Digital AC Energy Measurement Circuit V2 RMS Voltage, RMS Current, Real Power, Power Factor, Energy KWh

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Power Factor Energy KWh

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Disclaimer: Some parts of this circuit carry dangerous Mains voltage. If you are a beginner, seek guidance from experienced users.

Dealing with the 110V/220V AC mains voltage and measuring the AC load parameters are regarded as a challenge for electronic designers, both in circuit design and calculations. The situation becomes more complex when dealing with inductive loads because they cause a phase shift between voltage and current and alter the sine-wave shape of the AC signal (resistive loads do not). The power factor of resistive loads is theoretically equal to 1.

In this article/video, I introduce a circuit that can measure AC RMS voltage, RMS current, active power, power factor, and energy consumption (KWh) of the loads. I used a low-cost STM32 Microcontroller and provided four push buttons for initial calibration. The device can independently measure the parameters and display the results on a bright 1.3-inch OLED display. The measurement error rate is around 0.5% or lower.

For the schematic and PCB design, I use Altium Designer 23. I shared the PCB project with my colleague for feedback and edits through Altium 365's secure cloud space. The Octopart component search engine proves invaluable for obtaining component information and generating the Bill-of-Materials (BOM). To ensure the production of high-quality fabricated boards, I forwarded the Gerber files to PCBWay. I used the Siglent SDM3045X benchtop multimeter to calibrate the circuit. That's a quick and easy process.

It's a cool device for everyday electronics, so let's get started! :-)

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Circuit Analysis

Figure 1 shows the schematic diagram of the AC-Mains input and shunt resistor. P1 and P2 are input/output terminals for the AC input and load connection.

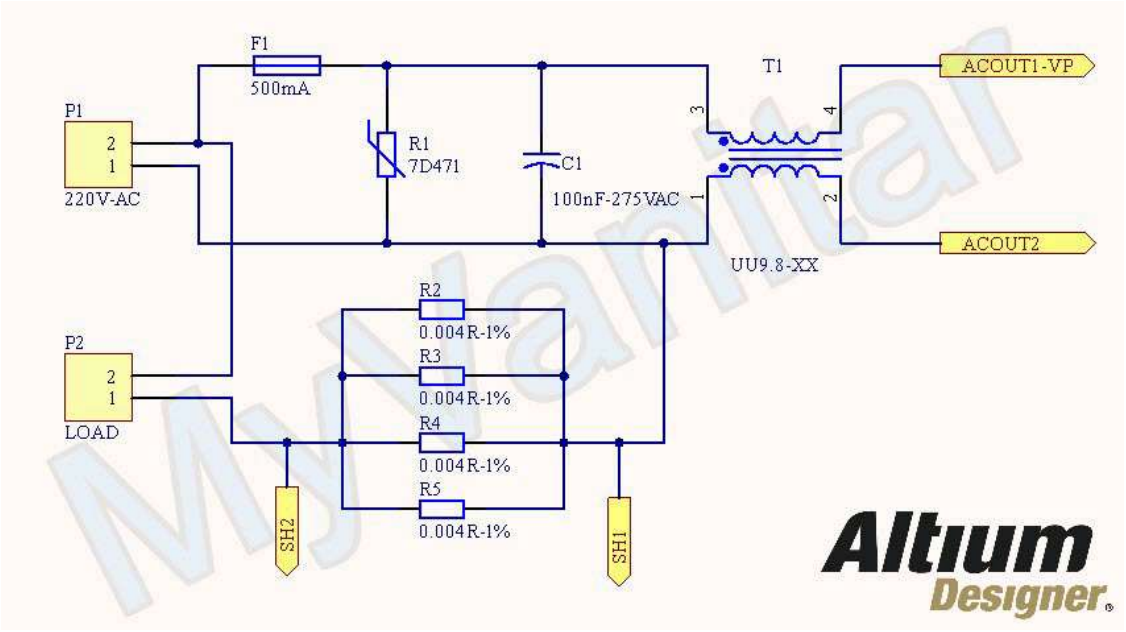

Figure 1

Schematic diagram of the AC input, Load terminal, shunt resistor, and input protection

F1 is a 500mA fuse [1] and R1 is the 7D471 varistor [2] to protect the device against high-voltage transients. T1 is a 10mH common mode choke [3] and C1 is a 100nF-X2 capacitor [4] to reduce the noise. The circuit shunt resistor should be a 1-milliohm resistor; however, the power rating of the shunt also matters. Therefore, you can use R2 … R5 resistors in parallel to increase the power rating of the shunt to up to 12W, by using four 4-milliohm 3W resistors in parallel. In my case, I used two 2-milliohm resistors in parallel.

Figure 2 shows the power supply section of the circuit, isolated output and non-isolated. The power supply of the measurement part should be non-isolated and referenced to one of the AC-Mains terminals.

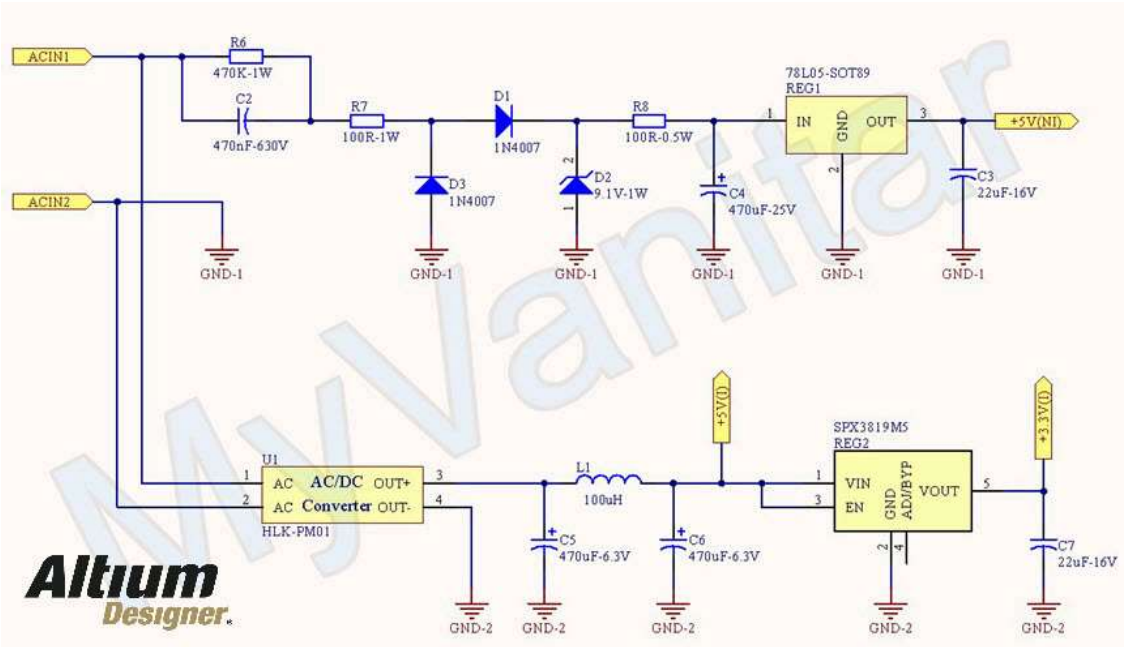

Figure 2

The power supply section of the circuit

C2 is a 470nF-630V capacitor [5] to reduce the AC voltage. R6 discharges the capacitor at power OFF. D1 and D3 are 1N4007 [6] diodes to rectify the AC voltage and D2 reduces to voltage to be applied to the 78L05 [7] regulator. U1 is

the HLK-PM01 [8] AC to DC conversion module that converts 220V-AC to 5V-DC. C5, L1, and C6 create a Pi network to reduce the noise REG2 is the SPX3819M5 regulator [9] to prepare a 3.3V supply rail. C7 stabilizes the output of the regulator.

Figure 3 shows the measurement part that consists of the HLW8032 chip, PC817 optocoupler [10], and some passive components.

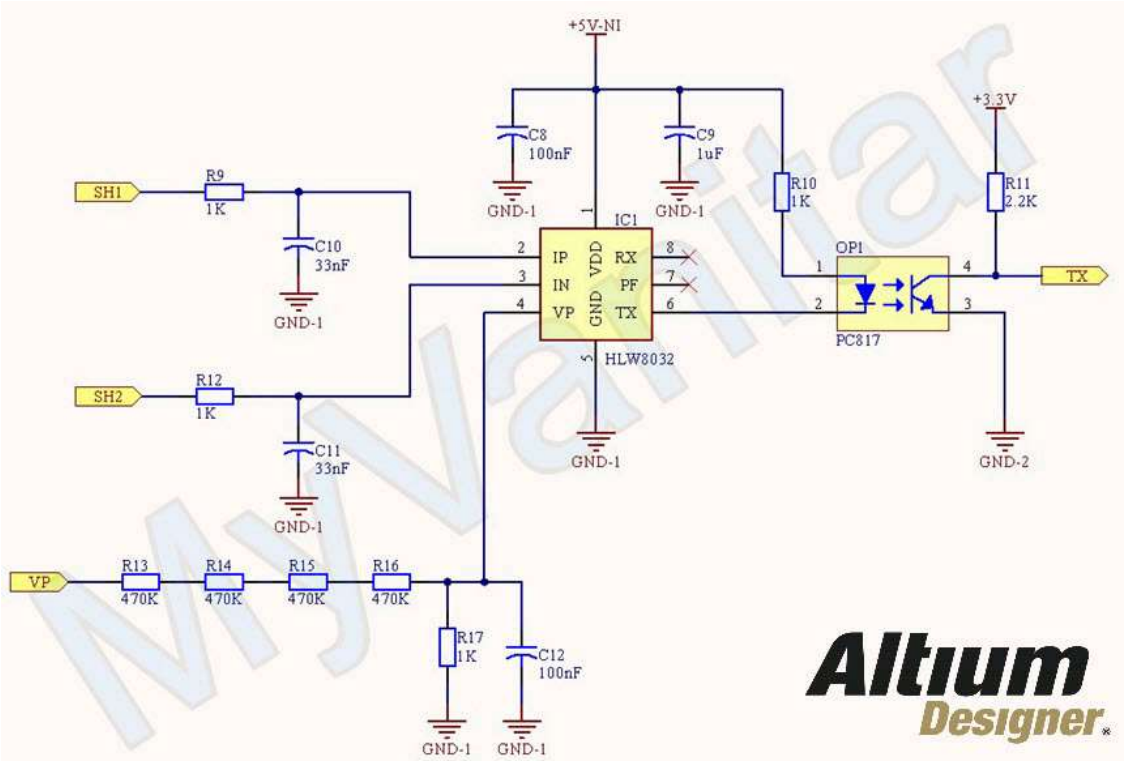

Figure 3

The measurement section of the circuit

C8 and C9 are decoupling capacitors to reduce the noise of the IC1 supply. R10 limits the current of the optocoupler diode and R11 is a pull-up resistor for the collector of the transistor. R13 … R17 resistors reduce the input voltage to be applied to the IC1 and C12 reduces the high-frequency noise.

Figure 4 shows the microcontroller section of the board which mainly consists of the STM32G030F6 microcontroller [11]. R18 … R21 are pull-up resistors and C13 … C16 are debouncing capacitors for SW1 … SW4. OCS is the 16MHz oscillator XO [12] to prepare the clock for the MCU. T2, T3 [13], R22, and R23 are used for level conversion between the MCU and the OLED display module.

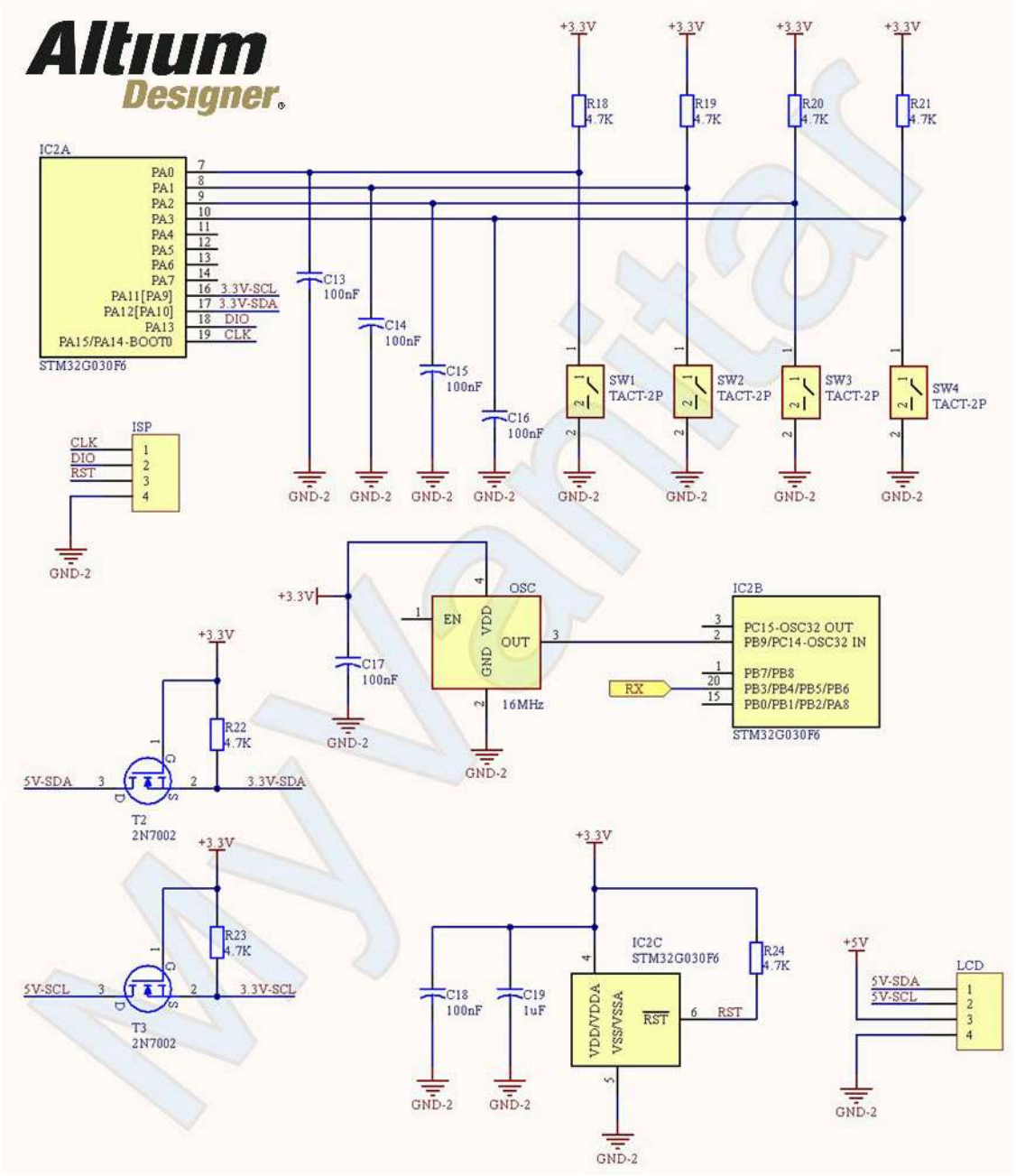

Figure 4

The microcontroller section of the circuit

PCB Layout

Figure 5 shows the PCB layout of the design. It's a two-layer PCB board with a mixture of SMD and through-hole components. Figure 6 shows the wiring diagram of the board. Figure 7 shows the assembled board. If you are a beginner or have no time to purchase and solder the components yourself, you can order the board assembled.

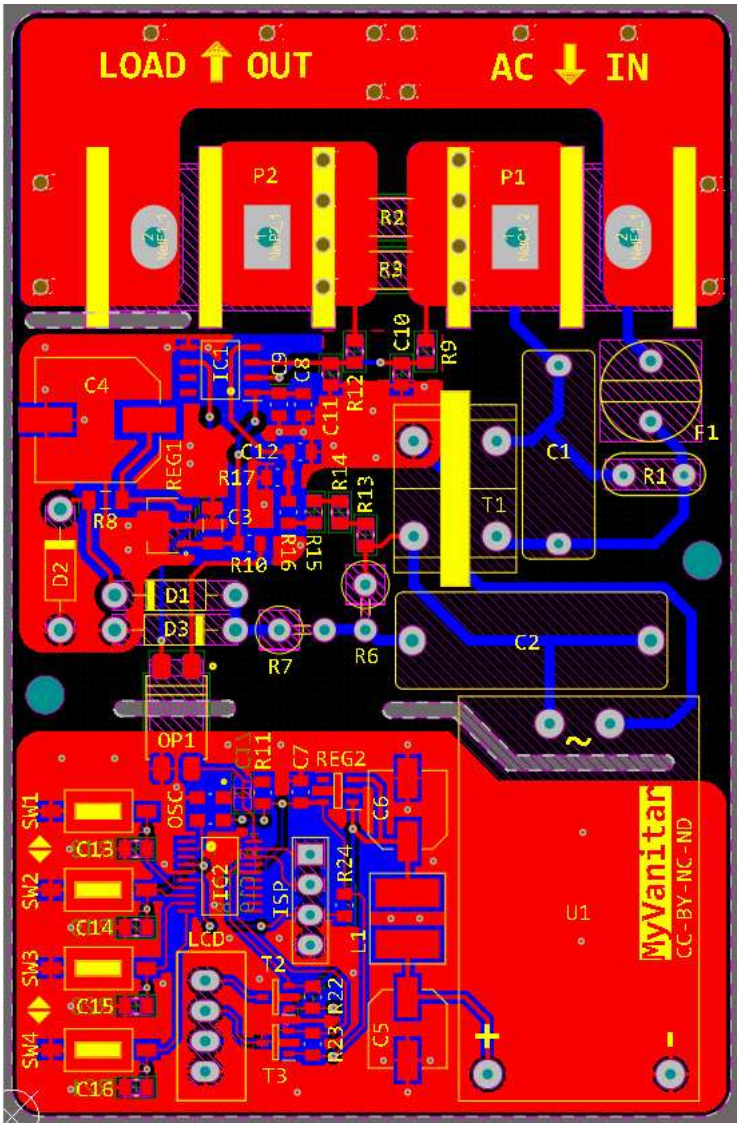

Figure 5

PCB layout of the AC energy meter circuit

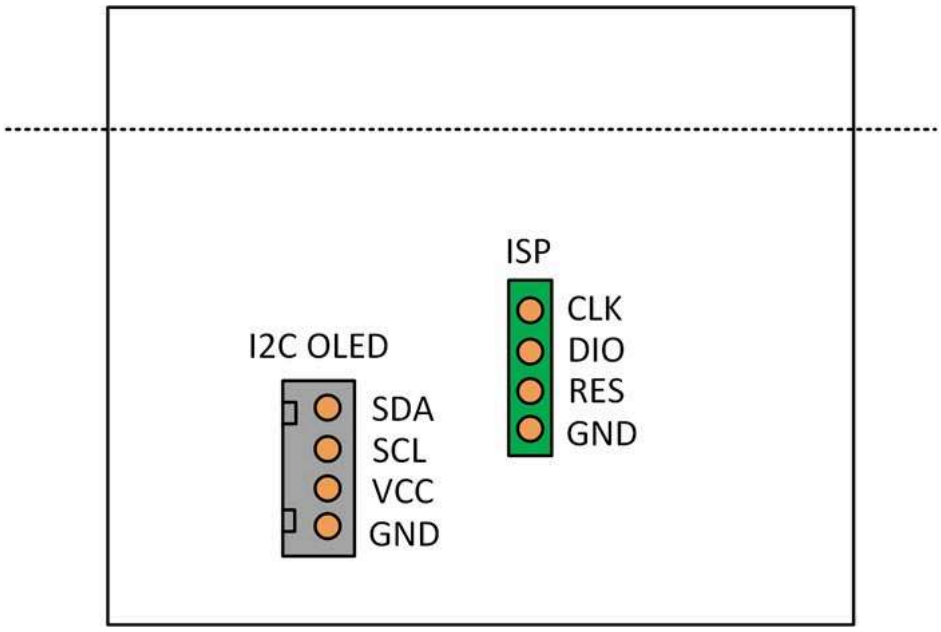

Figure 6

Wiring diagram of the AC energy meter circuit

Figure 7

Assembled PCB board of the AC energy meter circuit

Calibration & Code

To calibrate the board, you need to have an accurate True RMS multimeter. Please watch the YouTube video completely for more information. You can download the compiled HEX file from here [14].

Bill of Material

Figure 8 shows the bill of materials. Octopart website provides free tools to build any kind of BOM.

Octopart

*Designator	*Qty	*Mfg Part #	Description / Value
C1	1	SMQP104K275XXD2B1515	100nF ±10% X2 275V P=15mm Suppression Capacitors
C2	1	KP474J2J2001	470nF ±5% 630V Plugin,P=20mm Polypropylene Film Cap
C3	1	CL31A226KOHNNNE	22uF-16V X5R ±10% 1206 Multilayer Ceramic Capacitors
C4	1	RVT1E471M1010	470uF-25V Aluminum Electrolytic Capacitor
C5, C6	2	RVT0J471M0607	470uF-6.3V Aluminum Electrolytic Capacitor
C7	1	CL21A226MQQNNNE	22uF-6.3V X5R 0805 Multilayer Ceramic Capacitors
C8, C12, C13, C14, C15, C16, C17, C18	8	C0805B104K500NT	100nF-50V X7R ±10% 0805 Multilayer Ceramic Capacitors
C9, C19	2	CL21B105KAFNNNE	1uF-25V X7R ±10% 0805 Multilayer Ceramic Capacitors
C10, C11	2	0805B333K500NT	33nF-50V X7R ±10% 0805 Multilayer Ceramic Capacitors
D1, D3	2	1N4007	1A 1000V 1.1V@2A DO-41 Diodes
D2	1	1N4739A,113	±5% 1W 9.1V DO-41 Zener Diodes ROHS
F1	1	37205000431	Fuse Subminiature Fast Acting 0.5A 250V Radial 8.5 X 8mm
IC1	1	HLW8032	SOP-8 Energy Metering Ics
IC2	1	STM32G030F6P6	32KB Flash ARM Cortex-M0 8KB RAM 64MHz Microcontroller
ISP	1	HB-PH3-25414PB2GOP	2.54mm Brass Black Plugin 1x4P 2.54mm Plugin
L1	1	HPC6045NF-221M	500mA 220uH ±20% SMD Power Inductors
LCD	1	XH-4A	1x4P XH P=2.5mm Wire To Board
OP1	1	PC817B	SMD-4P Optocouplers
OSC	1	CF4016M00012	16MHz 12pF ±10ppm 3225 Crystals
P1, P2	2	KF45C-9.5-2P	32A 750V Black 1x2P Midfoot Double Terminal
R1	1	RM07D471KC1IE100	300V Plugin,P=5.08mm Varistors
R2, R3, R4, R5	4	LR2512-23R004F4	3W 4mΩ ±25ppm/℃ ±1% 2512 Current Sense Resistors
R6	1	MO1WS-470K±5%-2T52	470kΩ 1W ±350ppm/℃ ±5% Plugin Through Hole Resistor
R7	1	CR1WS-100Ω±5%-XT52	100Ω 1W ±350ppm/℃ ±5% Plugin Through Hole Resistor
R8	1	FRP1206J101 TS	100Ω 0.5W 1206 Chip Resistor
R9, R10, R12, R17	4	0805W8F1001T5E	1kΩ 1% 125mW 0805 Chip Resistor
R11	1	0805W8F2201T5E	±1% 2.2kΩ 0805 Chip Resistor
R13, R14, R15, R16	4	0805W8F4703T5E	±1% 470kΩ 0805 Chip Resistor
R18, R19, R20, R21, R22, R23, R24	7	0805W8F4701T5E	4.7kΩ 1% 125mW 0805 Chip Resistor
REG1	1	78L05	**SOT-89** 5V Linear Voltage Regulators
REG2	1	SPX3819M5-L-3-3/TR	SOT-23-5 3.3V Linear Voltage Regulators
SW1, SW2, SW3, SW4	4	TS-1007S-AR02516	Brick nogging SPST SMD Tactile Switches
T1	1	UU9.8-10mH	10mH 1kHz 800mΩ 2 Plugin Common Mod s
T2, T3	2	2N7002	350mW N Channel SOT-23(TO-236) MOSF
U1	1	HLK-PM01	AC-DC 5V-DC Plugin Power Modules

Figure 8

Bill of materials of the AC energy meter circuit

References

[1]: Littelfuse 500mA: https://octopart.com/37005000410-littelfuse-39623899?r=sp

[2]: MOV-07D471K: https://octopart.com/mov-07d471ktr-bourns-19184728?r=sp

[3]: Bourns 7355-H-RC: https://octopart.com/7355-h-rc-bourns-12614152?r=sp

[4]: 100nF-X2: https://octopart.com/r46kf310000p1m-kemet-20074740?r=sp

[5]: 470nF-630V: https://octopart.com/ecw-fa2j474j-panasonic-22311695?r=sp

[6]: 1N4007: https://octopart.com/ecw-fa2j474j-panasonic-22311695?r=sp

[7]: 78L05 SOT89: https://octopart.com/ua78l05acpk-texas+instruments-525167?r=sp

[8]: HLK-PM01: https://octopart.com/hlk-pm01-hi-link-122345845?r=sp

[9]: SPX3819M5: https://octopart.com/spx3819m5-l-3-3%2Ftr-maxlinear-94414540?r=sp

[10]: PC817: https://octopart.com/pc817x1nip1b-sharp-80968503?r=sp

[11]: STM32G030F6: https://octopart.com/stm32g030f6p6-stmicroelectronics-103773023?r=sp

[12]: 16MHz XO: https://octopart.com/ecs-3225mv-120-cn-tr-ecs+international-95544585?r=sp

[13]: 2N7002: https://octopart.com/2n7002-diotec-109206764?r=sp

[14]: HEX File: https://drive.google.com/file/d/1YjMJoeoZTZRZ4UXn3D2VWpdxdK30F0ar/view?usp=sharing

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مثلا batt : 27 V ac :220 V I : 13 A P: 4300 W

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