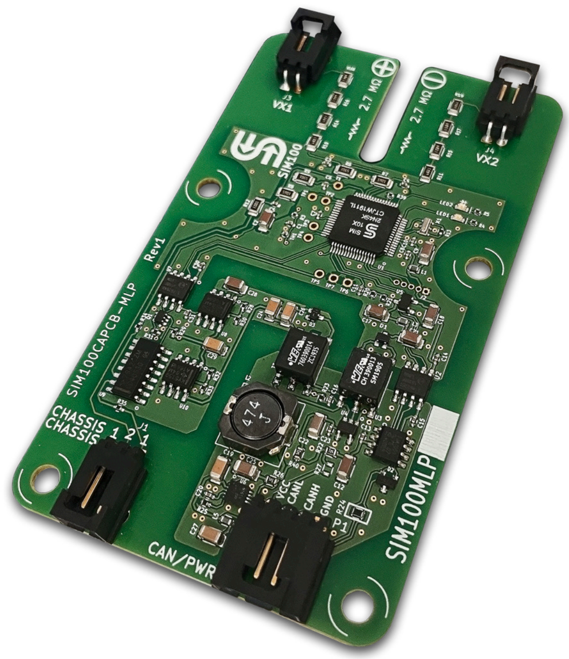
Sendyne®

Sendyne® Sensing Products Family

Sendyne Isolation Monitor For Unearthed (IT) DC Power Systems



Description

The Sendyne SIM100MLP is the first high voltage isolation monitoring device for EV/HEVs capable of operating correctly even when the battery is active, and experiencing large voltage variations, no variations, or even if the battery is not connected. The SIM100MLP continuously monitors the isolation resistance between a vehicle's IT (Isolated Terra) power system and chassis for deterioration of isolation and potentially dangerous levels of leakage current. The module detects not only resistive leakages but also capacitively stored energy that could be harmful to human operators.

Due to a proprietary, patented and patent pending advanced algorithm, the module is capable of detecting all sources of leakage, including multiple, simultaneous symmetrical and asymmetrical faults, as well as resistive paths between the chassis and points in the battery with the same potential as the chassis. In the case of an isolation fault, the unit identifies the position of the fault in relation to the battery's terminals. Battery-connected V_{X1} (Vp) and V_{X2} (Vn) voltage inputs can measure ±1.1 kV (max, see ordering options for other ranges) in reference to Chassis (0 V). Communications are achieved via an isolated CAN 2.0B interface and the unit operates over a wide temperature range of –40 °C to +105 °C. The Sendyne SIM100MLP was designed as a component for systems complying with ISO 6469-3:2011-12, UL 2231-1, UL2231-2, IEC 61557-A, CFR 571.305 and other applicable standards.

Applications

- *Monitoring ungrounded (IT) DC power systems for hazardous resistive and capacitive leaks*
- *Electric & hybrid vehicles*
- *Charging stations*
- *Energy storage facilities*
- *Battery Management Systems*

Operating Specifications

Parameter	Value
Power supply	+4.8 to +53 V (variable, accommodating +5 V to +48 V power supplies)
Interface	CAN 2.0B isolated, 120 Ω termination resistor (optional)
Voltage measurement range	2 Channels: ±1100 (max) V/channel continuous, no signal clipping
Rating	Automotive
Power consumption	< 375 mW (+5 V power supply), < 475 mW (+48 V power supply)
Module operating temperature range	-40 °C to +125 °C for electronics (-40 °C to +105 °C with connectors)

Table of contents

Features

- *Measures voltage of each battery terminal with refernce to chassis*
- *Reports battery voltage*
- *Reports accurate estimates of the isolation status while the battery is having large voltage variations*
- *When the battery is not connected or if the battery voltage drops below 15 V, the parallel combination of the two reported isolation resistances (for the high and low sides) is still accurate, as well as the sum total of the reported high and low capacitances*
- *Measures and reports modeled leakage resistances per model adapted by the safety standards ISO6469-1, FMVSS §571.305 and others*
- *Reports calculated isolation resistance in Ω/V per requirements of the safety standards*
- *Measures and reports the value of capacitance from each battery terminal to chassis*
- *Calculates and reports the energy stored by the total capacitance between the battery and chassis*
- *Reports uncertainty for all measured and calculated values*
- *Continuously monitors connections of the voltage sense lines to the battery terminals; reports inadequate connections*
- *Continuously monitors connection of the unit to chassis; reports inadequate connection*
- *Provides high immunity to common-mode noise that can be present on the battery terminals*
- *Provides nonvolatile storage for the value of the maximum (design) voltage of the battery (used in calculations of the isolation resistance and stored energy). If the actual observed battery voltage is higher than the set maximum voltage, the higher value is used in the calculations of the isolation resistance and stored energy*
- *Provides nonvolatile storage for calibration of the voltage measurements and other parameters; all reported measurements have their respective calibration parameters applied automatically*
- *Provides built-in galvanically isolated and intrinsically leakage-safe excitation source*
- *A single CAN message provides sufficient information for determination of the safety status of the system*
- *Initializes in under 6 seconds*
- *Fast detection of a rapid change in insulation resistance: The SIM100 detects an insulation value change in less than 5 secs*
- *Warning and Fault alerts provided in the STATUS byte for low insulation resistance values*

Safety of the IT power system

Ungrounded, unearthed, “floating” or IT (Isolé terre or Isolated Terra) are all terms used to describe power systems that have no intentional conductive connection to earth’s or chassis ground. The main advantage of the IT power system is that a single “short” will not disable its ability to continue delivering power. Figure 1 illustrates the basic topology of such a system.

The resistive connections, shown in Fig 1, between the terminals of the power source and the chassis are referred to as the “isolation resistances” ($R_{ISO,P}$ and $R_{ISO,N}$) and they represent the parallel combination of all resistive paths from the power source terminals to the chassis (including the ones the isolation monitor introduces). The values of isolation resistances are desirable to be high so leakage currents that travel through them are kept to a harmless minimum. The capacitors shown represent the parallel combination of all capacitances present, including the Y-capacitors typically used in DC IT systems to suppress EMI. The values of Y-capacitors are kept within limits in order to avoid hazardous accumulation of energy. The voltages V_p and V_n are shown each to be equal with half the battery voltage, which will be the case if the values of $R_{ISO,P}$ and $R_{ISO,N}$ are equal.

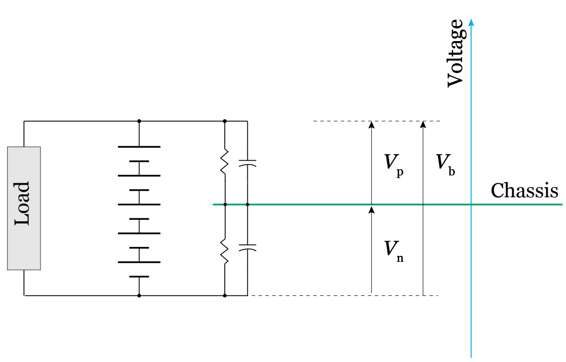


Figure 1: The IT power system topology

Isolation faults

If either of the isolation resistances decreases below the threshold of 100 Ohms/Volt a hazard occurs if a person makes contact with the terminal “opposite” to the leaking resistor. This hazardous situation is illustrated in Figure 2.

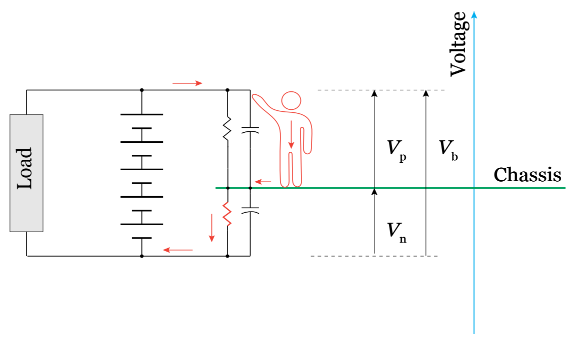


Figure 2: Single isolation fault

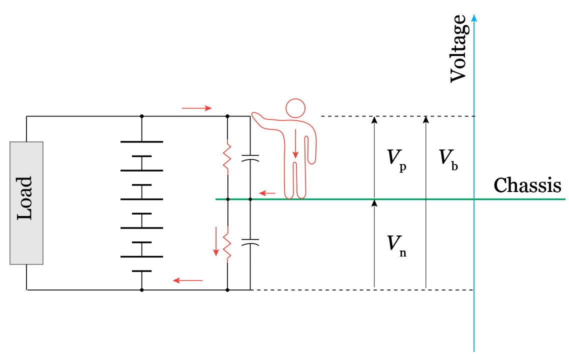


Figure 3: In a “symmetrical” isolation fault $V_n = V_p$

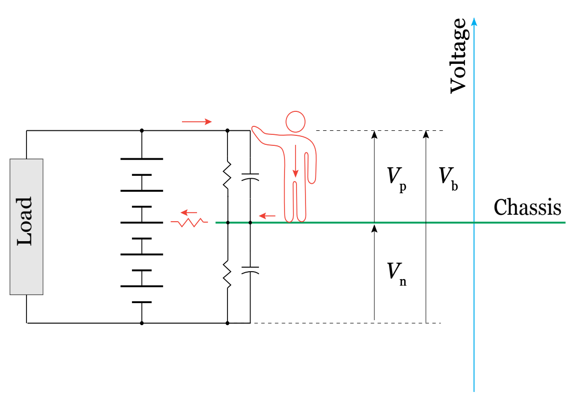


Figure 4: An isolation fault may originate from any point within a battery pack

This contact closes the circuit and current flows through a person's body. Note that although it is shown that $V_n < V_p$ in this example, an isolation fault cannot be detected based solely on voltage readings. The following illustrations show two examples where an isolation fault may be present while $V_n = V_p$.
A "symmetrical" or "double" isolation fault may occur through insulation failures in power connectors or other environmental and intrusion reasons and, depending on the value of leakage currents, may cause power loss, overheating and even fire. Detection of these types of faults is an absolute requirement for the safety of IT power systems.

Capacitive faults

Of equal importance to personal safety is another type of hazard. While international standards do not yet require it to be monitored, it is the hazard that can be caused by excessive energy stored in the IT power system capacitors. IT system designers ensure that design values of Y-capacitors prevent energy storage beyond the safety limit of 0.2 J. Sub-system failures, such as a coolant leakage or personnel interventions, may alter the originally designed capacitance values. In this case energy discharged through a person's body can create a hazardous event as shown in Fig. 5.

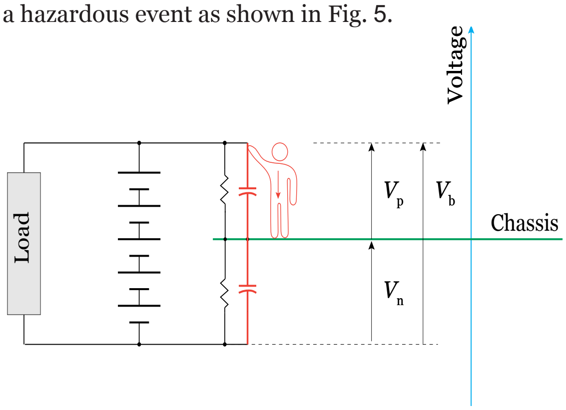


Figure 5: A capacitive fault will lead to excessive energy stored

Note that the stored energy limits are set for the parallel combination of all capacitances between the power terminals and chassis.

Sendyne's SIM100 is the only isolation monitor today that dynamically tracks IT system's capacitances and reports the maximum energy that can be potentially stored in them.

SIM100 performance

Sendyne's patented and patent pending method for monitoring the isolation state of the IT power system provides unique features not available in other commercial devices. Specifically, the SIM100 is capable of estimating accurately the state of the isolation system when the load is active and the battery voltage is continuously varying. This unique feature, while important for the safety of every IT electrical system, is especially important for the safety of systems that are engaged in commercial activities with very little down time, such as commercial vehicles and equipment.
In addition, the SIM100 is the only product in the market today that provides estimates for the isolation system capacitances. Besides the added safety provided by estimating the energy stored in them, capacitances estimation is necessary to be able to analyze the isolation system behavior dynamically and during transitions. Sendyne utilizes state-of-the-art stochastic filtering and numerical methods to evaluate the isolation state dynamically and accurately.
The SIM100 provides individual estimates for each isolation resistance and capacitance along with the uncertainty in their calculation. Typical accuracy of SIM100's estimates is better than ±5%.

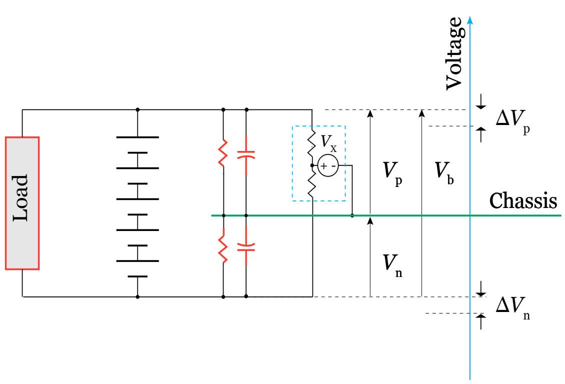


Figure 6: Sendyne's SIM100 estimates dynamically the isolation state taking into consideration the varying battery voltage and the Y-capacitances.

SIM100 response time

The SIM100 refreshes its estimates every 500 ms. Slow changes in the system isolation state can be tracked and updated within this interval. For large changes, such as the ones described in the UL 2231 tests, the response time of the SIM100 is less than 5 s.

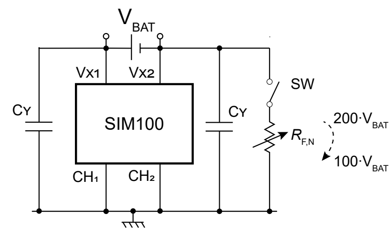


Figure 7: Circuit for testing SIM100 response time and accuracy in the successive insertion of a 200 Ohm/V and 100 Ohm/V resistor ($R_{F,N}$)

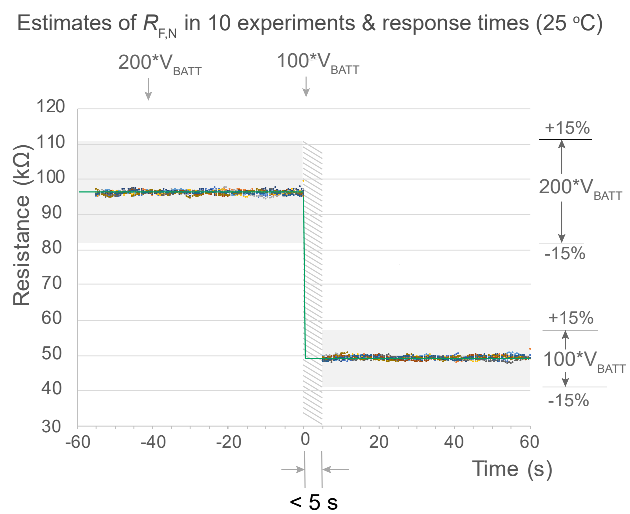


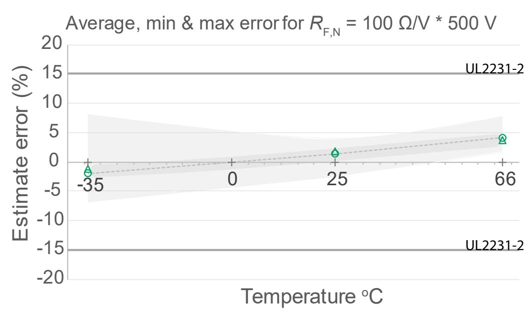
Figure 8: Estimates of $R_{F,N}$ provided in 10 successive experiments at room temperature. The green line represents the actual value of the inserted resistor. Greyed areas show UL2231-2 accuracy requirements.

As can be seen in Figure 8, SIM100 provides stable and accurate results within 5 sec of the transition. Response time is well below the 10 s requirement by different standards. Subsequent estimates are updated every 500 ms. In the same chart, highlighted in grey, are the ±15% accuracy levels specified by UL 2231-1 and -2. SIM100 estimate errors are below ±3%.

During the transition and while SIM100 is estimating the new isolation state, it will indicate a high level of uncertainty, so the host ECU can ignore those transition results. Similar results were obtained when testing the SIM100 on the positive side of the battery.

Thermal stability

Per UL 2231-2, the SIM100 was tested using the test apparatus of Figure 9 at different environmental temperatures. In the following illustrations the colored dots indicate the average error at each temperature obtained through approximately 1100 reports. The experiments were repeated for different Y-capacitor values (2 x 100 nF and 2 x 1 uF). The colored dots show the average values while the greyed areas show the spread of error in the reports indicating the max and min error on each experiment. We illustrate the worst case errors that occur at the smaller insertion resistance $R_{F,x}$. As can be seen all errors are well below the ±15% of the UL requirements.



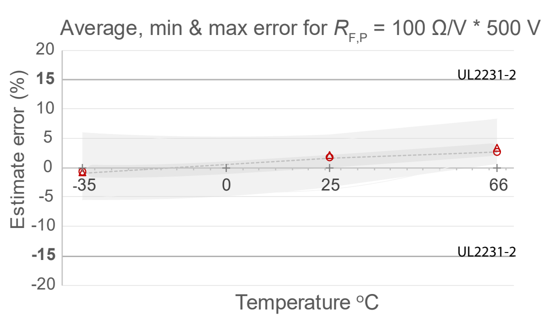


Figure 9: Inserted resistance estimate error at different temperatures

Uncertainty

Along with each report the SIM100 submits an estimate of the uncertainty associated with the estimates. The uncertainty is reported as a percentage of the estimated values and takes into consideration both the measurement and processing uncertainties. Uncertainty is derived in the interval of two standard deviations (95.45% of samples) and rounded to the next higher absolute value. For example, if the uncertainty calculated is ±1.4 % it will be rounded to ±2%. The SIM100 then adds to this value another ±3% to accommodate for factors that cannot be calculated, such as part values shifting over age, etc. As a result, the uncertainty value provided is a conservative one.
An illustration of the relationship between measurements distribution and uncertainties reported is shown in Figure 10. The green vertical line shows the actual value of the isolation resistance of the test circuit. Its value is the parallel combination of the 250 kΩ inserted resistance with the 2.7 MΩ resistance of the SIM100. The red vertical line shows the average value of SIM100 reports; the actual estimate error is 1.8%. Uncertainty is estimated to ±2% and then augmented by ±3% to provide the final estimate of ±5%. As can be seen in this experiment, uncertainty provides a very conservative estimate of the reported accuracy.

How to use the uncertainty

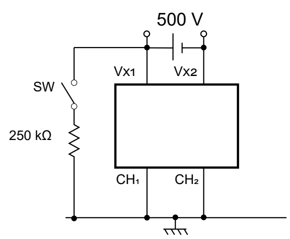
Uncertainties should be used in the most conservative way to calculate worst case scenarios. If, for example, the SIM100 reports a value of 100 kΩ with uncertainty of ±5%, the host should assume the worst case possibility that the actual isolation resistance is (100 – 5) kΩ.

Very high uncertainties

There may be instances that the SIM100 reports very high uncertainties. This may happen when there is no voltage present and there is a lot of noise in the IT system or during a large and rapid transition of isolation resistance values. During these instances, the SIM100 will flag the "High Uncertainty" bit to notify the host that these reports may be discarded.

Uncertainties in capacitance estimates

When there is no activity on the IT power system it is expected that individual capacitance estimates will have a high level of uncertainty. Nevertheless, the total value of isolation capacitance (the parallel combination of all capacitances) and the estimates for maximum energy that can be stored on them would be accurate. The uncertainty in capacitance estimation will become small (less than ±5%) as soon as there is activity on the IT power bus.



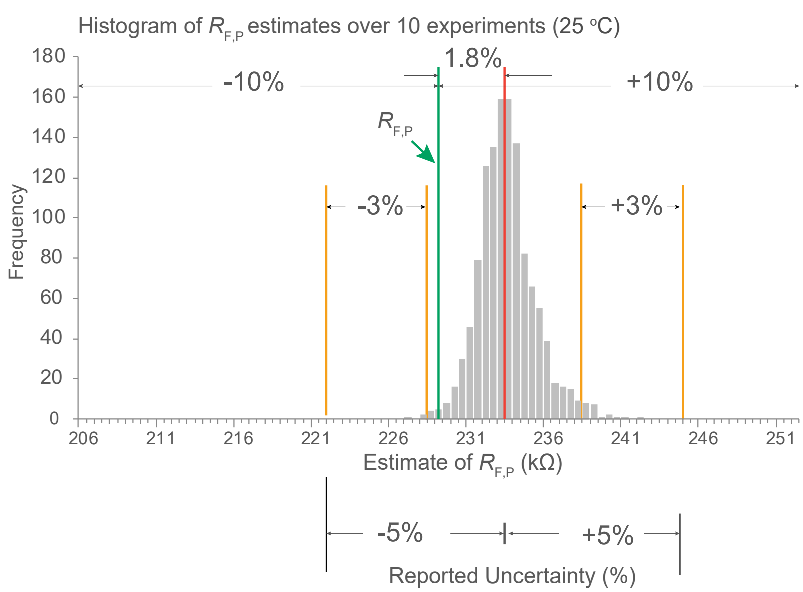


Figure 10: Distribution of reports over 10 experiments (1200 data points) and illustration of uncertainty reported by SIM100

Variable loads

The SIM100 is the only product today that can operate flawlessly in extremely noisy environments when the load of the IT power system is active. This is an important safety feature especially in commercial environments where the electrical equipment is in use most of the time. The SIM100 will provide accurate estimates even while the power system experiences violent swings of 10s or 100s of Volts.

Figure 11 shows the test setup and SIM100 responses under a battery load corresponding to an accelerated driving profile. In the test circuit a 250 kΩ resistor is connected and disconnected every 60 s. A driving profile load, accelerated and repeated multiple times, is simulated at the battery terminals. The resulting battery voltage is shown in the Battery voltage chart. The greyed areas indicate the 60 s intervals when the resistor is disconnected. The histogram shows the distribution of SIM100 reports in the periods when the resistor is connected.

The green vertical lines in the histogram show the actual isolation resistance when the 250 kΩ resistor is connected. As can be seen in the histograms, the error between the average reported value and the actual value is less than 1%.

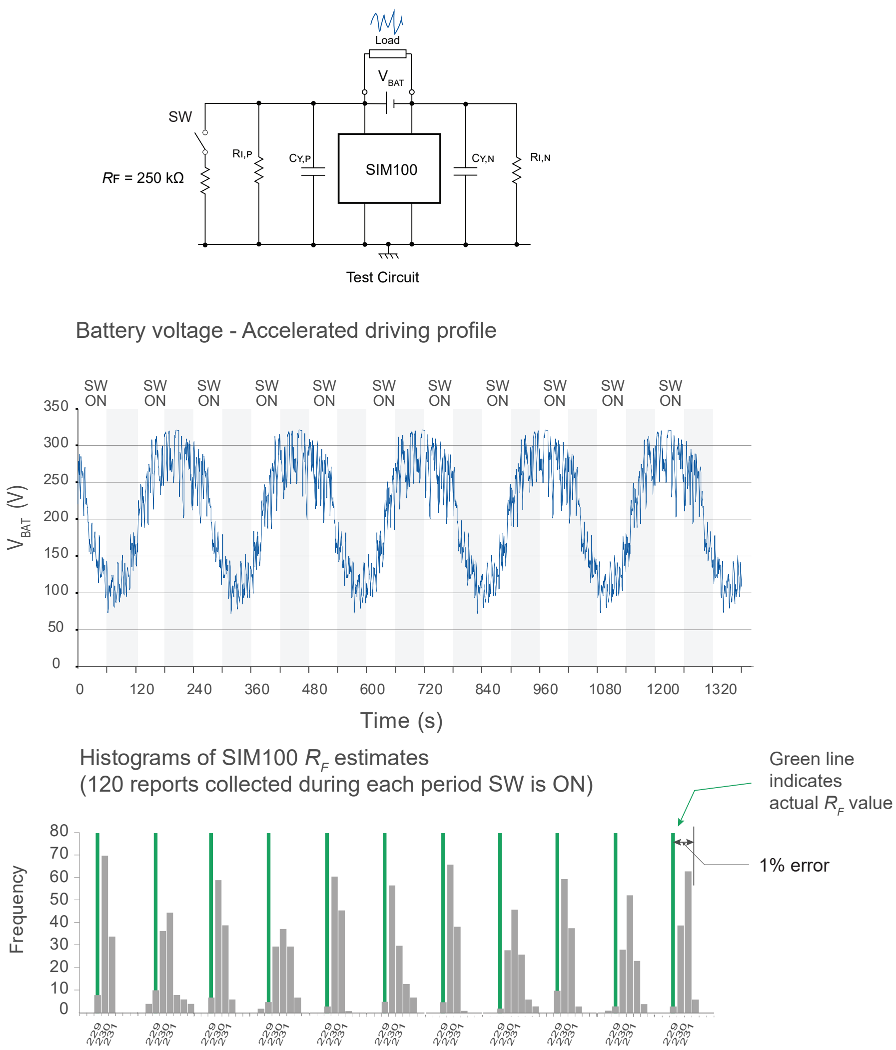


Figure 11: Testing of SIM100 under an accelerated driving profile

Technical Specifications

Electrical Specifications

Parameter	Min	Typ	Max	Units	Conditions/Comments
Power and General					
Electronics operating temperature range	-40		+125	°C	
Connector temperature ratings	-40		+105	°C	
Supply Voltage	4.8		53	V	
Supply Power			500	mW	
Start-up time		6		s	From application of power and power supply stabilization to availability of initial isolation values
Isolation Resistance Measurement					
Isolation resistance monitoring range	0		2.726	MΩ	From each side of the battery to chassis. (includes SIM100 resistances)
Isolation monitoring lines resistance		2.726		MΩ	This is the impedance imposed on the IT system by each of the two battery voltage monitoring lines and the maximum isolation resistance that can be measured
Isolation monitoring uncertainty		±5		%	For isolation resistance range of 100 kΩ to 500 kΩ, battery voltage above 15 V: The total measurement uncertainty includes the contribution by the noise and operations of the target system
Isolation values calculation period		0.5		s	The SIM100MLP calculates all reportable isolation values every 500 ms
Resistance value flagged as a short	0		5	kΩ	Reported isolation resistance value will be exactly 0 Ω/V
Voltage Measurement					
Nominal full-scale voltage range	±1520 ±1109	±1552 ±1132		V V	For SIM100MLP-xNx For SIM100MLP-xMx
Voltage offset error	-1	±0.2	+1	V	V_X = 0 V, applies over the full ambient operating temperature range, T_A = -40 °C to +125 °C

Electrical Specifications

Parameter	Min	Typ	Max	Units	Conditions/Comments
Voltage gain error	-1	±0.1	+1	%	Over the full ambient operating temperature range. Calibration and typical
Voltage noise error		200		mV_{RMS}	1 Hz reporting rate
Voltage measurement resolution		1		V	Minimum reportable voltage change
Permitted battery voltage	0 0		1500 1109	V V	For SIM100MLP-xNx For SIM100MLP-xKx If the battery voltage is under 15 V, only parallel resistance and capacitance will be accurate
Capacitance Measurement					
Capacitance monitoring range	0.1	1	2	µF	Capacitance from each terminal of the battery to chassis. A 100 nF capacitance (minimum) is required for normal functioning
Capacitance monitoring uncertainty		±15		%	200 nF to 2 µF, when battery voltage has at least 2 V periodic variations
Capacitance measurement resolution		1		nF	
Temperature Measurement					
Absolute temperature measurement error	-5	±0.5	+5	°C	Built-in temperature sensor
Temperature measurement resolution			10	m°C	Practical temperature measurement granularity
Noise Immunity of Measurements					
Common mode voltage on the battery terminals	20			$V_{PK\text{-}PK}$	No observable effect on isolation resistance value; measured with square and triangular wave test signals at 1 kHz, 10 kHz and 30 kHz
Differential mode voltage on the battery terminals (battery voltage variations)		100		$V_{PK\text{-}PK}$	No observable effect on isolation resistance value; tested with a battery-voltage driving profile that has multiple instantaneous voltage changes up to ±100 V and overall slow battery voltage fluctuation from 330 V to 125 V and back to 330 V

Electrical Specifications

Parameter	Min	Typ	Max	Units	Conditions/Comments
Test voltage			3	kV_{DC}	CAN interface to chassis, 1 min. duration
ESD tolerance			25	kV	Air discharge to VX1/VX2 terminals; CAN connector's signals and/or Chassis connector signals have continuity to reference GND of the ESD tester
			±15k	kV	Contact discharge to VX1/VX2 terminals, same conditions as above

Communications

Interface	Spec	Speed	Termination
CAN	2.0B	500 or 250 kbit/s	120 Ω termination resistor optional

Connectors

Interface	Manufacturer	Positions	Part number	Description
CAN & power on board	Molex	4	705510038	P1: 4 pos. right angle header, shrouded connector (2.54 mm), through hole tin
CAN & power mating con.	Molex	4	50579404 50579704 (with TPA)	Use appropriate crimp contacts (available for AWG 22, 24 and 26)
Voltage sensing on board	Molex	2	705510036	J1, J3, J4: MINIFIT JR HDR 02P 94V-0 30AU
Voltage sensing mating con.	Molex	2	50579402 50579702 (with TPA)	MINIFIT JR RCPT DR SIDETABS 2 CKT 94V-0. Crimp contacts available for AWG 18 to 28

The SIM100MLP uses Molex connectors, part numbers: 705510036 and 705510038.
For more details please go to www.molex.com

Connectors

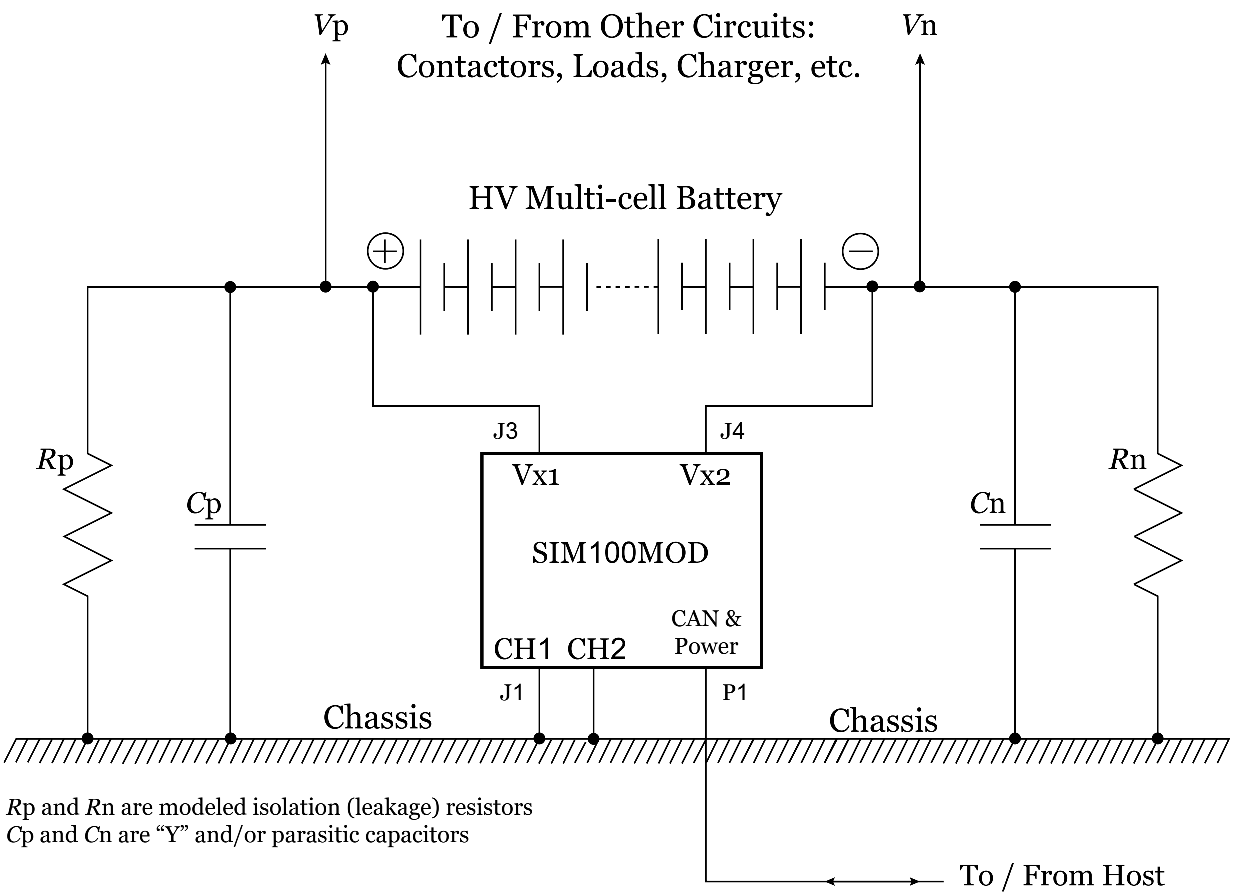
Pin Number	Signal Name	Comments
Connector J1		
1	CH1	Chassis connection 1. One of two independent connections to Chassis.
2	CH2	Chassis connection 2. One of two independent connections to Chassis.

Note: Signals CH1 and CH2 should have independent connections to Chassis. The SIM100 module continuously monitors continuity between these two signals. This information is used for examination of the assured connection of the SIM100 module to Chassis. Absence of solid Chassis connections is reported as a Fault; at that time the results of the Isolation Measurements are not valid.

Pin Number	Signal Name	Comments
Connector J3		
1	V_{X1}	To be connected to positive terminal of the Battery. The two pins in this connector are shorted on the PCB; either one or both (redundant) pins can be used for the electrical connection.
2	V_{X1}	Same as above.
Connector J4		
1	V_{X2}	To be connected to negative terminal of the Battery. The two pins in this connector are shorted on the PCB; either one or both (redundant) pins can be used for the electrical connection.
2	V_{X2}	Same as above.
Connector P1		
1	GND	Common / GND connection, negative return for the power supply.
2	CAN_H	One of two CAN communications lines. Termination resistor of 120 Ω is installed between these two lines on the SIM100 module.
3	CAN_L	One of two CAN communications lines. Termination resistor of 120 Ω is installed between these two lines on the SIM100 module.
4	VCC	Positive power supply, can be any voltage within +4.8 V to +53 V.

Note: Signal names for pins of connector P1 are labeled on the PCB. Signal GND is galvanically isolated from Chassis.

Typical Applications

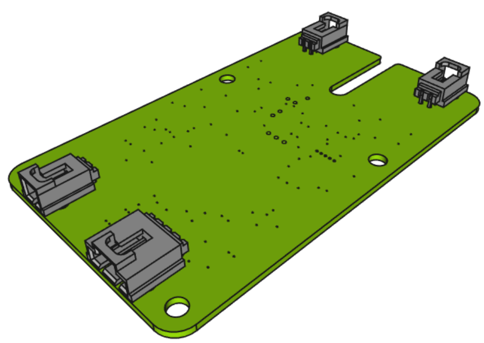


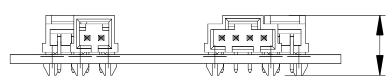
*R*p and *R*n are modeled isolation (leakage) resistors
*C*p and *C*n are "Y" and/or parasitic capacitors

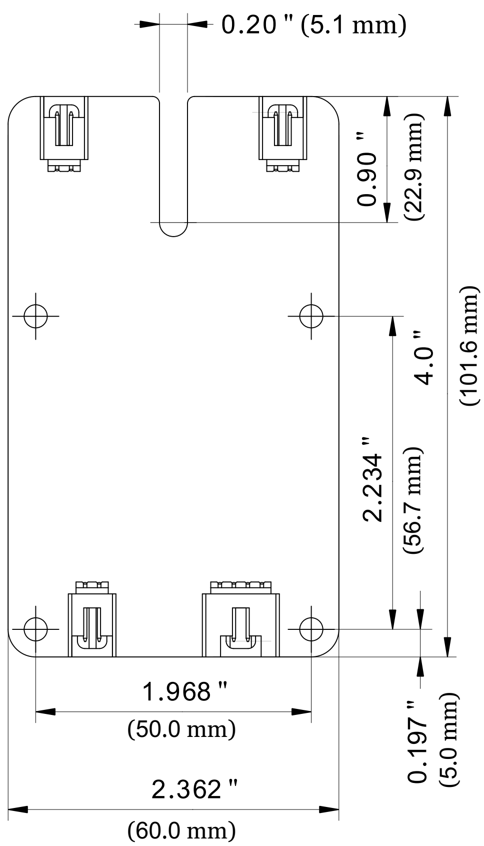
A 100 nF capacitance (minimum) for *C*p and *C*n is required for normal functioning.
For information on the Host controller interactions with the SIM100 module, and readout of the results of the module's measurements, please refer to the separate "SIM100MLP CAN Protocol" document.

Mechanicals

SIM100MLP general dimensions [inches]







Ordering Information

Part Number	Description
SIM100MLP-XXX	SIM100MLP module. See table below for XXX options.

Ordering Options (XXX)

SIM100MLP-XXX

CAN bus	**Voltage**	**Connectors & CAN termination**
A - 500 kbit/s	L - 100 V	A - All connectors, termination
B - 250 kbit/s	**K - 1100 V**	B - All connectors, no termination
	N - 1500 V	

xLx & xNx versions with special order

Revision History

Revision Table

Revision Number	Date	Comments
1.1a	3/12/2021	Corrected connectors part #
1.1	11/11/2019	Added 1.1 kV ordering code and spec
1.0	4/10/2019	Initial release

Patents
US Pat. 8,373,408
US Pat. 8,350,552
US Pat. 8,289,030
Other patents pending

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1234567890 1234567890

Sendyne®

Mailing Address: Sensata Technologies, Inc., 529 Pleasant Street, Attleboro, MA 02703, USA

CONTACT US

Regional head offices:

United States of America
Sensata Technologies
Attleboro, MA
Phone: 508-236-3800
E-mail: support@sensata.com

Netherlands
Sensata Technologies Holland B.V.
Hengelo
Phone: +31 74 357 8000
E-mail: support@sensata.com

China
Sensata Technologies China Co., Ltd.
Shanghai
Phone: +8621 2306 1500
E-mail: support@sensata.com