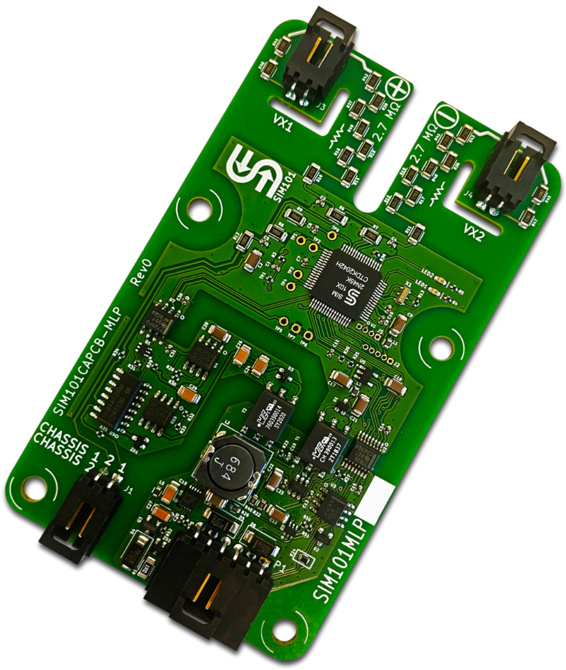
Sendyne® Sensing Products Family

Sendyne Insulation,Touch Energy & Voltage Monitor for Unearthed (IT) DC Power Systems



Applications

– *Monitoring ungrounded (IT) DC power systems for hazardous resistive and capacitive leaks and faults*
– *Electric & hybrid vehicles*
– *CHAdeMO and CharIN charging stations*
– *Energy storage facilities*
– *Battery Management System*

Description

The Sendyne SIM101MLQ is a safety device for high voltage unearthed IT (Isolated Terra) power systems. It monitors and reports the isolation resistance between each power rail and chassis, the total Y-capacitance and stored energy and the voltages between the power rails as well as between each power rail and chassis.

It communicates with the host ECU via CAN and provides two isolated lines to provide status information and signal "Warning" and "Fault" conditions.

The SIM101MLQ will detect and report single or symmetrical faults in less than 1 s. It reports accurately the system isolation state even when the power load is active, experiencing large voltage variations, no variations, or even if the DC high voltage power is not connected. It will detect leakages occuring in any place of the IT system, including inside the battery, DC/AC converters and AC motors.

The SIM101MLQ provides estimates of the total capacitances present between power rails and chassis and dynamically estimates the maximum energy stored providing alerts for harmful to human operators levels.

The SIM101MLQ provides accurate voltage measurements updated each 10 ms for the IT power supply, as well as for power rail to chassis voltages.

The Sendyne SIM101MLQ was designed as a component for systems complying with ISO 6469-3, UL 2231-1, UL2231-2, IEC 61557-8, CFR 571.305, CHAdeMO, CharIN and other applicable standards.

Operating Specifications

Parameter	Value
Monitored IT supply voltage range	0 - 1100 V (0 -1500 V option available)
Power supply	+4.8 to +36V
Communication	CAN 2.0B isolated, Digital warning and fault signal lines
Rating	Automotive
Power consumption	< 375 mW (+5 V power supply), < 400 mW (+36 V power supply)
Module operating temperature range	-40 °C to +105 °C (-40 °C to +125 °C for electronics)

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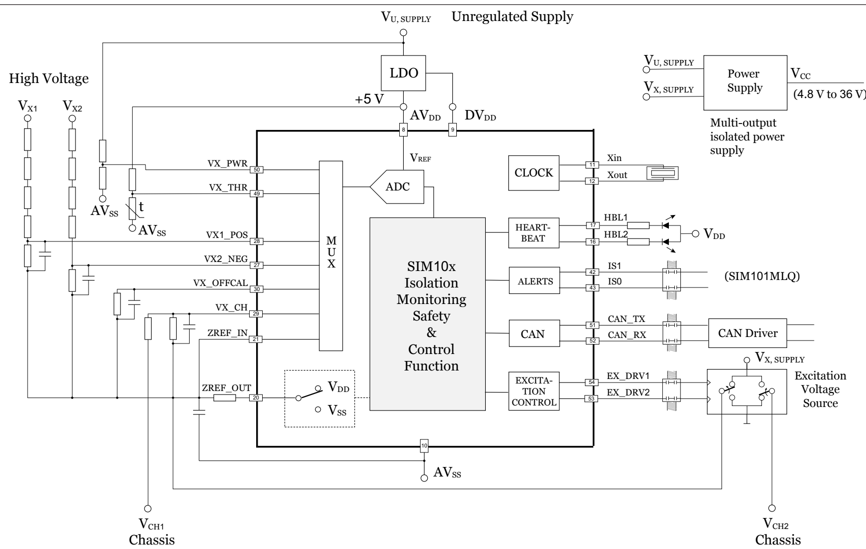
Features



– *Measures voltage of each power terminal with refernce to chassis*
– *Reports IT power supply (or battery) voltage*
– *Reports accurate estimates of the isolation status while the battery is having large voltage variations*
– *Detects isolation violations per programmed maximum voltage as well as the total of capacitances even when power source is disconnected*
– *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 total system capacitance*
– *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*
– *Protected mode for setting operating parameters and limits*
– *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 SIM10x detects an insulation value change in a compliant system in less than 1 sec*
– *Warning and Fault alerts provided in dedicated signal pins and 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.

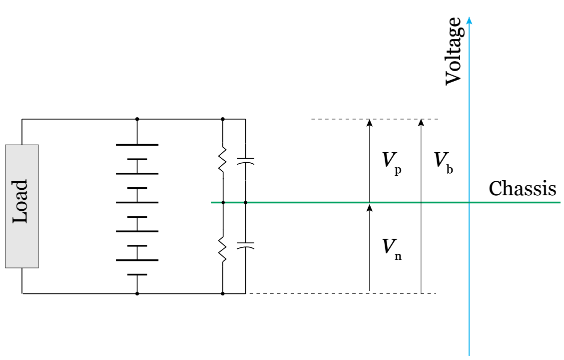


Figure 1: The IT power system topology

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.

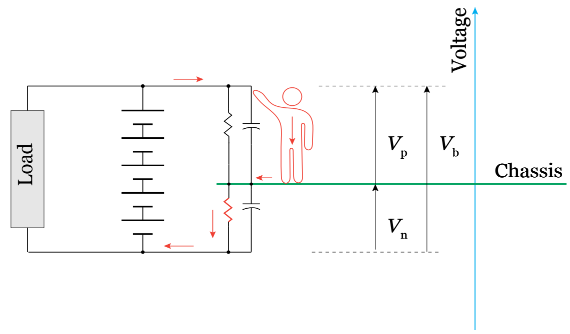


Figure 2: Single isolation fault

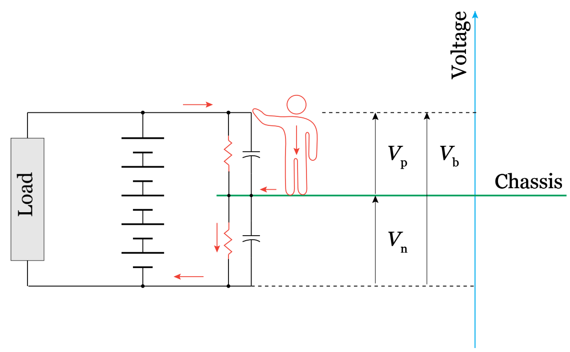


Figure 3: In a “symmetrical” isolation fault $V_n = V_p$

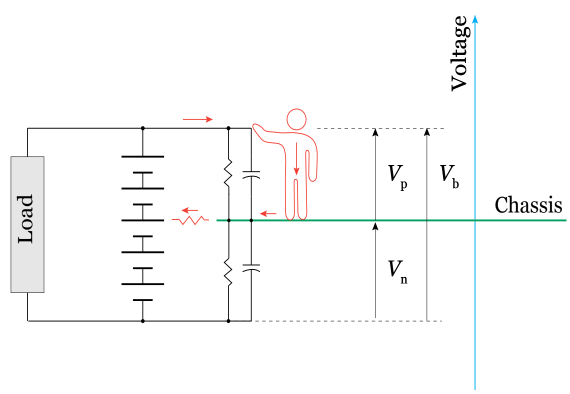


Figure 4: An isolation fault may originate from any point within a battery pack

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" , "asymmetrical" 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.

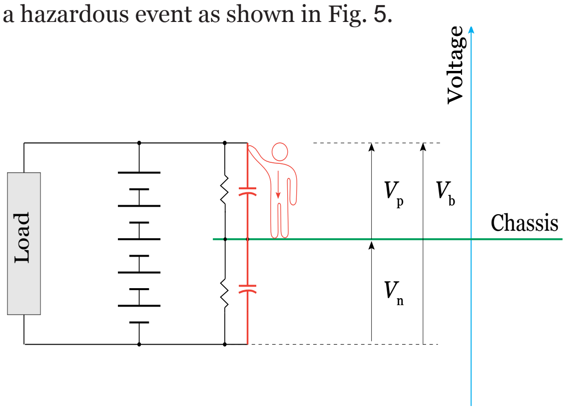


Figure 5: A capacitive fault will lead to excessive energy stored

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

Sendyne's SIM101 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.

SIM101 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 SIM101 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 SIM10x are the only products in the market today that provide 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 system identification methods to evaluate the isolation state dynamically and accurately. The SIM101 provides individual estimates for each isolation resistance and total capacitance along with the uncertainty in their calculation. Typical accuracy of SIM101's estimates is better than ±5%.

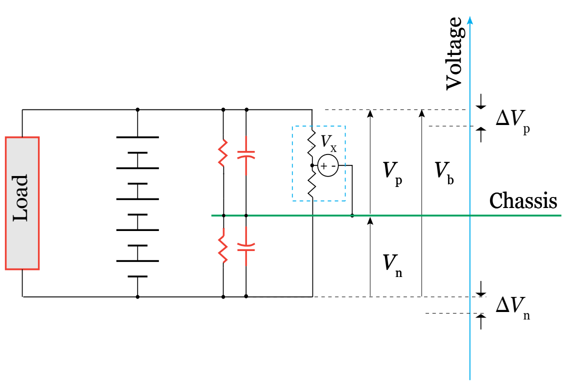


Figure 6: Sendyne's SIM101 estimates dynamically the isolation state taking into consideration the varying battery voltage and the Y-capacitances.

SIM101 response times

Warning and Fault alerts in less than 1 s

The SIM101MLQ provides two methods for quick detection of a "Warning" or "Fault" condition.

Alerts through CAN communications

A Warning (@ 500 Ω/V) or Fault (@ 100 Ω/V) condition can be detected through CAN communications by monitoring the status of the IS0-IS1 `Isolation_status_bits` in the `Status_bits` signal group (see "SIM101 CAN Protocol Reference Manual" for details). The `Isolation_status_bits` will be set according to the maximum IT system voltage set, utilizing the SIM101 protected "Maintenance mode" (see "SIM101 Maintenance Mode" document for details). If the maximum voltage is not set, SIM101 will use for its calculations the maximum voltage detected during its operation.
In less than 1 second the SIM101 will detect a single, a symetrical (both positive and negative isolation resistances fail at the same time) or asymetrical fault (both isolation resistances change but only one fails). The `Isolation_status_bits` are debounced for a period of 200 ms to avoid spurious alerts. The `Status_bits` will reset accordingly as soon as the isolation state of the system changes. Note that in maintenance mode OEMs have the ability to set their own limits in Ω/V for warnings and fault alerts.
The following table illustrates the different states of the isolation status bits.

ISO1	*ISO0*	*Isolation status*
0	0	Isolation status OK
0	1	Isolation state unknown. Set when excitation signal is disabled.
1	0	Warning. Isolation resistance < 500 Ohm/V limit (the Ohm/V value can be changed in the maintenance mode)

ISO1	*ISO0*	*Isolation status*
1	1	Isolation fault. Isolation resistance <100 Ohm/V limit (the Ohm/V value can be changed in the maintenance mode)

Alerts through hardware signals

Two dedicated pins on connector P1 provide open drain signals to the host system corresponding to the status of the IS1-IS0 bits of the `Status_bits` register. These signals can be used by the host system to assert interrupts alerting for a change in the isolation status of the monitored system.

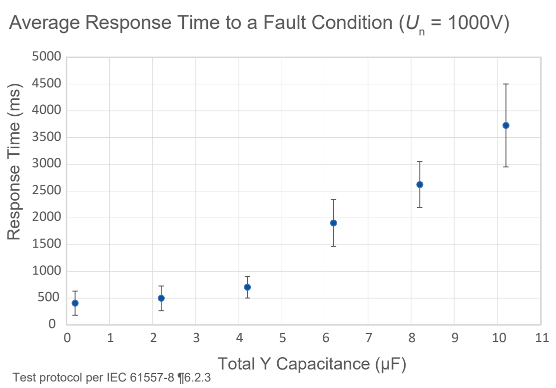


Figure 7: Average response time to the introduction of a Fault condition as function of the total system capacitance. Response times are the same for single, symmetrical or asymmetrical faults. Vertical bars indicate the standard deviation.

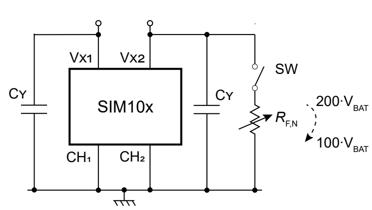


Figure 8: Circuit for testing SIM101 in the absense of power in the monitored system

Estimation of isolation state in the absense of IT power

SIM101 is capable of accurately detecting the isolation state of the monitored IT system even in the total absense of power. This feature is useful in systems where the host controller needs to ensure in advance that no isolation violation will occur when the high voltage power source is connected. “Warning” and “Fault” levels in such a condition are calculated based on the stored values of $V_{BAT, MAX}$.

The following chart illustrates the typical responses of SIM101 while switching between two isolation resistance values representing 200* $V_{BAT, MAX}$ and 100* $V_{BAT, MAX}$ respectively.

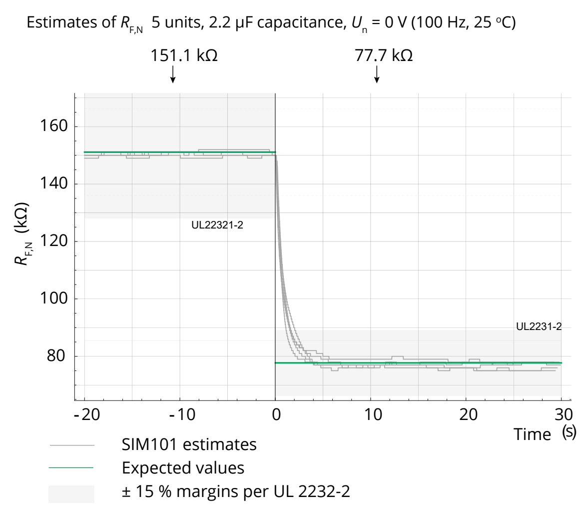


Figure 9: In a UL 2231 type test the isolation resistance is switched from 151 kΩ to 77.7 kΩ. The chart illustrates the responses of 5 units.

Accuracy of isolation resistances estimates

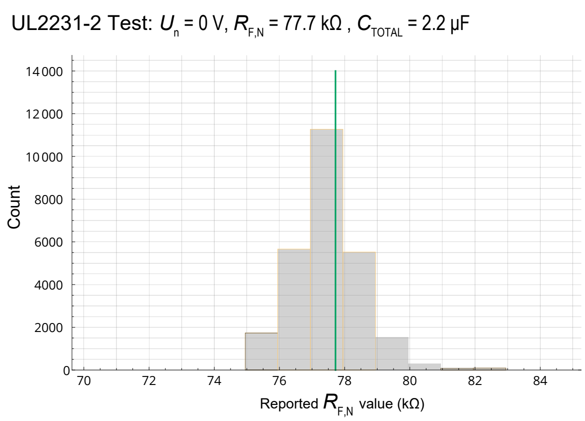


Figure 10: Histogram of SIM101 estimates taken after 4 time constants. Green line represents the expected value.

Estimation of $R_{ISO,P}$, $R_{ISO,N}$ values (< 3 s)

The SIM101 refreshes its estimates of $R_{ISO,P}$, $R_{ISO,N}$ values every 10 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 SIM101 is less than 3 s. The reason that value estimates are slower to produce than alerts, is that SIM101 applies filtering to the estimated values to avoid noisy outputs.

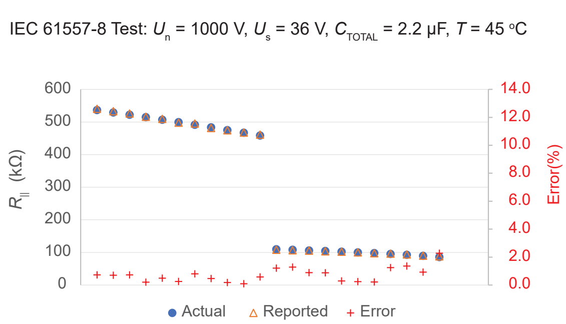


Figure 11: SIM101 can accurately track small variations of the isolation resistances during a test of inserting a symmetrical fault.

Thermal stability

Per UL 2231-2, the SIM101 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. 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.

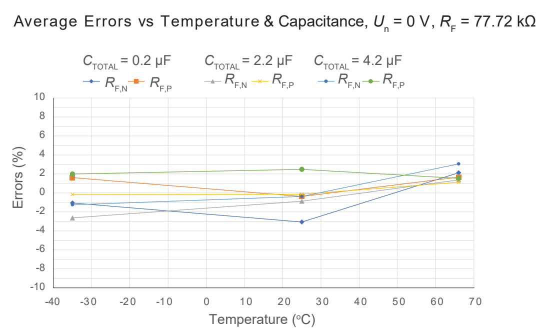


Figure 12: Average errors during a UL 2231-2 test, inserting a 77.72 kΩ resistance alternatively between the positive and negative rails and chassis, for different temperatures and different total system capacitances. The test was performed with zero power on the rails.

Uncertainty

Along with each report the SIM101 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 nearest integer value.

For example, if the uncertainty calculated is ±1.6 % it will be rounded to ±2%. The SIM101 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 SIM101. The red vertical line shows the average value of SIM101 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 SIM101 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 SIM101 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 or in the presence of high system capacitances. During these instances, the SIM101 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.

Variable loads

The SIM101 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 SIM101 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 SIM101 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 SIM101 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%.

SIM101 Self-testing

The SIM101 performs a continuous self-testing process. During the self-test, the SIM101 checks the validity of all connections and the integrity of all references and critical hardware components. Details on the self-test process can be found in the "SIM101 Safety Manual"

Field upgradeable

The SIM101 comes equipped with Sendyne's proprietary boot-loader. The boot-loader relies on AES128 cryptographic standard to ensure that firmware updates are not compromised. It can be accessed through CAN -bus and allows field upgrades of the SIM101 software.

CAN communications

The SIM101 CAN protocol description can be found in the "SIM101 CAN 2.0B Protocol Document" and the "SIM101.dbc" files. The SIM101 can be configured with CAN running at 250 kb/s or 500 kb/s. The SIM-101MLP can be ordered with or without CAN bus termination resistors. For information on ordering see the "Ordering information" section of this document.

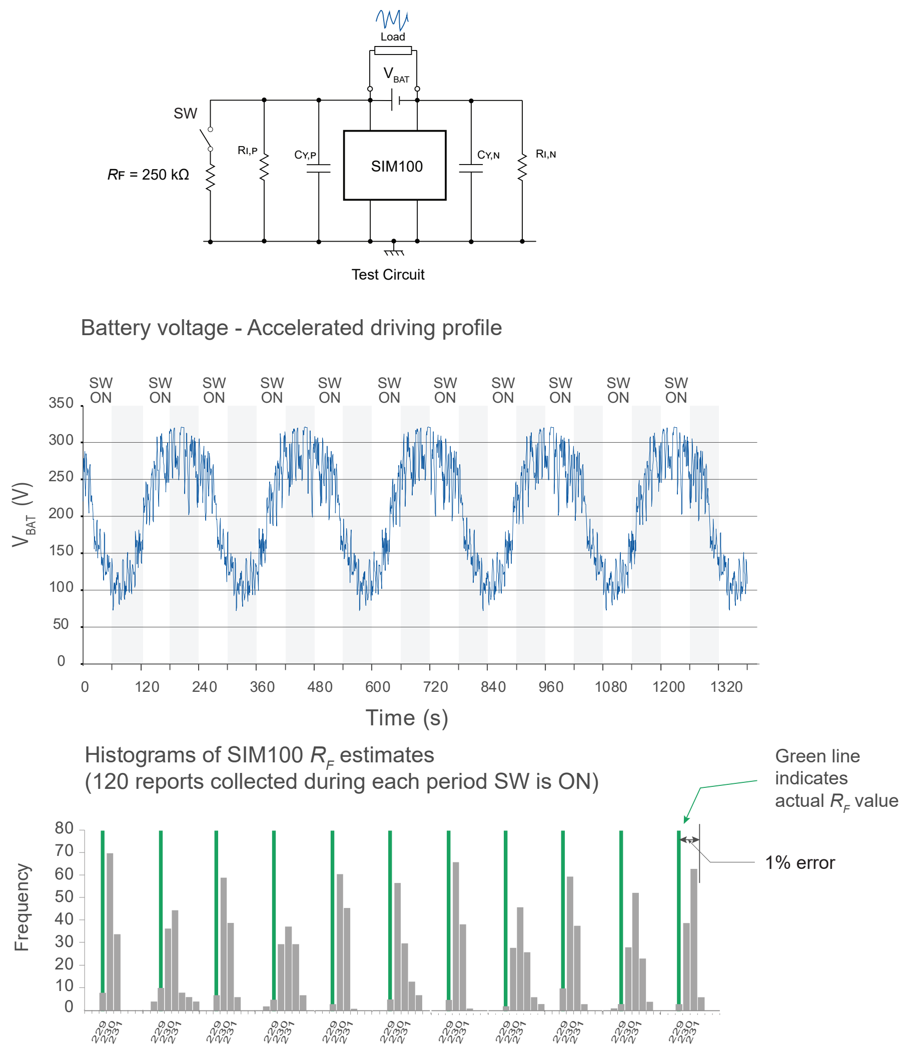


Figure 13: Testing of SIM100 under an accelerated driving profile

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		36	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 SIM101 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 SIM101 calculates all reportable isolation values every 10 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	±1109	±1132		V	
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

Parameter	Min	Typ	Max	Units	Conditions/Comments
Voltage gain error	-1	±0.1	+1	%	Over the full ambient operating temperature range.
Voltage noise error		200		mV_{RMS}	1 Hz reporting rate
Voltage measurement resolution		1		V	Minimum reportable voltage change
Permitted battery voltage	0		1109	V	For SIM101MLQ-xNx
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-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-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
Test voltage			3	kV_{DC}	CAN interface to chassis, 1 min. duration

Table: *Electrical Specifications*

Electrical Specifications

Parameter	Min	Typ	Max	Units	Conditions/Comments
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
COM & power on board	Molex	6	705510040	P1: 6 pos. right angle header, shrouded connector (2.54 mm), through hole tin
COM & power mating con.	Molex	6	50579406 50579706 (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

Connectors

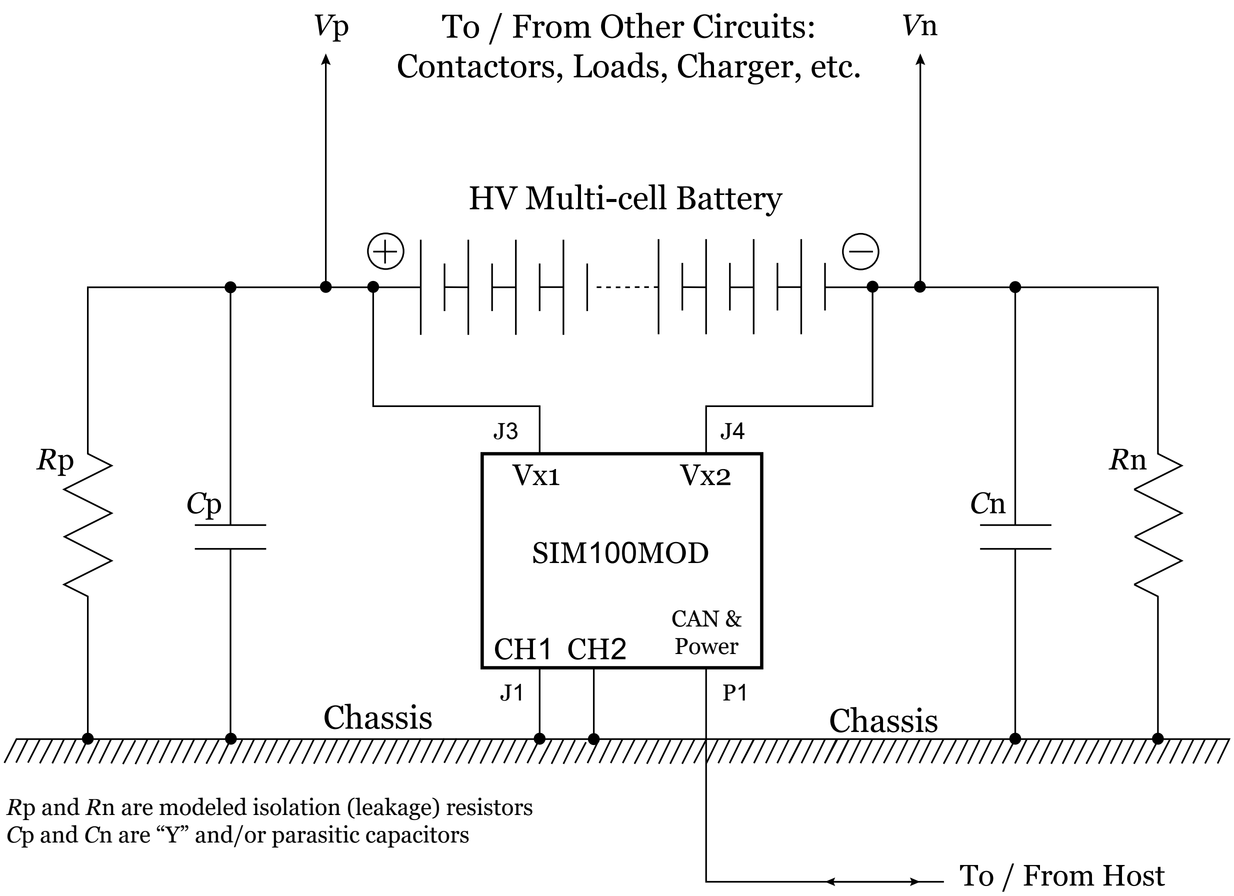
Pin Number	Signal Name	Comments
Connector J1		
1	CH1	Chassis connection 1. One of two independent connections to Chassis.
2	CH2	Chassis connection 2. One of two independent connections to Chassis.

Note: Signals CH1 and CH2 should have independent connections to Chassis. The SIM101 module continuously monitors continuity between these two signals. This information is used for examination of the assured connection of the SIM101 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 SIM101 module.
3	CAN_L	One of two CAN communications lines. Termination resistor of 120 Ω is installed between these two lines on the SIM101 module.
4	VCC	Positive power supply, can be any voltage within +4.8 V to +36 V.
5	ISO_0	Open drain output signal corresponding to IS0 isolation status bit. Requires external pull-up, max output voltage +36 V.
6	ISO_1	Open drain output signal corresponding to IS1 isolation status bit. Requires external pull-up, max output voltage +36 V.

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

Typical Applications

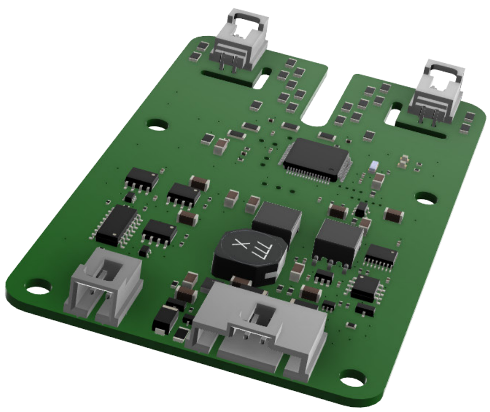


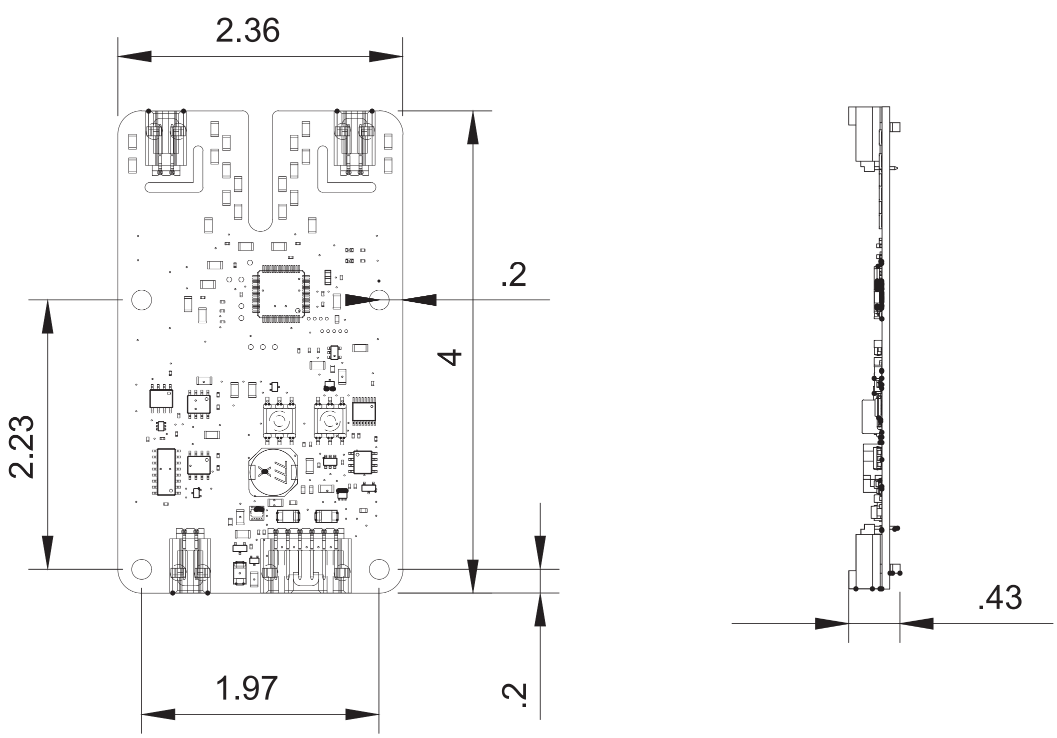
*R*p and *R*n are modeled isolation (leakage) resistors
*C*p and *C*n are "Y" and/or parasitic capacitors

A 100 nF capacitance (minimum) for Cp and Cn is required for normal functioning.
For information on the Host controller interactions with the SIM101 module, and readout of the results of the module's measurements, please refer to the separate "SIM101 CAN Protocol" document.

Mechanicals

SIM101MLQ general dimensions [inches]





Ordering Information

Part Number	Description
SIM101MLQ-XXX	SIM101MLQ module. See table below for XXX options.

Ordering Options (XXX)

SIM100MLP-XXX

CAN bus
A - 500 kbit/s
B - 250 kbit/s

Voltage
L - 100 V
K - 1100 V
N - 1500 V

Connectors & CAN termination
A - All connectors, termination
B - All connectors, no termination

xLx & xNx versions with special order

Revision History

Revision Table

Revision Number	Date	Comments
1.1	8/10/2021	Updated test charts
1.0	5/25/2021	Initial release #

Information contained in this publication regarding device applications and the like, is provided only for your convenience and may be superseded by updates. It is your responsibility to ensure that your application meets with your specifications.

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Patents
US Pat. 10,852,332
US Pat. 8,373,408
US Pat. 8,350,552
US Pat. 8,289,030
Other patents pending

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