UM10401

STARplug Mini demo board

Rev. 1 — 21 July 2011 **User manual**

Document information

Info	Content
Keywords	STARplug, SMPS, flyback converter
Abstract	This user manual describes the STARplug Mini version 3.10, both in the 5 V/3 W and 12 V/5 W version.

Revision history

Rev	Date	Description
v.1	20110721	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 STARplug Mini Switched Mode Power Supply (SMPS) demo board comes in two versions: a 5 V version and 12 V version. The circuit implemented on this board is typically suited to low-power adapter applications.

The board has a universal mains input. The total nominal output power is rated at 3 W for the 5 V version and 5 W for the 12 V version. The flyback circuit is built around the NXP Semiconductors TEA1521T or TEA1522T STARplug IC. The STARplug Mini demo board allows customization of the input filtering, snubber circuit, regulation feedback scheme etc. Small changes in output voltage (up to ±20 %) are also supported.

If an alternative transformer is considered, the Printed-Circuit Board (PCB) can generate virtually any output voltage. These features make the STARplug Mini demo board a highly versatile and reliable starting point for developing custom low-power boards.

This versatility comes at the cost of PCB space, so the board is not a showcase for minimal PCB space usage and cannot be looked upon as an end-solution. However, it is very useful for exploring the STARplug family of IC's features and functionality during development of a low-power SMPS final solution.

Refer to the *TEA152x* and *TEA162x data sheets* for details on the STARplug devices and to the *STARplug application note AN00055* for general application information.

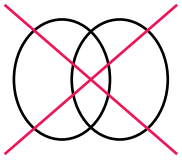
1.1 Features

- Universal mains input
- Isolated output
- 5 V/3 W and 12 V/5 W version available as default configurations
- Stable regulated voltage
- Highly flexible and easily tuned to meet user requirements
- Used with the TEA1520T, TEA1521T and TEA1522T devices (SO14 package)
- Highly efficient: 5 V version > 68 %, 12 V version > 79 %
- Low standby (no-load) power: < 80 mW
- OverPower Protection (OPP)
- OverTemperature Protection (OTP)
- Built-in basic differential mode ElectroMagnetic Interference (EMI) filter.

2. Safety warning

This demo board is connected to a high AC voltage (up to 276 V). Avoid touching the demo board during operation. An isolated housing is obligatory when used in uncontrolled, non-laboratory environments. Galvanic isolation of the mains phase using a fixed or variable transformer (Variac) is always recommended. These devices are indicated with the symbols shown in Figure 1

a. Isolated



b. Not isolated

Fig 1. Variac isolation symbols

3. Technical specification

Table 1. Input specification

Parameter	Condition	Value	Remark
Input voltage	-	90 V (AC) to 276 V (AC)	universal mains
Input frequency	-	47 Hz to 63 Hz	-

Table 2. Output specification for STARplug Mini

Parameter	Condition	Value	Remark
5 V/3 W configuration			
Output voltage 1	-	5 V	-
Output voltage 1 tolerance	load 75 %	±5 %	-
Output voltage 1 stability	-	±5 %	over full power range
12 V/5 W configuration			
Output voltage 1	-	12 V	-
Output voltage 1 tolerance	load 75 %	±2.5 %	-
Output voltage 1 stability	-	±4 %	over full power range

4. Performance data

4.1 Output voltage and no-load power consumption

Table 3 shows the no-load power consumption values for the STARplug Mini demo board default configuration.

Table 3. No-load output voltage and power consumption

Condition	Energy start 2.0 requirement	Output voltage 1 (V_o)	Power consumption (P_i)
5 V/3 W configuration			
115 V/60 Hz	≤ 300 mW	5 V	75 mW
230 V/50 Hz	≤ 300 mW	5 V	75 mW
12 V/5 W configuration			
115 V/60 Hz	≤ 300 mW	11.9 V	75 mW
230 V/50 Hz	≤ 300 mW	11.9 V	75 mW

4.2 Efficiency performance data

Table 4 shows the efficiency values for the STARplug Mini demo board default configuration.

Table 4. Efficiency

Power supply	Energy star requirement	Efficiency (η)				
		average	25 % load	50 % load	75 % load	100 % load
5 V/3 W version						
115 V/60 Hz	64.3 %	70.2 %	72.6 %	72.6 %	67.1 %	68.3 %
230V/50 Hz	64.3 %	68.7 %	68.3 %	67.8 %	68.4 %	70.4 %
12 V/5 W version						
115 V/60 Hz	72.3 %	81.6 %	81.1 %	82.3 %	81.7 %	81.2 %
230 V/50 Hz	72.3 %	79.5 %	75.1 %	80.1 %	81.3 %	81.3 %

Remark: The warm-up time is 15 minutes and the settle time after load change, is 90 s.

4.3 ElectroMagnetic Compatibility (EMC) performance data

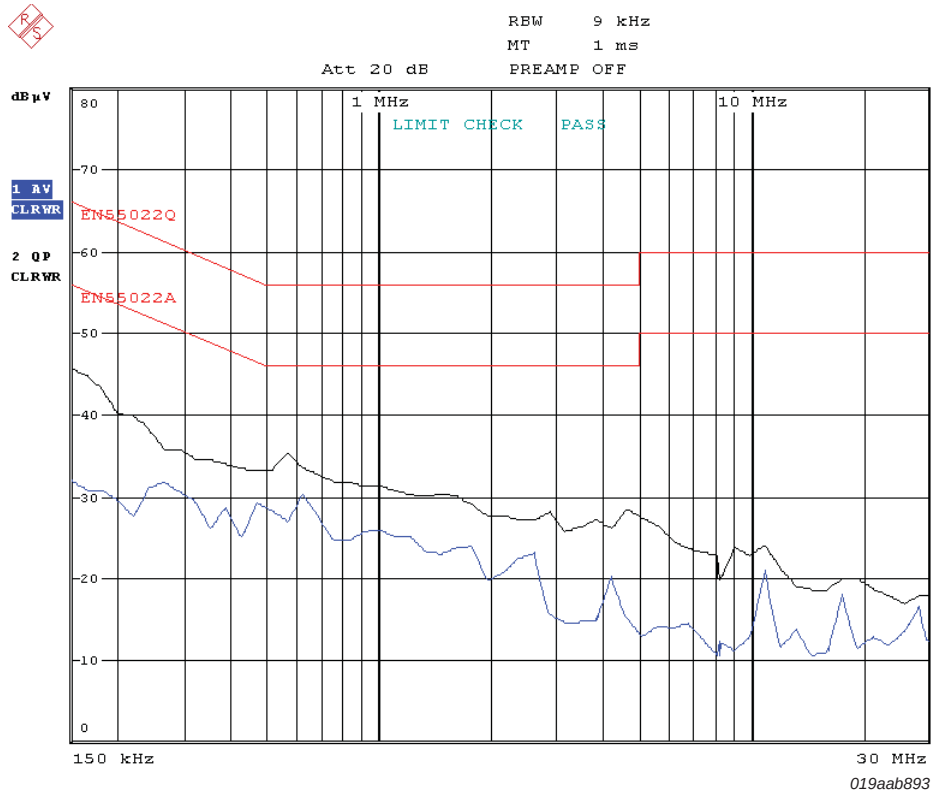


Fig 2. Conducted EMC test 5 V/3 W version: V_{IN} = 115 V (AC); P_o = 3 W

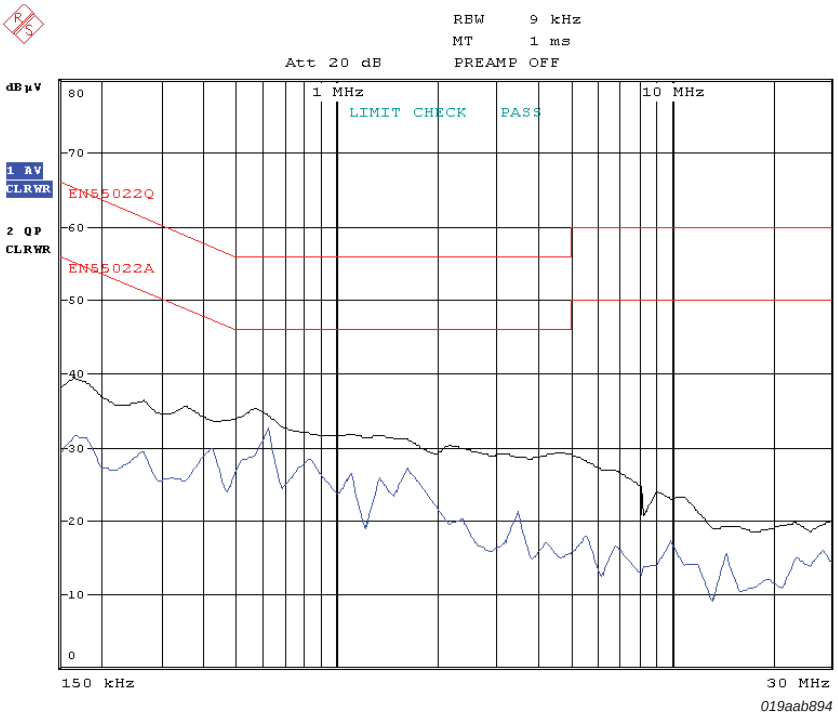


Fig 3. Conducted EMC test 5 V/3 W version: V_{IN} = 230 V (AC); P_o = 3 W

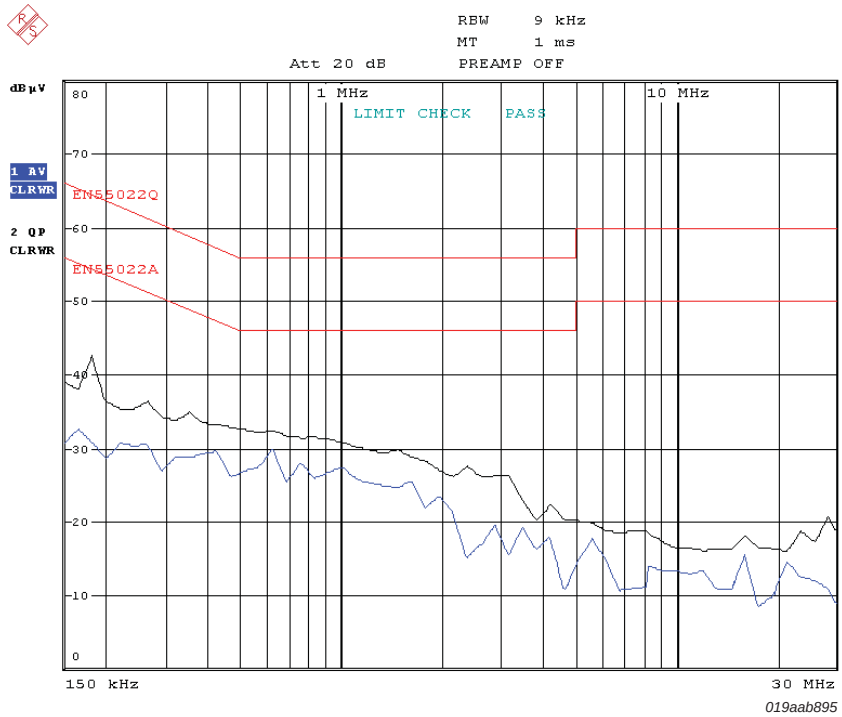


Fig 4. Conducted EMC test 12 V/5 W version: V_{IN} = 115 V (AC); P_o = 5 W

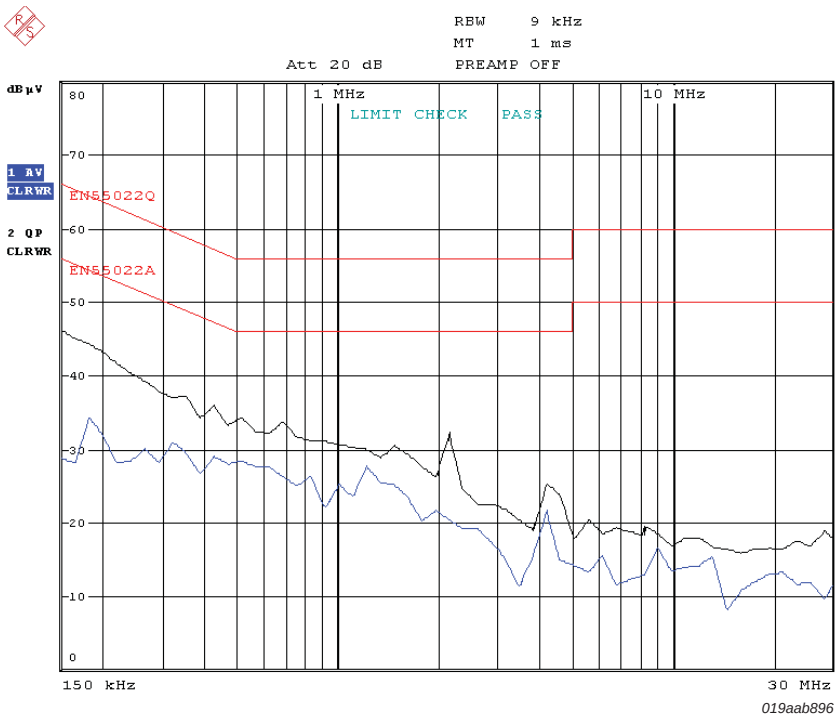


Fig 5. Conducted EMC test 12 V/5 W version: V_{IN} = 230 V (AC); P_o = 5 W

Remark: Average and quasi-peak EMC performance of the STARplug Mini demo board comply with the EN55022 standard.

5. Board connections

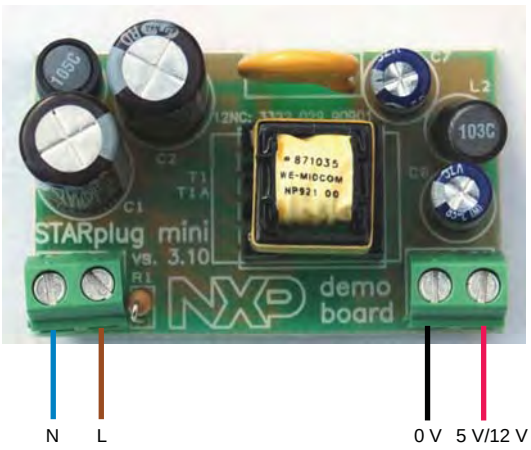


Fig 6. Demo board connections

Remark: Reversing the Live (J2) and Neutral (J1) connections has no effect on the operation of the STARplug Mini demo board. Terminals J3 and J4 produce the 5 V or 12 V output voltage (J4 positive with respect to J3).

6. Circuit description

The default STARplug Mini SMPS demo board comprises a single-phase full-wave rectifier circuit and sections for filtering, switching, output and feedback. The default configuration for the STARplug Mini demo board full PCB circuit diagram is shown in Figure 7. The component list is shown in Table 5.

6.1 Rectification section

The single-phase full wave rectifier is realized with a single rectifier bridge component. Capacitors C1 and C2 function as reservoir capacitors for the rectified input voltage. Resistor R1 limits the inrush current. This resistor must be a carbon resistor, not a metal film resistor because it could work as a fuse instead of an inrush current limiter. Terminals J1 and J2 connect the input to the electricity utility network. For convenience J1 is referred to as Neutral and J2 as Live. Swapping these two wires has no effect on the operation of the STARplug Mini converter.

6.2 Filtering section

The filtering section consists of a basic Π filter comprising C1, L1 and C2. The filtering configuration effectively reduces the noise and harmonic content that would otherwise be injected from the TEA152x switching electronics into the electricity utility network. The circuitry helps to achieve the EMC performance required by EN55022.

6.3 Switching section

The switching section uses an NXP Semiconductors STARplug TEA1521T or TEA1522T IC in a SO14 package. The operating frequency is set using the combination of R2 and C3. Resistor R5 limits the peak current that can occur in the STARplug internal MOSFET switch and consequently, in the primary winding of Transformer T1. The current limitation simultaneously prevents the internal MOSFET switch from being overstressed and triggers overload protection of the SMSP output. The maximum switch current is given in Equation 1:

$$I_{DS(max)} = \frac{0.5}{R5} \quad (1)$$

An auxiliary winding on transformer T1 generates the supply voltage for the TEA152x IC. The voltage from the auxiliary winding is (half-wave) rectified by diode D4. Capacitor C6 is charged via the current limiting resistor R9. The voltage on C6 is the supply voltage for the TEA152x VCC pin. The AUX pin of the IC receives information regarding the magnetization status of transformer T1 via resistor R6.

A snubber circuit that manages the voltage spikes and the associated energy occurring because of the leakage inductance of the primary winding of transformer T1. It works using the diode-Zener snubber (D1 and D2). This snubber conserves energy and is EMI friendly but can also be a more expensive option when compared to an RCD snubber (see Section 6.2).

6.4 Output section

The output section of the STARplug Mini application produces either 5 V or 12 V depending on the demo board version. The output section consists of diode D5, capacitors C7, C8, C9 and inductor L2. The output section provides a good level of ripple filtering and noise suppression by using a Π filter configuration.

6.5 Feedback section

In the default configuration, the feedback signal is taken directly from the secondary output voltage (5 V or 12 V). The feedback network on the secondary side consists of R13, R14, R15, C10, C11 and voltage reference IC3 (a TL431A). Resistors R14 and R15 form a voltage divider and which determines the secondary output voltage. The programmed output voltage (terminals J3, J4) is calculated using Equation 2.

$$V_o = V_{REG} \cdot \frac{R14 + R15}{R15} \quad (2)$$

The factor V_{REG} comes from the reference voltage of IC3 and for a normal TL431 this voltage is 2.5 V.

R11 and C12 provide the supply power for the feedback network. R12 functions as a current limiter for the LED in the optocoupler IC2. The feedback signal crosses the isolation barrier through optocoupler IC2. On the primary side, the signal is fed to the TEA1522 REG pin.

The REG pin is pulled down when the optocoupler is in the off-state by resistor R8. The noise is filtered and a pole is added with capacitor C5. Zener diode D3 provides protection if the optocoupler fails (for example, through aging). In this case, Zener diode D3 limits the output voltage instead of allowing it to rise in an uncontrolled manner.

Refer to the *TEA152x data sheet* for detailed and accurate information on the STARplug TEA152x ICs operation and *application note AN00055* for STARplug circuits dimensioning information.

7. Alternative circuit options

7.1 Alternative snubber circuit

The D1/D2 diode-Zener snubber is a good solution for snubbering the transformer's primary winding leakage energy, however, a cheaper RCD solution can be used. The STARplug Mini demo board has a provision that allows the mounting of an RCD snubber circuit (D1, C4, R3, R4) instead of a diode-Zener snubber. The "R" part from the RCD is split in two. Power dissipation and voltage drop is equally divided over the "R" part using standard (1206-sized) SMD resistors.

The circuit diagram shown in Figure 8 and the component changes in Table 6 show the STARplug Mini application using an RCD snubber.

7.2 Primary feedback

The STARplug Mini demo board allows primary feedback schemes to be implemented in an isolated SMPS application. The consequence of the primary feedback option that can be implemented on this board, is that voltage regulation is (much) less accurate. The cost saving of the primary feedback version is significant.

To have a reasonably good voltage regulation, the magnetic coupling between the secondary and the auxiliary windings of the transformer is very good. This requirement could add considerable cost because of the transformer construction.

The circuit diagram shown in Figure 9 and the component changes in Table 7 illustrate the simplified circuit diagram is and the shortened parts list.

7.3 Self-supplied TEA152x

This option enables the TEA152x SMPS IC to generate its own power supply using the built-in JFET. The advantage of this is that the auxiliary winding of the transformer T1 is not required, so costs could be saved. The disadvantage of generating the supply voltage through the built-in JFET is an additional power loss. As a consequence, the high efficiency figures and low standby figures as shown in Table 3 and Table 4, no longer apply.

Apart from supplying the STARplug IC's VCC power, the transformer's auxiliary winding also informs the IC's AUX pin about the magnetization status of the transformer. When the auxiliary winding is no longer there, an alternative method is required to inform the AUX pin about the magnetization status of the transformer. This information can be provided using capacitive coupling.

The “hot” connections of the respective transformer T1 windings are in phase during operation. This enables the voltage (or “information”) on the “hot” side of the primary winding to be used to indicate if the transformer is demagnetized. Creating a capacitive coupling between the “hot” side of the primary winding and the STARplug IC AUX pin allows the information to be easily transferred. The impedance of the AUX pin is relatively high meaning that a small capacitive coupling is enough. To guarantee the AUX pin voltage is below 100 mV during start-up, pull the pin to ground using a high value resistor (around 500 kΩ).

The capacitor C14* in Figure 10 acts as the capacitive coupler between the transformer’s “hot” side and the STARplug IC AUX pin. A typical value for this capacitor is around 2 pF. The parasitic capacitance created by the PCB layout generally provides sufficient coupling and usually there is no need to mount an actual C14* component.

To be formally correct, the ~500 kΩ impedance between the IC AUX pin and GND is split in two resistor values: R6 and R10. R6 limits the current that can be injected into the AUX pin through the capacitive coupling (typical value 100 kΩ).

Remark: Overcurrent into the AUX pin can damage the IC.

The combination of R6 and R10 builds the impedance that pulls the AUX pin to ground during start-up (typical value for R10: 390 kΩ).

When the STARplug IC is self-supplying using the built-in JFET, Zener diode D3 is not used because the VCC voltage never rises high enough. In this mode, the protection circuit described in Section 6.5 is also no longer active.

Remark: A defective or degraded optocoupler IC2 results in an uncontrolled output voltage(s) increase in the SMPS.

See Table 8 for the component changes involved.

7.4 Simplified secondary feedback

In the default configuration, the secondary feedback uses a TL431 voltage reference IC. A simpler feedback circuit can be constructed using a Zener diode. This option has a cost advantage but as a consequence, reduced performance must be tolerated. Figure 11 and Table 9 show the circuit diagram and the modifications of the parts list.

7.5 Combining options and features

Options and features can be combined as described in Section 7.1 to Section 7.4. Check any new combination of options and features ensure that the specific combination does not cause an electrical conflict. If needed, contact NXP Semiconductors application support for additional application help.

8. Schematics

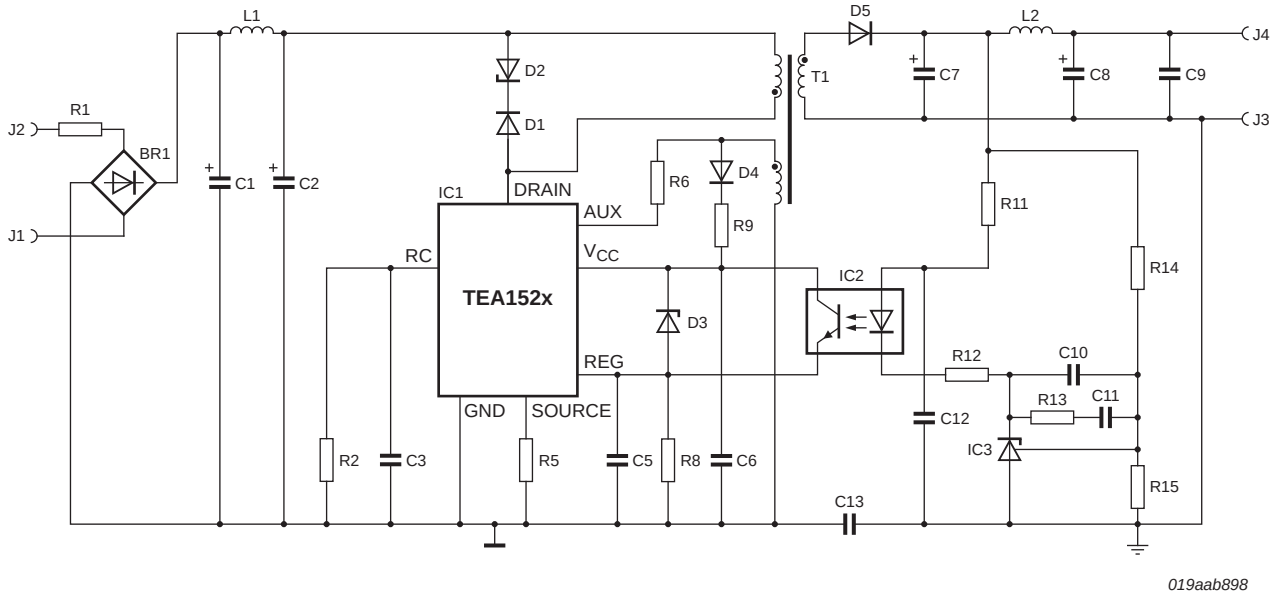


Fig 7. Circuit diagram: default STARplug Mini configuration

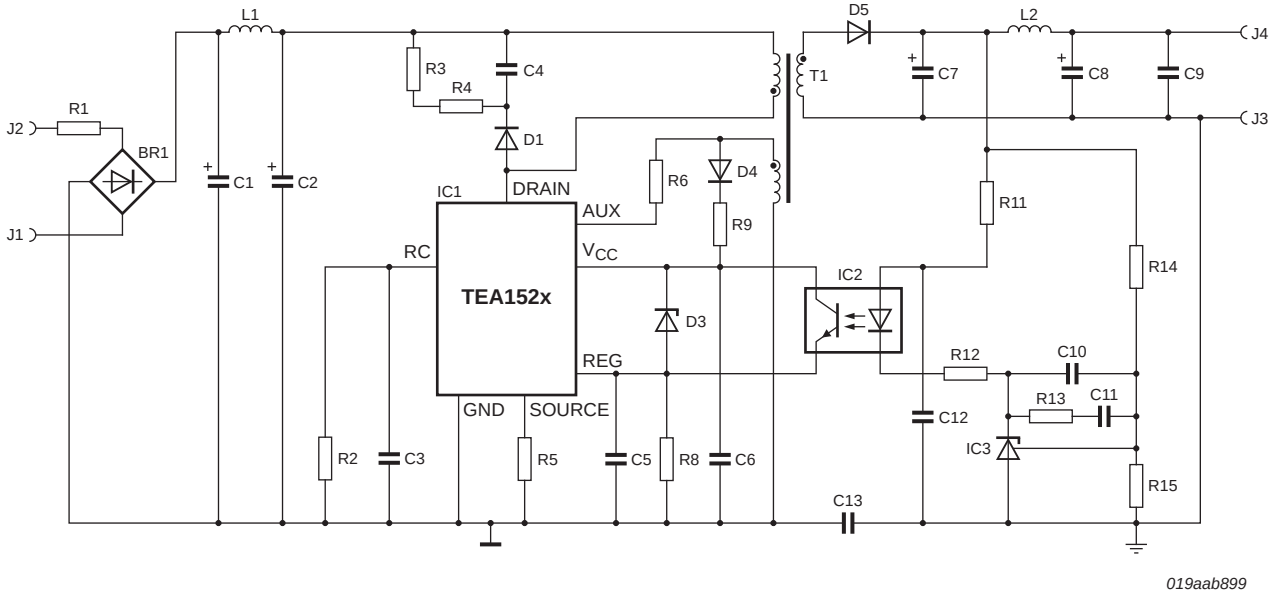


Fig 8. Circuit diagram: STARplug Mini with RCD snubber

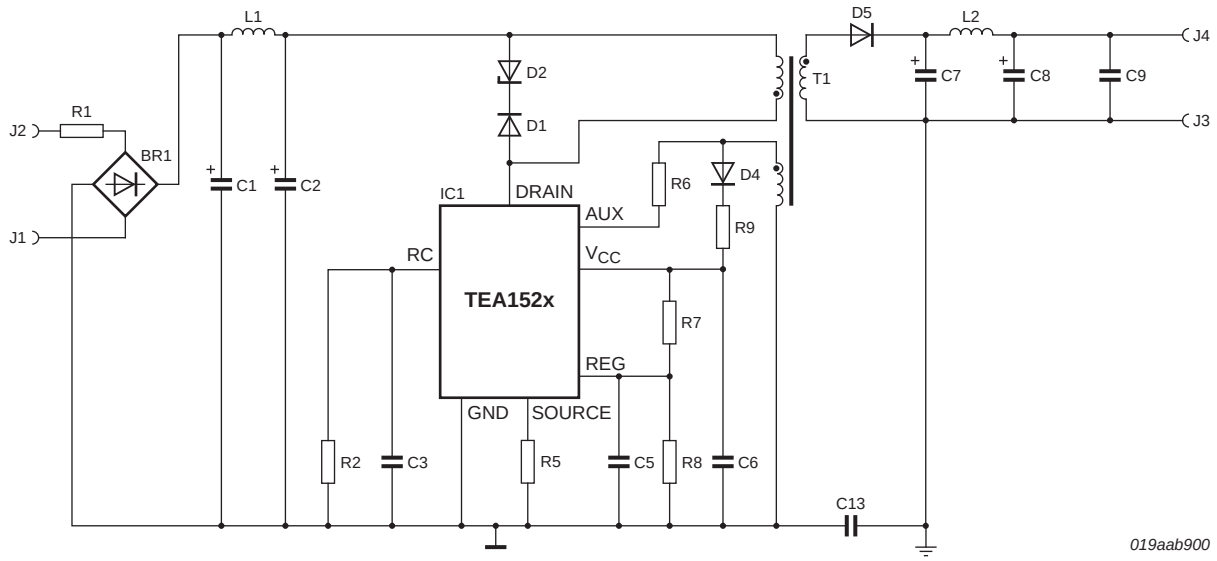


Fig 9. Circuit diagram: STARplug mini with primary feedback

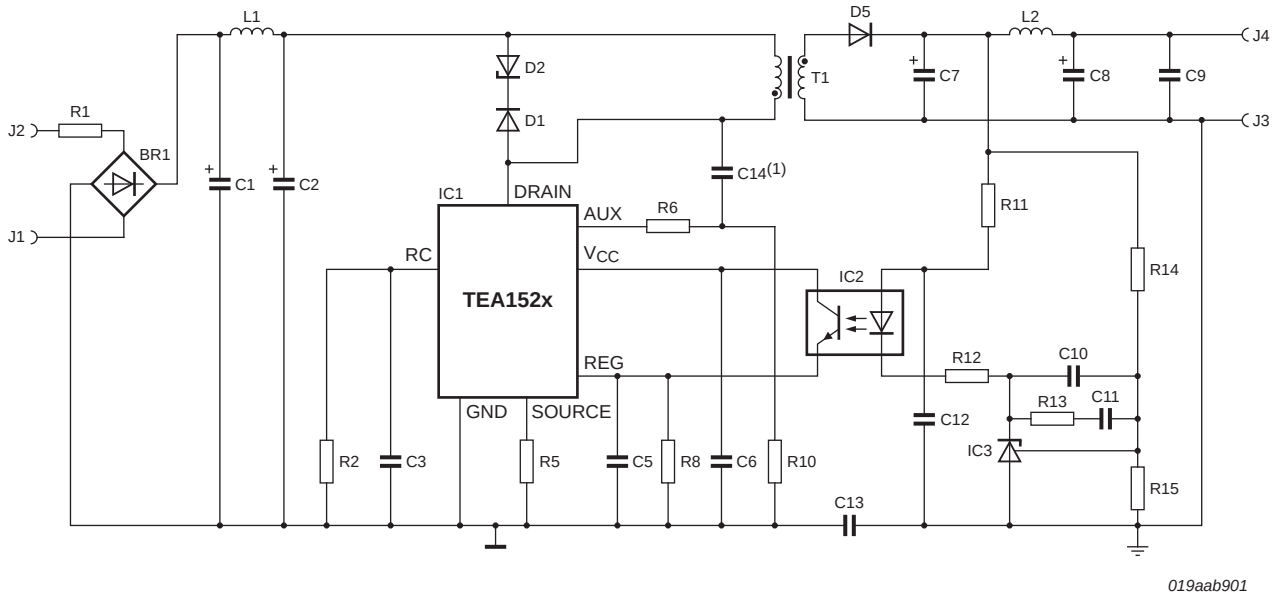


Fig 10. Circuit diagram: STARplug mini self-supply option

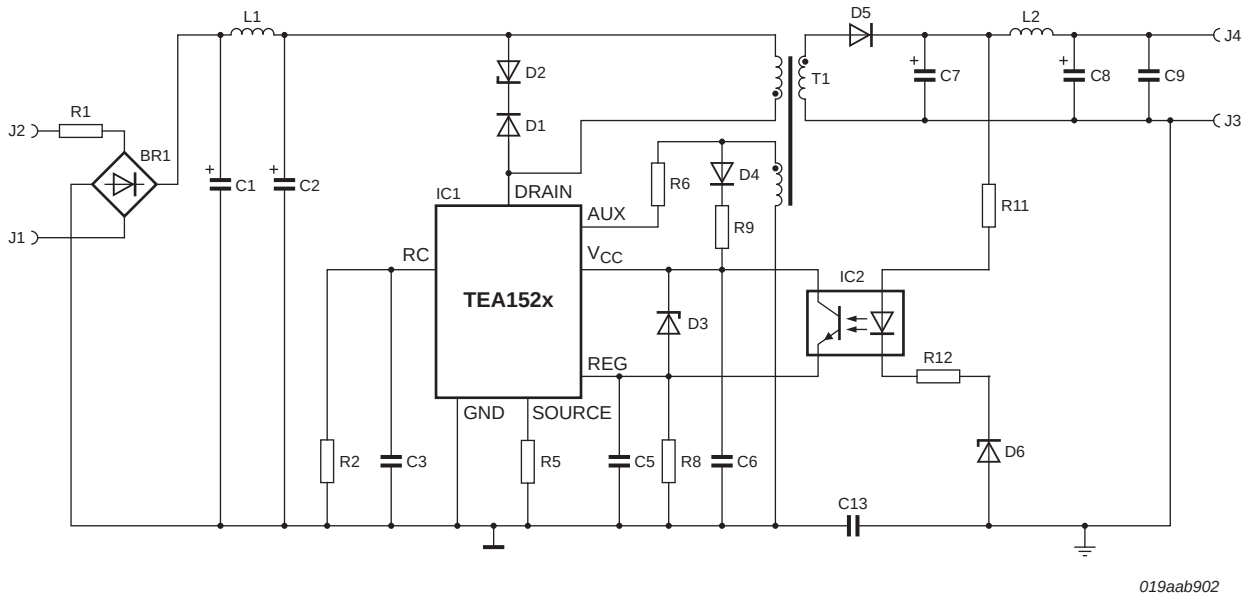


Fig 11. Circuit diagram: STARplug mini with simplified secondary feedback

9. Component list

Table 5. Default component list: 5 V/3 W and 12 V / 5 W version

Part reference	Description	Package	Remarks
IC1	NXP Semiconductors TEA1521T	SO14	5 V/3 W version
	NXP Semiconductors TEA1522T	SO14	12 V/5 W version
IC2	Vishay SFH6156-4	SMD-4	-
IC3	NXP Semiconductors TL431AMSDT	SOT23	mirrored pinning
BR1	DF08S	DIL SMD	-
D1	Vishay RS1J	DO214-AC	-
D2	Vishay BZG03C180	DO214-AC	-
D3	NXP Semiconductors BZX384-C24	SOD323	-
D4	NXP Semiconductors BAS321	SOD323	-
D5	NXP Semiconductors PMEG6010CEJ	SOD323	5 V/3 W version
	Vishay 10MQ100NPbF	DO214-AC	12 V/5 W version
D6	NXP Semiconductors BZX384-C3V0	SOD323	not mounted
	NXP Semiconductors BZX384-C10	SOD323	not mounted
T1	custom made transformer Würth Elektronik 750871013	-	5 V/3 W version; Würth Elektronik number 750871013
	custom made transformer Würth Elektronik 750871035	-	12 V/5 W version; Würth Elektronik number 750871035
L1	inductor ELC06D; 1 mH	-	22R105C
L2	inductor ELC06D; 10 μH	-	22R103C

Table 5. Default component list: 5 V/3 W and 12 V / 5 W version *…continued*

Part reference	Description	Package	Remarks
C1	electrolytic capacitor; 4.7 μF; 400 V	2E pitch; ∅10.5 mm	5 V/3 W version
	electrolytic capacitor; 10 μF; 400 V	2E pitch; ∅10.5 mm	12 V/5 W version
C2	electrolytic capacitor; 4.7 μF; 400 V	2E pitch; ∅10.5 mm	5 V/3 W version
	electrolytic capacitor; 10 μF; 400 V	2E pitch; ∅10.5 mm	12 V/5 W version
C3	330 pF; 50 V	0805	-
C4	1 nF; 500 V	1206	not mounted
C5	22 nF; 25 V	0805	-
C6	220 nF; 50 V	1206	-
C7	electrolytic capacitor; 220 μF; 10 V	1E pitch; ∅8 mm	5 V/3 W version
	electrolytic capacitor; 220 μF; 16 V	1E pitch; ∅8 mm	12 V/5 W version
C8	electrolytic capacitor; 220 μF; 10 V	1E pitch; ∅8 mm	5 V/3 W version
	electrolytic capacitor; 220 μF; 16 V	1E pitch; ∅8 mm	12 V/5 W version
C9	100 nF; 25 V	0805	-
C10	5.6 nF; 25 V	0805	-
C11	22 nF; 25 V	0805	-
C12	100 nF; 25 V	0805	-
C13	Y-capacitor; 2.2 nF; 2 kV	4E pitch	-
C14	2.2 pF; 500 V	-	not mounted; Section 7.3
R1	47 Ω; 0.5 W; carbon	1E pitch	mounted upright
R2	7.5 kΩ	0805	-
R3	47 kΩ; 0.5 W	1206	not mounted
R4	47 kΩ; 0.5 W	1206	not mounted
R5	1.5 Ω; 0.25 W	1206	5 V/3 W version
	1.0 Ω; 0.25 W	1206	12 V/5 W version
R6	100 kΩ	0805	-
R7	22 kΩ	0805	not mounted
R8	4.3 kΩ	0805	-
R9	10 Ω	0805	-
R10	390 kΩ	0805	not mounted
R11	1 kΩ	1206	5 V/3 W version
	8.2 kΩ	1206	12 V/5 W version
R12	1 kΩ	0805	-
R13	24 kΩ	0805	-
R14	2.4 kΩ; 1 %	1206	5 V/3 W version
	9.1 kΩ; 1 %	1206	12 V/5 W version
R15	2.4 kΩ; 1 %	0805	-
J1/J2	2-pole terminal block	2E pitch	Phoenix: 1729128
J3/J4	2-pole terminal block	2E pitch	Phoenix: 1729128

Table 6. Component list modification for alternative (RCD) snubber

Part reference	Description	Package	Remarks
D2	Vishay BZG03C180	DO214-AC	not mounted
C4	1 nF; 500 V	1206	-
R3	47 kΩ; 0.5 W	1206	-
R4	47 kΩ; 0.5 W	1206	-

Table 7. Component list modification for primary feedback

Part ref.	Description	Package	Remarks
IC2	Vishay SFH6156-4	SMD-4	not mounted
IC3	NXP Semiconductors TL431AMSDT	SOT23	not mounted
D3	NXP Semiconductors BZX384-C24	SOD323	not mounted
C10	5.6 nF; 50 V	0805	not mounted
C11	22 nF; 50 V	0805	not mounted
C12	100 nF; 50 V	0805	not mounted
R7	22 kΩ	0805	-
R11	1 kΩ	1206	not mounted
	8.2 kΩ	1206	not mounted
R12	1 kΩ	0805	not mounted
R13	24 kΩ	0805	not mounted
R14	2.4 kΩ; 1 %	1206	not mounted
	9.1 kΩ; 1 %	1206	not mounted
R15	2.4 kΩ; 1 %	0805	not mounted

Table 8. Component list modification for self-supplied TEA152x

Part ref.	Description	Package	Remarks
D3	NXP Semiconductors BZX384-C24	SOD323	not mounted
D4	NXP Semiconductors BAS321	SOD323	not mounted
T1	transformer without auxiliary winding	-	or cut auxiliary winding on original transformer
C14	2.2 pF; 500 V	-	no need to mount; see Section 7.3
R9	10 Ω	0805	not mounted
R10	390 kΩ	0805	-

Table 9. Component list modification for simplified secondary feedback

Part ref.	Description	Package	Remarks
IC3	NXP Semiconductors TL431AMSDT	SOT23	not mounted
D6	NXP Semiconductors BZX384-C3V0	SOD323	5 V/3 W version
	NXP Semiconductors BZX384-C10	SOD323	12 V/5 W version
C10	5.6 nF; 50 V	0805	not mounted
C11	22 nF; 50 V	0805	not mounted
C12	100 nF; 50 V	0805	not mounted
R12	0 Ω; 0 Ω jumper	0805	-
R13	24 kΩ	0805	not mounted
R14	2.4 kΩ; 1 %	1206	not mounted
	9.1 kΩ; 1 %	1206	not mounted
R15	2.4 kΩ; 1 %	0805	not mounted

10. Printed-Circuit Board (PCB)

The STARplug Mini demo board PCB is a single-sided board. The dimensions are 51 mm × 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 accommodate several implementations of the STARplug Mini SMPS as outlined in Section 6, Section 7, Section 8 and Section 9.

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

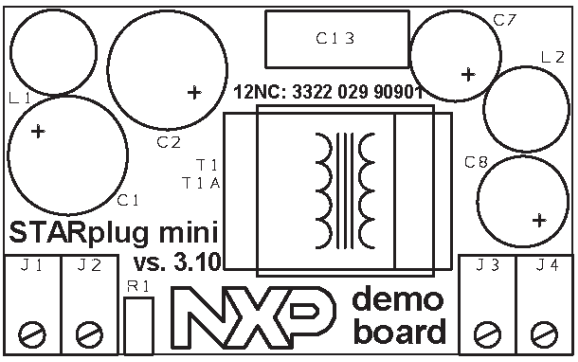


Fig 12. PCB top silk screen

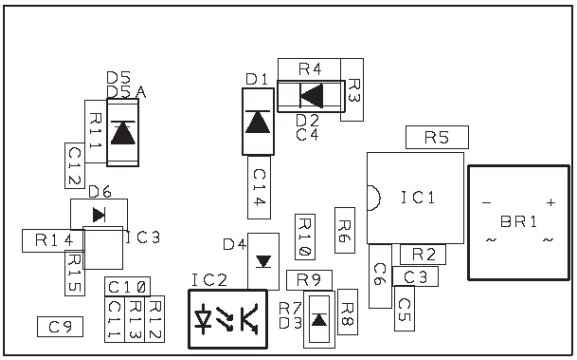


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Fig 13. PCB bottom silk screen

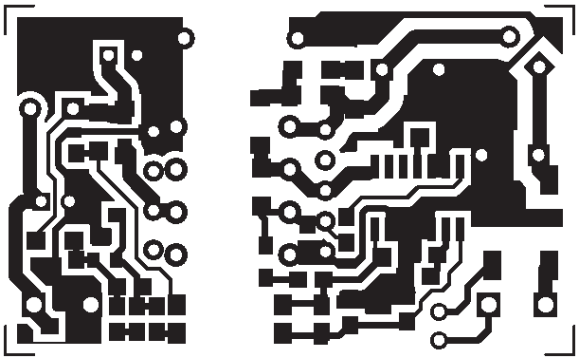

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Fig 14. PCB bottom copper (bottom view)

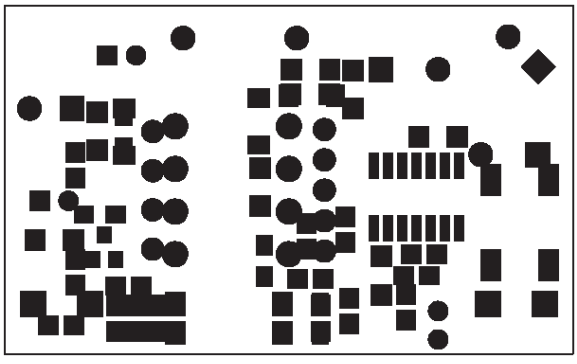

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Fig 15. PCB bottom solder masks (bottom view)

11. Legal information

11.1 Definitions

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