AN-2122 SM3320-RF-EV Reference Design

ABSTRACT

The SolarMagic™ SM3320-RF-EV reference design integrates a power optimizer and a low-cost 2.4GHz radio to add a remote shutdown feature to a PV system. The remote shutdown feature can be used during installation, maintenance, or emergency situations to de-energize the PV system.

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1 Introduction

Although its principal purpose is to communicate shutdown intent, this RF system is 2-way and can be used for a wide variety of communication applications, including monitoring, security and identification.

The SolarMagic SM3320-RF-EV is based off of the SM3320-1A1 power optimizer, and shares all of its best-in-class power optimization features. This includes its ability to mitigate real-world mismatch, its 99.5% peak efficiency, and its Panel-Mode operation. In addition, the same ultra-low profile form factor of the original SM3320-1A1 is maintained so that it can be integrated into the same junction box designs. This evaluation board should work as a power optimizer even without a transmitter

The wireless RF communications in the SM3320-RF-EV is implemented using a low-cost Nordic nRF24LE1 chip. This is a low-cost, 2.4GHz radio and 8051 microcontroller on a single chip. The 2.4GHz radio uses narrow band modulation (as opposed to direct sequence spread spectrum), which can be used either with or without frequency hopping. Example software is provided that implements the remote shutdown feature on the 8051 microcontroller in the nRF24LE1.

One of the unique features of the SM3320-RF-EV is its use of the DC power lines as an RF antenna and transmission line. This enables the SM3320-RF-EV to maintain radio communication even when it is mounted in the junction box of the module. This antenna design can be used with other 2.4GHz radio chipsets besides the nRF24LE1 by straightforward modification of the provided design files.

The SM3320-RF-EV reference design provides a flexible platform for developing value added features in firmware with no additional hardware development. Examples of these features include module-level monitoring, security (theft-detection and theft-deterrence), and identification. Similarly, firmware development on this platform can be used to customize the SM3320-RF-EV to be compatible with an existing monitoring system or inverter communication protocol if a customer desires.

SolarMagic technology is an overall solution that works in existing and new installations, residential, commercial, and utility scale projects. Texas Instruments 50 years of experience in the electronics industry delivers unsurpassed manufacturing, design, and development technology.

2 System Overview

Figure 1 depicts how the SM3320-RF-EV design would be implemented in its intended application. In this example, every module is connected to an SM3320-RF-EV power optimizer. Under normal conditions, the central transmitter sends a signal to each SM3320-RF-EV power optimizer indicating that it is ok to operate and output power. When an emergency condition occurs, the central transmitter will send a signal command to all the SM3320-RF-EV to shutdown. This de-energizes the output of each SM3320-RF-EV, and in doing so brings down the voltage of the DC bus and all DC wiring to a safe voltage level.
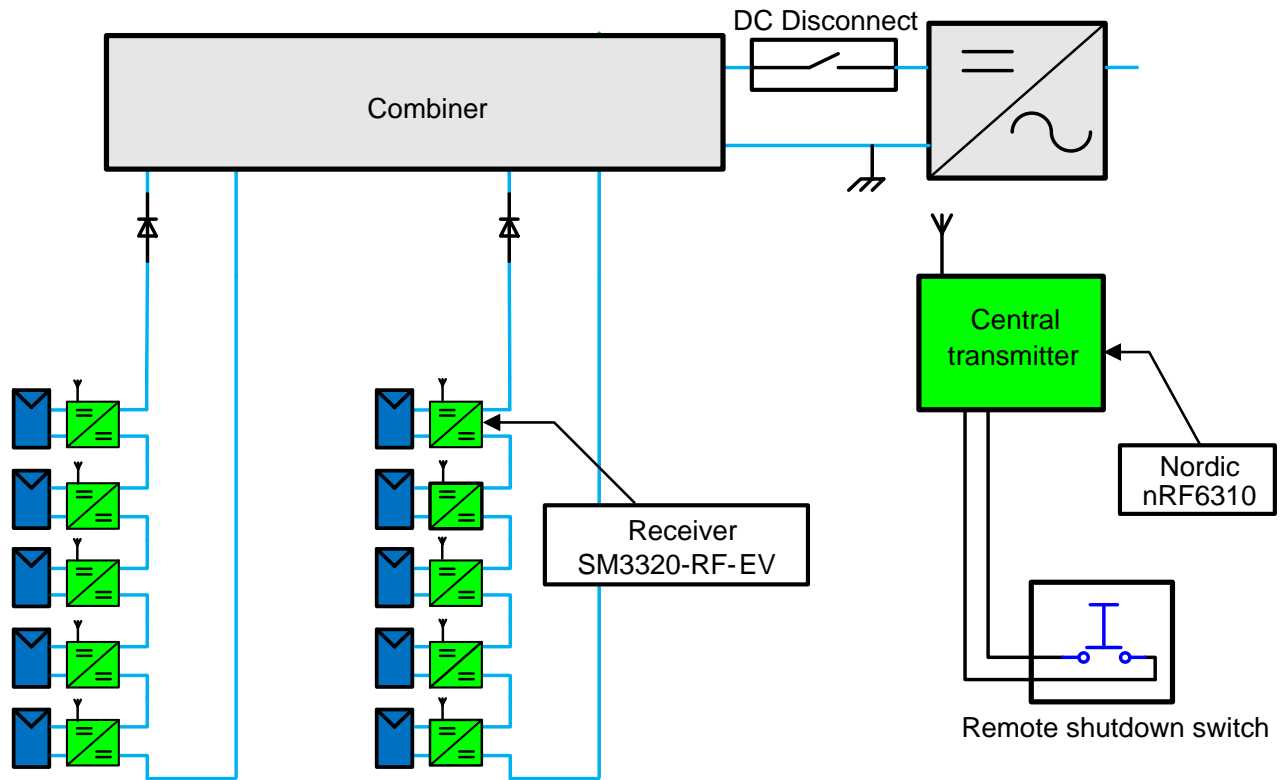
Figure 1. System Overview Showing Intended Application of SM3320-RF-EV Board in a PV System

3   SM3320-RF-EV Design Specification

Table 1. SM3320-RF-EV Design Specification

Symbol	Parameter	Min	Typ	Max
V_{MPP}	PV Module MPP Voltage	15 Vdc		40Vdc
P_{MPP}	PV Module Power	10 W		350 W
V_{OC}	PV Module Open Circuit Voltage			50 Vdc
I_{SC}	PV Module Short-Circuit Current			11A
V_{OUT}	Output Voltage	0 Vdc		43 Vdc
I_{OUT}	Output Current			12.5A
OVP	Overvoltage Protection Threshold		45V	
OTP	Overtemperature Protection Threshold		125ºC	
MPP_{EFF}	MPP Efficiency		98.5%	
PM_{EFF}	Panel-Mode Efficiency		99.5%	

3.1   SM3320 RF-EV Kit

Included in the SM3320-RF-EV are the following items:

• SM3320-RF-EV PCB
• Software for the Receiver (SM3320-RF-EV) – compiled and source code
• Software for the Central Transmitter (nRF6310) - compiled and source code
• Design files – Schematic, BOM and Gerbers

In order to get started as quickly as possible with this kit, users are recommended to purchase a Nordic nRF6310 motherboard. Using the included Central Transmitter sample code will enable users to test the enable/disable and Panel-Mode functionality.

3.2 Features

- Wireless shutdown for SM3320-1A1
- Wireless Panel-Mode operation for SM3320-1A1
- MPPT for Photovoltaic Panel
- 2.4 GHz ISM band operation
- Enhanced 8 bit 8051 compatible microcontroller
- Power line antenna

3.3 Design Description

The Sirius RF evaluation board shares the same power specifications as the SolarMagic SM3320-1A1 Power Optimizer. The controller for the power optimizer consists of an SM72442 programmable MPPT controller for PV panels and a Nordic nRF24LE1 low power system-on-chip wireless solution. The nRF24LE1 has a built in 2.4GHz transceiver (250kbps, 1Mbps and 2Mbps air data rates) and an 8051 compatible microcontroller. Operation at 250kbps is recommended.

3.3.1 Receiver

The nRF24LE1 IC will be located in the SM3320-RF-EV board and used as a receiver that controls the forced shutdown and Panel-Mode operation.

By utilizing these two ICs (SM72442 and nRF24LE1),the evaluation board is capable of tracking the maximum power point of PV panels during normal operation as well as controlling a shutdown during emergency conditions. Two of the GPIO outputs (P0.0 and P0.1) from the microcontroller are used to send a shutdown or Panel-Mode signal into the SM72442. The shutdown signal will pull the RESET pin low in order to deactivate the PWM signals that are coming out from SM72442. Panel-Mode operation can be forced on the SM72442 by pulling the PM pin of the SM72442 low.
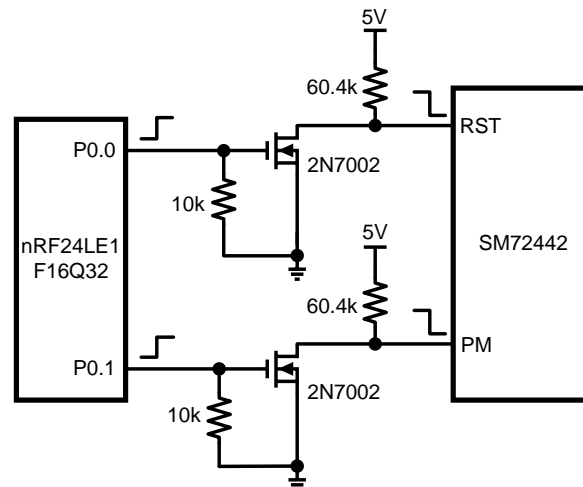
Figure 2. Forced Panel-Mode and Reset Using nRF24LE1

Figure 2 shows one sample application where the GPIO outputs of nRF24LE1 are used to force a reset or Panel-Mode condition on the SM72442. The nRF24LE1 radio uses the power line as an antenna by coupling into the output wire of the SM3320-RF-EV. This implementation is shown on Figure 3. In order to not short the output of the radio to ground, an air wound inductor (L104 in schematic) is placed between the OUT (-) terminal and the actual string wire. The inductor, together with the capacitors to ground at the DC power feed (C116) and the series capacitor between it and the RF transceiver device (C113), create an LC Network to couple RF in and out of the string wire terminal without shorting it to the DC power feed, and at the same time carrying the DC from the power feed to the string wire. The other string wire has a capacitor (C117) to ground to provide a return for the RF through the ground planes to the RF transceiver device. The dimensions for the air wound inductor are attached in Figure 4. This inductor introduces approximately 10 dB loss at 2.4 GHz. For better manufacturability, the inductor can be redesigned with a core so it is smaller. It still needs to carry the full string current
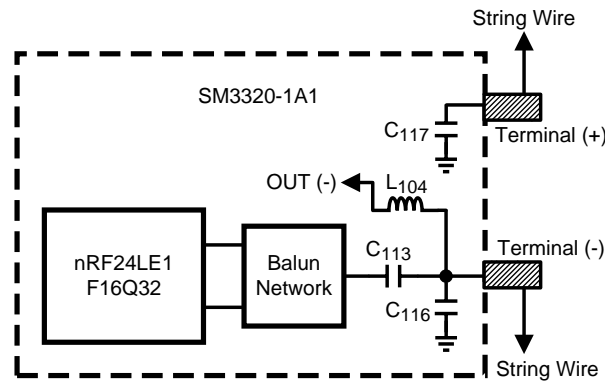
Figure 3. Power Line Antenna Implementation
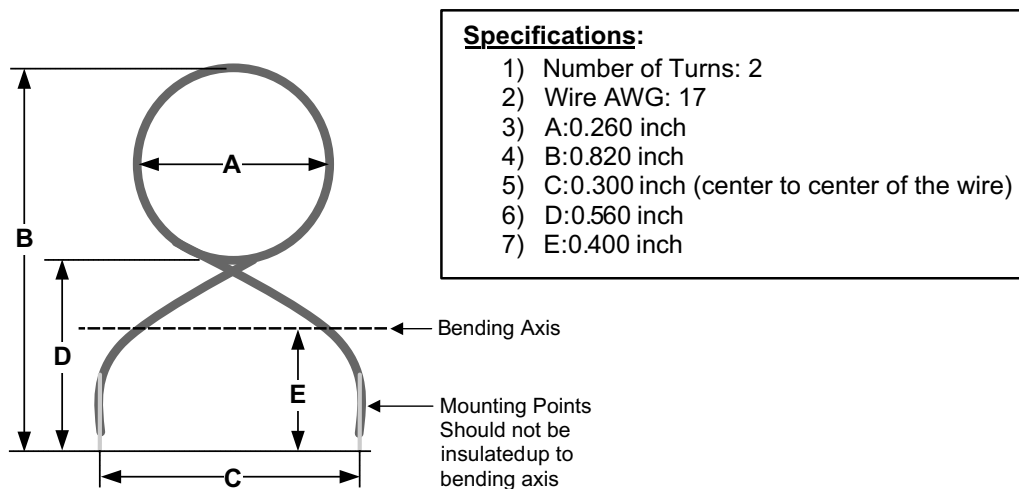
Figure 4. Inductor Dimension

Specifications:
1) Number of Turns: 2
2) Wire AWG: 17
3) A:0.260 inch
4) B:0.820 inch
5) C:0.300 inch (center to center of the wire)
6) D:0.560 inch
7) E:0.400 inch

3.3.2 Central Transmitter

For this evaluation board, a Nordic module (nRF2723) is used as a transmitter. In general, any Nordic RF module with an nRF24xx IC and external antenna connection can be used as a transmitter, however additional software development could be required. To minimize programming and hardware development time, the transmitter can be made of a Nordic RF module with nRF24xxIC along with Nordic Motherboard (nRF6310), which is included in the Nordic starter kit nRF6700. You can download the transmitter.hex file included in this kit onto the Nordic module in order to use it as a transmitter to send a shutdown or Panel-Mode signal towards the receiver. The motherboard has buttons that can be manually connected to the GPIO pins from the module. By doing this, the transmitter module will receive button input from you and send an appropriate signal towards the receiver located on the SM3320-RF-EV board.

Both sample codes and hex files for the receiver and transmitter are provided in the .zip file.

3.4 Flash Programming

A Nordic Motherboard (nRF6310) is required to program the transmitter and receiver ICs. The sample code and hex files provided can be used as a start to program both ICs. Please remove R101 and R102 from the board before downloading the .hex file into the receiver. The receiver IC in the SM3320-RF-EV board is pre-programmed with functions to enter a reset condition or to operate into a forced Panel-Mode condition. Logic high will appear on P0.0 and P0.1 of the receiver IC once an appropriate signal command is received from the transmitter. You also have the flexibility to program the Flash memory in the receiver IC by using the 10 pin connector (J101 on schematic) located in the board. These 10 pins should be connected with the external ISP interface on the Nordic Motherboard (nRF6310) to enable the in-circuit programming. Table 2 shows the table of pinouts for the 10 pin header on SM3320–Rf-EV board and an external ISP interface from the Nordic Motherboard.

Table 2. Pinouts for 10 Pin Headers and Nordic Motherboard

Pin	10 Pin Headers	Nordic Motherboard (nRF6310)
1	P0.4	RF_VDD
2	PROG	Not Used
3	SCK	PROG
4	GND	CSN
5	MOSI	MOSI
6	GND	RESET
7	MISO	MISO
8	3.3VDC	SCK
9	CSN	Not Used
10	RESET	GND

Each of the pins of the 10 pin header should be connected to the appropriate pin on the Nordic Motherboard. Pin 1 of the 10 Pin Header can either be connected to pin 2 of the Nordic Motherboard or it can be left floating during programming. All of the other pins on the header should be connected to its appropriate pin on the Nordic nRF6310 external interface. For example pin 2 on the header should be connected to pin 3 of the Nordic nRF6310. The SM3320-RF-EV kit also provides a schematic and gerber file for a connector board, which will aid in the programming between the receiver IC and the Nordic nRF6310 motherboard, as shown in Figure 5. You can then download your own hex file into the Flash memory of nRF24LE1 that is located on the SM3320-RF-EV board.

The RF_VDD (pin 1 of nRF6310) should be connected to the 3.3VDC (pin 8 on SM3320–RF-EV). Since the RF_VDD pin is used as a signal level shifter on the Nordic Motherboard, the power supply voltage from the motherboard does not need to match the power supply voltage from the application board (SM3320-RF-EV in this case). However, an input voltage of minimum 15V should be applied to the SM3320-RF-EV in order to provide a 3.3VDC voltage on pin 8 of the header.
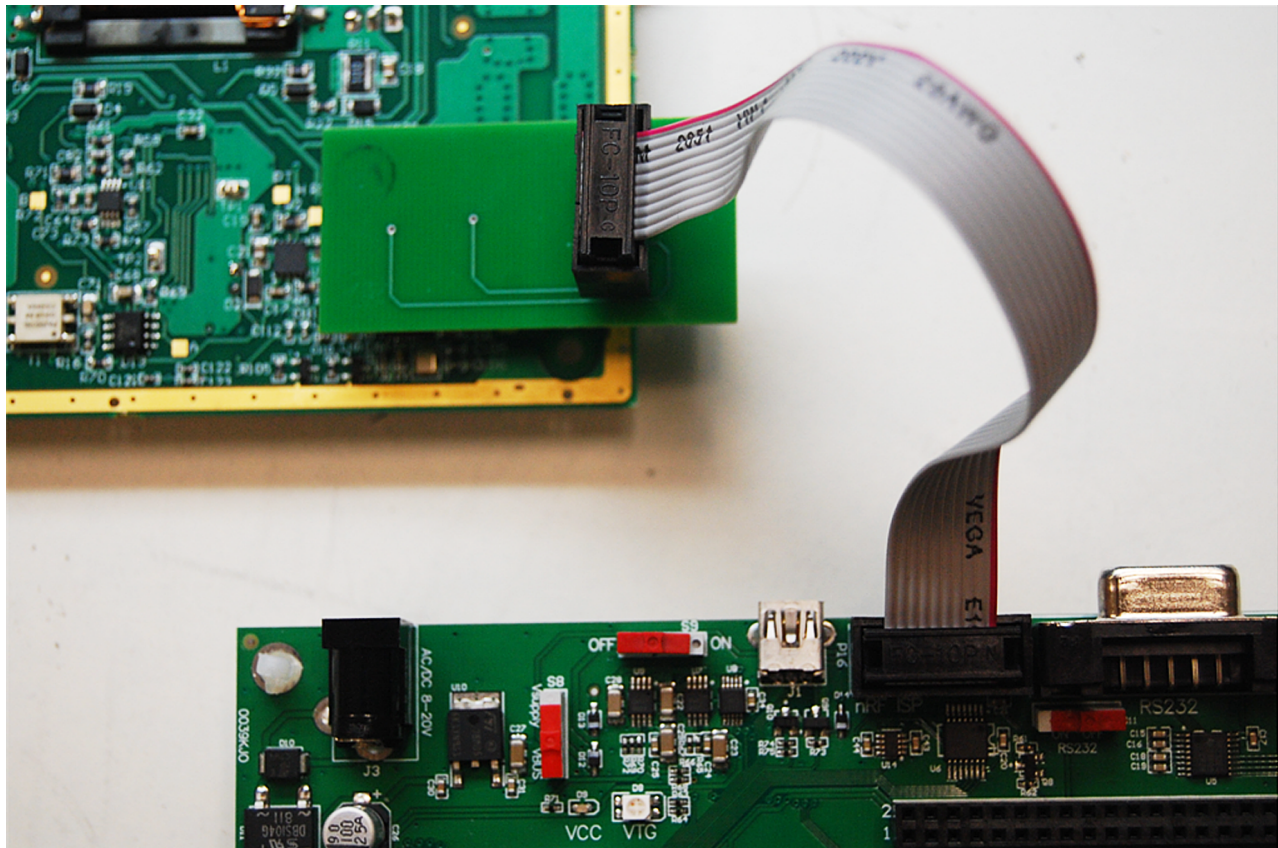
Figure 5. Connector Board interface

In order to start programming on the nRF radio IC, the following software has to be downloaded:

1. µVision IDE from Keil

2. nRFgo Studio

The nRFgo Studio is provided on the nRFgo Starter Kit (nRF 6700). The nRFgo Studio will download the .hex file generated by µVision IDE into the flash memory on the receiver. To program the flash using the external ISP interface from the motherboard, an nRF ISP interface has to be manually selected in the nRFgo Studio. A complete download of the hex file into the IC is indicated by a successful verification of the flash memory. Note that both R101 and R102 (see Section 4) on the SM3320-RF-EV board have to be removed during the programming.

3.5   *I2C Interface*

Using a connector board that is supplied in this kit, you have the ability to access the SCL and SDA pins on the SM72442 as well as W2SCL (P0.4) and W2SDA (P0.5) on the 32 pin nRF24LE1. Pin 1 and 3 on the 10 Pin Header are connected to P0.4 and P0.5 respectively through R101 and R102, see Section 4. Please make sure that both resistors are assembled on the SM3320-RF-EV board. The SM72442 and nRF24LE1 are cond as a slave. A master can be used to communicate to SM72442. External pull-up resistor of 2kΩ to 3.3V is required. The address for SM72442 is 1 whereas the address for the nRF24LE1 can be cond using setting the address W2SADR on the SFR register (for more information, see the nRF24LE1 data sheet from Nordic Semiconductor). The I2C protocol for communicating with *SM72442 can be found on the SM72442 Programmable Maximum Power Point Tracking Controller for Photovoltaic Solar Panels Data Sheet* (SNVS689).

3.6   Layout Consideration

- RF IC layout assumes an adjacent ground plane. If the adjacent layer is a power plane, a bypass capacitor should be added between ground and power plane in the vicinity of the RF IC. In our case, three 0.01µF and three 100pF capacitors are connected between ground and the power plane, and are placed near nRF24LE1.

- The distance from an RF trace and a plane around it should be at least two times the width of the RF trace to avoid co-planar coupling that lowers the line impedance, unless co-planar ground flood is included in the calculation.

- The trace going into the crystal oscillator should be wide enough (~15 mils in our case) to reduce the line inductance for more reliable starting at low temperature. On the other hand, increasing these traces should also increase the line capacitance to ground, which can affect starting as well. However, this effect can be counteracted by reducing the value of C105 and C106.

3.7   Heatsinking

SM3320-RF-EV evaluation board does not come with a heatsink. Therefore, in order to run the evaluation board at elevated power ratings, an appropriate heatsink should be added on Q1, Q2, Q3 and Q4 as well as diode D1. Care must be taken prevent electrical contact between the drains of the MOSFETs in the process of proper heatsinking. At elevated power operation please note the increase in temperature across these semiconductor devices.

3.8   Test Setup

To perform an evaluation on a single SM3320-RF-EV, it is suggested that you connect the input to a solar array simulator (SAS) and the output to a load bank.
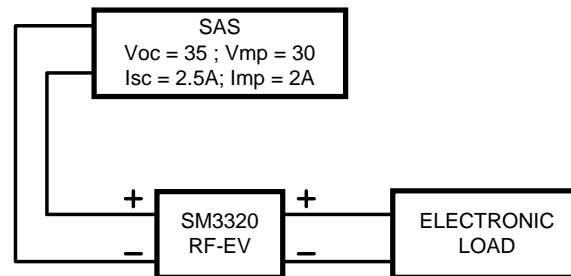
Figure 6. Test Setup for SM3320-RF-EV

Listed below are example settings for the SAS and electronic load:

3.8.1   SAS

Voc = 35V; Vmp = 30V; Isc = 2.5A; Imp = 2A.

Electronic Load: Constant Current Mode (CC) at 1.5A

3.8.2   Test Results
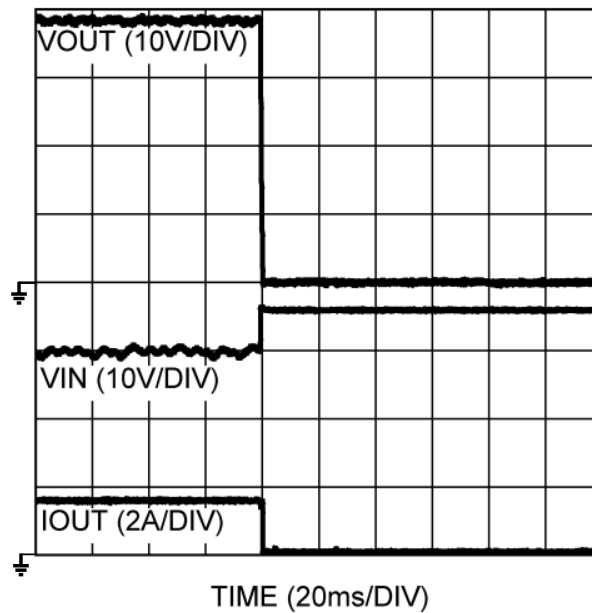
Figure 7. RF Shutdown

When the electronic load is turned on at 1.5A load current, SM3320-RF-EV will operate in Panel Mode for at least 128 seconds. After this period, the MPPT mode is then entered. During MPPT, the output voltage is at 38V with an input voltage of 30V. Once the shutdown signal is received by the receiver, one of the Nordic GPIO output will pull the reset line down causing the SM3320-RF-EV to stop switching and resulting the output voltage will go down (Figure 7).

4   Schematic
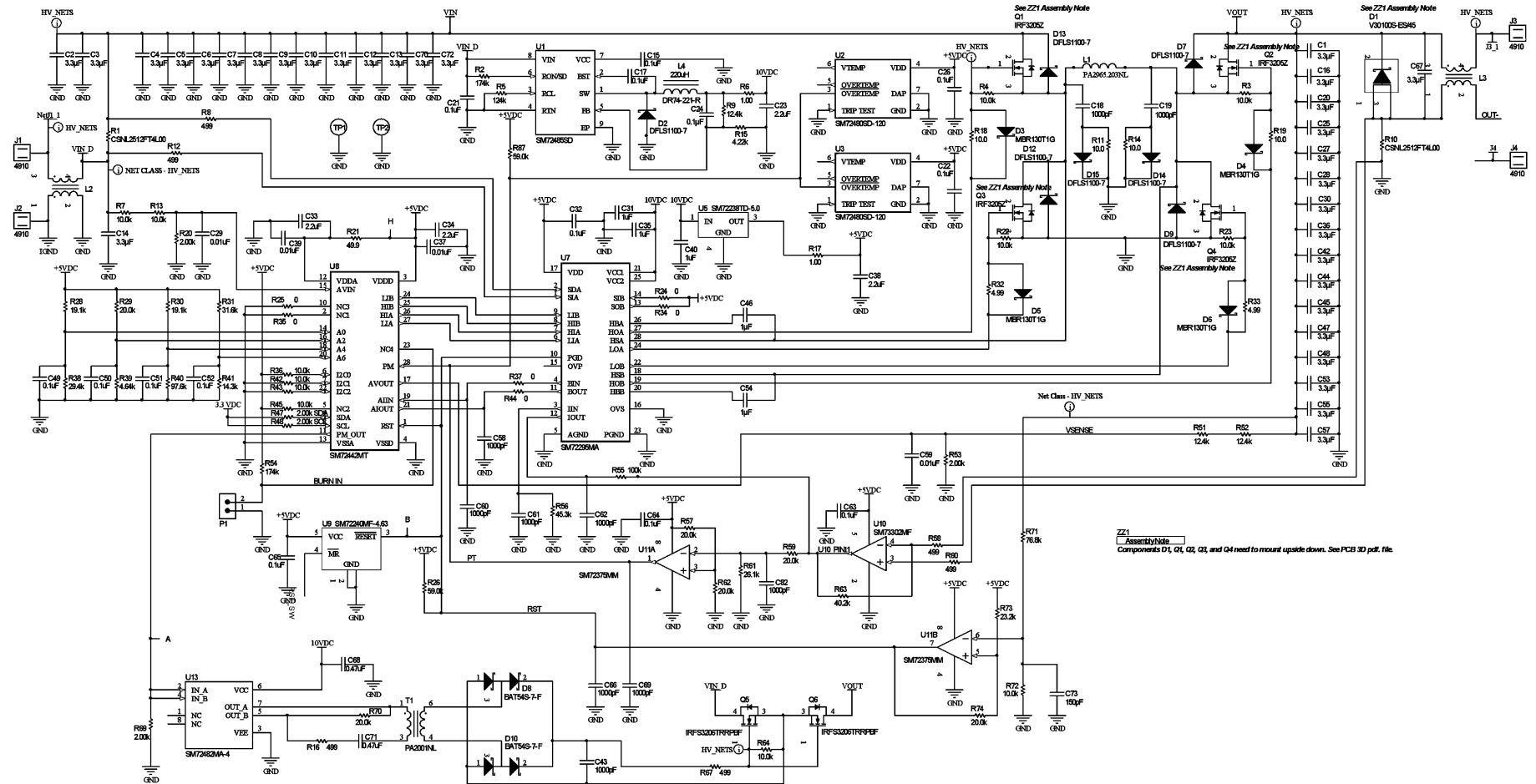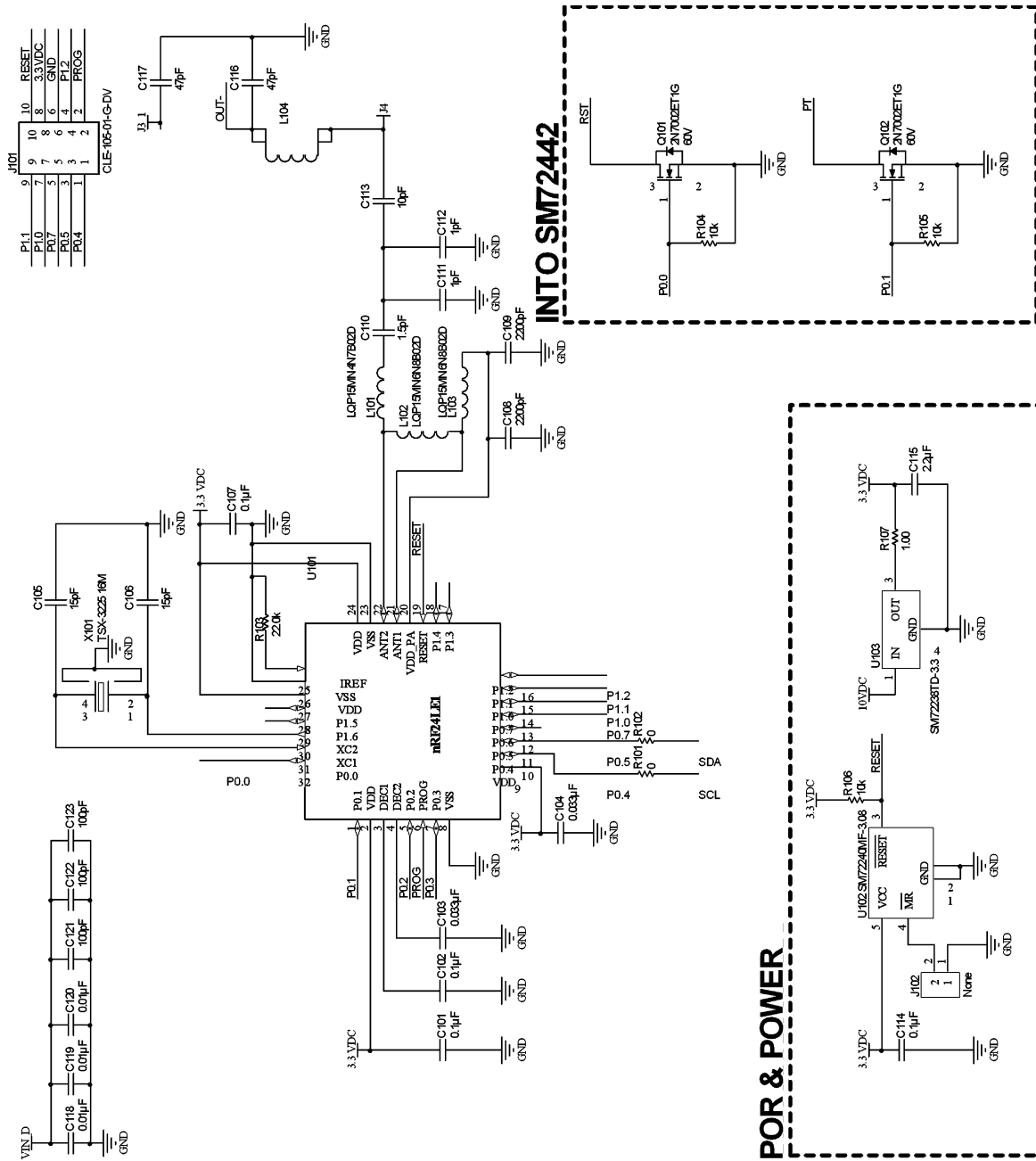
5 References

- *SM72442 can be found on the SM72442 Programmable Maximum Power Point Tracking Controller for Photovoltaic Solar Panels Data Sheet* (SNVS689)
- nRF24LE1 data sheet from Nordic Semiconductor

IMPORTANT NOTICE

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