Short-circuit Isolation

in Addressable Fire Detection and Alarm Systems

The requirement for isolation

Analogue addressable fire detection systems are usually designed as loops, with the connecting wires starting and finishing at the fire control panel. Detection devices, manual call points and interfaces are connected at intervals along the cables. Depending on the national or local regulations, audible and visual alarm devices are connected either to the same loop as the detection devices or via dedicated loops. Spurs may be connected at any point of the loop, either directly from the loop wires or from an interface, subject to national or local regulation.

Short-circuits do not occur very often, but when they do, the consequences can be serious, possibly making the affected loop entirely inoperative. It is for this reason that isolators have been designed and incorporated into various devices that are connected to the loop. The purpose of these isolating circuits is to protect the loop in the event of a short or partial short-circuit by disconnecting the part of the loop where the short-circuit has occurred. When the short-circuit fault has been rectified, the isolating circuitry automatically reconnects the affected section of the loop.

Features of isolating circuits

Isolators are available in different forms:

- As a stand-alone 'isolator' which is fitted onto special detector style 'isolator bases'
- Incorporated into the detector mounting base, known as 'isolating bases'
- Integrated into Apollo devices such as manual call points, audible and visual alarm devices, interfaces or detection devices (see Table 1)

Isolators are intended for use with Apollo systems using XP95®, Discovery® and CoreProtocol®. Isolators are polarity sensitive and switch the negative line of the loop.

Devices including or fitted to isolators remain operative when an adjacent loop section is in the isolated state. The isolated state is normally indicated by a LED illuminated yellow on the device and through the protocol for CoreProtocol systems.

Equivalent Detector Load

The Equivalent Detector Load (EDL) is a rating value attributed to each device on an XP95/Discovery/CoreProtocol loop, which enables consistent and correct design of the system, when Isolators are used.

Apollo isolating circuits allow the connection of between one and 20 detectors (an EDL of 20) between isolators. The 'equivalent load' for Apollo devices is one for most devices. The 'equivalent load' for devices which are greater than one is given in Table 1. The maximum load for a node is an EDL of 20, this is calculated by adding up the EDL for all devices fitted between two isolators.

Operating principles

Under normal operating conditions the isolator provides a low resistance in either direction. If the loop voltage falls to a pre-set level, the isolator will switch from the closed state to the open state in order to isolate the loop 'in' and 'out' lines.

The isolated section is automatically tested with a test current and is re-connected at a pre-set load resistance value (see Table 2).

Isolator type

There are three types of isolator used in Apollo products:

- The original circuit known as 20D, has been in use since the introduction of XP95
- The 20I circuit was developed in order to reduce the test current which is applied to isolated sections of the loop. It reduces the test current by half.
- The 20C isolator is the latest development which performs much like the 20I isolator but with advanced features that allow additional control of the isolator through Apollo CoreProtocol.

Fire control panel compatibility

Fire control panels that are certificated by Apollo are also compatible with Apollo isolators.

CoreProtocol enabled control panels are able to send a command to 20C isolators which will set a switch open (isolated) state. When the command is reset the isolator will autonomously revert to a closed switch state if no short-circuit is present. It is not possible for 20C isolators to be remotely switched from an open switch to a closed switch state.

System design

It is essential that both loop loading and isolator requirements are taken into consideration when designing a fire detection system.

Generally the loop devices are wired in sequence, so the number of devices between isolators should equal an EDL of 20. If a star configuration is used at a node in the system there may be more than one isolator being powered at the same time so 4 EDL should be added to the node for each additional isolator being powered simultaneously.

Apollo offers a software programme with which the loop loading viability of a design can be checked. The LoopCalc programme can be downloaded at www.apollo-fire.co.uk

Note: All detectors and other devices between any two isolators or isolating devices must be in the same fire zone because communications will be lost if a short circuit occurs between isolators. This design consideration may be subject to national or local regulations.

Testing isolators in situ

Isolators should be tested after installation to ensure the isolators operate correctly.

Devices with accessible screw terminals:

- Apply a short circuit to the input side and ensure the yellow LED is lit continuously.
- Apply a short circuit to the output side and ensure the yellow LED is lit continuously.

Devices that plug into an XPert8 base:

- Connect a link wire between L1 and L2 and plug the device into the XPert8 base. Ensure that the yellow LED is lit continuously.
- Connect a link wire between L1 OUT and L2 and plug the device into the XPert8 base. Ensure that the yellow LED is lit continuously.

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Quick-start process guide

To work out the isolator loading of a loop:

- Identify the devices between each pair of isolators
- Use Table 1 to determine the EDL of each device

  Note: If any devices are star connected and include isolators, then add four EDL for each device. Do not include any devices past the isolator in this node.
- Verify that the sum of the EDL values is less than or equal to 20
- Put the full loop configuration into the ApolloLoopCalc tool
- Verify that the LoopCalc tool confirms 'Loop Design Satisfactory'

Table1: Apollo products

Part No.	Product name	Isolator type and EDL value			
		20D	20I	20C	EDL*
45681-277APO	XP95 Sounder Base - Isolating	X			2
45681-278APO	XP95 Sounder Base				2
45681-284APO	XPERT 7 Base - Isolating	X			0
45681-286MAR	XPERT 7 Marine Base - Isolating [SIL2]	X			0
45681-290APO	XP95 Sounder Base - Slow Whoop - Isolating	X			2
45681-291APO	XP95 Sounder Base - Slow Whoop				2
45681-300APO	XP95 Sounder Base - DIN Tone - Isolating	X			2
45681-330APO	XP95 Sounder VID Base (Red Flash) - Isolating	X			1
45681-332APO	XP95 Sounder VID Base (Red Flash) - Slow Whoop - Isolating	X			1
45681-333APO	XP95 VID Base (Red Flash) - Isolating	X			1
45681-393APO	Discovery Sounder VID Base (Red Flash) - Isolating		X		1
45681-393SIL	Discovery Sndr VID Base (RD Fl) - Iso [SIL2]		X		1
45681-394MAR	Discovery Marine Sndr VID Base (RD Fl) - Iso [SIL2]		X		1
45681-700APO	Discovery Sounder VAD Base Cat. O (White Flash) - Isolating		X		1
45681-702APO	Discovery Sounder Base - Isolating		X		1
45681-705APO	XP95 Sounder VAD Base Cat. O (White Flash) - Isolating	X			1
45681-707APO	XP95 Sndr VAD Base Cat. O - DIN Tone (WT Fl) - Iso	X			1
45681-709APO	XP95 VAD Base Cat. O (White Flash) - Isolating	X			1
55000-001APO	XP95 Open-Area Sounder - Red Body - Isolating		X		1
55000-002APO	XP95 Open-Area Sounder - White Body - Isolating		X		1
55000-005APO	XP95 O-A Sndr VID - RD Bdy (RD Fl) - Iso		X		1
55000-006APO	XP95 O-A Sndr VID - WT Bdy (RD Fl) - Iso		X		1
55000-009APO	XP95 Open-Area VID - Red Body (Red Flash) - Isolating		X		1
55000-010APO	XP95 Open-Area VID - White Body (Red Flash) - Isolating		X		1
55000-020APO	XP95 Flame Detector (IR3)				9
55000-021APO	XP95 Exd Flame Detector (IR3) - Flameproof				9
55000-022APO	XP95 Flame Detector (UV) - Base Mounted				9
55000-023APO	XP95 Flame Detector (UV/IR2) - Base Mounted				9
55000-024APO	XP95 Flame Detector (IR3) - Base Mounted				9
55000-027MAR	XP95 Marine Flame Detector (UV) - Base Mounted				9
55000-028MAR	XP95 Marine Flame Detector (UV/IR2) - Base Mounted				9
55000-029MAR	XP95 Marine Flame Detector (IR3) - Base Mounted				9
55000-034MAR	XP95 Marine Flame Detector (IR3) - Stainless Steel				9
55000-041USA	XP95A Open-Area Sounder - Red Body - Isolating		X		1
55000-181MAR	XP95 Marine DIN-Rail AV Control Module (8 Amperes)				3

Table1: Apollo products

Part No.	Product name	Isolator type and EDL value			
		20D	20I	20C	EDL*
55000-182APO	XP95 DIN-Rail AV Control Module (5 Amperes)				3
55000-268APO	XP95 Reflective Beam Detector (5-50m)	X			10
55000-273APO	XP95 Reflective Beam Detector (50-100m)	X			10
55000-274APO	XP95 Open-Area Multi-Tone Sounder - Outdoor - Red Body				2
55000-278APO	XP95 Open-Area Multi-Tone Sounder - Red Body				2
55000-279APO	XP95 Open-Area Multi-Tone Sounder - White Body				2
55000-280APO	XP95 Flame Detector (IR2)				20
55000-291APO	XP95 Open-Area Multi-Tone Sounder VID - Red Body (Red Flash)				2
55000-293APO	XP95 O-A Multi-Tone Sndr VID - RD Bdy (RD Fl) - Iso	X			2
55000-294APO	XP95 O-A Multi-Tone Sndr VID - WT Bdy (RD Fl) - Iso	X			2
55000-295APO	XP95 Exd Flame Detector (IR2) - Flameproof				20
55000-296APO	XP95 O-A Multi-Tone Sndr VID - Outdoor - RD Bdy (RD Fl)				2
55000-298APO	XP95 O-A Multi-Tone Sndr VID - Outdoor RD Bdy (RD Fl) - Iso	X			2
55000-299APO	XP95 O-A Multi-Tone Sndr VID - Outdoor WT Bdy (RD Fl) - Iso	X			2
55000-588APO	XP95 Input/Output Module - Three Channel - Isolating	X			7
55000-720APO	Isolator	X			0
55000-721MAR	Marine Isolator [SIL2]	X			0
55000-736APO	XP95 Open-Area VAD Cat. W - Red Body (Red Flash) (W-2.4-6)				16
55000-737APO	XP95 OpenArea VAD Cat. W - White Body (Red Flash) (W-2.4-6)				16
55000-738APO	XP95 Open-Area VAD Cat. C - Red Body (Red Flash) (C-3-8)				16
55000-739APO	XP95 Open-Area VAD Cat. C - White Body (Red Flash) (C-3-8)				16
55000-740APO	XP95 Open-Area VAD Cat. C - Red Body (White Flash) (C-3-15)				20
55000-741APO	XP95 Open-Area VAD Cat. W - Red Body (White Flash) (W-2.5-6)				16
55000-742APO	XP95 Open-Area VAD Cat. C - Red Body (White Flash) (C-3-8)				12
55000-743APO	XP95 Open-Area VAD Cat. C - Red Body (White Flash) (C-3-8)				20
55000-744APO	XP95 O-A VAD Cat. W - WT Bdy (WT Fl) (W-2.5-6)				16
55000-745APO	XP95 Open-Area VAD Cat. C - White Body (White Flash) (C-3-8)				12
55000-747APO	XP95 O-A VAD Cat. C - RD Bdy (WT Fl) (C-3-15) - Iso Kit				20
55000-748APO	XP95 O-A VAD Cat. C - WT Bdy (WT Fl) (C-3-15) - Iso Kit				20
55000-750USA	Isolator	X			0
55000-760APO	XP95 DIN-Rail Mini Switch Monitor Module - Isolating		X		1
55000-770MAR	XP95 Marine DIN-Rail Isolator - Dual Channel [SIL2]	X			0
55000-772MAR	XP95 Marine DIN-Rail Switch Monitor Plus Module				3
55000-773MAR	XP95 Marine DIN-Rail Zone Monitor Module	X			3
55000-774MAR	XP95 Marine DIN-Rail Input/Output Module [SIL2]				4
55000-775MAR	XP95 Marine DIN-Rail Mini Switch Monitor Module - Iso [SIL2]		X		1
55000-790USA	XP95A Priority Switch Monitor Module - Dual Channel				5
55000-797APO	XP95 DIN-Rail Input/Output Module (250V AC)				4
55000-802APO	XP95 DIN-Rail Isolator - Dual Channel	X			0
55000-805USA	XP95A Switch Monitor Module				3
55000-806USA	XP95A Priority Switch Monitor Module				3
55000-812APO	XP95 DIN-Rail Zone Monitor Module - Isolating	X			3
55000-820USA	XP95A Switch Monitor Input/Output Module				4
55000-825USA	XP95A AV Control Module				6
55000-830USA	XP95A Mini Priority Switch Monitor Module				3

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Table1: Apollo products					
Part No.	Product name	Isolator type and EDL value			
		20D	20I	20C	EDL*
55000-831USA	XP95A Mini Switch Monitor Module				3
55000-845APO	XP95 Zone Monitor Module - Isolating	X			3
55000-847APO	XP95 Input/Output Module - Isolating [SIL2]	X			4
55000-847SIL	XP95 Input/Output Module - Iso [SIL2]	X			4
55000-852APO	XP95 AV Control Module - Isolating	X			3
55000-859USA	XP95A Input/Output Module (120V AC)				4
55000-863USA	XP95A Relay Output Module				3
55000-982APO	Addressable Door Retainer – 200N			X	4
55010-182APO	XP95 DIN-Rail AV Control Module	X			2
55010-852APO	XP95 AV Control Module - Isolating	X			2
55100-908APO	XP95 Manual Call Point - Isolating		X		1
58000-005APO	Discovery Open-Area Sounder VID - Red Body (Red Flash)		X		1
58000-007APO	Discovery Open-Area Sounder VID - White Body (Red Flash)		X		1
58000-010APO	Discovery O-A Voice Sndr - RD Bdy - Iso		X		1
58000-011USA	Discovery UL Open-Area Sounder VID - Red Body (Red Flash)		X		1
58000-020APO	Discovery O-A Voice Sndr - WT Bdy - Iso		X		1
58000-030APO	Discovery O-A Voice Sndr VID - RD Bdy (RD Fl) - Iso		X		1
58000-040APO	Discovery O-A Voice Sndr VID - WT Bdy (RD Fl) - Iso		X		1
58100-908APO	Discovery Manual Call Point - Isolating [SIL2]		X		1
58100-908SIL	Discovery Manual Call Point - Iso [SIL2]		X		1
58100-951APO	Discovery Manual Call Point - Outdoor - Isolating [SIL2]		X		1
58100-953APO	Discovery Manual Call Point - Outdoor - Yellow - Isolating		X		1
58100-971MAR	Discovery Marine Manual Call Point - Isolating [SIL2]		X		1
58100-976MAR	Discovery Marine Manual Call Point - Outdoor - Iso [SIL2]		X		1
58200-951APO	Discovery Manual Call Point - Outdoor - Isolating		X		1
58200-951SIL	Discovery Manual Call Point - Outdoor - Iso [SIL2		X		1
58200-976MAR	Discovery Marine Manual Call Point - Outdoor - Isolating		X		1
FL5100-600APO	Soteria Dimension Optical Smoke Detector			X	1
FL6100-600APO	Soteria Dimension Optical Smoke Detector - Specialist			X	1
MA4700-300MAR	Intelligent Marine DIN-Rail Switch Monitor Module			X	1
MA4700-302MAR	Intelligent Marine DIN-Rail Input/Output Module			X	1
RW1700-030APO	REACH XP95 Loop Interface Module			X	20
SA4700-100APO	Intelligent Switch Monitor Module			X	1
SA4700-102APO	Intelligent Input/Output Module			X	1
SA4700-103APO	Intelligent Input/Output Module (250V AC)			X	2
SA4700-104APO	Intelligent Input/Output Module (Twin)			X	1
SA4700-300APO	Intelligent DIN-Rail Switch Monitor Module			X	1
SA4700-302APO	Intelligent DIN-Rail Input/Output Module			X	1
SA4700-403APO	Intelligent DIN-Rail Input/Output Module (250V AC)			X	2
SA4705-600APO	Soteria UL Mini Switch Monitor Module			X	1
SA4705-700APO	Soteria UL Input Module			X	1
SA4705-701APO	Soteria UL Relay Output Module			X	1
SA4705-703APO	Soteria UL Switch Monitor Input/Output Module			X	1
SA4705-706APO	Soteria UL NAC Module			X	1
SA4705-720APO	Soteria UL Dual Input Switch Monitor Module			X	1
SA4710-100APO	Intelligent Switch Monitor Module VDS			X	1
SA4710-102APO	Intelligent Input/Output Module VDS			X	1
SA4710-104APO	Intelligent Input/Output Module (Twin) VDS			X	1

Table1: Apollo products

Part No.	Product name	Isolator type and EDL value			
		20D	20I	20C	EDL*
SA4710-300APO	Intelligent DIN-Rail Switch Monitor Module VDS			X	1
SA4710-302APO	Intelligent DIN-Rail Input/Output Module VDS			X	1
SA5100-400APO	Soteria Heat Detector			X	1
SA5100-600APO	Soteria Optical Smoke Detector			X	1
SA5100-700APO	Soteria Multi-Sensor Detector (Optical/Heat)			X	1
SA5100-710APO	Soteria Multi-Sensor Detector (Dual Optical/Heat)			X	2
SA5100-810APO	Soteria Tri-Sensor Detector (Dual Optical/Heat/CO)			X	2
SA5150-450APO	Soteria UL Heat Detector			X	1
SA5150-650APO	Soteria UL Smoke Detector			X	1
SA5150-750APO	Soteria UL Multi-Criteria Detector (Smoke/Heat)			X	1
SA5300-300APO	Soteria Sounder Base			X	1
SA5300-320APO	Soteria VID Base (White Flash)			X	1
SA5300-321APO	Soteria VID Base (Red Flash)			X	1
SA5300-350APO	Soteria Sounder VID Base (White Flash)			X	1
SA5300-351APO	Soteria Sounder VID Base (Red Flash)			X	1
SA5302-300APO	Soteria Sounder Base			X	1
SA5302-350APO	Soteria Sounder VID Base (White Flash)			X	1
SA5302-351APO	Soteria Sounder VID Base (Red Flash)			X	1
SA5306-300APO	Soteria Sounder Base – Black			X	1
SA5306-350APO	Soteria Sounder VID Base – Black (White Flash)			X	1
SA5306-351APO	Soteria Sounder VID Base – Black (Red Flash)			X	1
SA5500-300APO	Intelligent Open-Area Sounder - Red Body			X	1
SA5500-350APO	Intelligent Open-Area Sounder VID - Red Body (White Flash)			X	1
SA5500-351APO	Intelligent Open-Area Sounder VID - Red Body (Red Flash)			X	1
SA5500-500APO	Intelligent Open-Area VAD - Red Body (White Flash)			X	2
SA5500-501APO	Intelligent Open-Area VAD - Red Body (Red Flash)			X	2
SA5500-550APO	Intelligent O-A Sndr VAD Cat. W - RD Bdy (WT Fl) (W-3.1-10)			X	2
SA5500-551APO	Intelligent O-A Sndr VAD Cat. W - RD Bdy (RD Fl) (W-3.1-9)			X	2
SA5501-300APO	Intelligent Open-Area Sounder - White Body			X	1
SA5501-320APO	Intelligent Open-Area VID - White Body (White Flash)			X	1
SA5501-321APO	Intelligent Open-Area VID - White Body (Red Flash)			X	1
SA5501-350APO	Intelligent Open-Area Sounder VID - White Body (White Flash)			X	1
SA5501-351APO	Intelligent Open-Area Sounder VID - White Body (Red Flash)			X	1
SA5501-500APO	Intelligent O-A VAD Cat. W - WT Bdy (WT Fl) (W-3.1-10)			X	2
SA5501-501APO	Intelligent O-A VAD Cat. W - WT Bdy (RD Fl) (W-3.1-9)			X	2
SA5501-550APO	Intelligent O-A Sndr VAD Cat. W - WT Bdy (WT Fl) (W-3.1-10)			X	2
SA5501-551APO	Intelligent O-A Sndr VAD Cat. W - WT Bdy (RD Fl) (W-3.1-9)			X	2
SA5900-100APO	Intelligent DIN Manual Call Point			X	1
SA5900-104APO	Intelligent DIN Manual Call Point – Yellow			X	1
SA5900-105APO	Intelligent DIN Manual Call Point – Blue			X	1
SA5900-106APO	Intelligent DIN Manual Call Point – Green			X	1
SA5900-903APO	Intelligent Manual Call Point - White			X	1
SA5900-904APO	Intelligent Manual Call Point - Yellow			X	1
SA5900-905APO	Intelligent Manual Call Point - Blue			X	1
SA5900-906APO	Intelligent Manual Call Point - Green			X	1

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Table1: Apollo products					
Part No.	Product name	Isolator type and EDL value			
		20D	20I	20C	EDL*
SA5900-907APO	Intelligent Manual Call Point - Orange			X	1
SA5900-908APO	Intelligent Manual Call Point			X	1
SA5900-928MAR	Intelligent Marine Manual Call Point			X	1
SA5900-951APO	Intelligent Manual Call Point - Outdoor			X	1
SA6700-100APO	Intelligent Switch Monitor Module (Twin)			X	1
SA6710-100APO	Intelligent Switch Monitor Module (Twin) VDS			X	1
SA7100-100APO	Intelligent Reflective Beam Detector - Auto-Aligning			X	10
XPA-IN-14050-APO	XPander Diversity Loop Interface Module	X			2

EDL* - Equivalent Detector Load

Notes-
55000-740/743 Loop-powered VAD (Cat C-15m) - Special Instructions: Product requires a specialist installation method, please purchase kit 55000-747APO (C-3-15, red body) or 55000-748APO (C-3-15, white body) and refer to IG:39215-365 for further information.

Table 2: EN 54-17 parameters				
EN 54-17 parameter	Description	Isolator type		
		20D	20I	20C
V_{min}	Loop dc voltage + Data Pulse Voltage	17 V + 5 V	17 V + 5 V	17 V + 5V
$V_{nominal}$	Loop dc voltage + Data Pulse Voltage	24 V + 9 V	24 V + 9 V	24 V + 9 V
V_{max}	Loop dc voltage + Data Pulse Voltage	28 V + 9 V	28 V + 9 V	35 V + 13 V
$V_{SO\ min}$	Isolation voltage	13.6 V	13.6 V	12.5 V
$V_{SO\ max}$	Isolation voltage	14.8 V	14.8 V	15 V
$V_{SC\ min}$	Voltage to de-isolate (on isolated section with test current applied)	12.9 V	12.9 V	12.8 V
$V_{SC\ max}$	Voltage to de-isolate (on isolated section with test current applied)	18 V	18 V	19.1 V
$I_{C\ max}$	Continuous switch current	1 A	1 A	1 A
$I_{S\ max}$	Maximum switch current	3 A	3 A	3 A
$I_{L\ max\ dc}$	Maximum Isolator leakage current (Test Current)	55mA (pulsed)	28.2mA (dc)	33mA (pulsed)
$Z_{C\ max}$	Maximum series resistance - switch closed	0.2Ω	0.2Ω	0.1Ω

Table 3: EN 54-17 parameters - VdS approved products				
EN 54-17 parameter	Description	Isolator type		
		20D	20I	20C
V_{min}	Loop dc voltage + Data Pulse Voltage	17 V + 5 V	17 V + 5 V	17 V + 5V
$V_{nominal}$	Loop dc voltage	24 V	24 V	24 V
V_{max}	Loop dc voltage + Data Pulse Voltage	28 V + 9 V	28 V + 9 V	35 V + 13 V
$V_{SO\ min}$	Isolation voltage	13.6 V	13.6 V	12.5 V
$V_{SO\ max}$	Isolation voltage	14.8 V	14.8 V	15 V
$V_{SC\ min}$	Voltage to de-isolate (on isolated section with test current applied)	12.9 V	12.9 V	12.8 V
$V_{SC\ max}$	Voltage to de-isolate (on isolated section with test current applied)	17 V	17 V	17 V
$I_{C\ max}$	Continuous switch current	1 A	1 A	1 A
$I_{S\ max}$	Maximum switch current	3 A	3 A	3 A
$I_{L\ max\ dc}$	Maximum Isolator leakage current (Test Current)	55mA (pulsed)	28.2mA (dc)	33mA (pulsed)
$Z_{C\ max}$	Maximum series resistance - switch closed	0.2Ω	0.2Ω	0.1Ω

Table 4: EN 54-17 parameters - NF approved products		
EN 54-17 parameter	Description	Isolator type
		20D
V_{min}	Loop dc voltage	17 V
$V_{nominal}$	Loop dc voltage	24 V
V_{max}	Loop dc voltage	28 V
$V_{SO\ min}$	Isolation voltage	13.6 V
$V_{SO\ max}$	Isolation voltage	16.1 V
$V_{SC\ min}$	Voltage to de-isolate (on isolated section with test current applied)	12.9 V
$V_{SC\ max}$	Voltage to de-isolate (on isolated section with test current applied)	28.5 V
$I_{C\ max}$	Continuous switch current	1 A
$I_{S\ max}$	Maximum switch current	3 A
$I_{L\ max\ dc}$	Maximum Isolator leakage current (Test Current)	1mA dc 55mA (pulsed)
$Z_{C\ max}$	Maximum series resistance - switch closed	0.4Ω

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