

# UM10369

## STARplug Switched Mode Power Supply (SMPS) for e-metering

Rev. 01 — 11 February 2011

User manual

### Document information

Info	Content
<b>Keywords</b>	STARplug, TEA1522, flyback, e-metering
<b>Abstract</b>	<p>The STARplug Switched Mode Power Supply (SMPS) for e-metering application implements a power supply that can be used in combination with all electricity utility networks worldwide i.e. single phase, two or three phase (assuming 120° phase angle) 100 V, 110 V, 120 V, 220 V, 230 V and 240 V (AC) <math>\pm</math> 20 % for each individual phase.</p> <p>This manual describes the STARplug e-metering SMPS demo board version 1.03. For details on the STARplug device please refer to the TEA152x data sheet and for general application information refer to STARplug application note AN00055.</p>



Revision history

Rev	Date	Description
v.1	20110211	first draft

# 1. Introduction

## 1.1 General description

**WARNING**

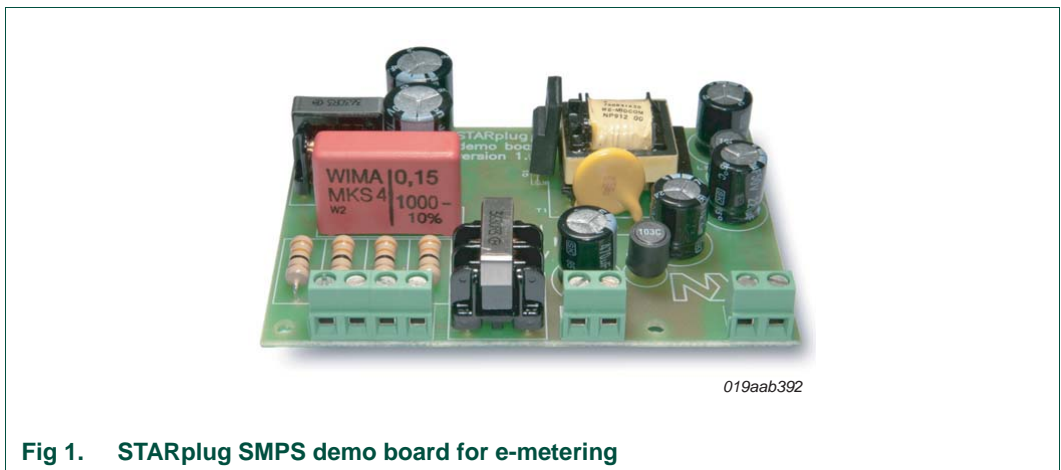
**Lethal voltage and fire ignition hazard**



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.

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The STARplug SMPS demo board shown in [Figure 1](#) has two galvanically isolated DC outputs, one 12 V (DC) the other 24 V (DC). By default, the ground level of the 12 V (DC) output is connected to the neutral wire of the electrical network via an inductor. When required by the application, this connection can be broken by removing the inductor L2. The 24 V (DC) output can be used as a power supply for other electronic metering equipment. The isolation barrier between the two DC outputs is 4 kV (AC).



**Fig 1. STARplug SMPS demo board for e-metering**

By re-dimensioning the transformer, other output voltages could be realized and a different isolation barrier between the input and the outputs could be implemented. Nominally, the output power that can be delivered by the board is 8 W in total. The maximum DC output power is approximately 10 W. Using a different transformer and other components from the STARplug *TEA152x* family other nominal output power levels can be achieved.

## 2. Technical specifications

**Table 1. Input specification**

Parameter	Value	Remarks
Input voltage	86 V (AC) to 310 V (AC)	-
Electricity utility network	1-phase, 2-phase, or 3-phase	assuming 120 ° phase angle
Input frequency	47 Hz to 420 Hz	-

Table 2. Input specification

Parameter	Value	Remarks
Output voltage (1)	12 V ( $\pm 5\%$ )	minimum to maximum load. Regulated output
Output current (1)	700 mA	maximum
Output voltage (2)	24 V	unregulated output
Output current (2)	350 mA	maximum
Total output power (1 + 2)	8 W	nominal
	10 W	maximum
Out1 to Out2 isolation	4 kV (AC)	1 minute
	5 kV (AC)	1 second

### 3. Performance data

#### 3.1 Output voltage and no-load power consumption

Table 3. No-load output voltage and power consumption

Condition	Energy star 2.0 requirement	Output voltage (1) (V)	Power consumption (W)
115 V; 60 Hz	$\leq 0.3$ W	11.9	0.09
230 V; 50 Hz	$\leq 0.3$ W	11.9	0.18

#### 3.2 Efficiency performance data

Table 4. Efficiency

Condition	Energy star 2.0 requirement	Efficiency average	25 % load	50 % load	75 % load	100 % load
115 V; 60 Hz	> 75.2 %	75.4 %	75.2 %	75.8 %	75.3 %	75.1 %
230 V; 50 Hz	> 75.2 %	76.3 %	73.3 %	76.8 %	77.2 %	77.6 %

**Remark:** Load is on Output\_1 (12 V) only. Warm-up time is 15 minutes, and the settle time after load change is 90 seconds.

### 3.3 Electro magnetic compatibility

Figure 2 below shows that the default implementation of the STARplug e-metering SMPS is within EN55022A ElectroMagnetic Compatibility (EMC) requirements.

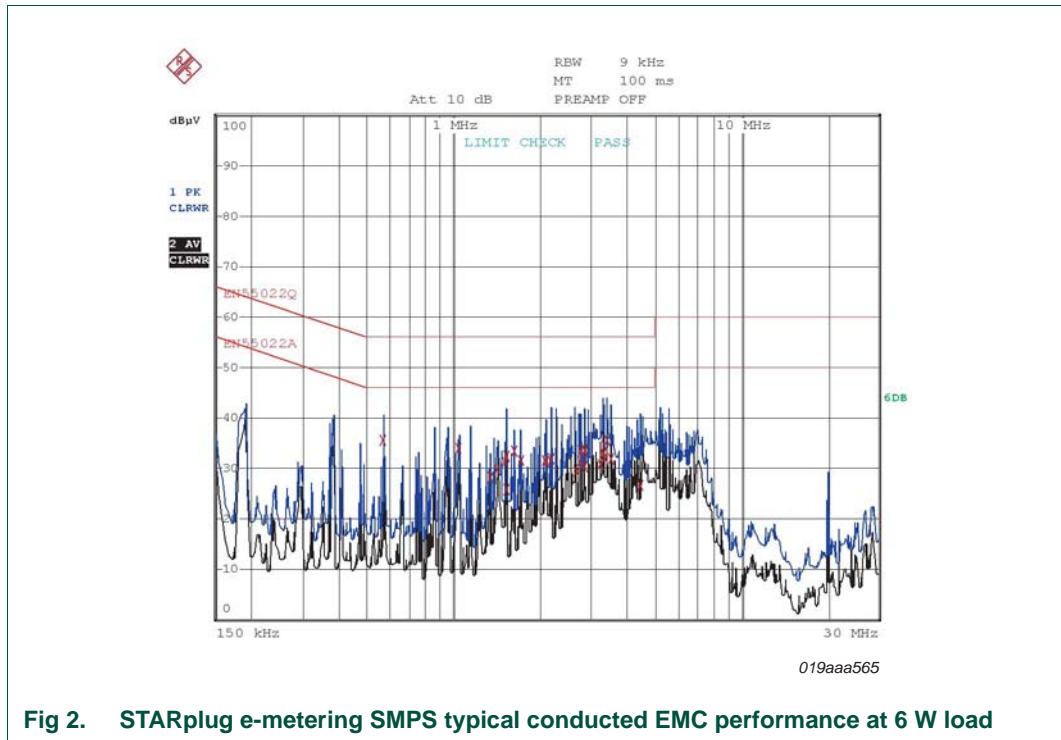
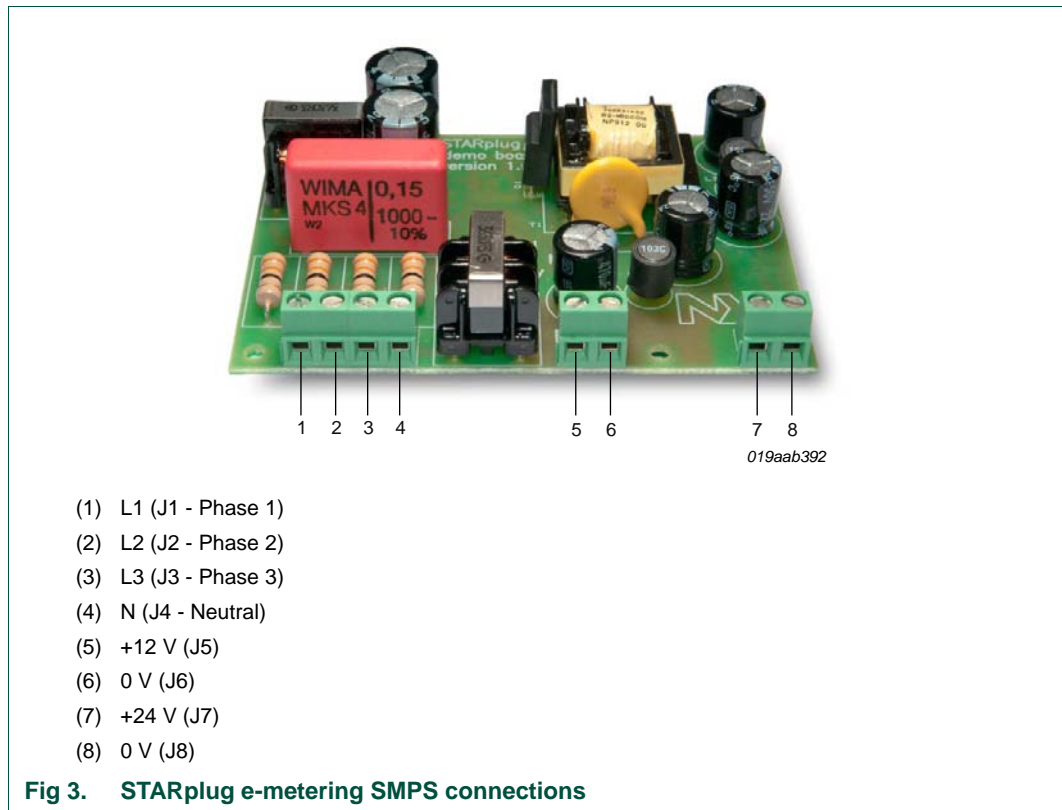


Fig 2. STARplug e-metering SMPS typical conducted EMC performance at 6 W load

It can be seen in Figure 2 that the noise and harmonics that are injected by the SMPS into the electricity utility network, are well within the accepted limits. This is achieved by filtering in the filter section and by the TEA1522 basic operation contributing to low ElectroMagnetic Interference (EMI) figures. The valley switching feature, for example, reduces sharp switching edges (high dV/dt, dI/dt), thus reducing high frequency content. More information can be found in the TEA152x family data sheet.

## 4. Connection of the demo board

Detailed information about the STARplug e-metering SMPS demo board connectivity is shown in Figure 3 below.



## 5. Circuit description

The default STARplug e-metering SMPS circuit consists of a three-phase full-wave rectifier circuit, a filtering section, a primary switching section operating in flyback mode, two separate output sections, and a feedback section. Each of these circuit sections are described in [Section 5.1](#) to [Section 5.5](#). Refer to the full circuit diagram shown in [Figure 4](#).

### 5.1 Full-wave rectifier section

The three-phase full-wave rectifier section consists of eight diodes that produce a rectified DC voltage between 100 V (DC) and 800 V (DC) depending on the electricity utility network the board is connected to. Inrush current is limited by resistors R1, R2, R3 and R4 connected in series with the neutral and live wires. Connectors J1, J2, J3 and J4 connect the primary side to the electricity utility network.

### 5.2 Filtering section

The filtering section uses a common-mode choke and capacitors in order to reduce noise and harmonic content caused by the primary switch. The leakage inductance of the common-mode choke acts as a differential mode filter. Zener diodes D9 to D12 and resistors R6 and R9 guarantee the correct distribution of the (high) DC input voltage across the C3 and C4 electrolytic capacitors. The second function of the Zener diodes is to prevent differential mode transient voltage spikes from reaching the primary switching section.

### 5.3 Primary switching section

The primary switcher uses a standard TEA1522 STARplug IC and a cascading MOSFET Q1. This combination creates a hybrid STARplug solution with a virtual > 1.2 kV breakdown voltage MOSFET. The high breakdown voltage is necessary to be compatible with high voltage three-phase electricity utility networks. The section operates in flyback mode.

### 5.4 Output sections

The 12 V (DC) and the 24 V (DC) output sections are standard secondary flyback stages, both outputs have low pass LC filters. Connectors J5 and J6 carry the 12 V (DC) (J5 is positive) and connectors J7 and J8 carry the 24 V (DC) (J7 is positive).

### 5.5 Feedback section

The feedback section measures the output voltage of the 12 V (DC) secondary section and feeds the information back to the TEA1522 IC via an optocoupler. The circuit uses an accurate TL431 voltage reference to produce a precisely regulated 12 V (DC) output. The 24 V (DC) output is unregulated. The output simply follows the regulation of the 12 V (DC) output.

## 6. Alternative circuit options

The following provides detailed information about alternative STARplug e-metering SMPS circuit board options.

### 6.1 Mains isolated 12 V (DC) output

A mains isolated 12 V (DC) output can be obtained by omitting inductor L2 as shown in [Figure 4](#). In addition, the Printed-Circuit Board (PCB) allows alternative L2 inductors to be installed e.g. a plain wire or other suitable component to experiment with the circuit. Refer to [Figure 5](#) and the component list in [Table 6](#).

### 6.2 Resistor capacitor diode snubber circuit

The default version of the STARplug e-metering SMPS demo board implements a Diode-Zener snubber to manage the energy stored in the stray inductance in the primary winding of the transformer. The Diode-Zener option is energy efficient and compact, which contributes to lower EMI, but it's not the cheapest option. Alternatively, a Resistor Capacitor Diode (RCD) snubber can be mounted on the same PCB. If the RCD option is used, diode D16 must be removed and capacitor C8 and resistors R16 and R17 must be installed. Refer to [Figure 6](#) and the component list in [Table 7](#).

### 6.3 Eliminated transient suppression

The STARplug e-metering SMPS demo board comes with a transient voltage suppression circuit consisting of D9, D10, D11, D12, R6, and R9 as shown in [Figure 4](#). These components operate as a transient voltage protection for the whole application and as a voltage divider for capacitors C3 and C4. This configuration provides a safe solution, but

is more expensive than the resistive voltage divider proposed in the [Figure 7](#) solution. If the extensive protection is not required, this option could be an alternative. Refer to [Figure 7](#) and the component list in [Table 8](#).

#### 6.4 Primary side feedback

For the most accurate secondary-side voltage regulation (on the 12 V (DC) output) the secondary side feedback option is preferred. However, in many circumstances (applications) very accurate voltage regulation is not required, so the primary side feedback can be used. This regulation option usually reduces costs as the voltage regulator IC, the optocoupler and other passive components can be removed. Refer to [Figure 8](#) and the component list in [Table 9](#).

#### 6.5 TEA1522 self-supplying option

The TEA152x family of ICs has the option to self-supply the internal circuitry but at the cost of lower efficiency and a higher standby power. When the self-supply option is used, no auxiliary winding on the transformer is needed. This simplifies transformer construction and can reduce costs. Refer to [Figure 9](#) and the component list in [Table 10](#).



# 7. Schematics

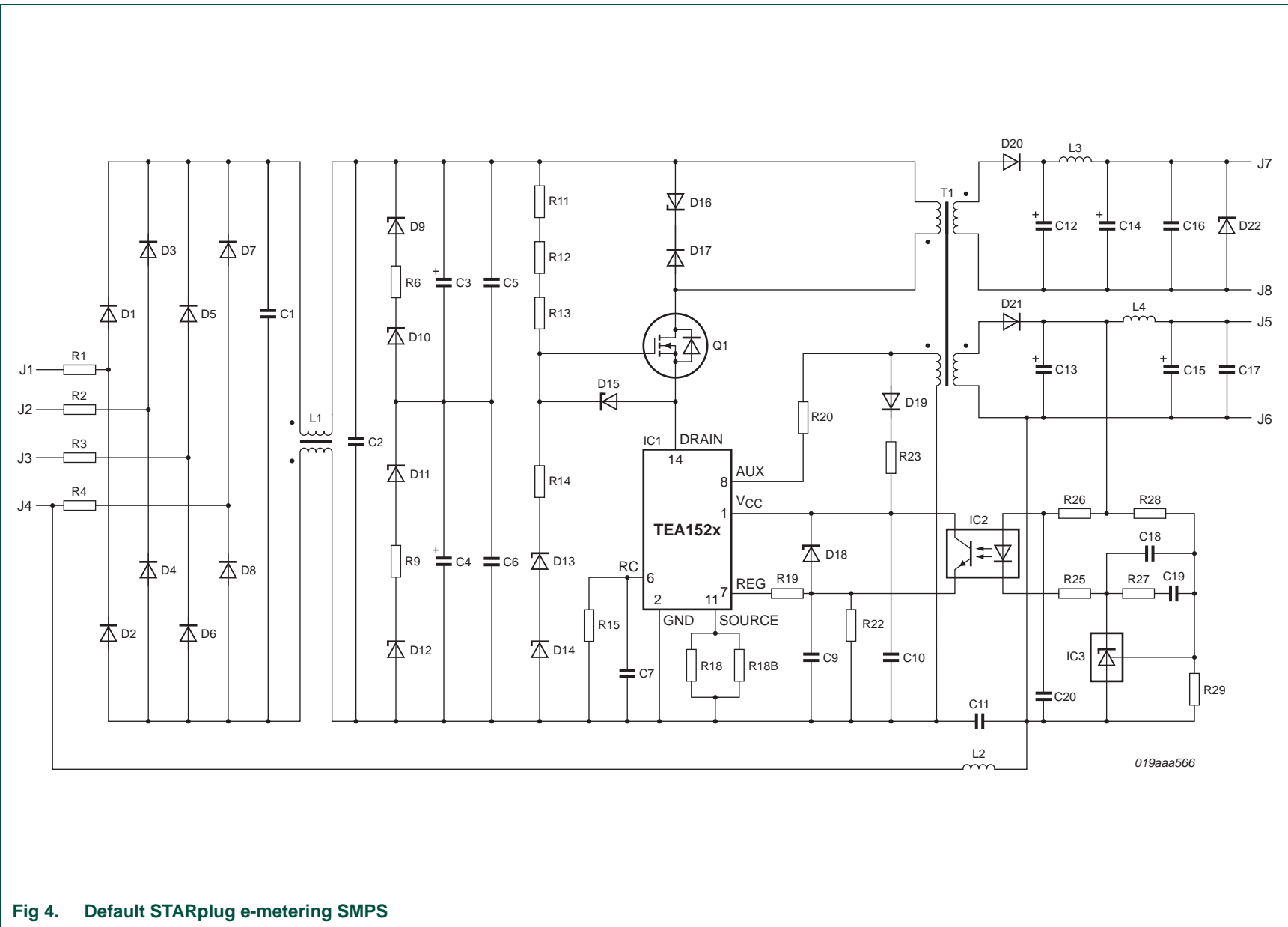


Fig 4. Default STARplug e-metering SMPS

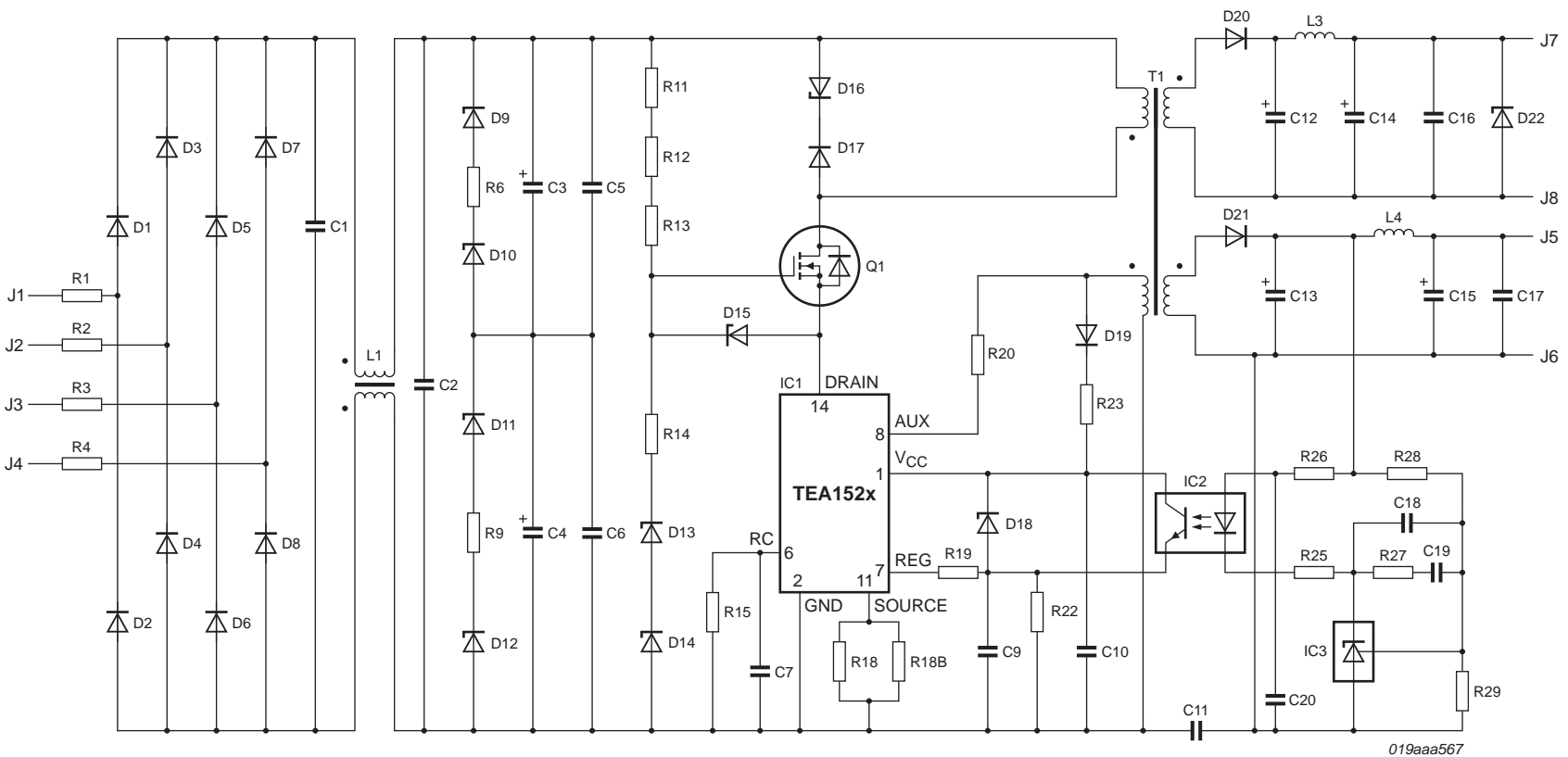
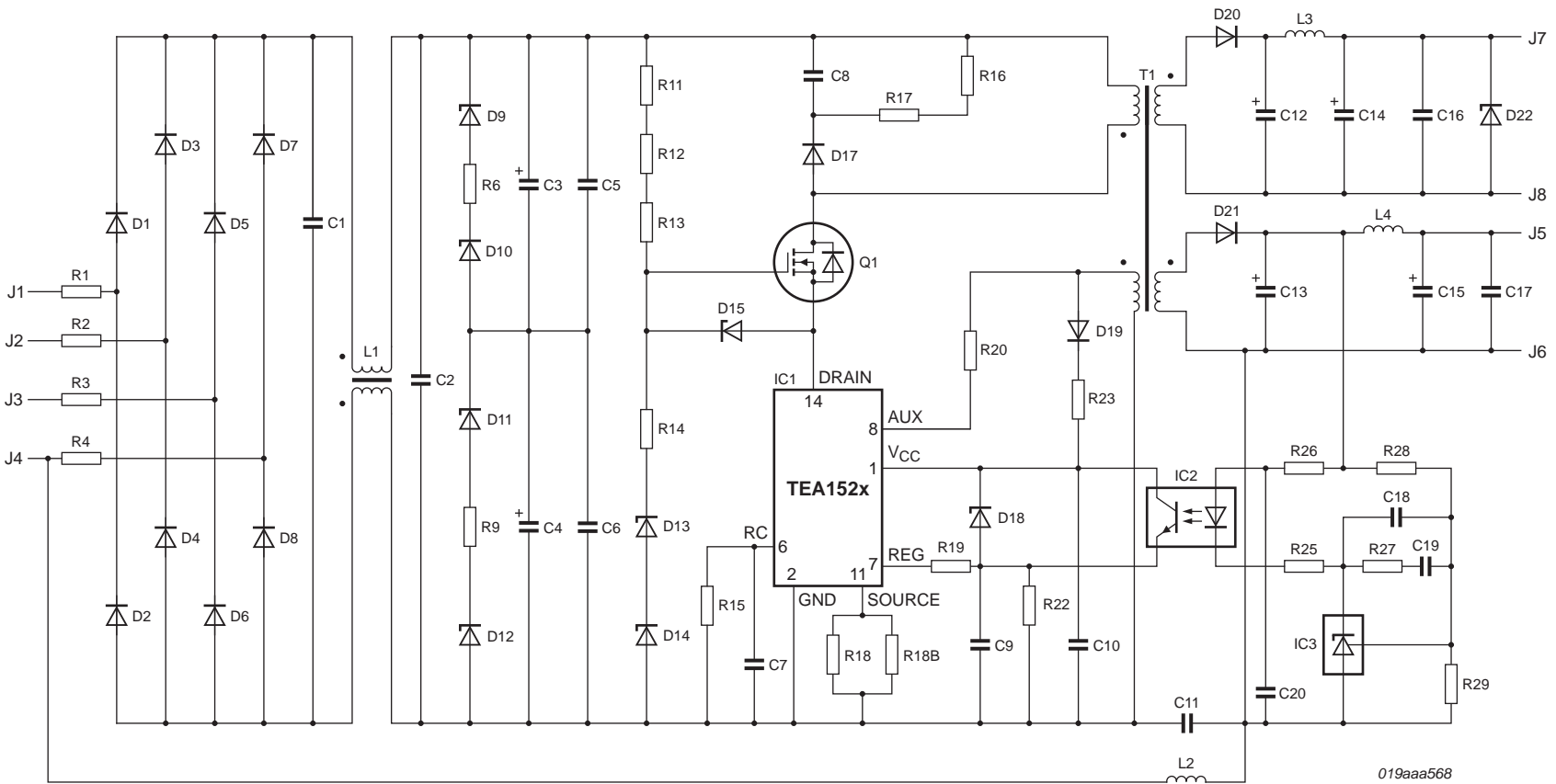
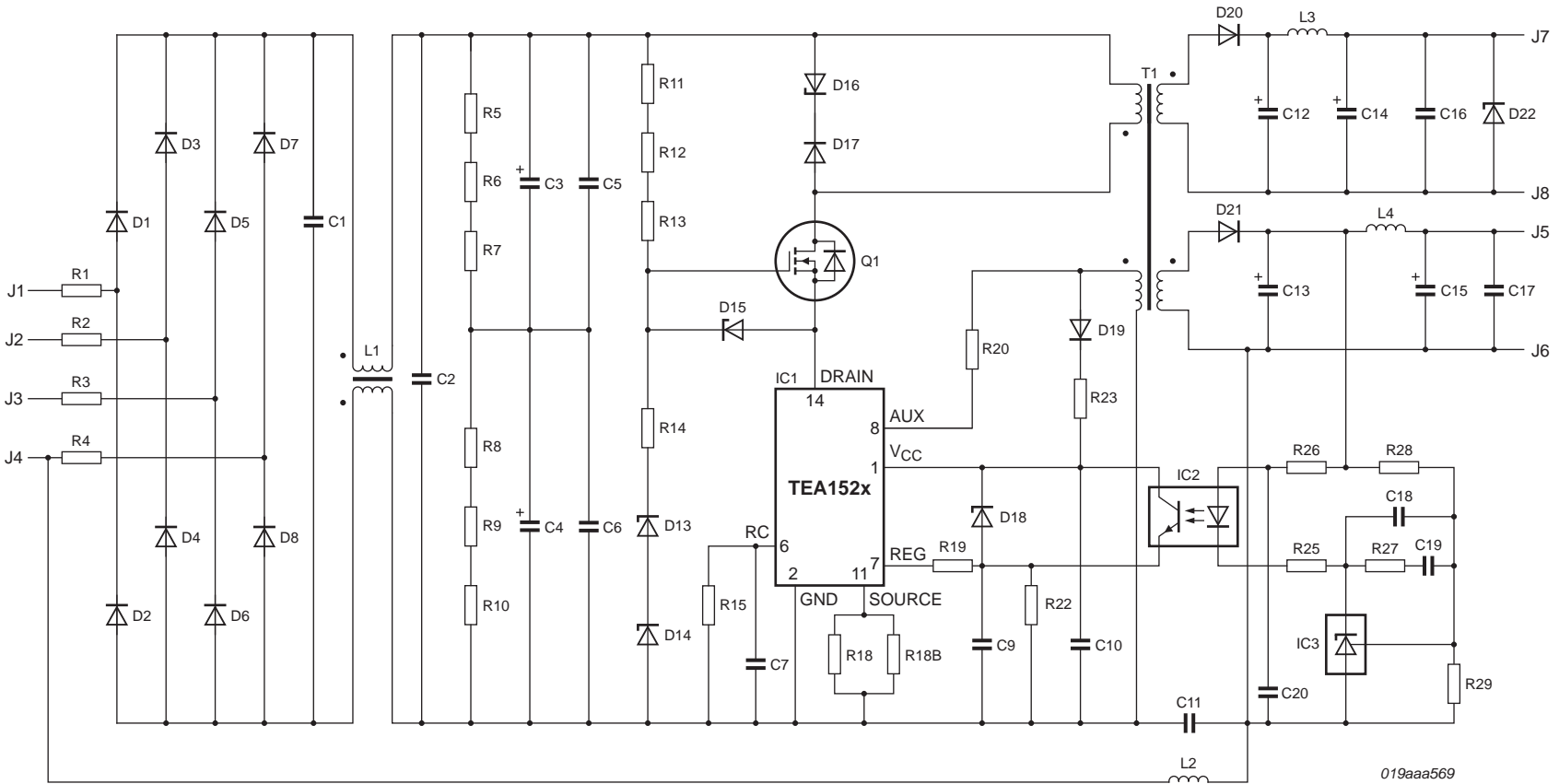


Fig 5. STARplug SMPS with isolated 12 V (DC) output



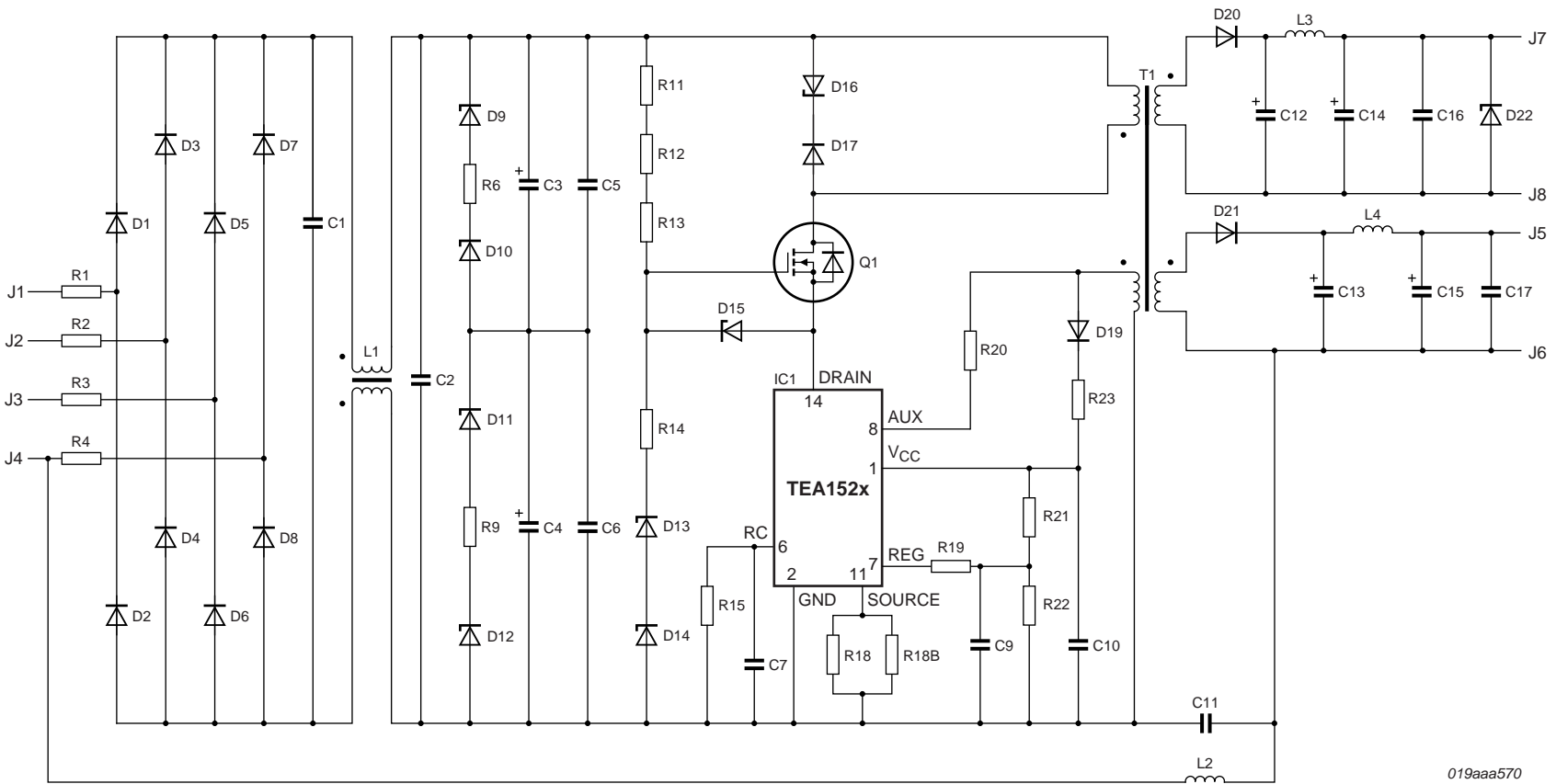
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Fig 6. STARplug SMPS with alternative (RCD) snubber network



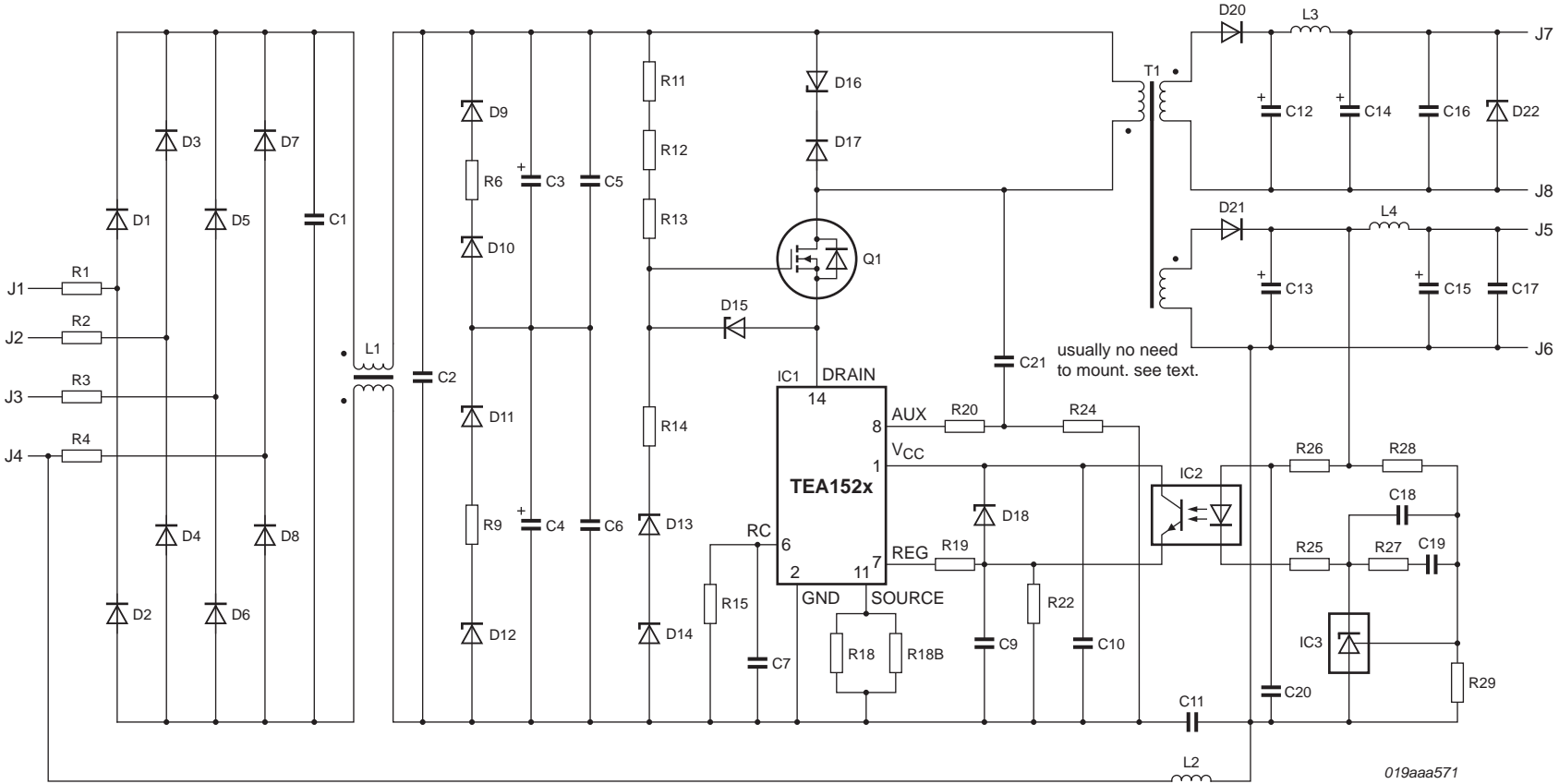
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Fig 7. STARplug SMPS without transient suppressor



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Fig 8. STARplug SMPS with primary side feedback



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Fig 9. STARplug SMPS with self-supplying option

## 8. Components list

The following tables provide detailed component information for the default and alternative STARplug solutions.

**Table 5. Default STARplug e-metering solution**

Reference	Component	Package	Remarks
IC1	NXP TEA1522T	SO14	-
IC2	Vishay SFH6156	SMD-4	-
IC3	NXP TL431A	SOT23	e.g. TL431AQDBZR
Q1	Fairchild FQPF2N80	TO-220F	-
D1	Vishay S1M	DO-214AC	-
D2	Vishay S1M	DO-214AC	-
D3	Vishay S1M	DO-214AC	-
D4	Vishay S1M	DO-214AC	-
D5	Vishay S1M	DO-214AC	-
D6	Vishay S1M	DO-214AC	-
D7	Vishay S1M	DO-214AC	-
D8	Vishay S1M	DO-214AC	-
D9	Vishay BZG03C220	DO-214AC	-
D10	Vishay BZG03C220	DO-214AC	-
D11	Vishay BZG03C220	DO-214AC	-
D12	Vishay BZG03C220	DO-214AC	-
D13	Vishay BZG03C220	DO-214AC	-
D14	Vishay BZG03C220	DO-214AC	-
D15	NXP BZX384C15	SOD323	-
D16	Vishay BZG03C220	DO-214AC	-
D17	Vishay US1M	DO-214AC	-
D18	NXP BZX384C24	SOD323	-
D19	NXP BAS321	SOD323	-
D20	Vishay BYG22D	DO-214AC	-
D21	Vishay ES1B	DO-214AC	-
D22	Vishay BZG03C27	DO-214AC	-
D22B	not mounted	SOD323	low power alternative for D22, e.g. BZX384C27
T1	Würth 750841630	-	custom made transformer.
L1	Murata 36 mH choke PLA10AN3630R3D2B	-	-
L2	Murata 36 mH choke PLA10AN3630R3D2B	-	may be removed or substituted with an alternative inductor. See <a href="#">Section 6.1</a> .
L2A	not mounted	Radial	alternative for L2
L3	Murata 10 $\mu$ H 22R103C	Radial	-
L4	Murata 10 $\mu$ H 22R103C	Radial	-

Table 5. Default STARplug e-metering solution ...continued

Reference	Component	Package	Remarks
C1	150 nF; 1000 V	Radial; 9E	-
C2	1 nF; 1000 V	Radial	-
C3	10 $\mu$ F; 450 V	Radial; 2E	-
C4	10 $\mu$ F; 450 V	Radial; 2E	-
C5	100 nF; 500 V	1812	-
C6	100 nF; 500 V	1812	-
C7	330 pF; 25 V	0805	-
C8	not mounted	1206	alternative snubber. See <a href="#">Section 6.2</a> .
C9	22 nF; 50 V	0805	-
C10	220 nF; 50 V	1206	-
C11	1 nF; 2 kV	Radial	Y-cap
C12	220 $\mu$ F; 63 V	Radial; 2E	-
C13	470 $\mu$ F; 16 V	Radial; 2E	-
C14	220 $\mu$ F; 63 V	Radial; 2E	-
C15	470 $\mu$ F; 16 V	Radial; 2E	-
C16	100 nF; 50 V	1206	-
C17	100 nF; 50 V	1206	-
C18	5.6 nF; 50 V	0805	-
C19	22 nF; 50 V	0805	-
C20	100 nF; 50 V	0805	-
C21	not mounted	1206	alternative self-supply option. See <a href="#">Section 6.5</a> .
R1	33 $\Omega$ ; 1 W	Axial; 6E	carbon film
R2	33 $\Omega$ ; 1 W	Axial; 6E	carbon film
R3	33 $\Omega$ ; 1 W	Axial; 6E	carbon film
R4	33 $\Omega$ ; 1 W	Axial; 6E	carbon film
R5	not mounted	1206	-
R6	22 $\Omega$ ; 0.125 W	1206	-
R7	not mounted	1206	-
R8	not mounted	1206	-
R9	22 $\Omega$ ; 0.125 W	1206	-
R10	not mounted	1206	-
R11	680 k $\Omega$ ; 0.125 W	1206	-
R12	680 k $\Omega$ ; 0.125 W	1206	-
R13	680 k $\Omega$ ; 0.125 W	1206	-
R14	110 $\Omega$ ; 0.125 W	1206	-
R15	7.5 k $\Omega$ ; 0.0625 W	0805	-
R16	not mounted	1206	alternative snubber. See <a href="#">Section 6.2</a> .
R17	not mounted	1206	alternative snubber. See <a href="#">Section 6.2</a> .



**Table 5. Default STARplug e-metering solution ...continued**

Reference	Component	Package	Remarks
R18	1.5 $\Omega$ ; 0.25 W	1206	-
R18B	1.5 $\Omega$ ; 0.25 W	1206	-
R19	2.2 k $\Omega$ ; 0.0625 W	0805	-
R20	100 k $\Omega$ ; 0.0625 W	0805	-
R21	not mounted	0805	-
R22	5.6 k $\Omega$ ; 0.0625 W	0805	-
R23	10 $\Omega$ ; 0.0625 W	0805	-
R24	not mounted	0805	alternative self-supply option. See <a href="#">Section 6.5</a> .
R25	1 k $\Omega$ ; 0.0625 W	0805	-
R26	2.4 k $\Omega$ ; 0.0625 W	0805	-
R27	24 k $\Omega$ ; 0.0625 W	0805	-
R28	9.1 k $\Omega$ ; 0.0625 W; 1 %	0805	-
R29	2.4 k $\Omega$ ; 0.0625 W; 1 %	0805	-
J1; J2; J3; J4	4-pole terminal block, e.g. Phoenix contact	-	pitch 2E
J5; J6	2-pole terminal block, e.g. Phoenix contact	-	pitch 2E
J7; J8	2-pole terminal block, e.g. Phoenix contact	-	pitch 2E

**Table 6. Component list modification for mains-isolated 12 V (DC) output**

Reference	Component	Package	Remarks
L2	not mounted	-	-

**Table 7. Component list modification for RCD snubber option**

Reference	Component	Package	Remarks
D16	not mounted	DO-214AC	-
C8	1 nF; 500 V	1206	-
R16	47 k $\Omega$ ; 0.5 W	1206	-
R17	47 k $\Omega$ ; 0.5 W	1206	-

**Table 8. Component list modification SMPS without transient voltage suppression circuit**

Reference	Component	Package	Remarks
D9	not mounted	DO-214AC	-
D10	not mounted	DO-214AC	-
D11	not mounted	DO-214AC	-
D12	not mounted	DO-214AC	-
R5	910 k $\Omega$ ; 0.125 W	1206	-
R6	910 k $\Omega$ ; 0.125 W	1206	component value change
R7	910 k $\Omega$ ; 0.125 W	1206	-

**Table 8. Component list modification SMPS without transient voltage suppression circuit**

Reference	Component	Package	Remarks
R8	910 k $\Omega$ ; 0.125 W	1206	-
R9	910 k $\Omega$ ; 0.125 W	1206	component value change
R10	910 k $\Omega$ ; 0.125 W	1206	-

**Table 9. Component list modification for primary side feedback**

Reference	Component	Package	Remarks
IC2	not mounted	SMD-4	-
IC3	not mounted	SOT23	-
D18	not mounted	SOD323	-
C18	not mounted	0805	-
C19	not mounted	0805	-
C20	not mounted	0805	-
R21	22 k $\Omega$ ; 0.0625 W	0805	-
R25	not mounted	0805	-
R26	not mounted	0805	-
R27	not mounted	0805	-
R28	not mounted	0805	-
R29	not mounted	0805	-

**Table 10. Component list modification for self-supply option**

Reference	Component	Package	Remarks
D19	not mounted	SOD323	-
R23	not mounted	0805	-
T1	alternative transformer without auxiliary winding	-	-
C21	2.2 pF; 500 V	1206	parasitic capacitance of the board and the circuit usually suffices. No need to mount.
R24	390 k $\Omega$ ; 0.0625 W	0805	-

## 9. Printed-Circuit Board (PCB)

Physical aspects of the demo board PCB and implementation options are detailed in this section. [Figure 10](#) to [Figure 13](#) provide detailed views of the demo board.

The STARplug e-metering SMPS PCB is a single-sided board measuring 91 mm × 64 mm. Demo PCBs are produced on 1.6 mm FR4 with single-sided 1 Oz copper (35 μm). FR2 can also be used as the PCB material.

The demo board accommodates a number of implementations of the STARplug e-metering SMPS. The default component population implements an SMPS with a good balance between performance and cost. However, other implementations with different trade-off between performance and cost are possible.

The Gerber file set for production of the PCB is available from NXP. Normally the bottom silk is not used for PCB production but just as a reference for component positions.

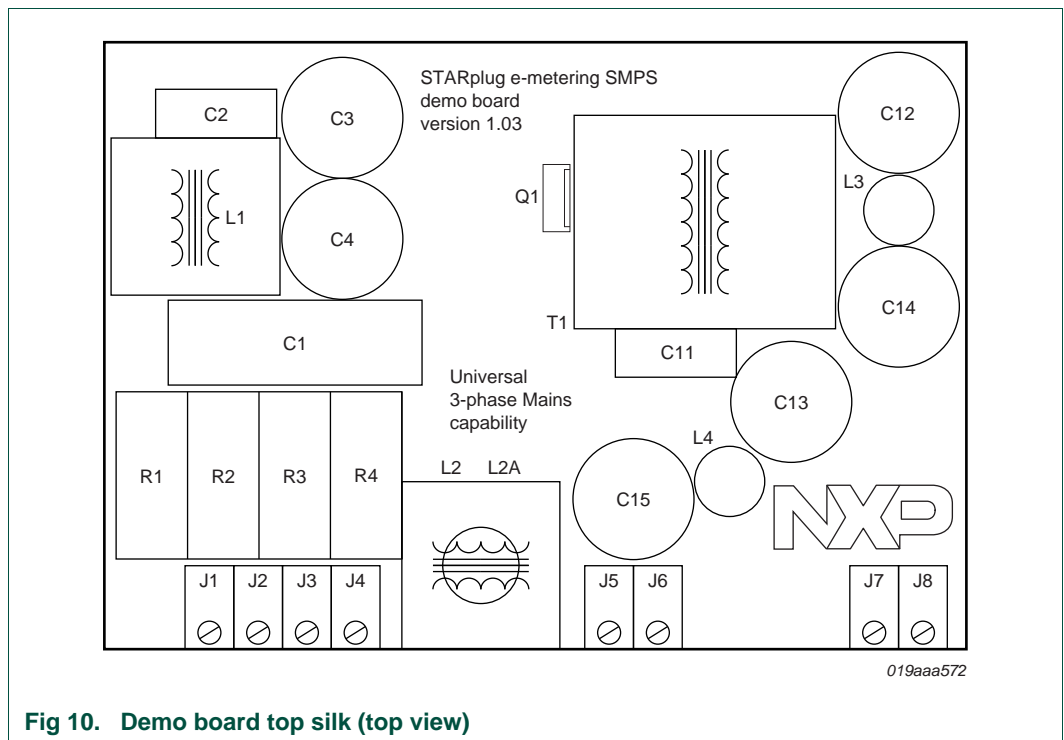


Fig 10. Demo board top silk (top view)

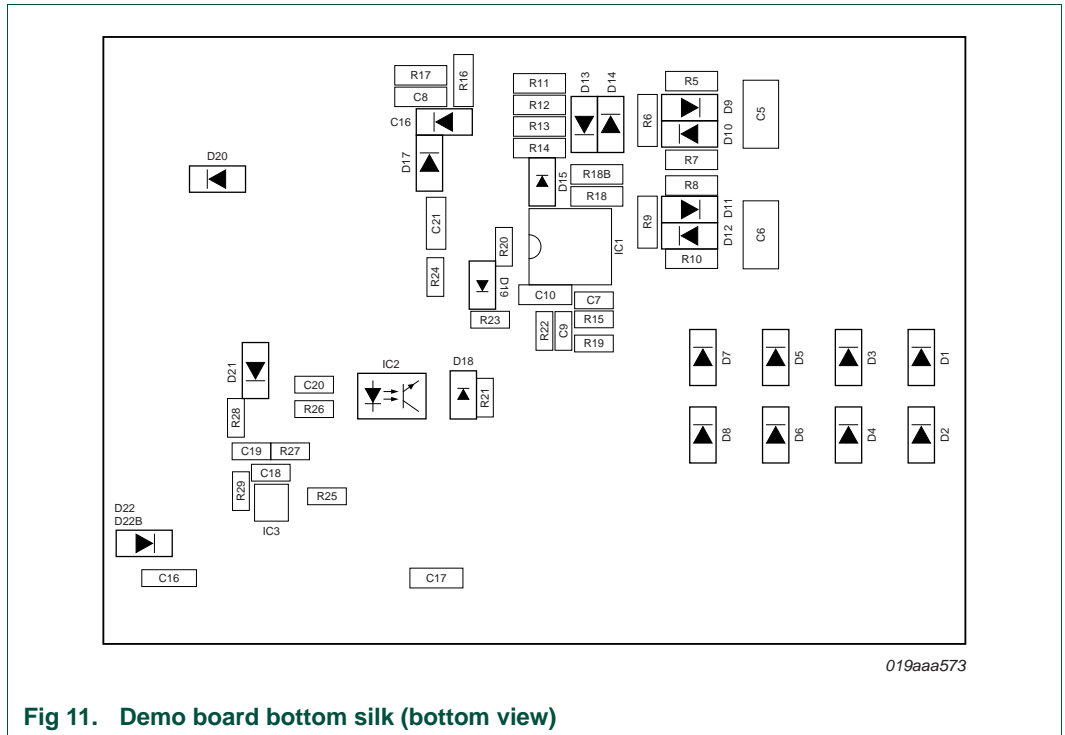


Fig 11. Demo board bottom silk (bottom view)

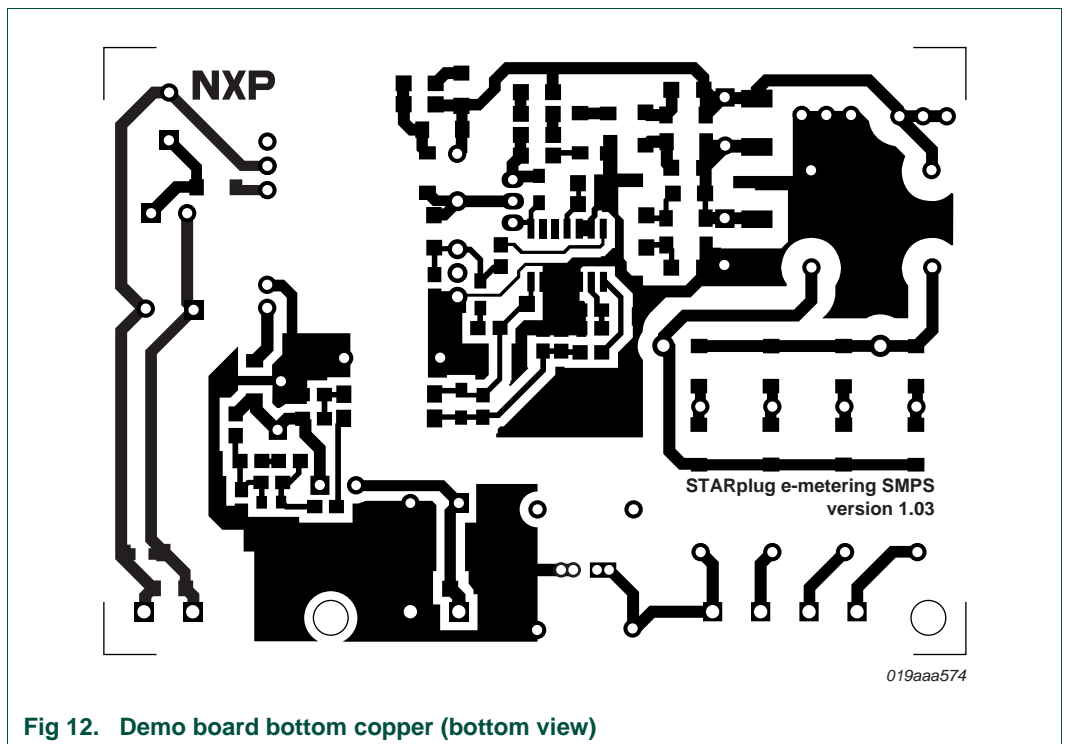


Fig 12. Demo board bottom copper (bottom view)

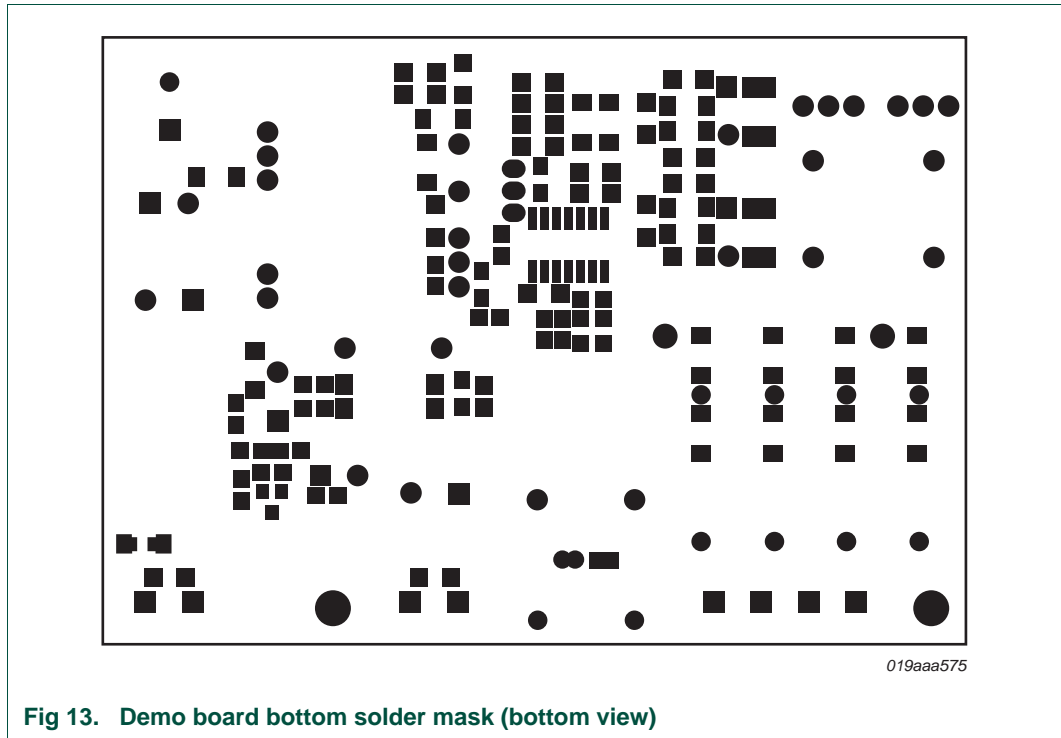


Fig 13. Demo board bottom solder mask (bottom view)

## 10. Abbreviations

Table 11. Abbreviations

Acronym	Description
EMC	ElectroMagnetic Compatibility
EMI	ElectroMagnetic Interference
MOSFET	Metal-Oxide Semiconductor Field-Effect Transistor
RCD	Resistor Capacitor Diode
SMPS	Switched Mode Power Supply

## 11. References

- [1] TEA152x — TEA152x family data sheet.
- [2] AN00055 — STARplug application note.

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Date of release: 11 February 2011

Document identifier: UM10369