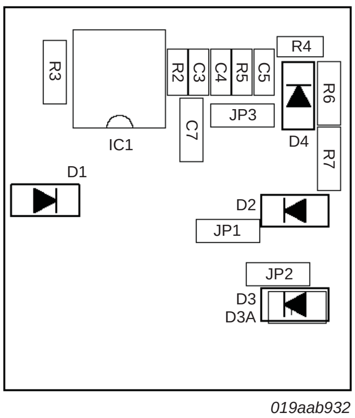

Fig 12. Bottom silk screen (bottom view)

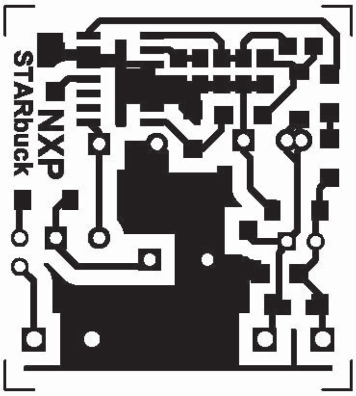

Fig 13. Bottom copper (bottom view)

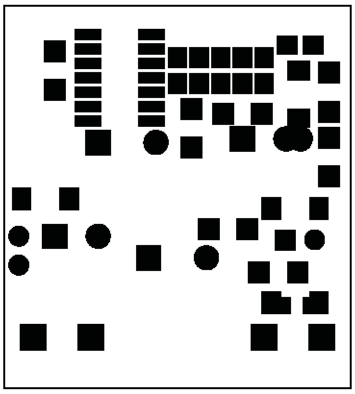

Fig 14. Bottom solder mask (bottom view)

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Date of release: 4 May 2011
Document identifier: UM10371