Smart Plug Reference Design

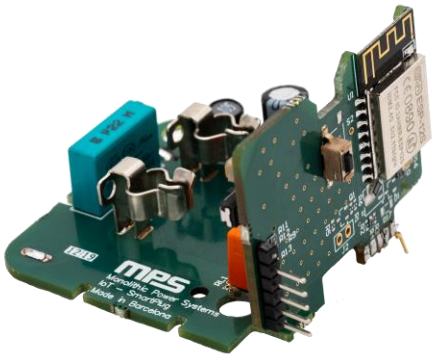
MP161 Non-Isolated Buck Regulator with ESP8266

Table of Contents

1 Overview

1.1 Description

Nowadays everything is connected. So why not also connect the wall plugs? MPS presents a reference design with the MP161 part that will allow customers to join the IoT market. This is a two boards product, one for the DC/DC converter and the relay and the other for the Wi-Fi module. The configuration is designed to fit into a wall-plug.



1.2 Features

- Integrated IC supply solution (12V + 3V3 + Relay Driver)
- Wi-Fi 802.11 b/g/n (HT20) protocol
- 35.4 mW active input power under stand-by operation

1.3 Applications

- IoT non-isolated designs

Warning: Although this board is designed to satisfy safety requirements, the engineering prototype has not been agency approved. Therefore, all testing should be performed using an isolation transformer to provide the AC input to the prototype board.

2 Reference Design

2.1 Block Diagram

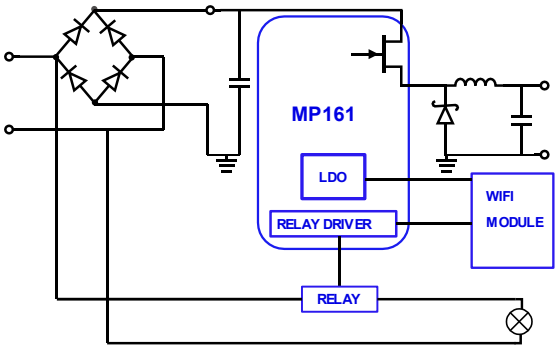


Figure 1: Block diagram

2.2 Related Solutions

This reference design is based on the following MPS solutions:

Table 1: System MPS Integrated circuits

MPS Integrated Circuit	Description
MP161B-33	High voltage buck regulator + LDO

2.3 System Specifications

Table 2: System Specifications

Parameter	Specification
Input Voltage Range	90 V to 265 V AC
Output Voltage	12 V ±1.5% DC
Nominal Load	12 V / 17.5mA, 3.3V / (70 mA for T1 – 250 mA for T2)
Peak Output Current	270 mA (at 12V output)
Output Voltage of LDO	3.3 ±1.5% V
Output Current of LDO	70 – 250 mA
Switching Frequency	40 kHz (under nominal conditions)
Board form factor	50 x 50 x 30 mm
Efficiency	> 90 %
12V output ripple	17 mV (under nominal conditions)
Wi-Fi protocol	802.11 b/g/n (HT20) ESP8266 based

2.4 MP161: Integrated non-Isolated Buck Regulator

The MP161 integrates a 700V switching regulator, a low-dropout linear regulator and two channel relay drivers. The MP161 also has a special standby mode to minimize standby power. The MP161 is designed for home automation, industrial automation, and any other applications that adopt relays and MCUs.

Features:

- Integrated 700V MosFET and current source
- Constant voltage regulation with internal loop compensation
- Optimized light-load efficiency by frequency modulation
- Standby mode
- Anti-audible noise operation by peak current modulation
- Adjustable or fixed 12V Output
- Low operating current
- Over-Temperature Protection (OTP), Short-Circuit Protection (SCP), Over-Load Protection (OLP) and Over-Voltage Protection (OVP)

Low-Drop Out (LDO) lineal regulator

- Up to 30V input voltage
- Fixed output, with 3V3 and 5V options
- Over-Temperature Protection (OTP)

Relay Driver

- 2 Ω On state resistance
- Rail voltage up to 30V
- Integrated freewheeling diode
- Nominal off driver

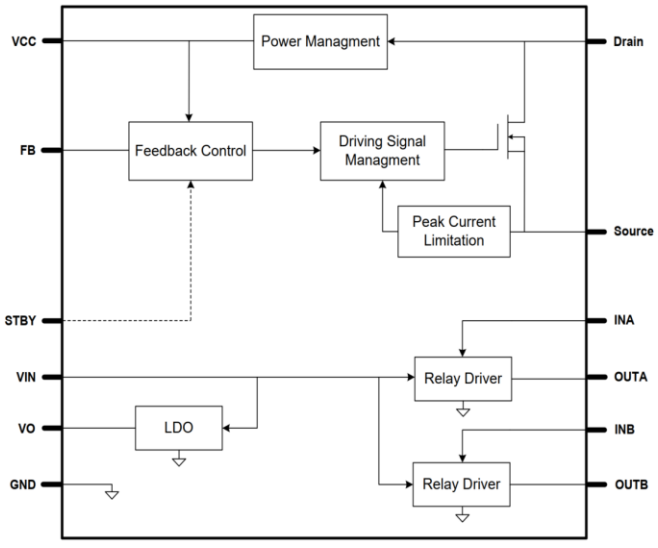


Figure 2: Internal block diagram of the MP161

3 Design

3.1.1 Inductor selection

The MP161 has a minimum off-time, 9.5 or 12 us depending on the IC variant A or B/C, that determines the maximum output power. With eq. 1 we can estimate the Over Load Point (OLP) under Continuous Conduction Mode (CCM)

With 1 mH inductor we can guaranty the output power 3.3W, taking the tolerance into consideration.

$$P_{o\,max} = V_o(I_{L\,limit} - \frac{V_o \tau_{\min off}}{2L}) \quad (1)$$

3.1.2 Output capacitor

We choose the output capacitor in order to fulfil the ripple requirement. In this case is 150mV.

With eq.2 we can estimate the voltage ripple under CCM: 33 mV with 100uF.

$$V_{out\,ripple} = \frac{\Delta_i}{8 f_s C_o} + \Delta_i R_{ESR} \quad (2)$$

3.2 Wi-Fi module consumption

The Wi-Fi module consumption is described in the figure below. This periodic load profile will be considered as nominal load condition (table 1). Where: T1 is 97 ms, T2 is 1.5 ms and T is T1+T2.

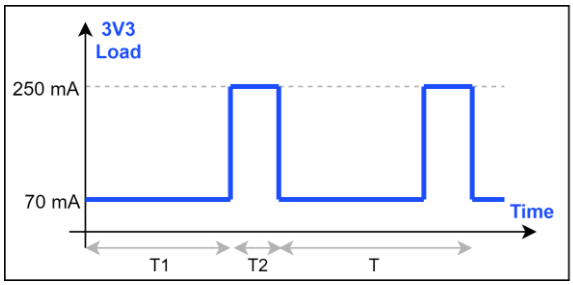


Figure 3: Block diagram

3.3 Schematic

This board is divided in two schematic files in order to separate the power stage (figure 4) and the communications (figure 5) one.

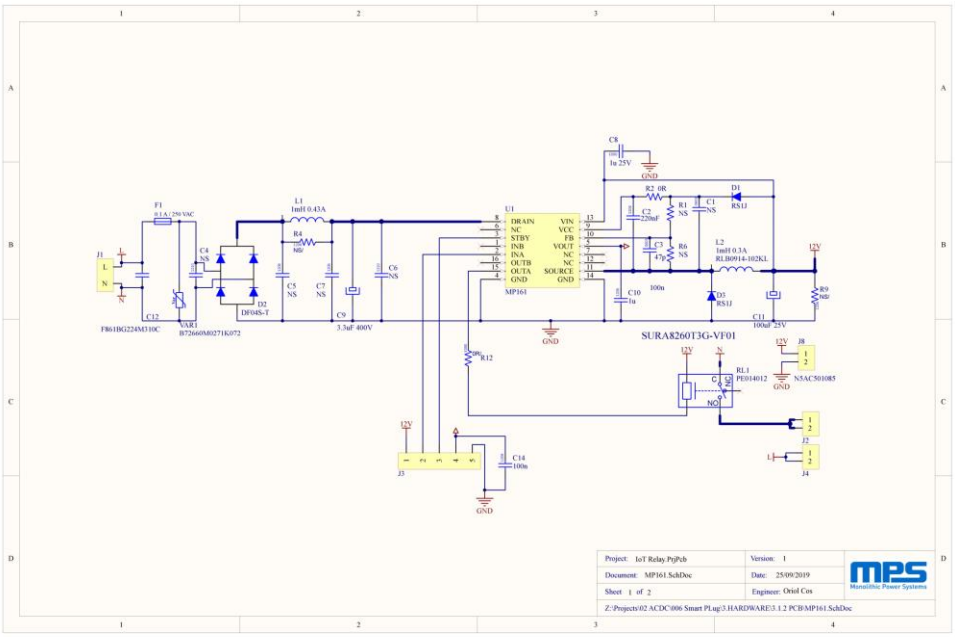


Figure 4: Power stage (Rectifier + DC/DC)

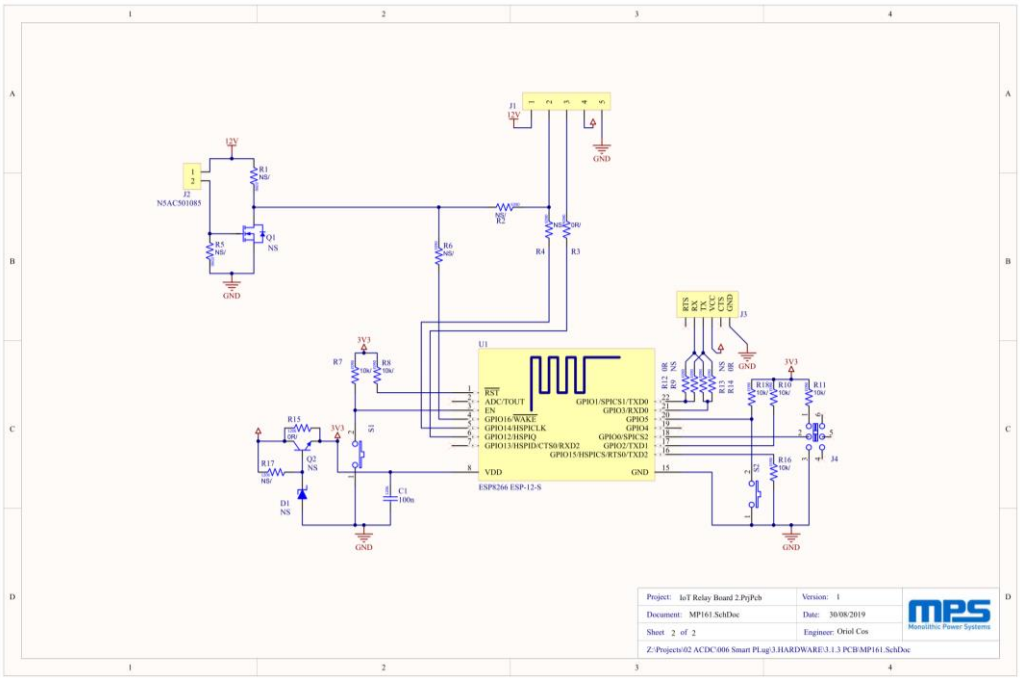


Figure 5: Wi-Fi module

3.4 BOM

Qty.	Designator	Manufacturer PN	Manufacturer	Value
7	C1, C4, C5, C6, C7, J1, J2			NS
7	J4, J8, R1, R4, R6, R9			NS
1	C2	1206 220nF		220nF
1	C3	0603 47pF		47pF
1	C8	0603 1uF 25V		1u 25V
1	C9	860021373005	Wurth	3.3uF 400V
1	C10	1206 1uF		1uF
1	C11	EKRG250ETD101MF09D	United Chemi-Con	100uF 25V
1	C12	F861BG224M310C	KEMET	F861BG224M310C
1	C14	1206 100nF		100nF
2	D1, D3	RS1J	DIODES	RS1J
1	D2	DF04S-T	Diodes Incorporated	DF04S-T
1	F1	3403.0156.24	Schurter	0.1 A / 250 VAC
1	L1	DR0608-105L	Coilcraft	DR0608-105L
1	L2	RLB0914-102KL	BOURNS	1mH 0.3A
2	R2, R12	0603 0R		0R
1	RL1	PE014012	OEG - TE CONNECTIVITY	PE014012
1	U1	MP161B-33	MonolithicPowerSystems	MP161
1	VAR1	B72660M0271K072	EPCOS	B72660M0271K072

Table 3: Bill of materials for the Power Stage

Qty.	Designator	Manufacturer PN	Manufacturer	Footprint	Value
1	C1	1206 100nF		1206	100nF
7	D1, J1, J2, J3, Q1, Q2, R1				NS
7	R2, R4, R5, R6, R9, R13, R17				NS
1	J4	JS202011SCQN	C&K	DIP-SWITCH	JS202011SCQN
3	R3, R12, R14	0603 0R		0603	0R
6	R7, R8, R10, R11, R16, R18	0603 10k		0603	10k
1	R15	1206 0R		1206	0R
2	S1, S2	FSMSMTR	TE Connectivity	TE FSM6JSMA	FSMSMTR
1	U1	ESP-12S	RF-Solutions	ESP8266 ESP-12-S	ESP-12S

Table 4: Bill of materials for the ESP8266 PCB

3.5 PCB Layout

In order to deliver a compact solution, we have divided the system into different boards, one for the power stage (figure 4) and the other for the Wi-Fi module (figure 5). These topics should be taken into account once routing this type of solutions we have:

- Even this is a non-isolated high voltage converter, it doesn't mean that we don't have to care about distance between traces. We have AC in this board (90-265 Vac) so it is recommended to leave 2.5mm between L and N, also 1.2mm between high and low voltage.
- We have high dV/dt voltage nodes and high dI/dt currents in the power loop so the use of decoupling capacitors is a must.

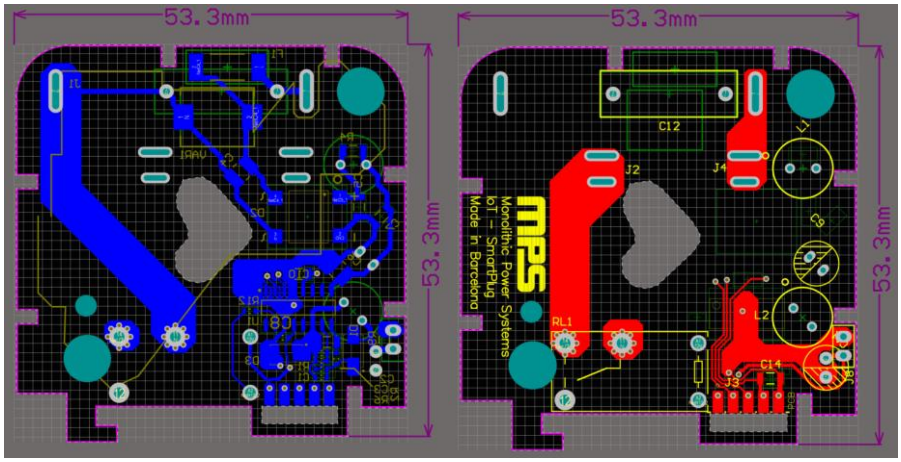


Figure 6: PCB Power bottom layer (blue) and top layer (red).

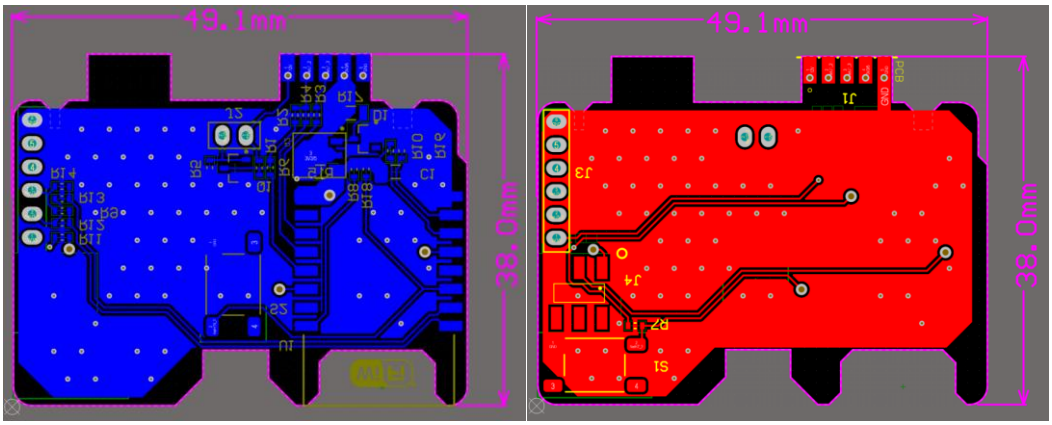


Figure 7: PCB ESP8266 bottom layer (blue) and top layer (red).

4 Test Results

4.1 Time Domain Waveforms

Figure 8: Input current and voltage.
(Nominal Load)

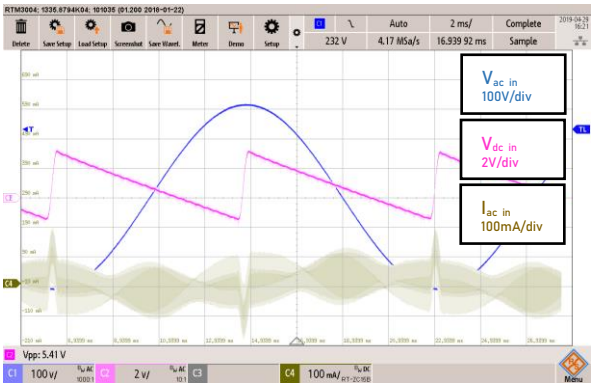


Figure 9: Diode anode-cathode voltage.
Vin 265Vac, Vo 12V, Io 270mA (SW Figure1)

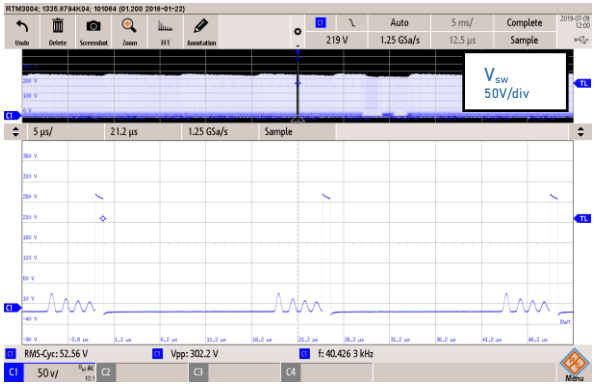


Figure 10: Output voltage and LDO.
(Nominal Load)

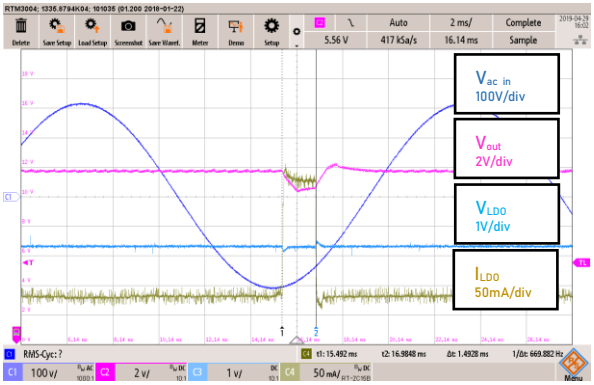


Figure 11: Load behaviour.
(Nominal Load)

Figure 12: LDO voltage ripple.
(Nominal Wi-Fi Load)

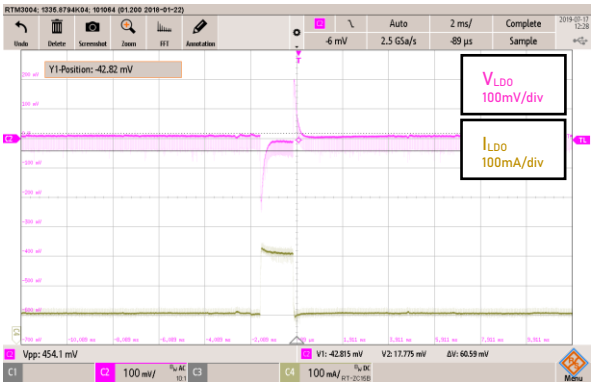


Figure 13: Normal operation consumption.
(Nominal Load)

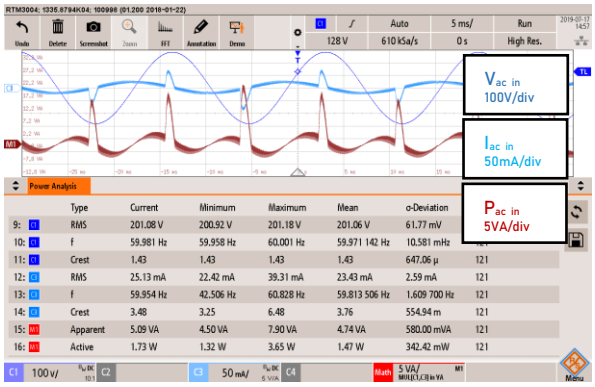
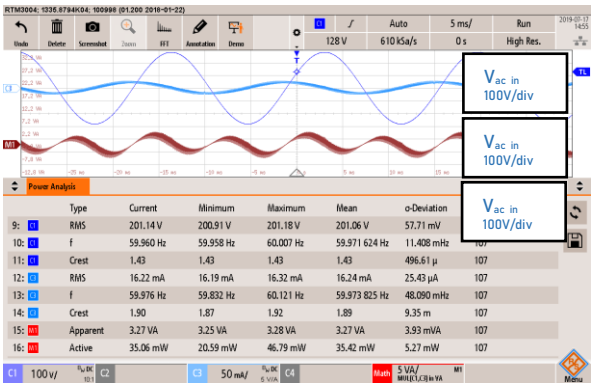
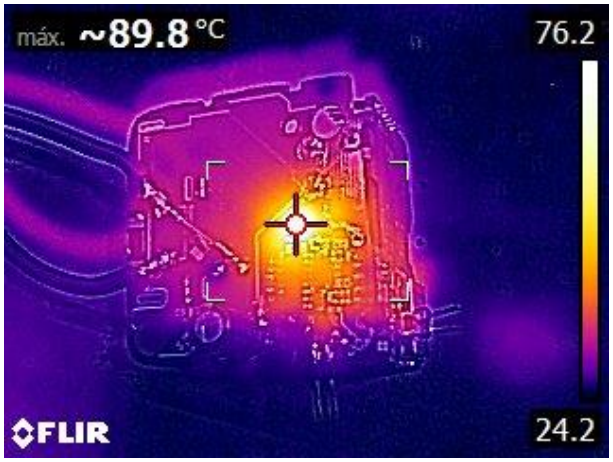


Figure 14: Stand-by operation consumption.
(Stand-by Load)



4.2 Thermal Measurements

Figure 15: Wi-Fi module
(Nominal Load)



4.3 EMC Measurements

AUTHOR	**Oriol Cos**
FACILITIES	MPS Barcelona
DATE	May 14, 2019
ENVIRONMENTAL COND.	25ºC / 31% / 1013 hPa
IC	MP161B-33
EVM	-
TOPOLOGY	Buck
COSTUMER	-
STANDARD	EN50011
ELECTRICAL COND.	Nominal Conditions
TEST EQUIPMENT	LISN: HM6050-2 Spectrum Analyser: R&S FPC1500 Software: Elektra v2.20

EN50011				
Detector		*Class*	*Frequency [MHz]*	*Limit [dBµV]*
Quasi peak		B	0.15 – 0.5	65-55
			0.5 – 5	45
			5 – 30	60
Peak		B	0.15 – 0.5	55 – 45
			0.5 – 5	45
			5 – 30	50
PORT		*RESULT*	*DETECTOR*	*CLASS*
INPUT	L	Passed	Pk, Qp	B
	N	Passed		

RESULTS DETAILS

Results are far enough from the limits to confirm that the board can pass the standard.

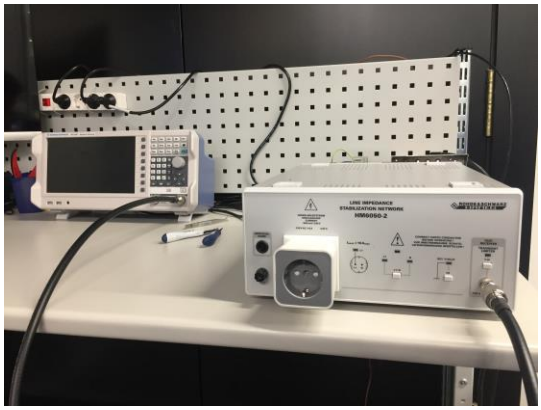


Figure 16: System set up

4.3.1 Input port: Live (L)

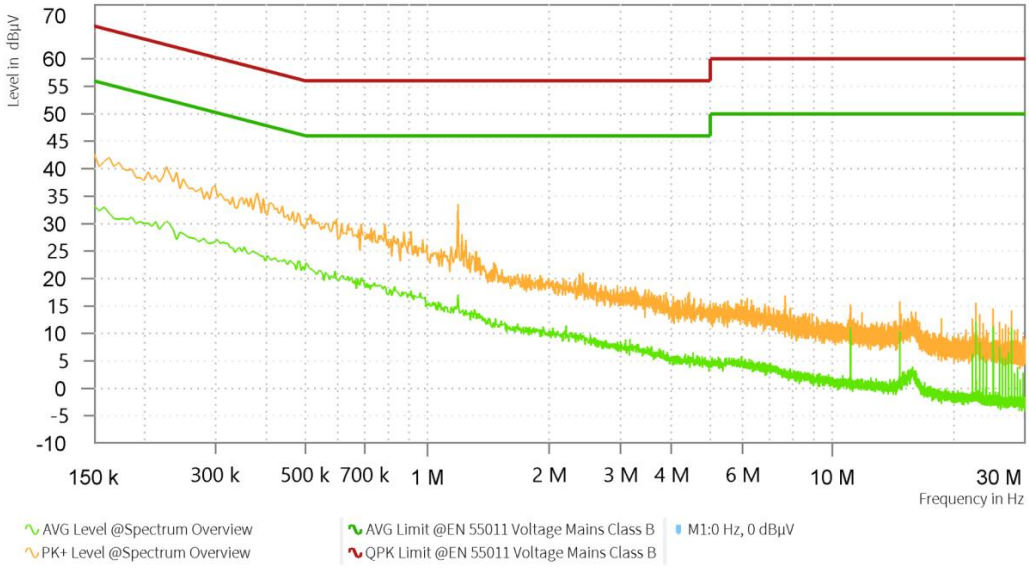


Figure 17: Live conducted emission spectrum

4.3.2 Input port: Neutral (N)

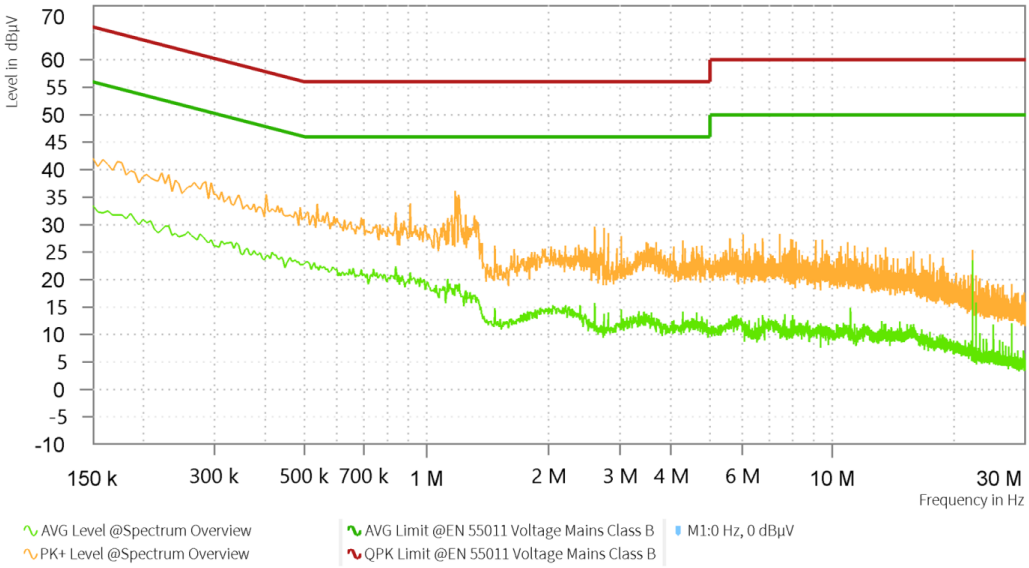


Figure 18: Neutral conducted emission spectrum

5 Start-Up

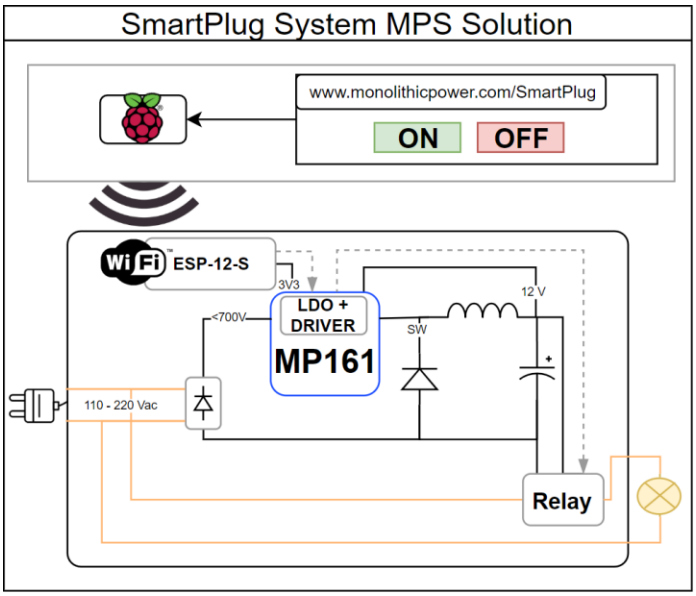


Figure 19: System components

Please follow the steps below to quick start the system.

1. Pre-set the AC power supply to 90 VAC ≤ VIN ≤ 265 VAC.
2. Turn the power supply off.
3. Modify the Wi-Fi credentials to allow the module access the router (Figure 20).
4. Connect the board and the PC with an FTDI 232-TTL converter interface (Figure 21).
    a. If the interface is **5V, do not connect pin 3 (VCC)** because the Wi-Fi module will be damaged. In this case turn on the AC power supply to program the device. The 3V3 will be generated by the internal LDO.
    b. Otherwise (3V3 output) the PC will supply the module and you can connect the VCC pin.

```
esp8266 §
// Load Wi-Fi library
#include <ESP8266WiFi.h>

// Replace with your network credentials
const char* ssid     = "XXXX";
const char* password = "XXXX";
```

Figure 20: Wi-Fi credentials.

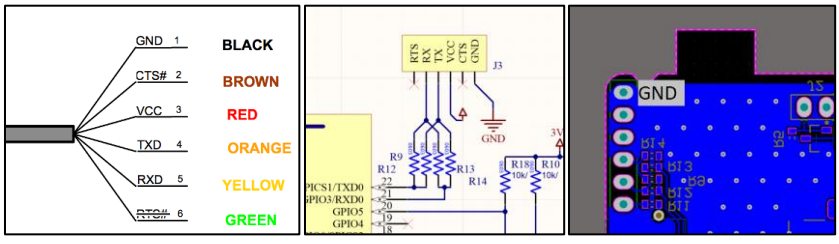


Figure 21: RX-TX interface.

5. Open the terminal and program the ESP8266 module. Once the process finishes (Figure 22) the module will send the IP address trough the communication port (Figure 23).

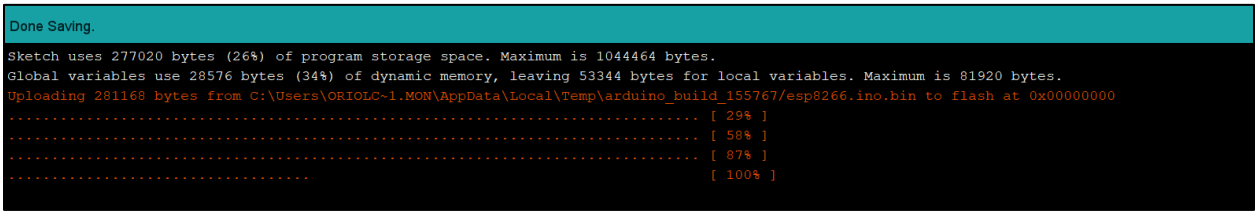


Figure 22: Programming LOG.

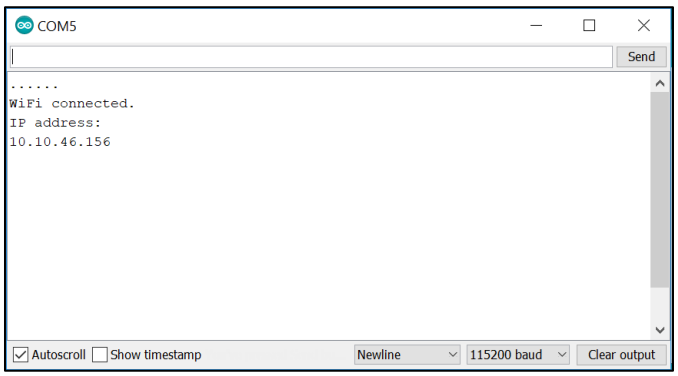


Figure 23: IP address assigned by the router to the module.

6. Then you can go to your browser with this IP and interact with the relay (Figure 24).

5.1 Web Layout

The web page interacts directly with the ESP8266 module. The module is connected with the integrated driver on the MP161 so once the user hits the button “GPIO 5” the relay will change their state.

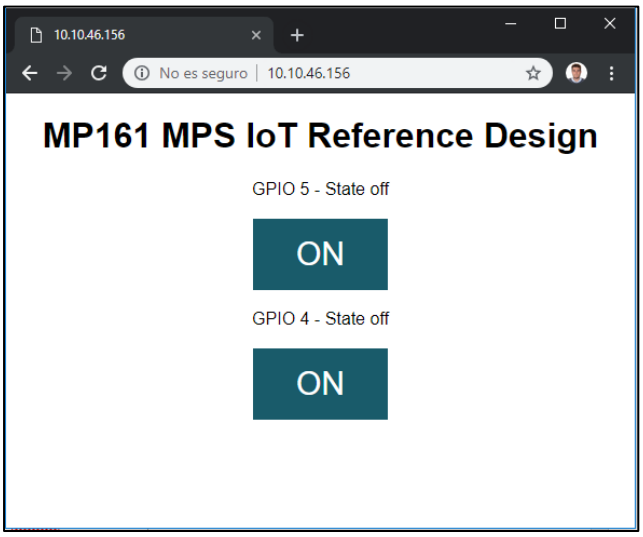


Figure 24: Web Layout

6 Disclaimer

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