SolarMagic RD-195 DC Arc Detection Evaluation Board

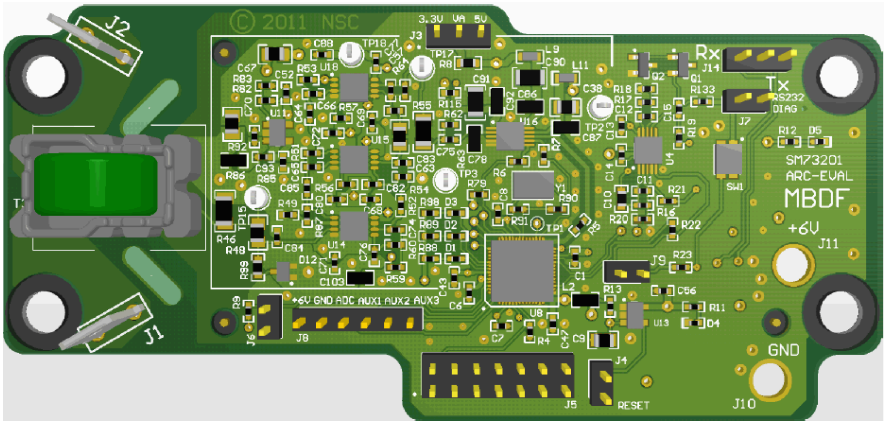
Texas Instruments
Application Note 2154
Florent Boico, Chris Oberhauser, Mike Stout, Jason Seitz
June 20, 2012

Introduction

The SolarMagic™ reference design kit RD-195 includes the SM73201-ARC-EV PCB which is a UL1699B compliant Photo-Voltaic Arc Detect System with a minimal footprint of less than 50mm x 30mm. The reference design utilizes National Semiconductor's advanced Analog technology along with an innovative dynamic filtering technique to effectively detect the signature of Arcing conductors in the presence of highly noisy real world environments. Implemented with National Semiconductor's PowerWise® technology, the Analog path requires less than 50mW of power to implement the active filtering. The operation range of the device covers the industrial temperature range of -40°C to +85°C. SolarMagic™ technology is an overall solution that works in existing and new installations, residential, commercial, and utility scale projects. National Semiconductor's 50 years of experience in the electronics industry delivers unsurpassed manufacturing, design, and development technology.

Features

- 1,000V isolation
- Effective detection at maximum DC string current of 15A
- Simple LED arc detection flag
- Self Test Capability
- Industrial Temperature Range (-40°C to +85°C)
- Small PCB footprint for active area of less than 50mm x 30mm, single sided
- Low power requirement <400mW, analog power < 50mW



30163827

FIGURE 1. Evaluation board

PowerWise® is a registered trademark of National Semiconductor.

Connection

The multiple connections on the Evalulation Board are labeled. Refer to the table below for a description of their usage.

Connection	Usage
J1	String Current A. J1 is a Flag connector.
J2	String Current B. J2 is a Flag connector.
J3	VA connection: If R8 shunt is not stuffed a jumper between 5V and VA must be present for operation.
J4	Reset: momentarily short these pins to reset the system.
J11/J8p1	Positive supply. Provide 5.4V< Vin <12.5V, with >90mA. J11 can use a banana plug.
J9	Install to generate continuous NOISE signal.
J10/J8p2	Ground. J10 can be connected with a banana plug.
J14	RS232 interface; {Pin1:Txout, Pin2:Gnd, Pin3:Rxin}.

Quick Setup Procedure

Step 1: Connect 6V power supply positive to +6V pin of J8 (J8p1) and negative to GND pin of J8 (J8p2). Alternatively connect positive terminal to J11 and and negative terminal to J10.

Step 2: Verify proper LED pattern: GREEN LED is on, YELLOW LED is blinking, RED LED is off.

LED functionality

Upon power-up, the green LED will turn on. While the board searches for an arc, the yellow LED will blink continuously. When an arc is detected the red LED will turn on and the yellow LED will stop blinking.

As shipped, a detected Arc is automatically cleared after 4 seconds and the board will resume looking for arcs. This behavior can be changed by the user.

RS232 Interface Operation

The Evaluation Board can output its arc detection status via an RS232 interface located at connector J14. It will periodically issue a message stating “No Arc Detected” or “Arc Detected” as appropriate.

A custom interface cable is required for this functionality; refer to the table below for pinouts

Pin Number	Function
1	TX (out)
2	GND
3	RX (in)

RS232 Settings

Use of any terminal program will work. On Windows computer systems, HyperTerminal is an available program that can communicate with the Eval Board. In Windows XP, HyperTerminal can be found on the Start Menu under Start>Programs>Accessories>Communications.

Once Hyperterminal starts, provide a name for the connection (e.g. “ArcDetectCon-nect”), and select the appropriate COM port. The port settings for the RS232 link must be set to 115200 baud (bits/sec), 8 Data Bits, No Parity, 1 Stop Bit and No Flow Control.

When connected and powered up, the Evaluation Board will send out a version information header, then will transmit either “Arc Searching” or “Arc Detected” on the console port.

Data Collection

The firmware provided on the unit provides the ability to modify the Evaluation board’s operation through the RS232 interface. The following instructions assume that you are connected to the RS232 interface and are using HyperTerminal as described above.

Entering ‘help’ will provide a list of instructions. Note that with the default Hyper-terminal settings, your typing will not be visible. To see your typing, chose the File>Properties on the menu; then select the ‘Settings’ tab. Press the ‘ASCII Setup...’ button, then check the box to the left of ‘Echo typed characters locally’, and finish by pressing ‘OK’ twice.

There are 3 basic commands that can be issued through the RS232 interface -”help”, “set”, and “get” (do not include quotes). The “help” command returns a list of commands. “get” retrieves the current value of a parameter, and “set” command allows for changing a parameter. Some commands require one or two parameters, for example “set T 250”, which would set the T parameter to 250. Note that commands are case sensitive. Parameters should be separated by a space. Care must be taken in changing the Arc Detect parameters (B, D, F, I, C, T) as the Arc Detect routine does not validate the settings, and these settings may not support proper operation.

Complete List of RS232 Commands

Command Parameter	Default	Name	Usage
B	30.0e3	Analysis Bandwidth	set/get Arc Detect Parameter 'B'. set requires a 2nd parameter which must be a number greater than 1.0 for proper operation. Note that the Arc Detection routine is re-initialized after a set command.
D	0.35	Bin Discard Factor: Controls how aggressive the filtering is and corrects for the arc signature shaping	set/get Arc Detect Parameter 'D'. set requires a 2nd parameter which must be a number be between [0.0, 1.0] for proper operation. Note that the Arc Detection routine is re-initialized after a set command.
F	4.00	Filter Weight: Controls how aggressive the filtering is and corrects for the arc signature shaping.	set/get Arc Detect Parameter 'F'. set requires a 2nd parameter which must be a number greater than 0.0 for proper operation. Note that the Arc Detection routine is re-initialized after a set command.
I	45.0e3	Min Frequency	set/get Arc Detect Parameter 'I'. set requires a 2nd parameter which must be a number greater than 1.0 for proper operation. Note that the Arc Detection routine is re-initialized after a set command.
C	55	Clipping Factor: Used to reduce the effect of quick transients causing false detects.	set/get Arc Detect Parameter 'C'. set requires a 2nd parameter which must be a number greater than 1.0 for proper operation.
T	250	Threshold for arc detection: Increasing this value reduces the likelihood of false detections. However, if it is too high, then there may be a risk of missing an arc.	Sets Arc Detect Parameter 'T' to provided number. set requires a 2nd parameter which must be a number greater than 1.0 for proper operation.
U	NA	Unit Specific Gain Correction	set/get the unit specific gain correction. This value is in dB, and should nominally be 0.0. set requires a 2nd parameter which is the desired correction for customers.
A	NA	Arc Detected Status	"get A" returns the string "Arc Detected" or "No Arc Detected" based on current sta-tus. "set A" will clear an Arc if an Arc has been detected and the Arc Automatic clear is disabled.
N	NA	Periodic RS232 Notifications Enable	"set N 1" will enable periodic RS232 notifications on Arc Detected Status (e.g. "No Arc Detected 0, (#Arcs=0)"). "set N 0" will disable periodic notifications on the arc detect status. "get N" will return the string "Notifications On" or "Notifications Off" based on the current setting. The default setting is notifications enabled.
R	NA	Arc Detection Enable	"set R 1" will enable arc detection. "set R 0" will disable arc detection. "get R" will return the string "Arc Detect Running" or "Arc Detect not Running" based on the current setting. The default setting is arc detection enabled. Note when arc detection is disabled, the Green LED will turn off and the Yellow LED will rapidly blink.
S	NA	EEPROM Settings	"set S 0" will save the current settings to the on-board EEPROM. "set S 1" will retrieve the settings from the EEPROM. "get S" is not a valid command.
V	NA	Firmware Version	"get V" will return the firmware version information. "set V" is not a valid command.

Command Parameter	Default	Name	Usage
W	NA	Capture ADC Sample Data	“get W” will return <number> sequential raw ADC samples. If <number> exceeds 2048, then 2048 samples will be returned. Note that this is the only get command which accepts an additional parameter. The W command also returns the stored sample rate. “set W” is not a valid command.
X	NA	Arc Detect Automatic Clearing	“set X 1" will enable the automatic clearing of detected arcs (a detected arc will be cleared approx. 4sec after detection without any command issued). “set X 0" will disable the automatic clearing. When auto-clear is disabled, a “set A” is the only way to clear a detected arc. “get X” will return the string ‘Detected Arcs Auto-Cleared” or “Detected Arcs not Auto-Cleared” based on the current setting. The default setting is automatic clearing of detected arcs.
Z	NA	Self Test	“set Z 1” enables self test. “get Z” returns self test status “INACTIVE” or “ACTIVE”.

Commands to Capture Raw Data

For most efficient capturing of raw ADC codes, turn off the notifications and disable arc detection, by sending the following instructions:

set N 0

set R 0

Once these commands are issued, you should configure HyperTerminal to save the raw data to a file by selecting Transfer>Capture Text, and then set the filename to the conditions that are on the line (e.g. inverter_A_10panels_no_arc.txt), when click ‘Start’. You can then capture the data with:

get W 2000

Once the text transfer is complete (approx. 2), close the HyperTerminal file by selecting Transfer>Capture Text>Stop. You can then repeat the file open, get W, and file close process until all desired conditions are saved in a text file.

Theory of Operation

Arcing present in a PV system creates random noise current in the cabling used for the PV string. The current noise of the arc itself has a Gaussian distribution with a spectrum extending to several MHz. Because of the geometry of the cabling in a typical PV system, the noise current density above 200 kHz, varies significantly with frequency. The inverters used in PV systems usually use switch mode controllers to regulate the incoming DC voltage. These switching regulators usually operate in the kHz range, generally below 50kHz, and cause a high noise level on the PV string wiring at the switching frequency. For these reasons, noise in the band of frequencies between 40 kHz and 100 kHz was selected for arc detection. The point in the PV string in which the arc detection system is used may be at a potential of as high as 1000 VDC. The current monitored by the system may have a DC component as high as 15 Amps DC. To isolate the high DC voltage and current from the arc monitoring circuit, an isolation transformer is used. A reasonably sized transformer meeting these requirements has relatively low magnetization inductance. Because of this, the noise signal at the secondary of the transformer is relatively low.

The 50 to 100 KHz spectrum is used by services such as maritime radio navigation, and standard time services. The large loop area of a standard PV cabling system may intercept these low frequency signals and create line current many times that of the noise signals caused by arcing. In addition, the switching noise from the inverter or other electronics present on the PV systems may also create noise sources at this frequency. An effective way to eliminate these signals is by digitally processing these signals after A/D conversion. However, in order to eliminate unwanted signals digitally, the signal chain including the A/D converter must have the dynamic range to process the high level CW signals while detecting the low level noise signal created by the arc. This drives the selection of a 16-bit ADC which has a dynamic range of 96dB. This enables the signal path to handle CW signals 93 dB greater than the noise that needs to be measured for arc detection purposes. *Figure 2* shows the spectrum (10kHz-130kHz) in dB of the sensed current (after filtering and sampling) with arc and no arc condition. The arc is occuring in a PV string with a DC current of 12A.

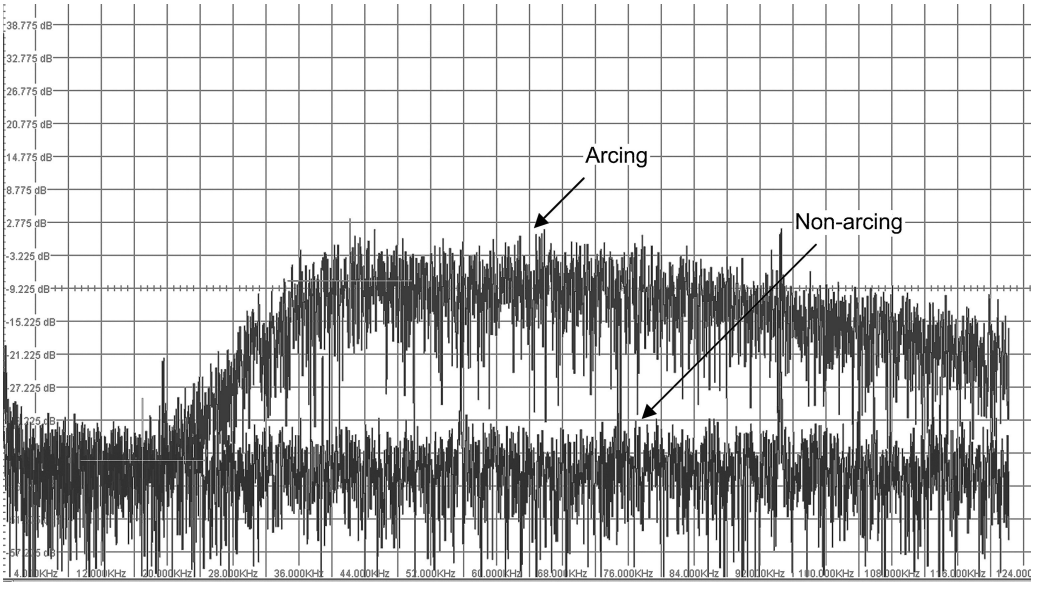


FIGURE 2. Spectrum of Digitized Current on SM73201

System Implementation

The arc detection board is comprised of a transformer, where the string current flows through the primary and that reacts to AC noise present on the string line. The signal appearing on the secondary is amplified and filtered to be fed to an A/D converter. The signal is then fed to a microcontroller for signal processing and arc detection. The board also supports a self test circuit which produces a signal that mimics an arcing event.

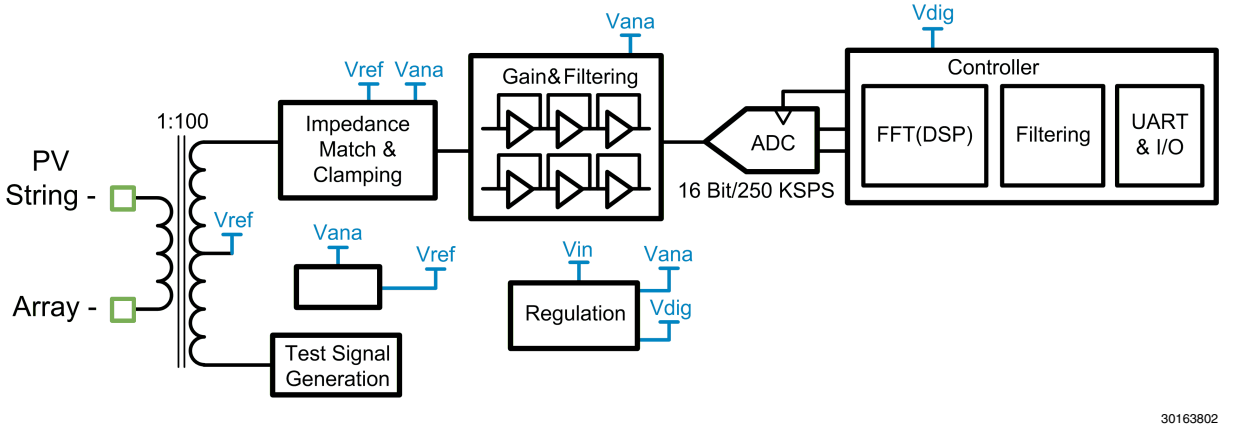


FIGURE 3. System Diagram

The board is designed to fit in a single string configuration as shown in *Figure 4*. The board connects on the negative side of the string. Arrays containing multiple PV strings can be serviced by connecting one arc detection board per string.

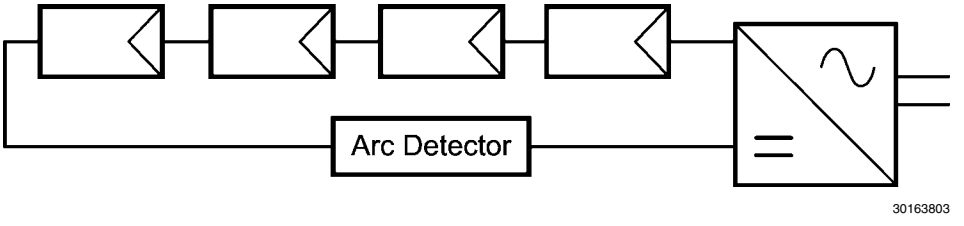


FIGURE 4. System Insertion

The board has a 1000V isolation capability. Therefore, the board could be connected at mid-string or on the positive side of the string if the voltage does not exceed 1000V. However, this is not recommended due to safety concerns regarding handling. The 6V power supply used to power the board is fed through J10 and J11. The current carrying the string current connects through J1 and J2. See *Figure 5*.

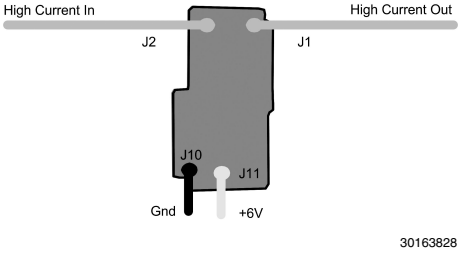


FIGURE 5. Board Connection

Design Description

The analog signal path is shown in *Figure 8*. The current is sensed through T3. U15A and U18A form a 4 pole Butterworth high pass filter, while U14B, U15B, and U18B form a 5 pole low pass filter. U18B and U14A add gain to the system with low noise floor operational amplifiers. The output of U18B is the input to the A/D conversion circuit. The filter has a cutoff frequency of 40kHz for the low limit and 100kHz for the high limit. This bandwidth is necessary for the proper operation of the software programmed in the microcontroller.

The op-amps are powered from a 5V rail provided by a linear regulator. The op-amps inputs are biased using a reference voltage derived from another op-amp circuit shown in *Figure 6*.

The board also supports a self test circuit which produces a signal that mimics an arcing event. See *Figure 7*. The self test circuit produces a noise signal that can be controlled manually with switch SW1, or with the CPU using the NOISE_EN input. For manual test (J9 open) press SW1 to generate a noise signal, simulating an arcing event. For CPU test (J9 open) set NOISE_EN signal (AIO10) high to generate a noise signal. In software this is done with “set Z 1” command. If an arc is detected, Z resets, and turns off self test circuit. If no arc is detected, Z continues to stay at 1, and the self test circuit is enabled. Install J9 jumper to generate a continuous noise signal. +V should be between 8 and 12 volts for proper operation of the noise circuit.

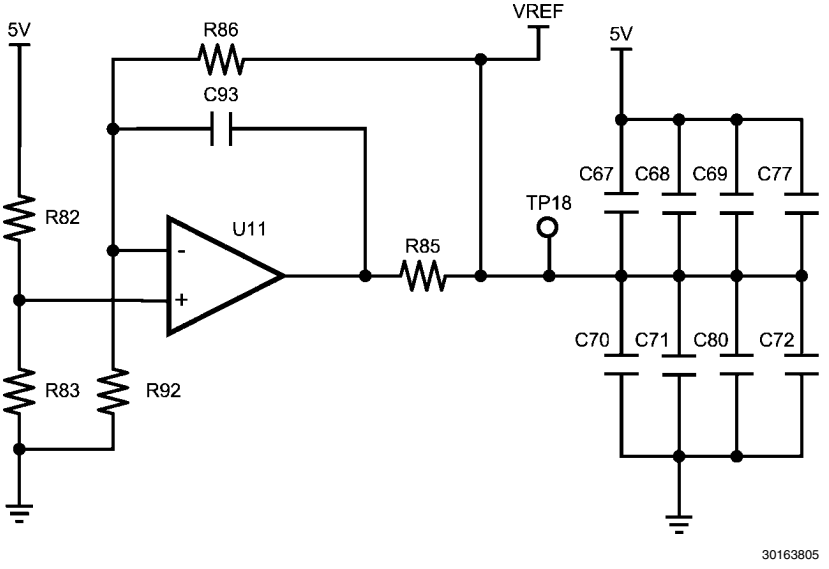


FIGURE 6. Reference voltage

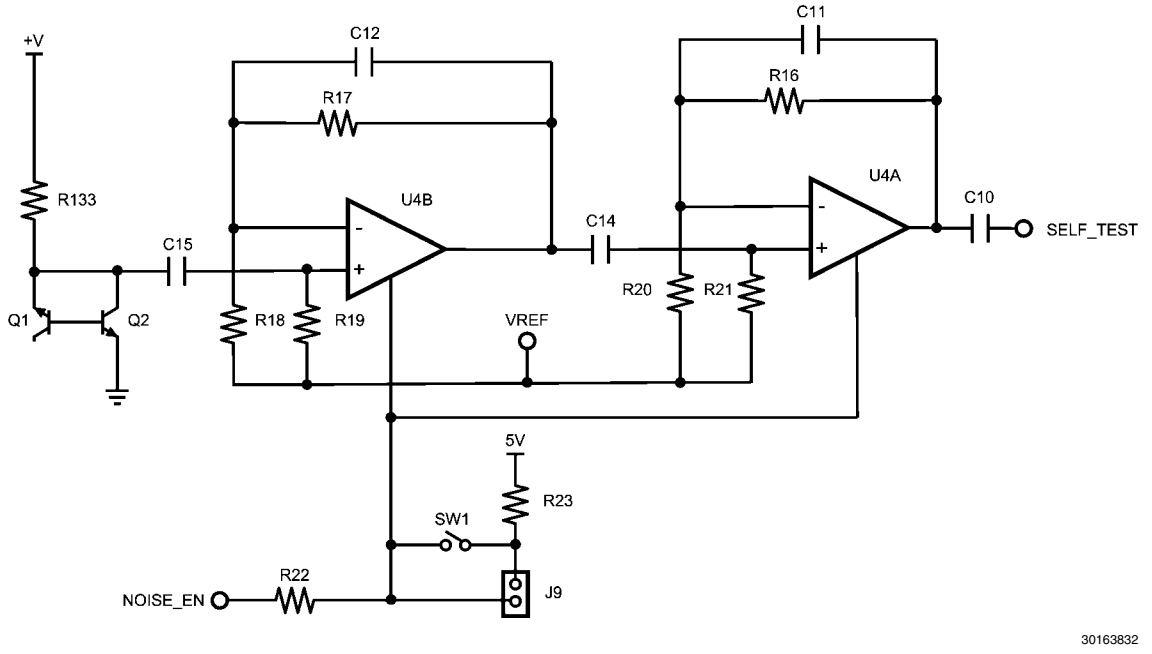


FIGURE 7. Self Test Circuit

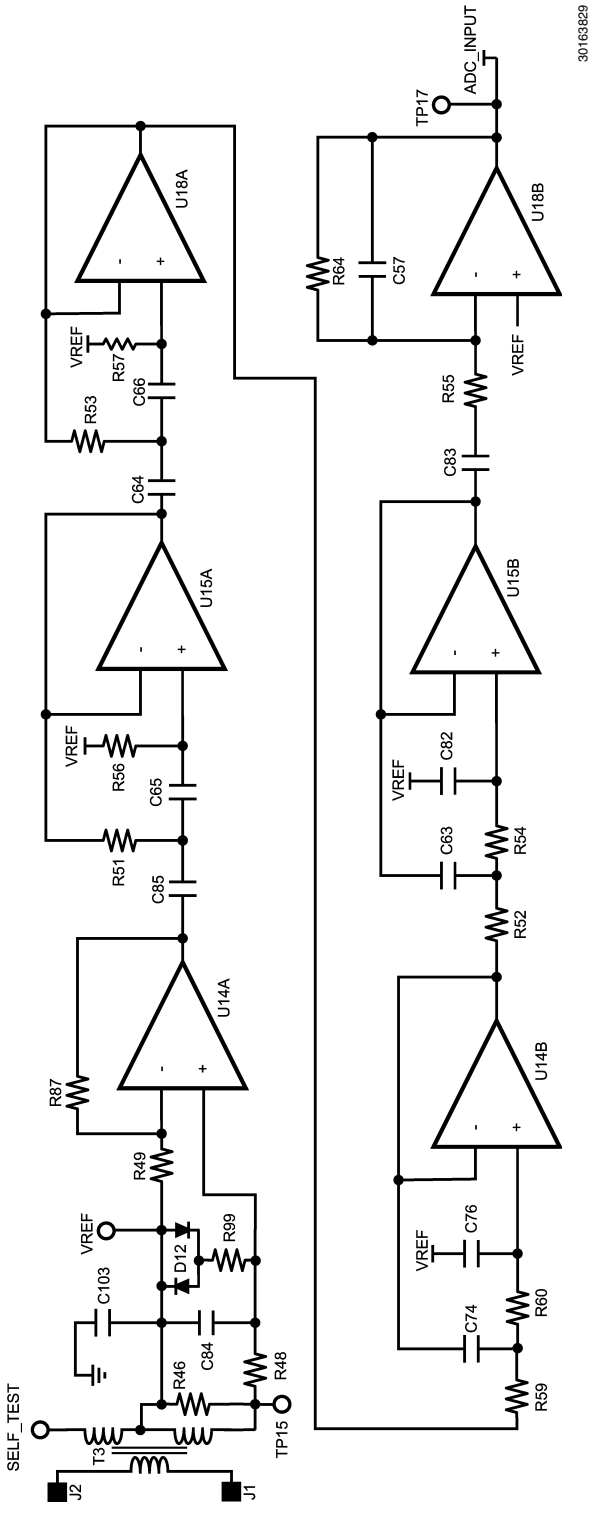


FIGURE 8. Analog Front End

The A/D converter is a 16bit converter operating at approximately 250kS/s. The high resolution translates to a high dynamic range for the sensed signal, thereby allowing the arc signature to be sensed properly without clipping due to the potentially higher amplitude of interference signals from the inverter. The converter sampling rate is controlled by the microcontroller. The connection is shown in *Figure 9*.

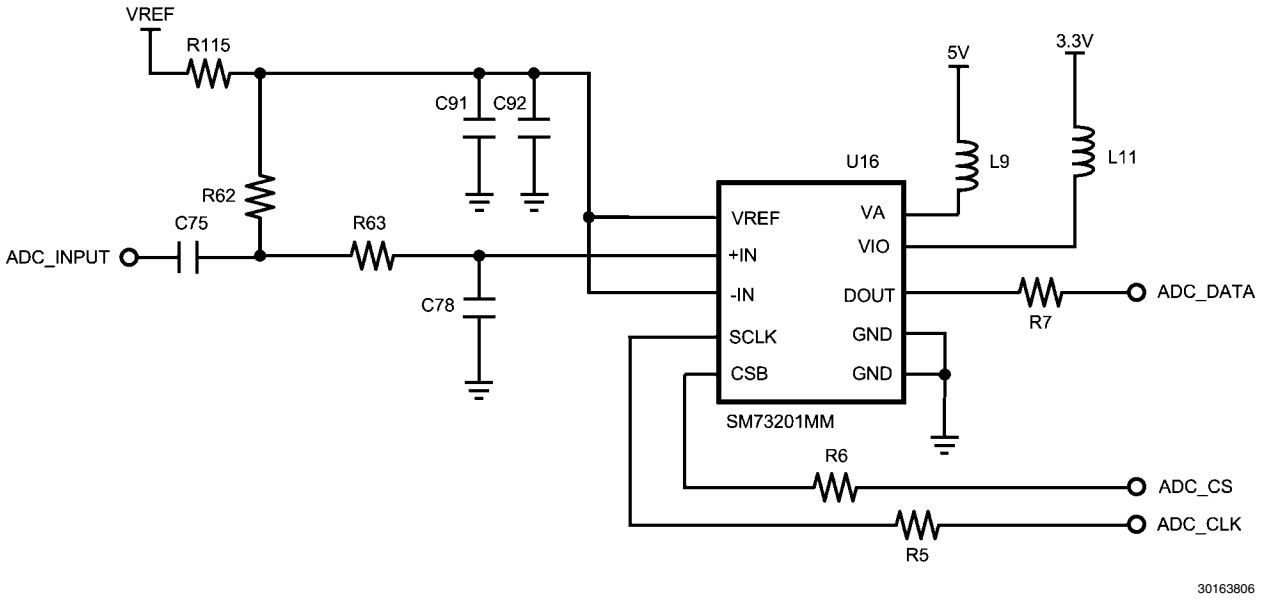


FIGURE 9. A/D Converter

Safety

Caution must be used at all times while generating arcs. The high voltages present in a PV system pose a lethal hazard. Incandescent metal sparks and open flame can be present. Use all necessary safety gear, including Eye/Face protection, electrical gloves rated for the electrical conditions, and any other equipment appropriate for the conditions. Texas Instruments assumes no liability for any damage or injury that may occur.

Layout

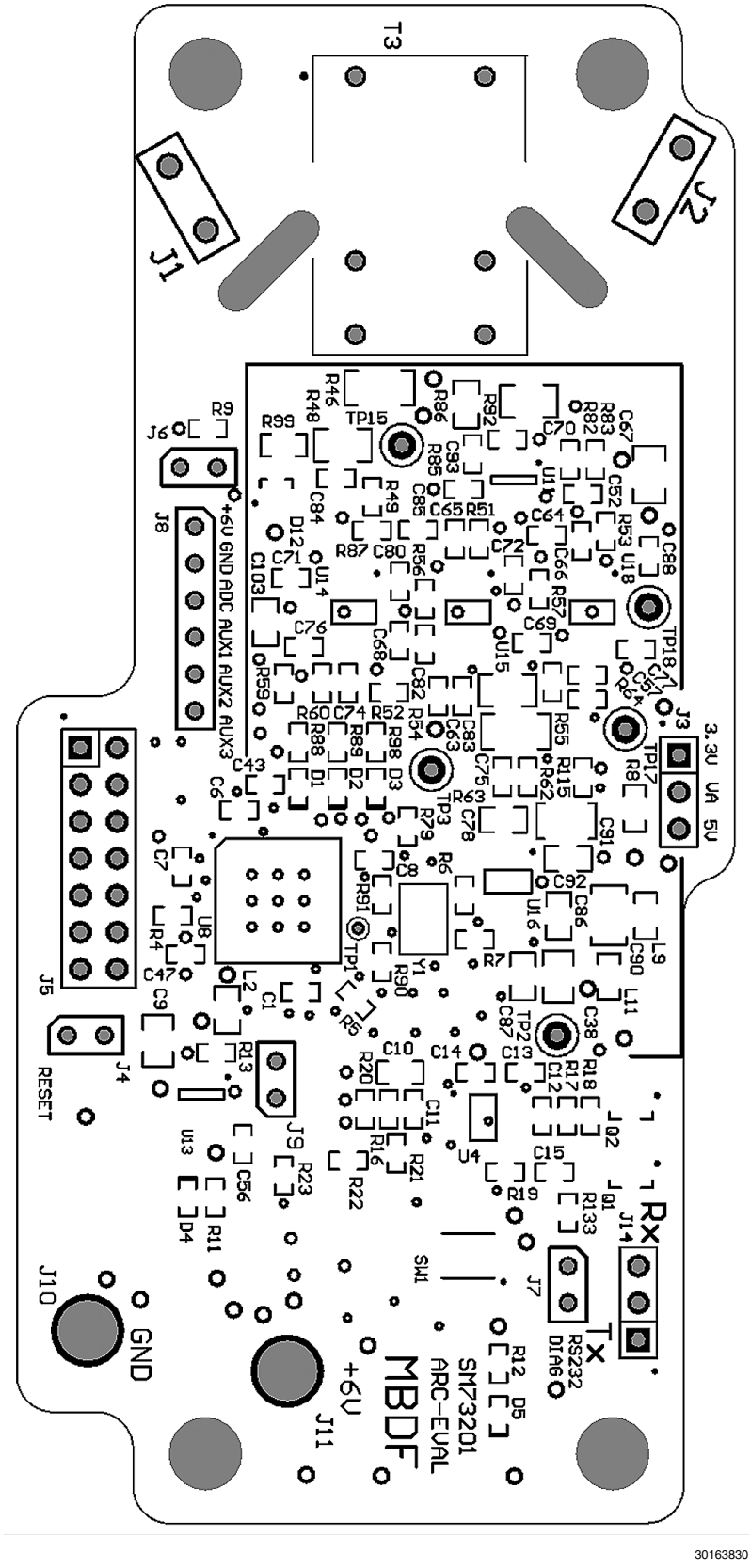


FIGURE 10. Board Assembly TOP

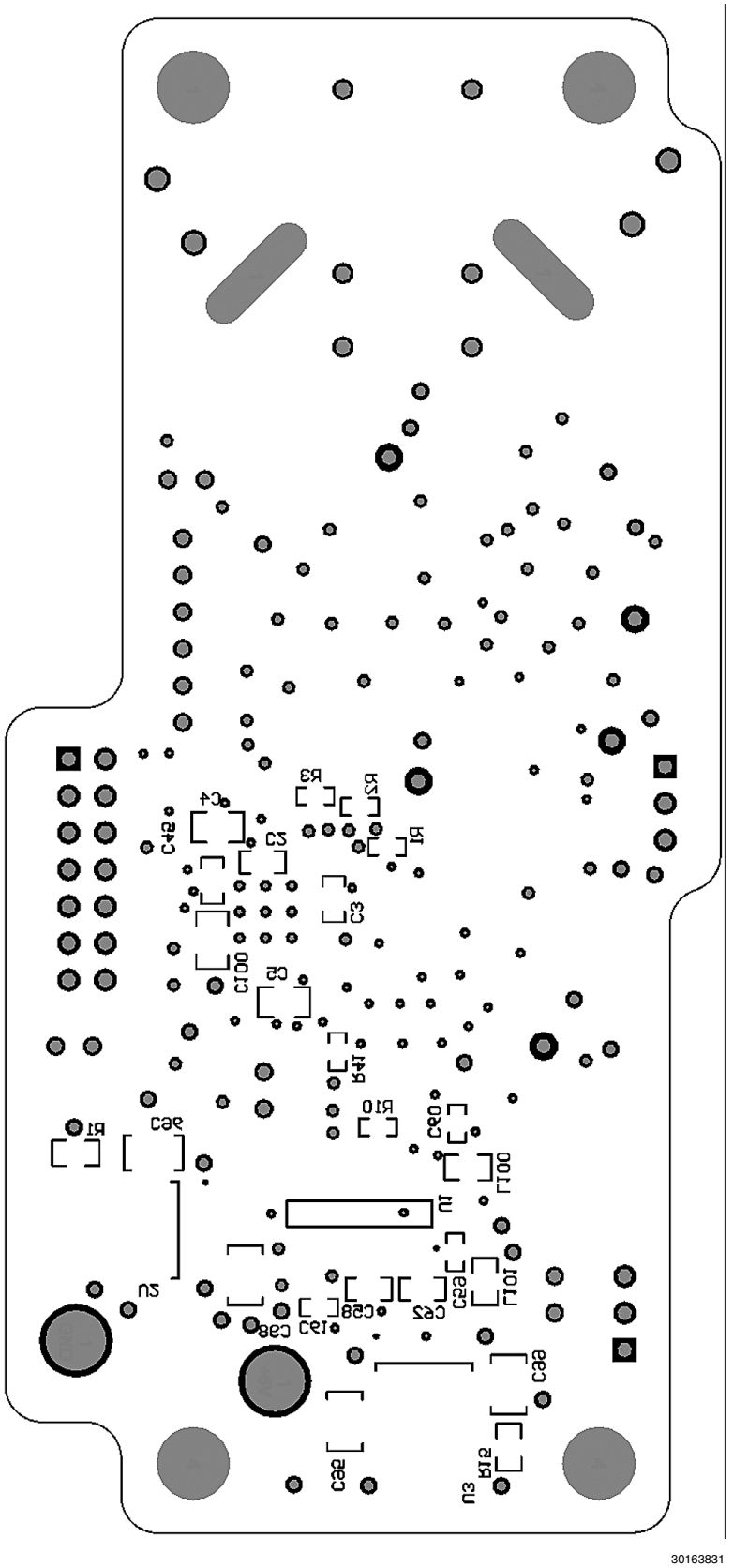


FIGURE 11. Board Assembly BOTTOM

Bill of Materials

Designator	Description	Manufacturer	LibRef	Quantity
C1, C6, C7, C8, C13, C43, C47, C52, C56, C59, C60, C61, C68, C69, C71, C72, C77, C80, C88	CAP CER .10UF 16V X7R AUTO 0402	TDK	CGA2B1X7R1C104K	18
C2, C3, C45	CAP, CERM, 1.5uF, 6.3V, +/-10%, X5R, 0603	Kemet	C0603C155K9PACTU	3
C4, C5, C38, C90, C91, C95, C98	CAP, CERM, 1uF, 16V, +/-10%, X7R, 0805	Taiyo Yuden	EMK212B7105KG-T	7
C9, C96, C99	CAP, CERM, 2.2uF, 16V, +/-10%, X7R, 0805	Taiyo Yuden	EMK212B7225KG-T	3
C10	CAP, CERM, 0.022uF, 50V, +/-10%, X7R, 0603	Murata	GRM188R71H223KA01D	1
C11, C12, C93	CAP CER 10PF 50V C0G 0402	Murata	GCM1555C1H100JZ13D	3
C14, C15, C84	CAP CER 2200PF 25V 5% C0G 0402	Kemet	C0402C222J3GACTU	3
C57, C63, C64, C65, C66, C76, C85	CAP CER 1000PF 50V 5% C0G 0402	Murata	GRM1555C1H102JA01D	7
C58, C62, C86, C87, C92	CAP, CERM, 0.1uF, 25V, +/-10%, X7R, 0603	Murata	GRM188R71E104KA01D	5
C67, C70	CAP, CERM, 4.7uF, 10V, +/-10%, X5R, 0805	Murata	GRM219R61A475KE34	2
C74	CAP CER 1500PF 25V 5% C0G 0402	Kemet	C0402C152K3GACTU	1
C75	CAP CER 47000PF 50V 5% C0G 1206	Murata	GRM31M5C1H473JA01L	1
C78	CAP, CERM, 4700pF, 100V, +/-10%, X8R, 0603	TDK	C1608X8R2A472K	1
C82	CAP CER 91PF 50V 5% C0G 0402	TDK	C1005C0G1H910J	1
C83	CAP, CERM, 0.033uF, 25V, +/-5%, C0G/NP0, 0805	TDK	C2012C0G1E333J	1
C100	CAP, CERM, 2.2uF, 10V, +/-10%, X5R, 0805	AVX	0805ZD225KAT2A	1
C103	CAP, CERM, 2200pF, 50V, +/-5%, C0G/NP0, 0603	TDK	C1608C0G1H222J	1
D1, D4, D5	LED 0402 GREEN 54MW 20MA SMD	Rohm	SML-P11MTT86	3
D2	LED 0402 YELLOW 52MW 20MA SMD	Rohm	SML-P11YTT86	1
D3	LED 0402 RED 50MW 20MA SMD	Rohm	SML-P11UTT86	1
D12	DIODE SW DUAL 75V 200MW SC70-3	Diodes	BAV99W-7-F	1
J1, J2	TERM QF .032DIA .250" STURDY MT"	Keystone	1289-ST	2
J3, J14	Header, TH, 100mil, 3x1, Gold plated, 230 mil above insulator	Samtec	TSW-103-07-G-S	2
J4, J6, J9	CONN HEADER 2POS .100 T/H GOLD"	Samtec	TSW-102-07-L-S	3
J5	Header, TH, 100mil, 7x2, Gold plated, 230 mil above insulator	Samtec	TSW-107-07-G-D	1
J8	CONN HEADER 6POS VERT .100 GOLD	TE Connectivity	644884-6	1
L2, L9, L11, L100, L101	FERRITE CHIP 330 OHM 1200MA 0603	Murata	BLM18PG331SN1D	5
Q1, Q2	Transistor, NPN, 40V, 0.2A, SOT-23	Diodes Inc.	MMBT3904-7-F	2
R1, R2, R3, R10, R13, R41, R62, R79, R82, R83	RES, 10.0k ohm, 1%, 0.063W, 0402	Vishay-Dale	CRCW040210K0FKED	10
R4, R90	RES, 2.21k ohm, 1%, 0.063W, 0402	Vishay-Dale	CRCW04022K21FKED	2
R5	RES, 64.9 ohm, 1%, 0.063W, 0402	Vishay-Dale	CRCW040264R9FKED	1
R6, R7, R3, R49, R55	RES, 1.00k ohm, 1%, 0.063W, 0402	Vishay-Dale	CRCW04021K00FKED	5
R8	RES, 0 ohm, 5%, 0.1W, 0603	Vishay-Dale	CRCW06030000Z0EA	1

Designator	Description	Manufacturer	LibRef	Quantity
R9, R22	RES, 20.0k ohm, 1%, 0.063W, 0402	Vishay-Dale	CRCW040220K0FKED	2
R11, R88, R89, R98	RES, 330 ohm, 5%, 0.063W, 0402	Vishay-Dale	CRCW0402330RJNED	4
R12	RES, 787 ohm, 1%, 0.063W, 0402	Vishay-Dale	CRCW0402787RFKED	1
R14, R15	RES, 0.22 ohm, 1%, 0.1W, 0603	Panasonic	ERJ-3RQFR22V	2
R16, R17, R19, R21	RES, 121k ohm, 1%, 0.063W, 0402	Vishay-Dale	CRCW0402121KFKED	4
R18, R20, R133	RES, 4.75k ohm, 1%, 0.063W, 0402	Vishay-Dale	CRCW04024K75FKED	3
R52, R54	RES, 5.11k ohm, 1%, 0.063W, 0402	Vishay-Dale	CRCW04025K11FKED	2
R46	RES, 200 ohm, 1%, 0.25W, 1206	Vishay-Dale	CRCW1206200RFKEA	1
R48	RES, 100 ohm, 1%, 0.125W, 0805	Vishay-Dale	CRCW0805100RFKEA	1
R51	RES, 2.61k ohm, 1%, 0.063W, 0402	Vishay-Dale	CRCW04022K61FKED	1
R53	RES, 1.78k ohm, 1%, 0.063W, 0402	Vishay-Dale	CRCW04021K78FKED	1
R56	RES, 3.92k ohm, 1%, 0.063W, 0402	Vishay-Dale	CRCW04023K92FKED	1
R57	RES, 10.5k ohm, 1%, 0.063W, 0402	Vishay-Dale	CRCW040210K5FKED	1
R59, R60	RES, 1.27k ohm, 1%, 0.063W, 0402	Vishay-Dale	CRCW04021K27FKED	2
R63	RES, 49.9 ohm, 1%, 0.063W, 0402	Vishay-Dale	CRCW040249R9FKED	1
R64	RES, 1.65k ohm, 1%, 0.063W, 0402	Vishay-Dale	CRCW04021K65FKED	1
R85, R115	RES, 1.00 ohm, 1%, 0.063W, 0402	Vishay-Dale	CRCW04021R00FKED	2
R86	RES, 0.33 ohm, 1%, 0.1W, 0603	Panasonic	ERJ-3RQFR33V	1
R87	RES, 9.09k ohm, 1%, 0.063W, 0402	Vishay-Dale	CRCW04029K09FKED	1
R91, R92	RES, 1.00Meg ohm, 1%, 0.063W, 0402	Vishay-Dale	CRCW04021M00FKED	2
R99	RES, 49.9 ohm, 1%, 0.1W, 0603	Vishay-Dale	CRCW060349R9FKEA	1
SW1	SWITCH TACTILE SPST-NO 0.02A 15V	Panasonic	EVP-AA202K	1
T3	XFRMR CURR SENSE 76MH 200:200:1 TH	PULSE	PA3655NL	1
TP1, TP2, TP3, TP15, TP17, TP18	Test Point, TH, Miniature, White	Keystone	5002	6
U1	TXRX DUAL 5V TIA/EIA-232 16-SOIC	TI	LMS202ECMX	1
U2	IC REG LDO 500MA 3.3V TO252	TI	LP38691DT-3.3	1
U3	IC REG VOLT MICROPWR 5V TO-252	TI	SM72238TD-5.0	1
U4	1.8V Dual Low Noise CMOS Input Op Amp with Shutdown	Ti	LMV792MM	1
U8	IC MCU	TI	TMS320F28033RSHT	1
U11	IC OPAMP LOW OFFSET RRO SC70-5	TI	SM73308MG	1
U13	5-Pin Microprocessor Reset Circuit 3.08V	TI	SM72240MF-3.08	1
U14, U15, U18	1.8V Precison, Dual Low Noise CMOS Input Op Amp	TI	SM73307MM	3
U16	IC ADC 16BIT 50/250KSPS 10-MSOP	TI	SM73201IMM	1
Y1	CER RESONATOR 6.00MHZ SMD	Murata	CSTCR6M00G53–R0	1