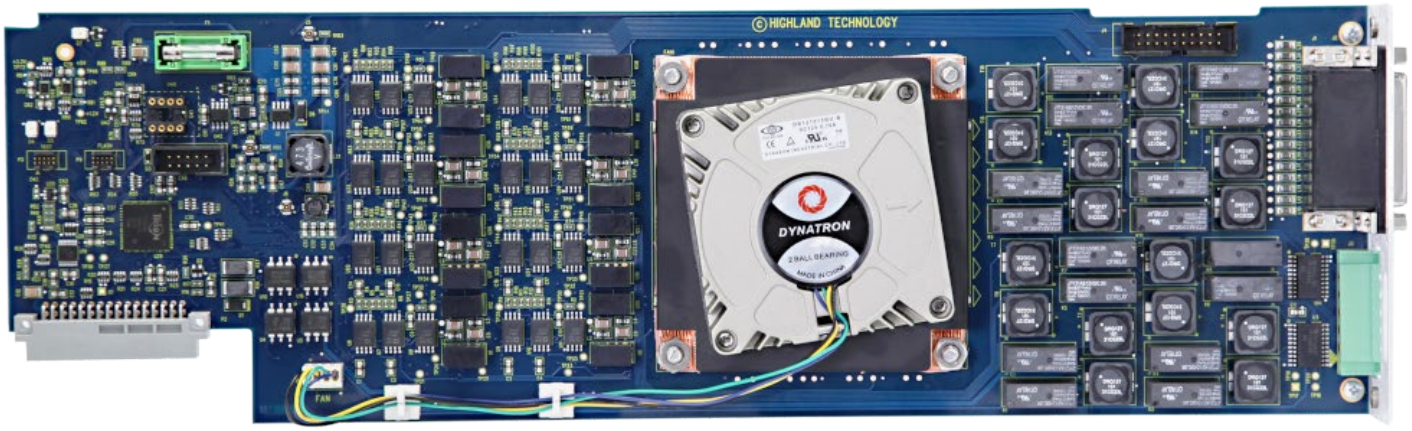
HIGHLAND TECHNOLOGY

MODEL P945

8-Channel Load Simulator



P940

Modular power system

a Highland Technology innovation

Manual B1

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Contents

1 *Introduction*

The P945 is an 8-channel isolated load simulation module for the P940 modular power system. Each of the channels is galvanically isolated and can sink up to 40V/2A/40W. External inductors may be switched into the channels to allow simulation of relays, solenoids, torque motors, or other magnetically operated devices.

P945 simulated loads are bipolar and support positive or negative applied voltages with respect to the labeled terminals; the polarity of the input signal only impacts polarity of reported voltage and current measurements.

The P945 is available in two variants. The P945-1 can draw up to 2A per channel and is optimized for simulation of high-power loads such as solenoids or contactors. The P945-2 trades current handling capability for precision measurement of small currents and is optimized for smaller, precision loads such as torque motors.

As a part of the P940 system, the P945 is easily synchronized with other P940 modules, enabling system architects to build whatever power and simulation environment they may require.

Features include:

- Eight independent, programmable loads up to 40W each
- 160W maximum total power dissipation
- Programmable channel resistances from 10Ω – 1000Ω
- Per-channel voltage, current, and power reporting
- Open and short-circuit capability
- Switchable external inductors
- Switchable “high-side” connection allows channels to be connected to a common power bus
- Optional jumper connects two P945s for a total of 320W, allowing 40W simultaneous loading on all 8 channels from a single input cable
- Real-time signal measurement capabilities for voltage, current, and instantaneous power
- Controllable and readable from P940 front panel
- Integrated SCPI command set with other P940 modules, available over Ethernet and USB

2 *Specifications*

2.1 *Overall*

FUNCTION	8-channel load simulator
SIZE	Single P940 slot
OPERATING MODES	Constant resistance, constant current, short circuit, open circuit

2.2 *Absolute Maximum Limits*

	P945-1	**P945-2**
VOLTAGE (PER CHANNEL)	±40V	
CURRENT (PER CHANNEL)	±3A	±300mA
POWER (PER CHANNEL)	40W	12W
POWER (PER MODULE)	160W	96W
HIGH-SIDE POWER BUS CONNECTOR CURRENT (PER PIN)	±12A	

2.3 *Performance*

	P945-1	P945-2
MINIMUM WORKING VOLTAGE[1]	±2V	±1.5V
RESISTANCE SIMULATION RANGE	10Ω – 1000Ω in 1Ω steps	40Ω – 1000Ω in 1Ω steps
RESISTANCE SIMULATION ACCURACY	5%	
CONSTANT CURRENT RANGE	0 – 2A in 0.001A steps	0 – 250mA in 0.001A steps
VOLTAGE MEASUREMENT ACCURACY	±1% of applied voltage ±10mV	
CURRENT MEASUREMENT ACCURACY	±1% of applied current ±1.5mA	±1% of applied current ±0.25mA
SHORT CIRCUIT MODE	≤2V up to maximum rated current	
OPEN CIRCUIT MODE	≤1mA up to maximum rated voltage	

[1] Accuracy specifications not guaranteed below minimum working voltage

2.4 *Typical Performance Characteristics*

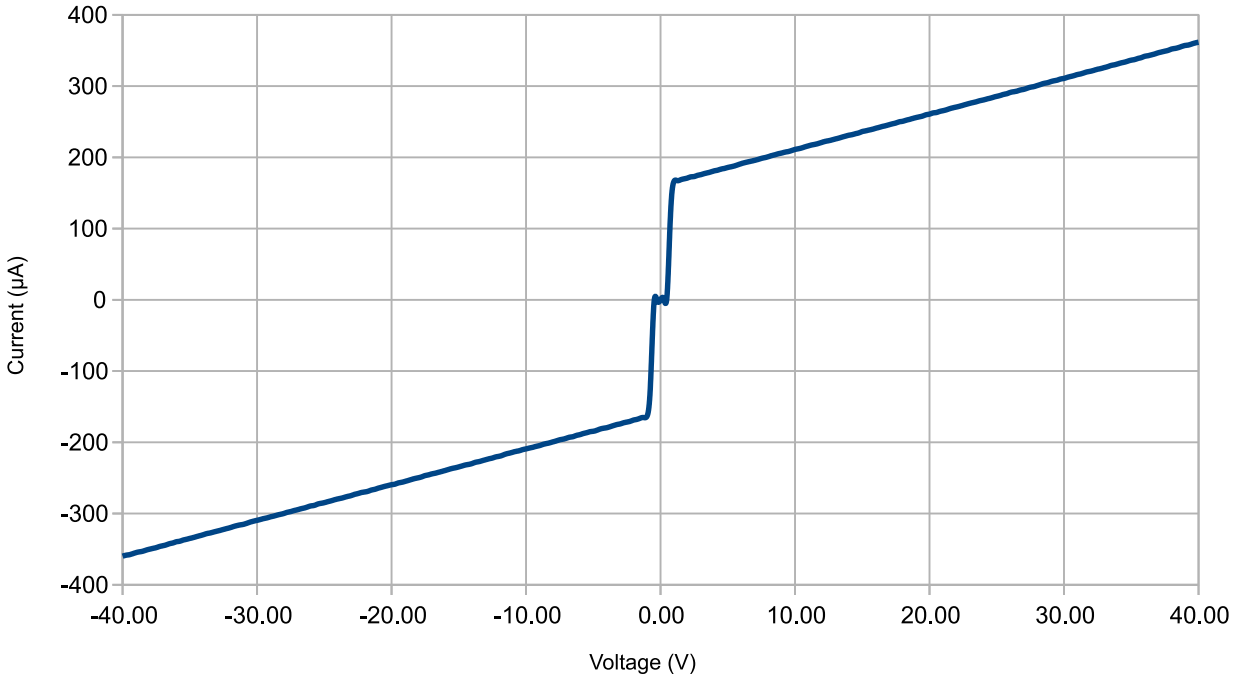


Figure 2-1: Open Circuit Behavior

3 *Hardware*

3.1 *Installation*

The P945 can be installed in any slot of a P940 chassis. Please follow the installation instructions in the P940 manual.

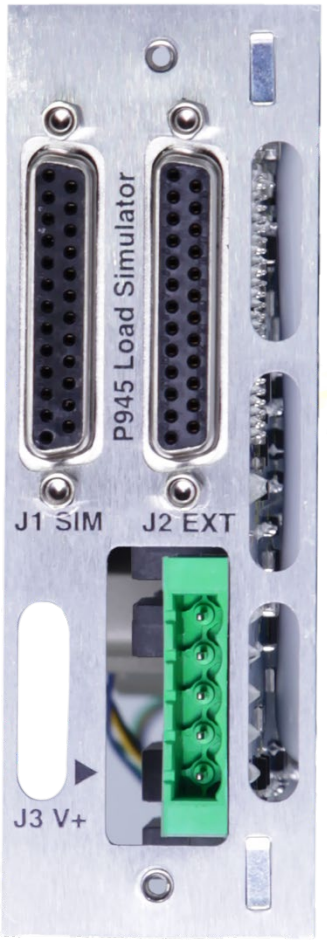
⚠ WARNING: Do not attempt to open the P940 chassis or perform any operations on an open P940 chassis with the power on. Module damage or operator injury may occur.

When connecting P945s together to create a 320W load bank, the P945s should be in adjacent slots, and the provided jumper cable connected across the tops of the two cards. Connection or disconnection of this jumper should not be performed with system power active.

When powered off, a P945 can be moved easily from one P940 system to another. This allows systems to be dynamically configured as desired.

3.2 *Connector Pinout*

Ground connections on the P945 should be used only for cable shields and are not expected to carry functional current.



3.2.1 *J1 SIM*

The **J1 SIM** D25 connector is the connection across which the P945 simulated load channels should be connected to the system being tested.

Note that SIM+ and SIM- are largely by convention; P945 channels are bipolar and will work for positive or negative voltages. If a DC voltage is applied with SIM+ positive and SIM- negative, the voltage and current reported by the P945 will be positive.

Additionally, when using the high-side power bus functionality J1 SIM+ is connected to the power bus internally to the P945. For channels connected to the power bus the only connection on the J1 SIM connector should be the return current on J1 SIM-.

Channel	J1 SIM+	J1 SIM-
A	1	14
B	2	15
C	3	16
D	4	17
E	5	18
F	6	19
G	7	20
H	8	21
Ground	13	25

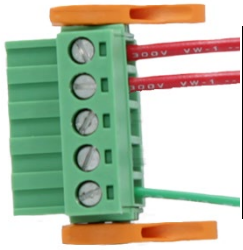
3.2.2 *J2 EXT*

The **J2 EXT** D25 connector allows external inductors to be connected in series to the P945 channel. Internal relays allow each inductor to be present or shorted out under software control.

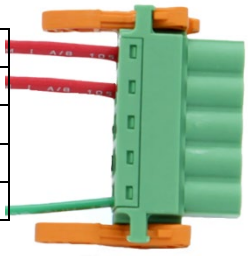
Channel	J2 EXT+	J2 EXT-
A	1	14
B	2	15
C	3	16
D	4	17
E	5	18
F	6	19
G	7	20
H	8	21
Ground	13	25

3.2.3 *J3 V+*

A five-pin 0.200" pitch power connector is provided to bring a common voltage in to the J1 SIM+ pins of multiple channels. This provides a convenient common high-side power bus for low-side switching applications. The connector is compatible with that from the P941, making the P941 an optimal power source for this application. The two V+ pins are electrically connected in parallel.



5	Top	V+
4		V+
3		not used
2		not used
1	Bottom	Chassis Ground



The mating connectors are discrete-wire connectors that accept AWG12-AWG24 wire. One of these connectors is provided with each P945, and additional ones can be purchased directly through Highland Technology, see **Chapter 6- Accessories**.

3.3 *Front-Panel Monitors*

Voltage, current, and power on the P945 channels can be brought out to the P940 monitor connectors for real-time observation, selecting their routing via the front-panel interface or ASCII commands. When observing P945 signals, the monitors output 1V per 10V for voltage signals, 1V per 1A for current signals, and 1V per 10W for power signals.

If setting this via ASCII commands (see **`SOURce:ROUTe`** in the main P940 manual), the available sources for channel *X* of a P945 in slot *N* are:

Measurement	Indicator	Front Panel Display Text
Channel X Voltage	**slotn-x-voltage**	N:Volt X
Channel X Current	**slotn-x-current**	N:Curr X
Channel X Power	**slotn-x-power**	N:Pwr X

4 *Instrument Behavior*

Throughout this section, ASCII commands used to perform relevant tasks are referenced. Many of these functions can also be performed using the P940 chassis' front-panel user interface.

For more details about how to use a referenced command, see *5.2 List of ASCII Commands*. Note that applying changes to channel operating parameters requires the use of the **`SYST:STROBE`** command; see *5.1 ASCII Command Interface*.

4.1 *Load Simulation*

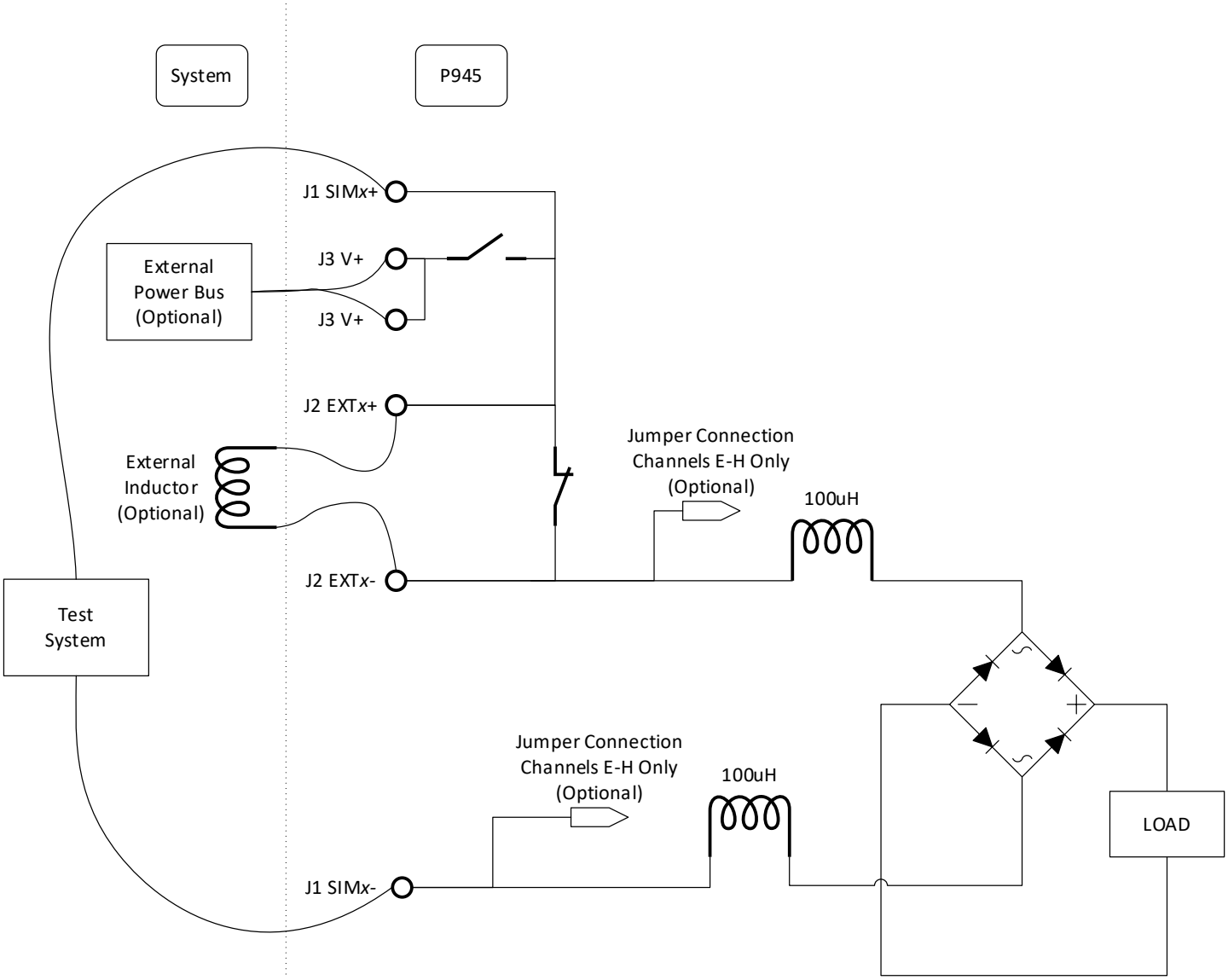


Figure 4-1: Full Single Channel Diagram

The basic operation of the P945 is load simulation. Power is applied to the load between the SIM+ and SIM- connections on the SIM connector, and the programmable load draws current from that

path as requested. In resistance simulation mode, that current is proportional to the voltage applied. In constant-current mode, the current is constant so long as more than the minimum working voltage is applied.

Load simulation requires a minimum working voltage. Below this voltage, accuracy specifications are not guaranteed, and the ability to draw current is diminished. As a load, the appropriate amount of current to draw at 0V is 0A, so this limitation has little impact on practical load systems.

Averaged readings are available for voltage, current, and true power. These readings can be read using **`SENSe:VOLTage?`** **`SENSe:CURRent?`** and **`SENSe:POWer?`** queries.

Channels can also be configured for operation as a short-circuit or open-circuit; still subject to the voltage and current limitations described in the specifications section.

The power-on default state of the P945 sets all 8 channels to open-circuit.

4.1.1 *Open Circuit Simulation*

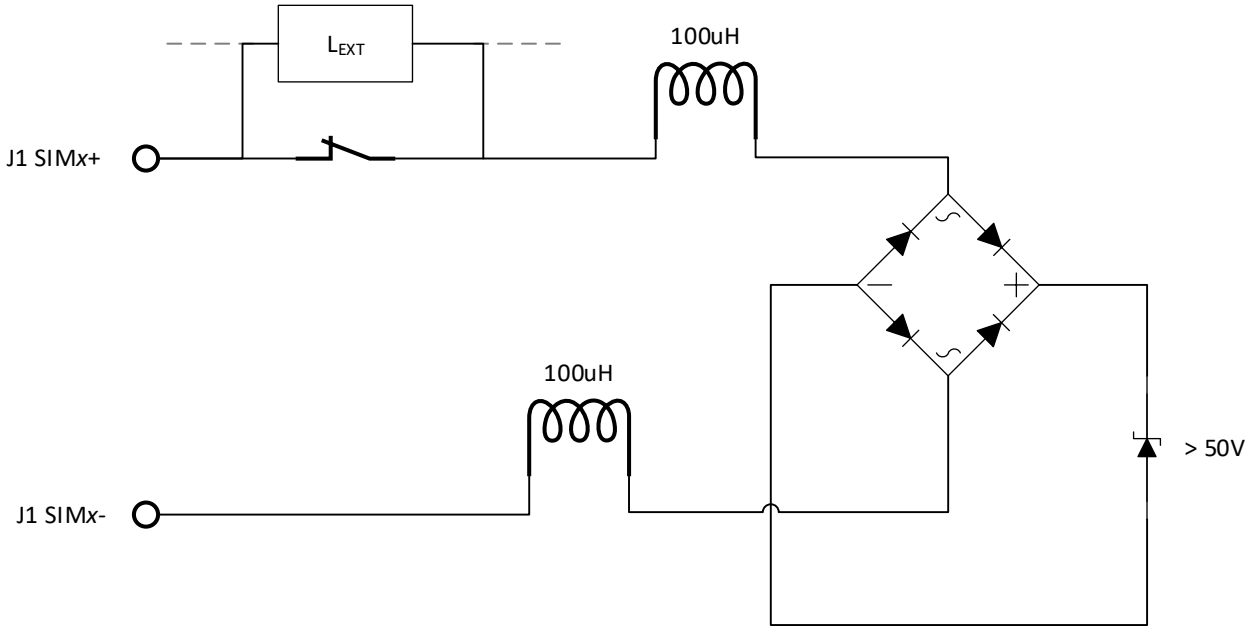


Figure 4-2: Simplified Model of Open Circuit Mode

When configured as an open circuit, the P945 draws only microamps of current, substantially less than it would as a functioning load. Open circuit mode is the default power-up operation (for safety) and can be used to simulate loss of connection to a load.

4.1.2 *Short Circuit Simulation*

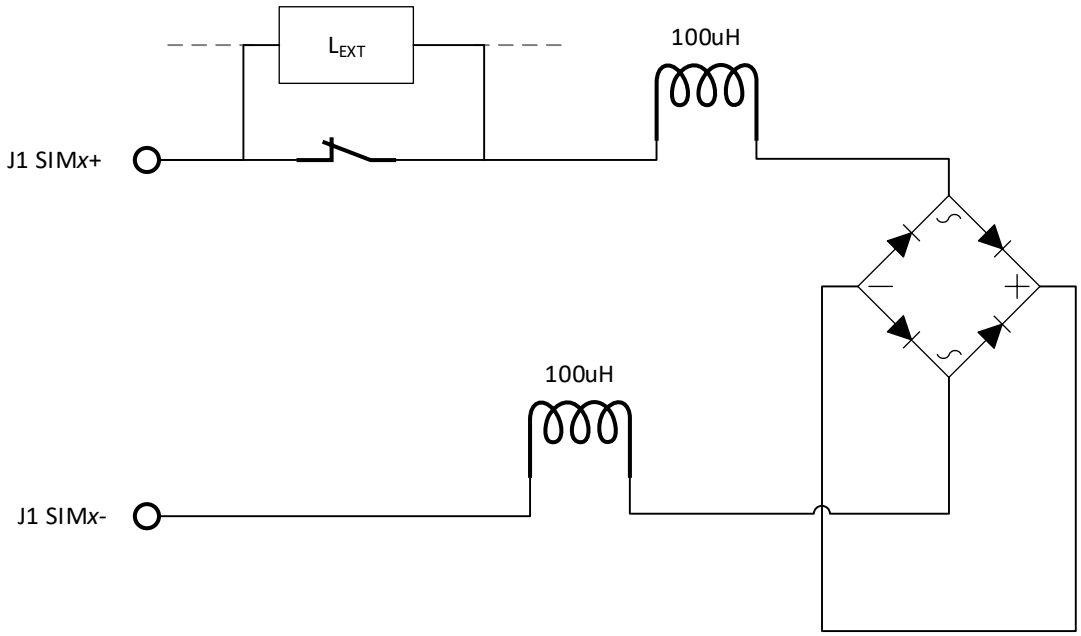


Figure 4-3: Simplified Model of Short Circuit Mode

When configured as a short circuit, the P945 attempts to draw up to its maximum allowable current from the source. Short circuit mode can be used to simulate a shorted connection to the load.

4.1.3 *Constant Resistance Simulation*

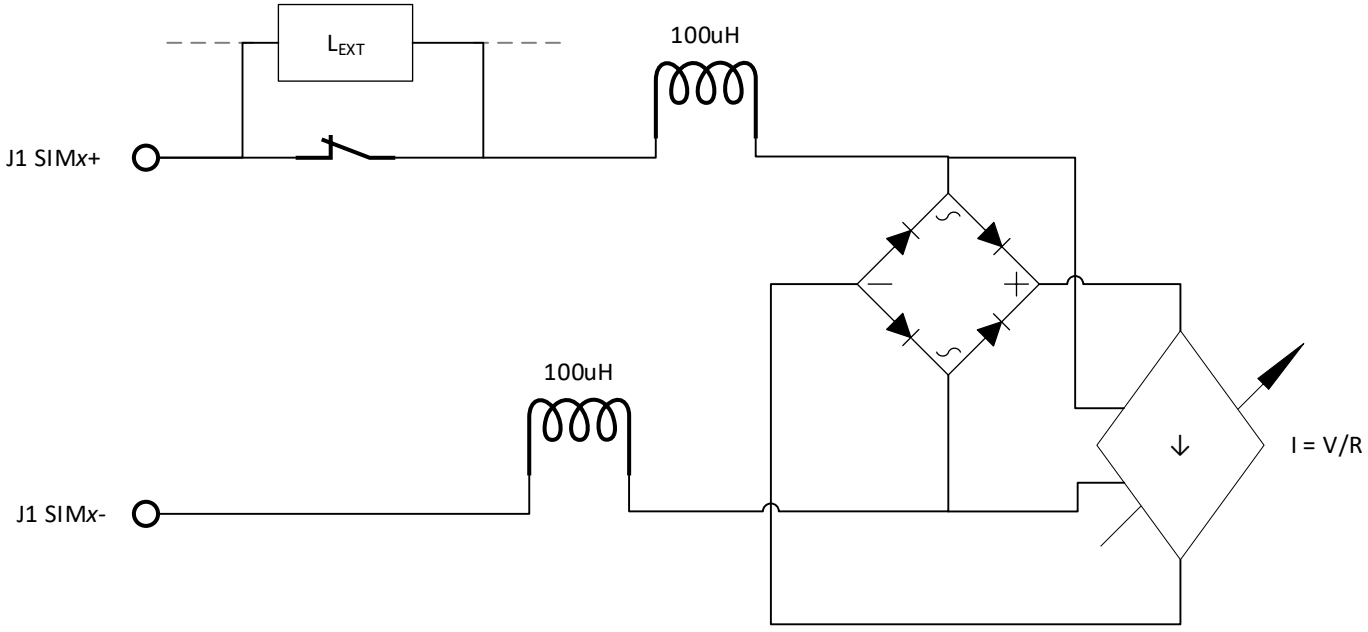


Figure 4-4: Simplified Model of Constant Resistance Mode

When configured as a constant resistance load, the P945 attempts to behave as a resistor,

maintaining the proportional relationship $\frac{V}{I} = R$. For a PWM voltage, it can be expected that this relationship continues to hold true for the averaged quantities, $\frac{\overline{V}}{\overline{I}} = R$.

4.1.4 *Constant Current Simulation*

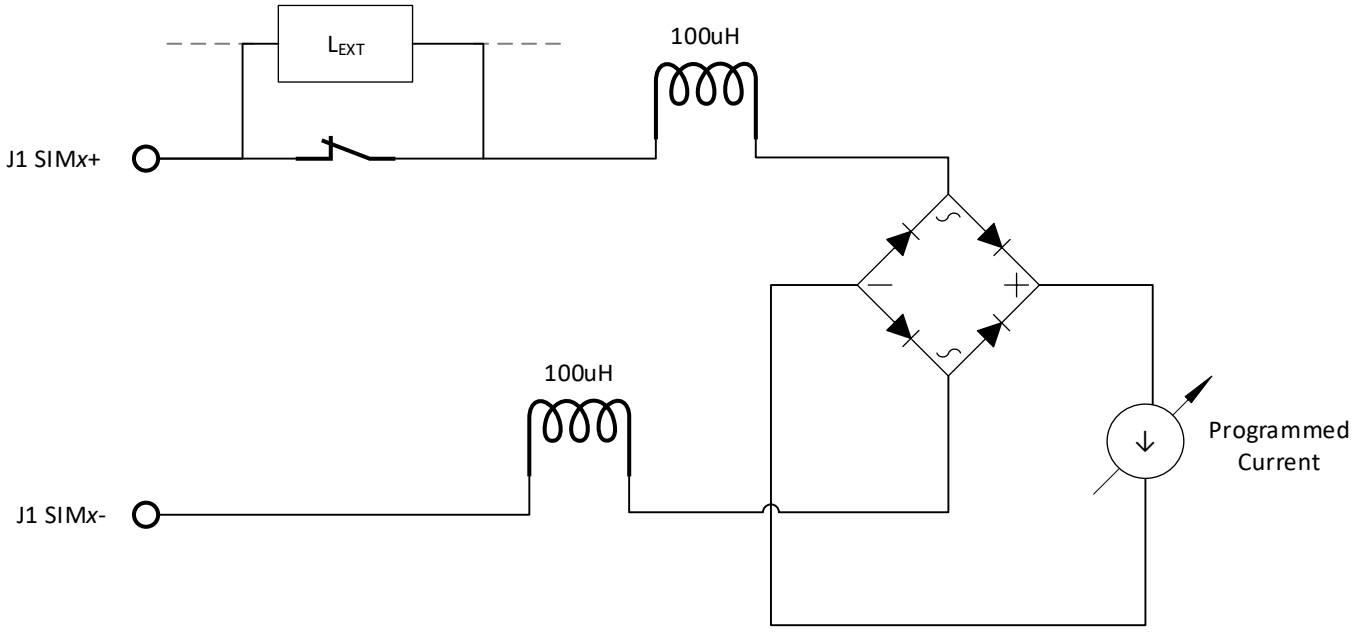


Figure 4-5: Simplified Model of Constant Current Mode

When configured as a constant current load, the P945 attempts to keep the current equal to the programmed value I whenever there is voltage applied to the load.

4.2 *External Inductance*

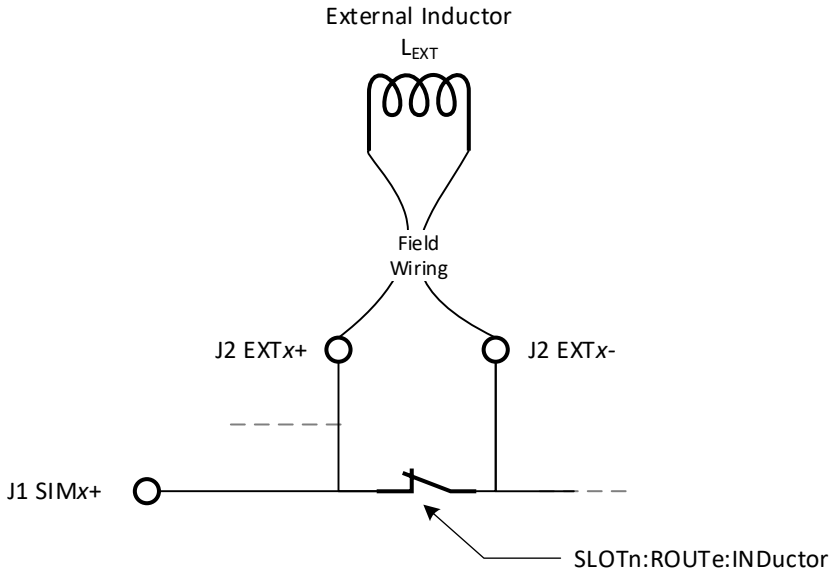


Figure 4-6: Connection of External Inductance

A major use-case for the P945 is simulation of magnetically-operated devices such as solenoids, relays, and motors. To better simulate the dynamics of these loads, external inductance can be applied in series with each channel by connecting an inductor across the J2 EXT+/- pins on the J2 EXT connector and opening the normally-closed shorting relay with the **`SLOTn:ROUTe:INDuctor`** command.

4.3 *High-Side Power Bus*

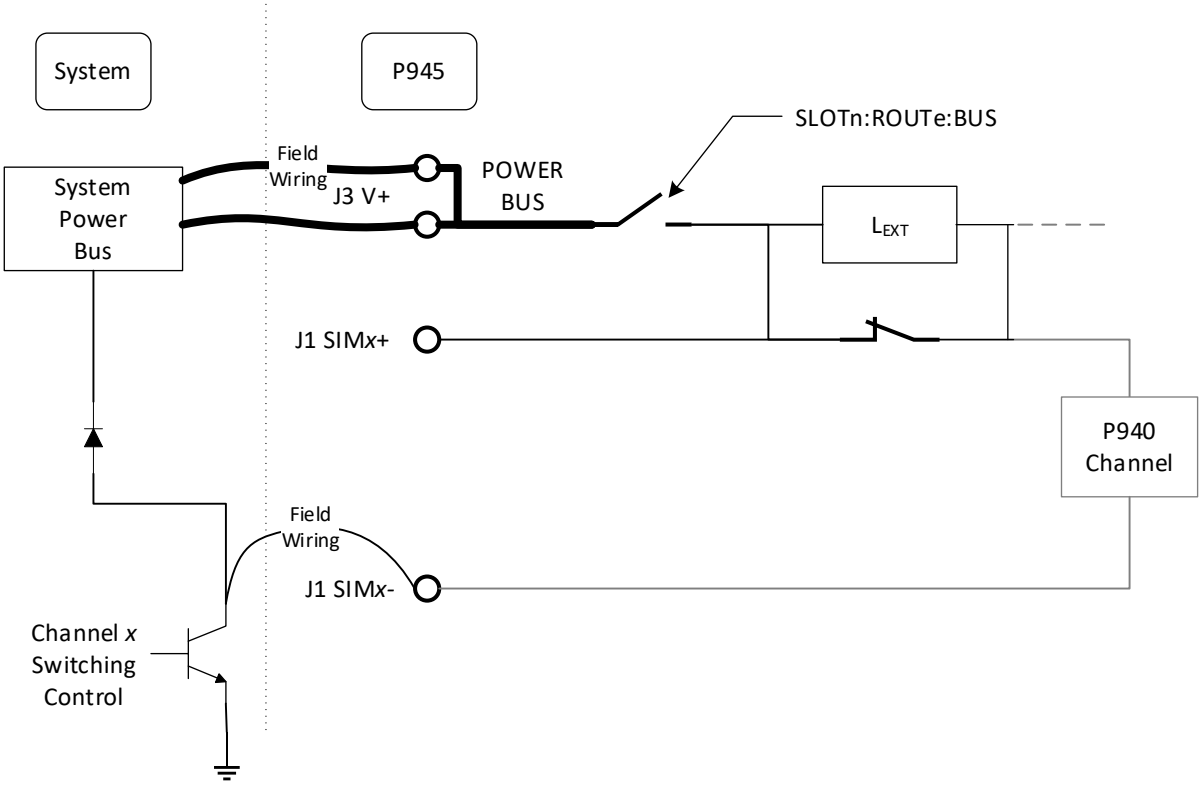


Figure 4-7: Simplifying High-Side Loads with P945 Power Bus

A common load situation is a high-side power bus directly connected to several relays or solenoids, with the low (return) side of the load switched to turn the relay/solenoid on and off.

The P945 simplifies this common situation by providing a high-current connector that can be connected to the load channels in lieu of the J1 SIM+ connection. The connection to this power bus is controlled by the **`SLOTn:ROUTe:BUS`** command.

When using the high-side power bus, ensure that there is a dedicated return current path from the low-side switch in the system-under-test to the return voltage connection of the power supply. The P945 does not connect to the return of the power supply. Use of P940 chassis ground for return current is *not* advised.

4.4 *Combining P945 Modules*

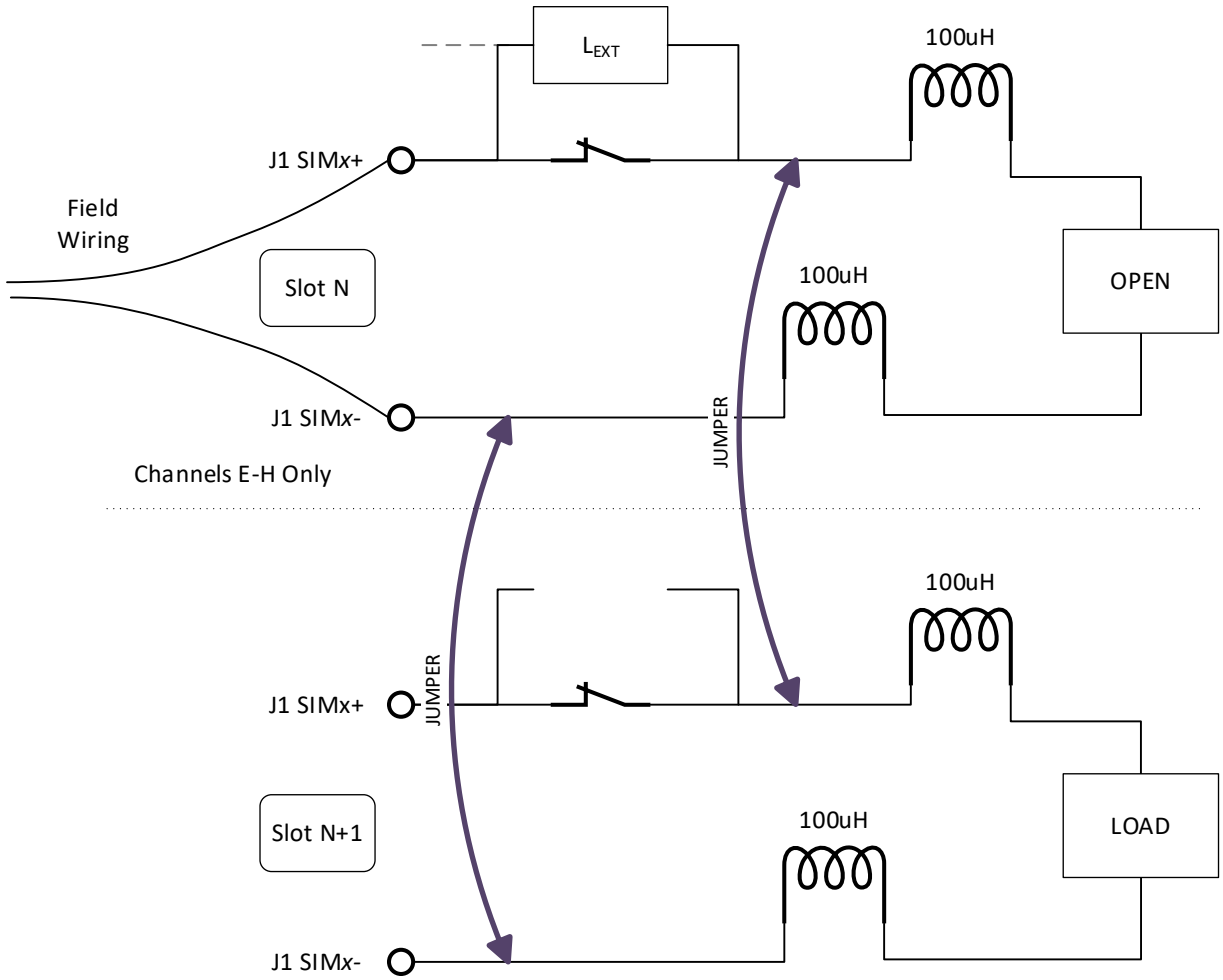


Figure 4-8: Combining 2 P945s with Ribbon Jumper

To allow all P945 channels to run at full power without exceeding the total module power limit, two adjacent P945 modules can be combined with the provided jumper cable. This allows a single D25 cable to have the J1 SIM connections for both ganged P945s, and a second D25 to have the optional J2 EXT connections for both ganged P945s, while still spreading the power load across two modules.

The jumper cable parallels channels E-H to be shared between the two boards. The P945 with the D25 cable(s) is referred to as the primary module, the other (with no D25 cables connected) is referred to as the secondary. The primary module should load channels A-D and the secondary should load channels E-H. This allows all 8 channels to run at the full 40W without exceeding the total module power limit.

If the J3 V+ high-side power bus is being used, it must be connected to the primary module. **`ROUT:BUS`** and **`ROUT:INDuctor`** commands addressed to this channel must be addressed to the primary. If the P940 BNC monitors are being used on the ganged channels, the monitor must be addressed to the primary for voltage, but the secondary for current.

Either module in a connected pair can be queried with the **`ROUTe:JUMPer?`** query to determine whether it is connected in a pair.

Highland Technology recommends the consistent use of the P945 in the lower-numbered slot as the primary module, using channels A-D on slot N and E-H on slot N+1.

There is no difference between a P945 used as a primary module and one used as a secondary module; intended use does not affect the orderable part number. Additional jumper cables can be purchased from Highland Technology, see Section 6 - Accessories.

4.5 *Error States*

When a P945 channel is subject to excessive power loading, the built-in thermal limit will automatically disable the channel into OPEN mode. What constitutes excessive loading depends on the power dissipation of other channels on the same module and the air temperature inside the P940 chassis; see Section 2.2 Absolute Maximum Limits for limits on the individual channel and total module dissipation under specified operating conditions. Operating a channel beyond these limits may cause overtemperature shutdown.

When a channel goes into overtemperature shutdown, an error is placed into the system error queue flagging the channel shutdown.

If the channel is to be reenabled after shutdown, the user must explicitly reenable the channel. This is done with the same commands (or front-panel operations) that configure a channel under normal operating conditions.

If the channel has not yet returned to a safe operating temperature (which may take tens of seconds), attempting to reenable the channel will cause it to immediately shut down again, inserting another error into the error queue. The customer may check explicitly whether the channel has recovered from the overtemperature with the **`SLOT<n>:TEST:OVERtemp?`** query.

5 *Software Interface*

The primary means of interfacing with a P940 system is through the ASCII command/reply interface, over either Ethernet or USB. Descriptions of this interface and its configuration can be found in the P940 system manual, and its commands are listed in the following sections. The P945 may also be controlled by the P940 front panel.

5.1 *ASCII Command Interface*

Parameter updates must be committed by having the P940 send a strobe to the module. This allows multiple parameters to be updated simultaneously, whether within a single channel, several channels of a P945 module, or across multiple modules. Individual P945 channels are referred to as channels A-H.

In addition to the P945-specific commands that follow, the P945 supports all commands listed as *General Module Commands* in the P940 system manual.

The primary interface of a P940 system is the ASCII command/reply interface, over either Ethernet or USB. Descriptions of this interface and its configuration can be found in the P940 system manual. The P941 may also be controlled by the P940 front panel and through the P940 web interface.

5.1.1 *Conventions*

5.1.1.1 *Channel Arguments*

P945 channel arguments begin with the @ character, followed by the channel letter (A through H) or the channel index (0 through 7, respectively). For example, `@C` and `@2` both indicate channel C.

5.1.1.2 *Integer Arguments*

Integer arguments conform to C-language formatting, which is an optional sign character followed by

- `0x` or `0X`, to be parsed as hexadecimal
- Otherwise, `0` to be parsed as octal
- Otherwise, to be parsed as decimal

5.1.1.3 *Float Arguments*

Floating-point arguments conform to C-language formatting, which is an optional sign character, a sequence of digits with an optional decimal point, and optional exponent.

5.1.1.4 *Boolean Arguments*

Boolean arguments must be `0` for false or `1` for true.

5.1.1.5 *Strobed Parameters*

Most parameters are strobed parameters; updates to these parameters must be committed by having the P940 send a strobe to the affected module. This allows multiple parameters to become effective

simultaneously, whether within a single channel, across all channels of a module, or across multiple modules.

Generally, SCPI commands related to strobed parameters are found in pairs, which are nearly, but not completely, symmetrical. Each pair consists of a command that sets the pre-strobe (pending) parameter value and a query that gets the post-strobe (effective) parameter value. The query will not be guaranteed to return the value from a successful command until a strobe to the targeted module has been performed.

The following example illustrates the two-step process of setting a strobed parameter.

```
SLOT0:OUTPut? @A                # Get initial value
OPEN
SLOT0:OUTPut:CURRent 0.75,@A    # First, set pending value
SLOT0:OUTPut? @A                # Effective value has not changed
OPEN
SYST:STRB 0x1                   # Second, propagate pending values
SLOT0:OUTPut? @A                # Effective value has changed
CURR,0.750
```

5.1.2 *P945 Strobed Parameters*

The following P945 parameters are strobed parameters.

Parameter	Command (sets pre-strobe value)	Query (gets post-strobe value)
Channel Output Mode/Value	SLOT<n>:OUTPut:CURRent SLOT<n>:OUTPut:OPEN SLOT<n>:OUTPut:RESistance SLOT<n>:OUTPut:SHORT	SLOT<n>:OUTPut?

5.1.3 *Example*

For a P945 in P940 slot 0, the following sequence will configure channel A as 100R resistor.

```
SLOT0:OUTPUT:RES 100,@A
SYST:STROBE 0x1
SLOT0:SENS:VOLT? @A
12.70
SLOT0:SENS:CURR? @A
```

0.127

SLOT0:SENS:POW? @A

1.61

5.2 *List of ASCII Commands*

The P945-specific commands are listed in the following sections. The P945 also supports all commands listed as *General Module Commands* in the P940 system manual.

5.2.1 *OUTPut Commands*

SLOT<n>:OUTPut? @<channel>

Returns the operating mode of the requested channel. If the channel is in open or short mode, the response will be **OPEN** or **SHORT** respectively. For constant-resistance mode, the response will be **RES,<res>** where **<res>** is the requested resistance. For constant current mode, the response will be **CURR,<cur>** where **<cur>** is the requested current in amperes.

SLOT<n>:OUTPut:CURRent <value>,@<channel>

SLOT0:OUTP:CURR 1.5,@A

SYST:STROBE 0x1

SLOT0:OUTP? @A

CURR,1.5

Sets the operating mode of the requested channel to be constant-current mode, with a current (in amperes) specified by value. A strobe on the slot must occur to effect this change.

SLOT<n>:OUTPut:CURRent:MINimum?

SLOT<n>:OUTPut:CURRent:MAXimum?

Returns the minimum or maximum allowable values for constant-current output mode.

SLOT<n>:OUTPut:OPEN @<channel>

SLOT0:OUTP:OPEN @A

SYST:STROBE 0x1

SLOT0:OUTP? @A

OPEN

Sets the operating mode of the requested channel to be open-circuit mode. A strobe on the slot must occur to effect this change.

SLOT<n>:OUTPut:RESistance <value>,@<channel>

SLOT0:OUTP:RES 91,@A

SYST:STROBE 0x1

SLOT0:OUTP? @A

RES,91

Sets the operating mode of the requested channel to be constant-resistance mode, with a resistance (in ohms) specified by value. A strobe on the slot must occur to effect this change.

SLOT<n>:OUTPut:RESistance:MINimum?

SLOT<n>:OUTPut:RESistance:MAXimum?

Returns the minimum or maximum allowable values for constant-resistance output mode.

SLOT<n>:OUTPut:SHORt @<channel>

SLOT0:OUTP:SHORT @A

SYST:STROBE 0x1

SLOT0:OUTP? @A

SHORT

Sets the operating mode of the requested channel to be short-circuit mode. A strobe on the slot must occur to effect this change.

5.2.2 *ROUTe Commands*

SLOT<n>:ROUTe:BUS <boolean>,@<channel>

SLOT<n>:ROUTe:BUS? @<channel>

As a command, sets the connection of the SIM+ input of this channel to the high-side power bus.

Value	Meaning	Physical Connections
0 (default)	Channel SIM+ is not connected to power bus by the P945.	Channel SIM+ pin should be connected to field wiring.

1	Channel SIM+ is internally connected to power bus by the P945.	Channel SIM+ pin should *not* be connected to field wiring; this pin is internally shorted V+ high-side power bus.

As a query, reports 1 if the channel is connected to the power bus or 0 if not.

SLOT<n>:ROUTe:INDuctor <boolean>,@<channel>

SLOT<n>:ROUTe:INDuctor? @<channel>

As a command, sets the connection of the IND+ and IND- input of this channel to an externally connected inductor.

Value	Meaning	Physical Connections
0 (default)	Channel IND+/- are internally shorted by the P945.	External inductance, if present on IND+/-, is bypassed and ignored.
1	Channel IND+/- are not internally shorted by the P945.	External series inductance should be present between the IND+/- pins. If these pins are unconnected, the channel is disconnected from SIM+.

As a query, reports 1 if the channel is connected to the IND port or 0 if not.

SLOT<n>:ROUTe:JUMPer?

Reports 1 if the P945 has a board-to-board jumper connecting it to another P945, or 0 if not.

5.2.3 *SENSe Commands*

SLOT<n>:SENSe:VOLTage? @<channel>

Reports the average voltage (in volts) on the requested channel.

SLOT<n>:SENSe:CURRent? @<channel>

Reports the average current (in amperes) on the requested channel.

SLOT<n>:SENSe:POWer? @<channel>

Reports the average power (in watts) on the requested channel.

5.2.4 *TEST Commands*

SLOT<n>:TEST:BIST

Starts the BIST test. If the BIST test is ongoing or cannot be started, then **-200,"Execution error"** will be created in the error queue or **ERROR_EXECUTION** will be returned. Any command modifying the state of the P945 received while the BIST test is ongoing will create **-200,"Execution error"** in the error queue or **ERROR_EXECUTION** will be returned. **SLOT<n>:TEST:BIST?** should be used to retrieve the status of the ongoing or completed test. An error will be submitted to the error queue for each test that fails.

SLOT<n>:TEST:BIST?

Returns the result of the last or ongoing BIST test. The return value of this function is a comma-separated list consisting of

- The overall status, one of **NEVERRUN**, **ONGOING**, **PASSED**, or **FAILED**
- A pair for each sub-test constituting BIST, consisting of
    - The test name, in quotes
    - The test status, one of **NEVERRUN**, **PENDING**, **ONGOING**, **ABORTED**, **PASSED** or **FAILED**

SLOT<n>:TEST:BIST:VERBose?

Returns the verbose result of the last or ongoing BIST test. The return value of this function is a comma-separated list consisting of

- The overall status, one of **NEVERRUN**, **ONGOING**, **PASSED**, or **FAILED**
- A triplet for each sub-test constituting BIST, consisting of
    - The test name, in quotes
    - The test status, one of **NEVERRUN**, **PENDING**, **ONGOING**, **ABORTED**, **PASSED** or **FAILED**
    - The test results, in quotes, consisting of a comma-separated list of measurements performed during the test

Information returned by the verbose report is not expected to be useful to customers, but may be requested by Highland technical support.

SLOT<n>:TEST:OVERtemp? @<channel>

Returns 1 if channel is currently at an excessive temperature, or 0 if not. As described in Section 4.5 - Error States, a channel currently overtemperature will immediately shut down again if an attempt is made to take it out of shutdown.

SLOT<n>:TEST:OVERtemp:SHUTdown? @<channel>

Returns 1 if channel has been shut down by the overtemperature protection described in Section 4.5 - Error States, or 0 if it is operating normally.

6 *Versions*

P945-1: 8-channel high current load plugin module for P940 modular power system

P945-2: 8-channel precision load plugin module for P940 modular power system

7 *Customization*

Consult factory for information about additional custom versions.

8 *Hardware and Firmware Revision History*

8.1 *Hardware Revision History*

Revision B	December 2023 Initial production release (23A945B)
Revision A	October 2023 Limited alpha release (23A945A)

8.2 *Firmware Revision History*

23C945-1-2.0	December 2023 Initial production release. P940 firmware 23E940-2-1.6

9 *Accessories*

9.1 *Available from Highland*

The following Highland accessories are compatible with the P945.

J94-1	5-pin terminal-block plug for P945 V+ connector 1 provided with P945
J96-1	2.5” ribbon cable for gang connection of 2 P945s 1 provided with P945
J97-8	8’ slimline D25M-D25M cable 2 provided with P945
J97-10	10’ slimline D25M-D25M cable

9.2 *Third Party*

The following parts have been found to work with the P945. Highland Technology is unable to guarantee compatibility for third-party products.

Norcomp 972-025-01SR011	Slimline plastic backshell for custom D25 cables
Amphenol FCI 8655MH2501BLF	Slimline metal backshell for custom D25 cables
Phoenix Contact 1808912	5-pin terminal-block plug