ADALM-SR1 hardware

Description

The ADALM-SR1 (Analog Devices Active Learning Module, Switching Regulator #1) board is a companion module for several switching regulator exercises covering buck and boost regulators:

Activity: Boost and Buck converter elements and open-loop operation
Activity: Buck Converters: closed loop operation
Activity: Boost Converters: closed loop operation

The circuits required for these exercises exceed the complexity that can be constructed on a breadboard, so the ADALM-SR1 is required to run them, although the simulations can be run beforehand to gain insight into the circuits' operation.

The Figures 1a and 1b show an overview of the board, along with connections to an ADALM2000 (m2k) and meters.

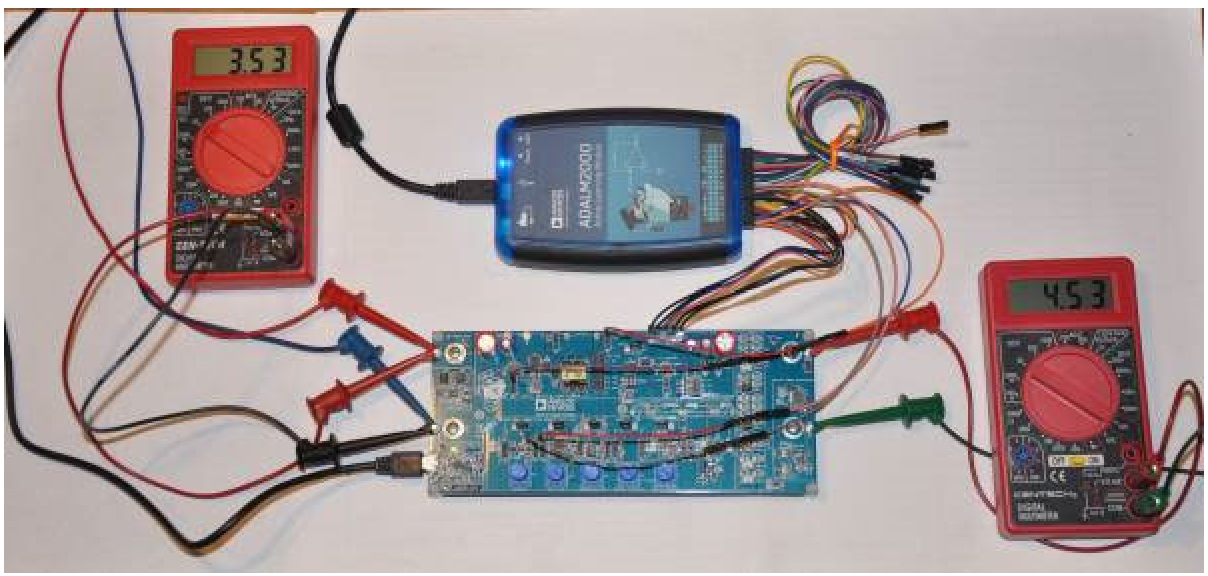


Figure 1a. ADSRALM overview

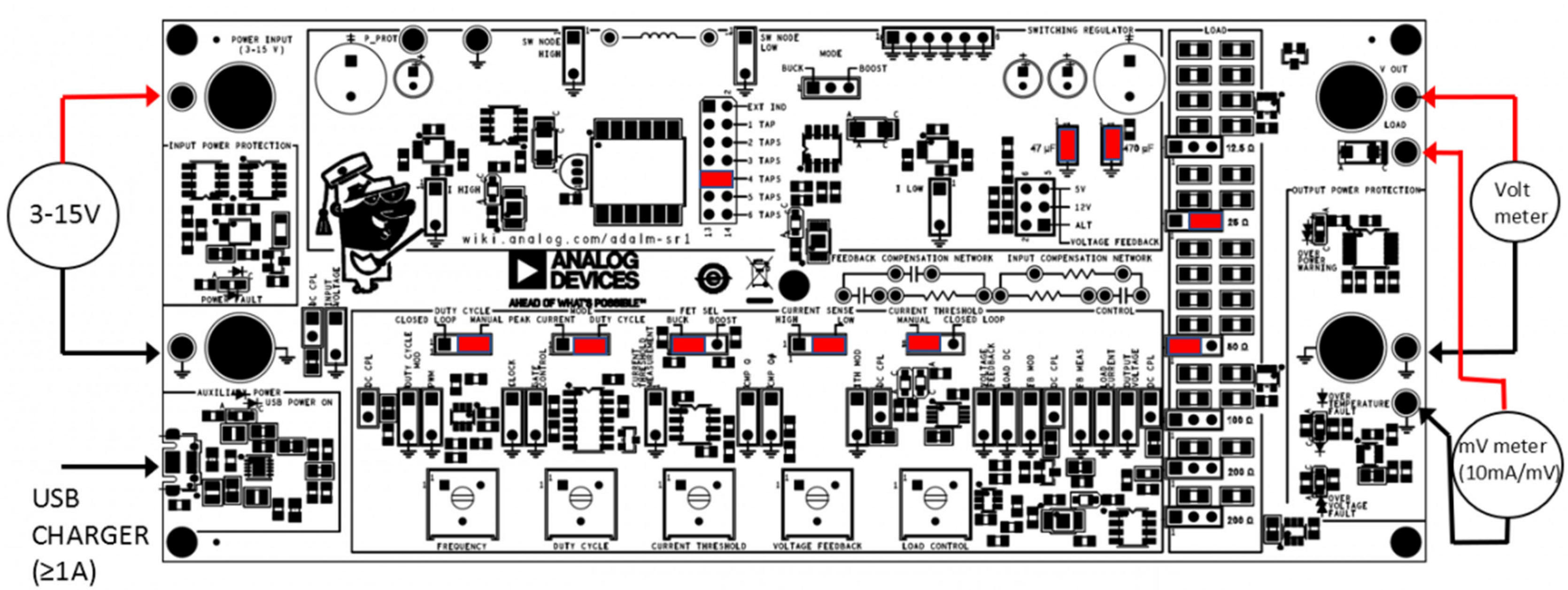


Figure 1b. ADSRALM overview

ADALM-SR1 Jumpers and Connections

The ADALM-SR1 uses 0.635mm (0.025-mil) headers for configuration jumpers, signal inputs, and signal outputs. Signal inputs and outputs are 2-conductor headers with 5.08mm (200-mil) pitch so that they cannot be confused with configuration jumpers. The lower conductor is always a ground connection (that is not always used) and an arrow indicates whether the upper conductor is an input or output.

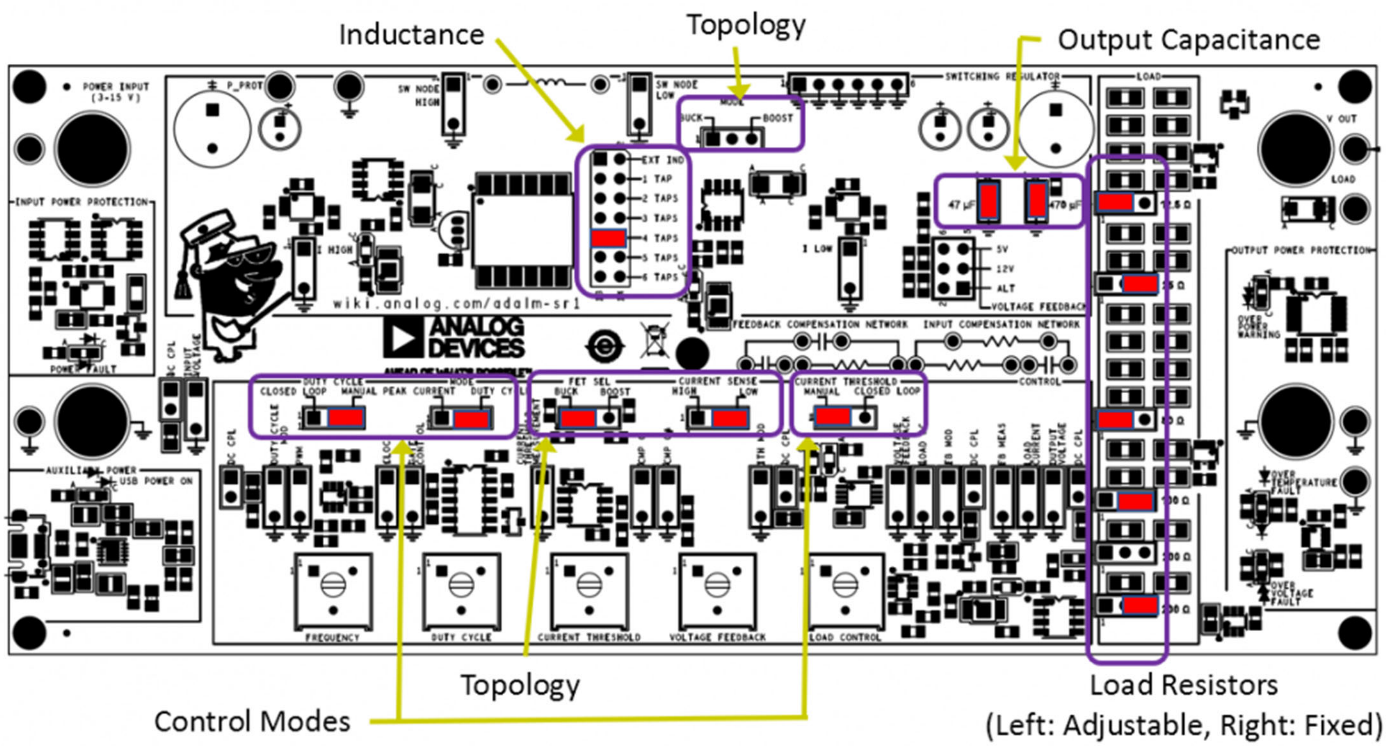


Figure 2. Topology, Mode selection, and Loads

Inductance Selection

A Wurth 749196141 6-winding coupled inductor is used in both boost and buck configurations. The datasheet inductance for a single winding is 8.5µH, with a DC resistance of 344 milliohms. The windings are connected in series on the ADALM-SR1, allowing the inductance to be changed as noted in the table below. (Values in the table are measured from a typical board.)

	Inductance Selection (P3)						
Jumper							
Position	EXT IND	1 TAP	2 TAPS	3 TAPS	4 TAPS	5 TAPS	6 TAPS
Function	Ext. inductor at TP3, TP4	7.7µH inductance	31.5µH inductance	72.6µH inductance	131.5µH inductance	216.2µH inductance	313.4µH inductance

Output Capacitors Selection

A 4.7µF capacitor is always connected to the output of the circuit. An additional 47µF and 470µF can be added by installing jumpers according to the table below.

	Output Capacitors Selection	
Jumper	**P8, P11**	
Position	Installed	Open
Function	P8 connect **additional** 47µF capacitance	No additional capacitance
	P11 connect **additional** 470µF capacitance	No additional capacitance

Load Resistors Selection

A resistive load may be connected to the output of the circuit. Resistances range from 12.5Ω to 200Ω, and may be added in parallel according to the table below. The jumpers are 3-position, with the right-hand position connecting the resistor to ground, and the left-hand position allowing the effective resistance to be adjusted by Pulse-width-modulating the ground connection.

	Load Resistors Selection	
Jumper	**P18, P14, P13, P17, P16, P15**	
Position	Installed	Open
Function	P18 connect 200 Ω load resistance	No additional load resistor connected
	P14 connect 200 Ω load resistance	No additional load resistor connected
	P13 connect 100 Ω load resistance	No additional load resistor connected

	Load Resistors Selection	
Jumper	**P18, P14, P13, P17, P16, P15**	
	P17 connect 50 Ω load resistance	No additional load resistor connected
	P16 connect 25 Ω load resistance	No aditional load resistor connected
	P15 connect 12.5 Ω load resistance	No aditional load resistor connected
Notes	**7V max across 25Ω, 12.5Ω resistors will turn on the Over Power LED illuminates as warning.**	

The R87 (LOAD CONTROL) potentiometer controls the duty cycle of all load resistors whose jumper is placed in the adjustable position, by swithcing the ground connection. (**YES** this is super weird, but it's convenient and it works much better than you'd think!) Duty cycle is guaranteed to be zero when fully counter-clockwise and 100% when fully clockwise. Thus the load can be a combination of fixed and variable resistances, and the exact duty cycle of the onboard PWM circuit can be measured at P40. The signal at P40 has a 1k impedance and maybe overdriven by a 3.3V logic signal, allowing the load to be stepped.
The load PWM frequency is fixed at 200kHz, approximately 10x the typical operating frequency of most experiments, thus appearing as a steady (DC) load.
A 0.1 ohm current sense resistor is in the ground return of the load resistors, allowing the total load current to be easily measured with meter set to the 200mV range at either the LOAD turret post (TP25) or the LOAD CURRENT jumper (P39).

Topology, FET and Current Sense Selection

The selection between boost or buck topologies is made by jumpers P25, P35, and P37.

	FET Selection		**Current Sense Selection**			
Jumper	**P37**		**P35**		**P25**	
Position	BUCK	BOOST	BUCK	BOOST	HIGH	LOW
Function	Select buck topology	Select boost topology	Select the proper FET for buck topology	Select the proper FET for boost topology	Used for buck topology	Used for boost topology
Notes	**Proper selection allows complete inductor waveform to be viewed.**					

In the boost configuration, P37 does **not** bypass Schottky diode D4, P35 routes the FET driver control to the low-side switch, and P25 selects the high-side current sense amplifier.
In the buck configuration, P37 bypasses D4, P35 routes the FET driver control to the high-side switch, and P24 selects the low-side current sense amplifier.

Close inspection of the operation of the circuit will show that in theory, either current sense amplifier will work for both topologies, but the amplifier that is NOT at the switch node is chose in order to minimize errors due to common-mode excursion.

Mode Selection

The ADALM-SR1 has several operational modes, set by the jumpers noted below.

The MODE jumper selects between peak current mode and duty cycle control:

- Peak Current: A fixed frequency clock starts the inductor current ramp by turning on a MOSFET switch, and the switch is opened when a peak current is reached.
- Duty Cycle: The duty cycle of the MOSFET switch is controlled directly.

	Control Mode Selection	
Jumper	**P32**	
Position	Peak Current	Duty Cycle
Function	Start on clock rising edge, stop on peak current	Direct duty cycle control
Notes	**Closed/open-loop determined by Duty Cycle or Current Threshold jumper.**	

The peak current circuit is always active, even in duty-cycle mode; increasing robustness in the event of an output short circuit.

Duty Cycle Source Selection

An LTC6992 Pulse-Width Modulator allows the switching MOSFET's duty cycle to be controlled directly, either manually by adjusting the DUTY CYCLE knob, or under the control of the error amplifier.

	Duty Cycle Source Selection	
Jumper	**P23**	
Position	Closed-loop	Manual

	Duty Cycle Source Selection	
Jumper	**P23**	
Function	Duty controlled by error amplifier	Duty controlled by potentiometer
Notes	**Current Threshold still operational for safety, determined by Current Threshold Potentiometer.**	

Current Threshold Source Selection

In peak-current control modes, the peak current can be controlled either manually by adjusting the CURRENT THRESHOLD knob, or under the control of the error amplifier. The current threshold is also always active in voltage control modes, maintaining per-cycle current limit as an added safety and robustness feature.

	Current Threshold Source Selection	
Jumper	**P22**	
Position	Manual	Closed-loop
Function	Threshold controlled by potentiometer	Threshold controlled by error amplifier
Notes	**Set Duty Cycle pot to approx. 50%. (not critical, rising edge controls start of the ramp)**	

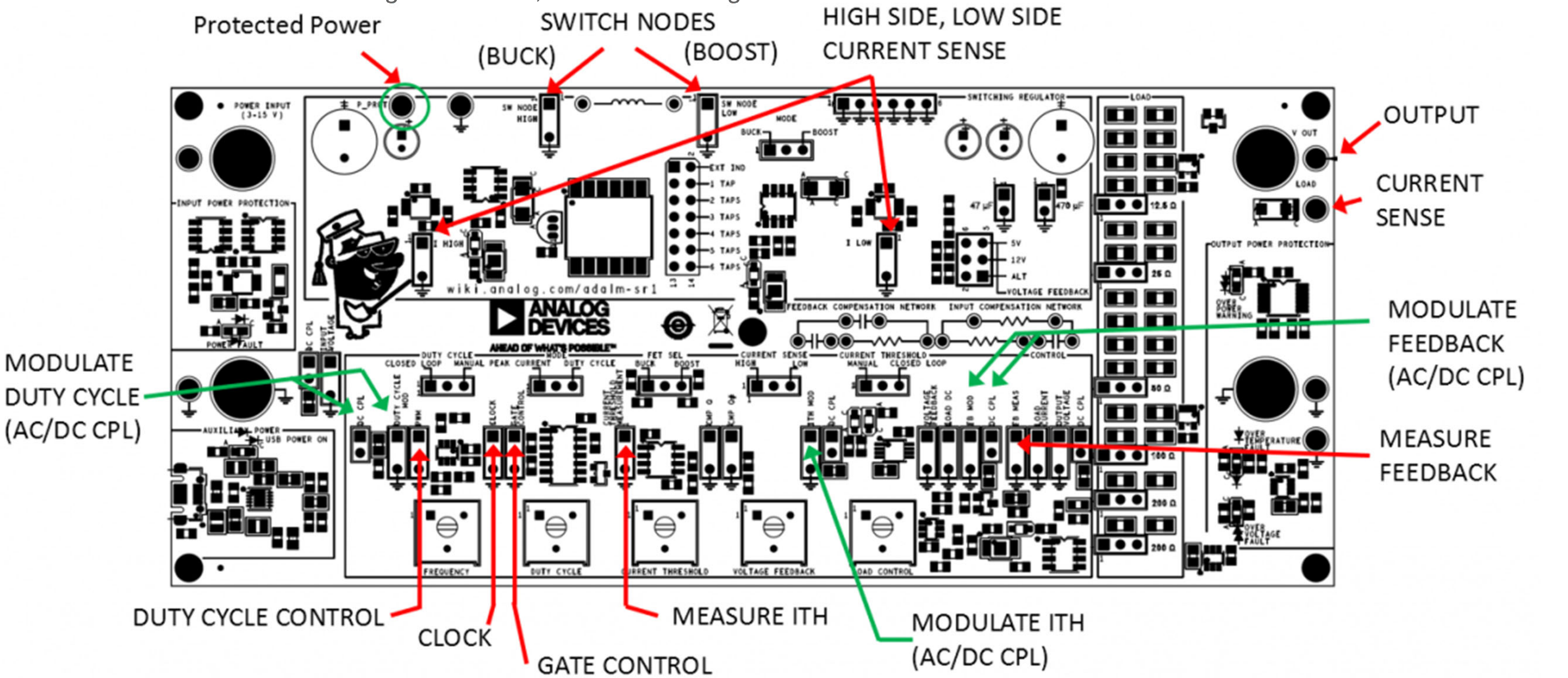
Feedback Selection

Three options for feedback network are provided, assuming a 1.25V reference voltage. The 5V option is usually used for buck experiments (input voltage greater than 5V), and the 12V option is usually used for boost experiments (input less than 12V). Footprints for optional 0603-sized resistors are included for user-defined feedback networks, selected by the third jumper option.

	Feedback Selection		
Jumper	**P20**		
Position	5V	12V	ALT
Function	Usually used for buck topology	Usually used for boost topology	Select user-installed feedback resistors

Signal Measurement and Injection Points

The ADALM-SR1 provides numerous test points for stimulating (modulating) and measuring the operation of the circuit, such as input and output voltage, inductor current, and output current. Several aspects of the circuit's dynamic response can also be measured:
* In open-loop voltage mode, modulate the duty cycle control voltage to characterize the response of the power stage * In open-loop current mode, modulate the current threshold (ITH) to characterize the response of the power stage * In any closed-loop mode, modulate the feedback divider to characterize the closed-loop response of the whole circuit.
Connections are summarized in Figure X below, and the following tables.



Measurement Points		
	Name	**Notes**
TP1	P_PROT	Overvoltage/overcurrent protected power.
P1	SW_NODE_HI	Switch node in buck topology.
P4	SW_NODE_LOW	Switch node in boost topology.

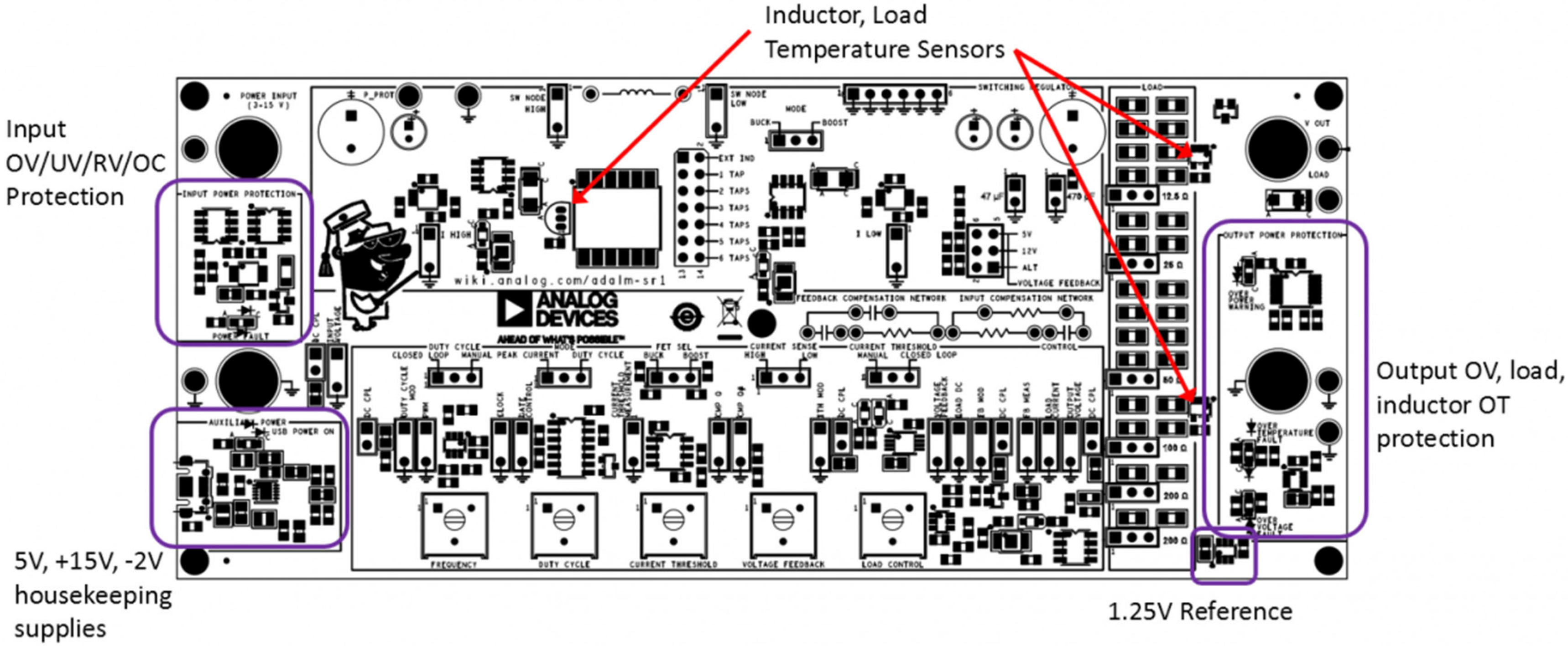
Measurement Points		
	Name	**Notes**
P2	IHIGH	Current sense amplifier output, boost configurations (0.1Ω sense R, G=7, 1.429A/V net output).
P12	ILOW	Current sense amplifier output, buck configurations (0.1Ω sense R, G=7, 1.429A/V net output).
P10, P9, TP5, TP7	V_OUT	Experiment output voltage. P10 can be AC coupled by removing P9.
P5	FB_MEAS	Feedback perturbation measurement (AC coupled).
P33	CLOCK	Master clock, 3.3V logic level.
P34	GATE CONTROL	FET gate control signal, 3.3V logic level.
Injection Points		
	Name	**Notes**
P28	ITH MOD	Peak current control modulation (1.429A/V). Install P29 to DC couple.
P27	DUTY CYCLE MOD	Duty Cycle modulation (100%/V). Install P26 to DC couple.
P7	FB_MOD	Feedback modulation for loop gain measurements (XXV/V). Install P6 to DC couple.

Hardware Setup Procedure

Refer to individual lab exercises for detailed setup information.

Auxiliary Circuit Details

The setup and operation of circuitry associated with the lab exercises is described in detail in the exercises themselves. The ADALM-SR1 includes various auxiliary housekeeping and protection circuits described here.

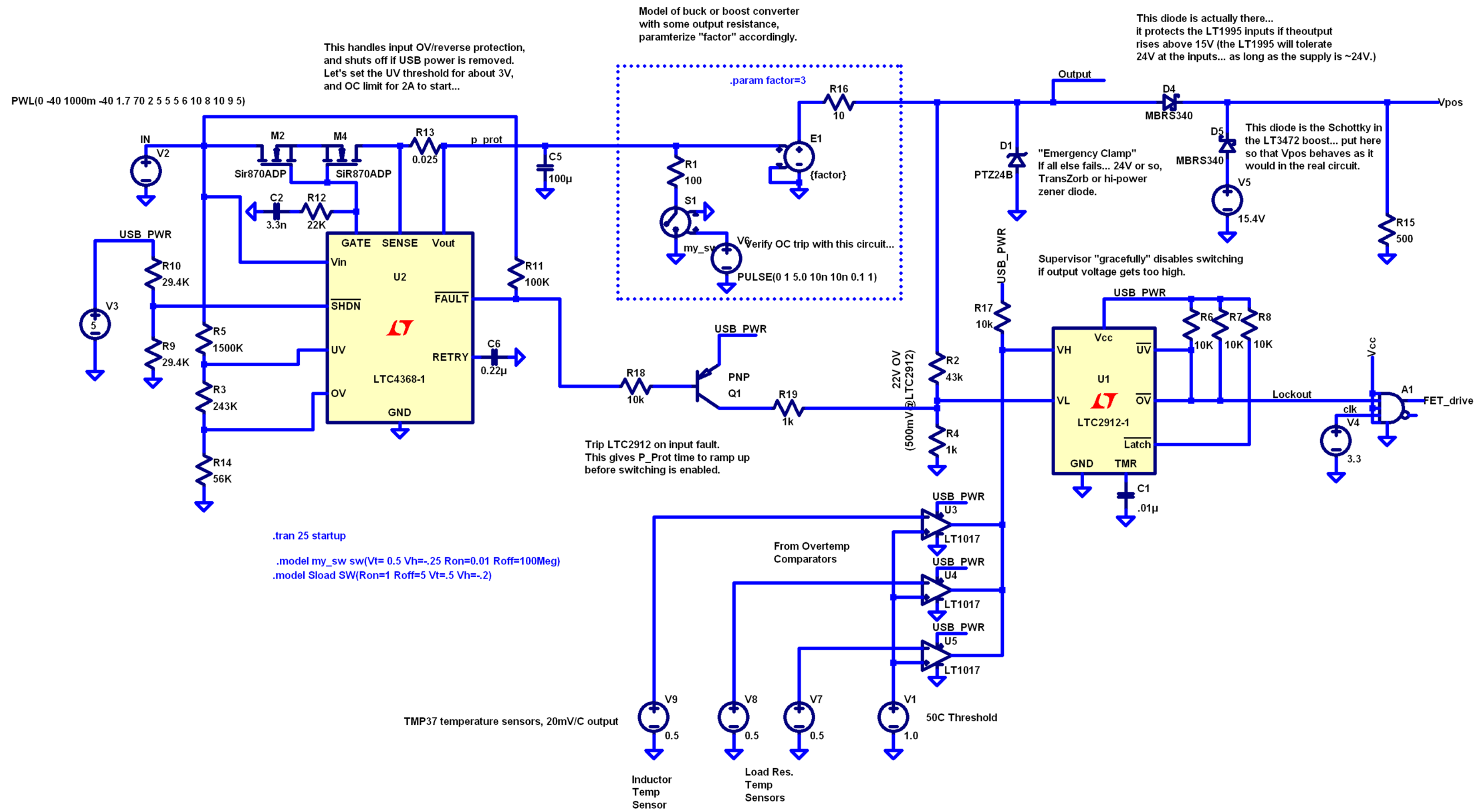


Housekeeping supplies and reference

The ADALM-SR1 has two power inputs. The experiment power input is supplied by the user, and the voltage will vary depending on the experiment being run. An additional micro USB connector is the input for a 5V “housekeeping” supply that powers all of the control circuitry, allowing the experiment power to vary over a wide range. An LT3472 boosts / inverts the 5V supply to +15 / -2V, respectively. This provides a high voltage and slightly negative voltage for the LT1995 current sense amplifiers, and a negative supply for the error amplifier.
An LT1970-1.25 provides an accurate reference for the error amplifier and duty cycle, current threshold adjustment potentiometers.

Input Overvoltage, Under-voltage, Reverse voltage, and Overcurrent

The Figure below shows an LTspice schematic of the ADALM-SR1's protection circuitry. The simulation file is available at OL_engineer_proofing.asc and running the simulation in LTspice will exercise some of the various fault conditions.



An LTC4368 and associated circuitry protects the experiment power input by only turning on when the supply is between 3V and 15V. The circuit is protected from voltages between -40V and +60V. The LTC4368 also functions as a fuse, shutting off the supply if the current exceeds 2A.

Output Overvoltage

In boost mode, the ADSRALM can produce high voltages under certain conditions: if the duty cycle is high and the load is light, or if feedback is disconnected. An LTC2912 overvoltage / undervoltage supervisor will disable the switching circuitry if the output exceeds 22V. An SMAJ24A, 24-volt TVS diode provides additional protection.

Inductor, Load Resistor Overtemperature

The inductor and onboard load resistors can get warm during certain experiments or if the board is misconfigured. Three temperature sensors measure the inductor temperature and the temperature of the high-dissipation areas of the load resistor bank. If any temperature exceeds 60ºC, switching is disabled for a 1.9 second cool-down period.

The low-resistance loads consist of parallel, single 100Ω, 1/2W resistors - An orange LED near the associated jumpers illuminates when the output voltage exceeds 7V as a warning that these must be disconnected.

The high resistance loads consist of multiples of two 100-ohm, 1/4W resistors in series, which will handle voltages up to 14V. A temperature sensor is still included in case the output voltage exceeds 14V or if the experiment is left running for an extended period of time.