AN2679
Application note

Smart inductive proximity switch

Introduction

The STEVAL-IFS006V1 inductive proximity switch demonstration board is designed based on the principle of metal body detection using the eddy current effect on the HF losses of a coil. It consists of a single transistor HF oscillator, an ST7LITEUS5 microcontroller and the TDE1708DFT intelligent power switch. The board is a compact and cost-effective solution for an inductive proximity sensor designed for simplicity and for a wide temperature range and supply voltage variations. Other board features include:

- Great flexibility: the MCU firmware can be modified depending on application requirements
- Sensitivity and hysteresis adjustment
- In-circuit programming and debugging capabilities
- Analog and digital temperature compensation
- PNP and NPN sensor functionality configurations
- Indicator status LED
- Overload and short-circuit protection
- GND and Vs open wire protection
- Compact design
- Supply voltage: 6 V to 48 VDC
- Temperature range: -25 °C to +85 °C

Figure 1. Smart inductive proximity switch demonstration board

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1 Sensor overview

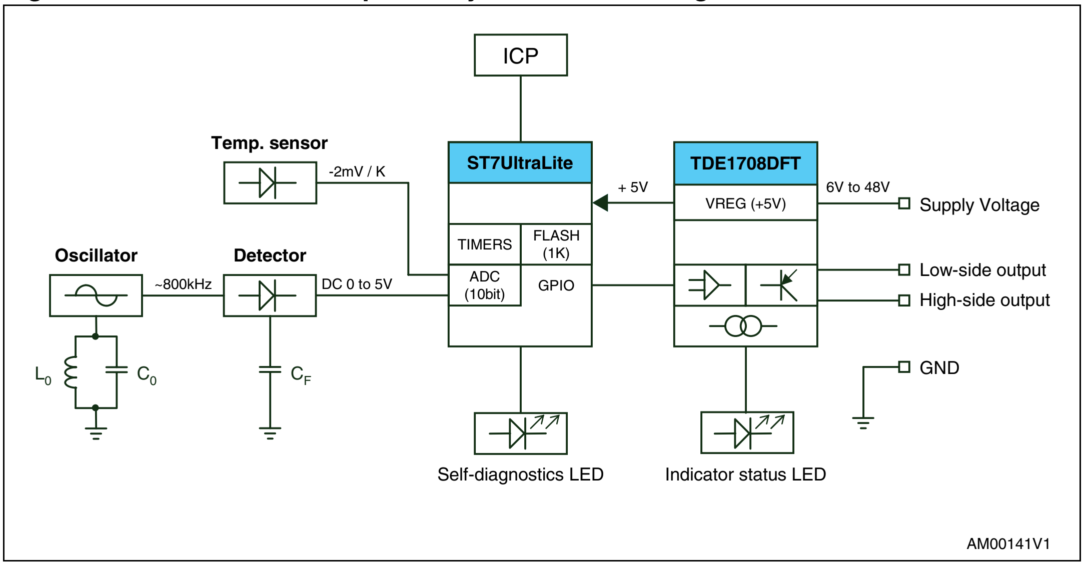
Proximity switches are generally used to sense the position of a moving object in manufacturing processes. Typically, they utilize an oscillator driver circuit in combination with an induction tank circuit. The tank circuit includes an induction coil as a means for sensing the presence of an object such as metal. The magnetic field induces eddy currents in a conductive object which enters within the generated magnetic field. The oscillation amplitude is attenuated due to the energy drawn from the induction coil. The amount of the attenuation is directly related to the distance between the metal object and the induction coil.

A typical inductive proximity switch employs a ferrite cup core as the sensing element. It allows the flux field to be focused in front of the cup and to further increase the sensing distance. The oscillator typically operates between 100 kHz and 800 kHz, where the eddy current losses are significant.

Some benefits of the MCU approach compared with a traditional solution are:

- more reliable operation thanks to the sensor self-diagnostics
- cheap and easy sensor trimming in the production line
- digital temperature compensation
- linearization of the sensor characteristic
- simple implementation of an analog or PWM output

Figure 2. Smart inductive proximity switch block diagram



2 Sensor circuit description

The sensor HF oscillator circuit is based on the Colpitts oscillator type which has a simple circuit configuration, produces a very clean sinusoidal wave signal and is capable of oscillating in a wide frequency range. The resonant circuit consisting from the inductor L1 and capacitors C12, C9 and C8 determine the frequency of the oscillations according to the formula in *Equation 1*. Actually the circuit will oscillate at a slightly lower frequency due to coupling capacitor C10, junction capacitances of transistor Q1 and other stray capacitances.

Equation 1

$$f = \frac{1}{2\pi\sqrt{L_1\left(C_{12} + \frac{C_8 C_9}{C_8 + C_9}\right)}}$$

The oscillator employs a transistor, Q1, operating in a common base configuration that derives its feedback from the capacitor divider C9 andC8. Resistors R3 and R6 set its bias point and the temperature of diode D2 stabilizes it.

The oscillator signal amplitude is further detected by diodes D4 and D5, and filtered by capacitor C13. Together with C10 this circuit acts as a charge pump, thus the full range of the ST7 ADC converter (0 V - 5 V) is used.

The other function of diode D2 is temperature sensing. The voltage across a diode operated at constant current is linear in a very large range of temperature and reduces with increasing temperature by approximately -2 mV/ k (see *Figure 9*). With the ST7 10-bit ADC converter, the temperature can be measured with an accuracy of approximately 2.5 °C which is enough for overall correction of the sensor temperature variations (see *Figure 8*).

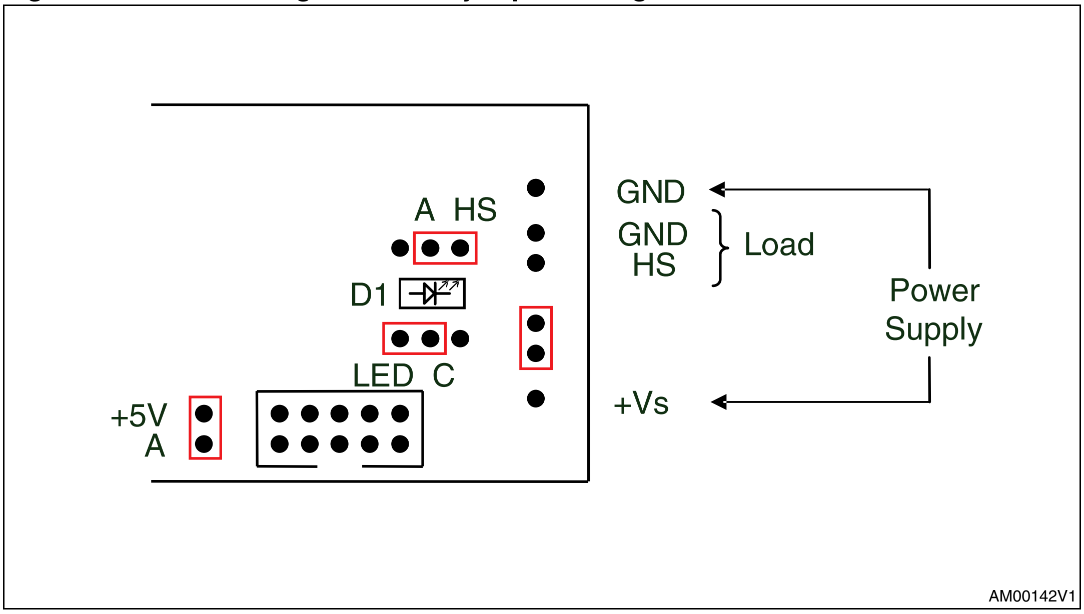
2.1 Initial configuration and jumper settings

Table 1 and *Figure 3* represent the initial (high side) output driver configuration and jumper settings. The diagnostic LED D3 shares the MCU pin 2 with the ICC connector. In case of programming/debugging problems, it can be disconnected by removing the jumper from pins P14 and P15.

Table 1. Initial configuration and jumper settings

Pins	Setting
P10 - P11	A - HS
P4 - P5	LED - C
P3 - P7	+Vs - LS
P14 - P15	+5V - A

Figure 3. Initial configuration and jumper settings



2.2 Output driver configurations

The demonstration board output can be configured using the jumpers for low side (see *Table 2* and *Figure 4*) and/or high side (*Table 3* and *Figure 5*) functionality.

Table 2. Low side (NPN) output driver configuration jumper settings

Pins	Setting
P9 - P10	LED - A
P5 - P6	C - LS
P8 - P12	HS - GND

Figure 4. Low side (NPN) output driver configuration jumper settings

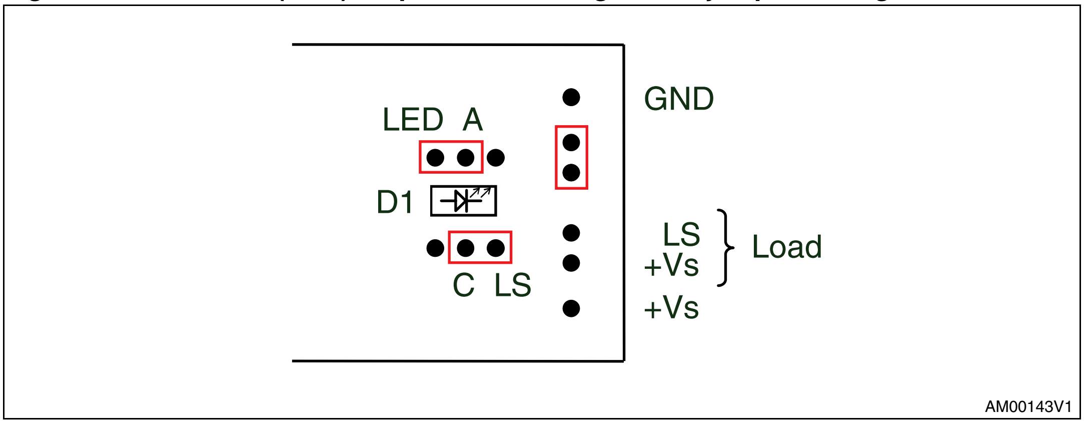
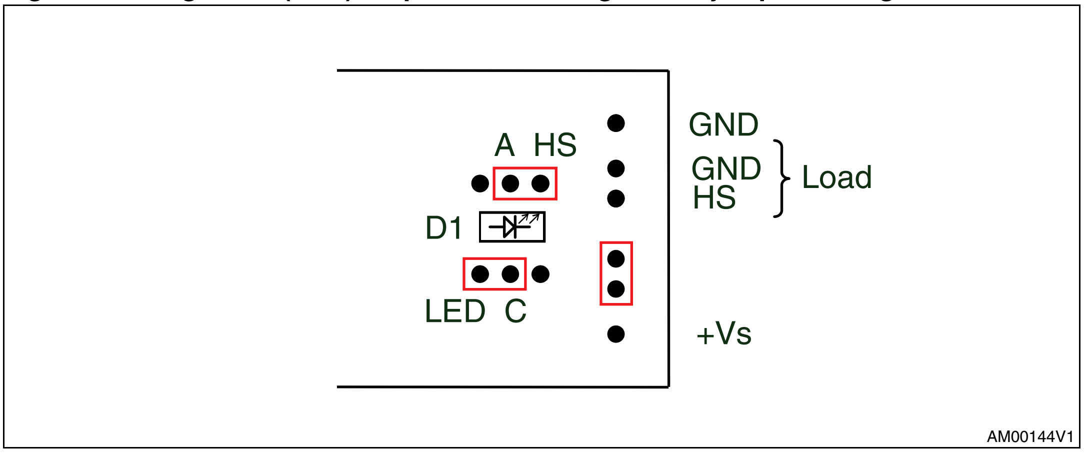


Table 3. High side (PNP) output driver configuration jumper settings

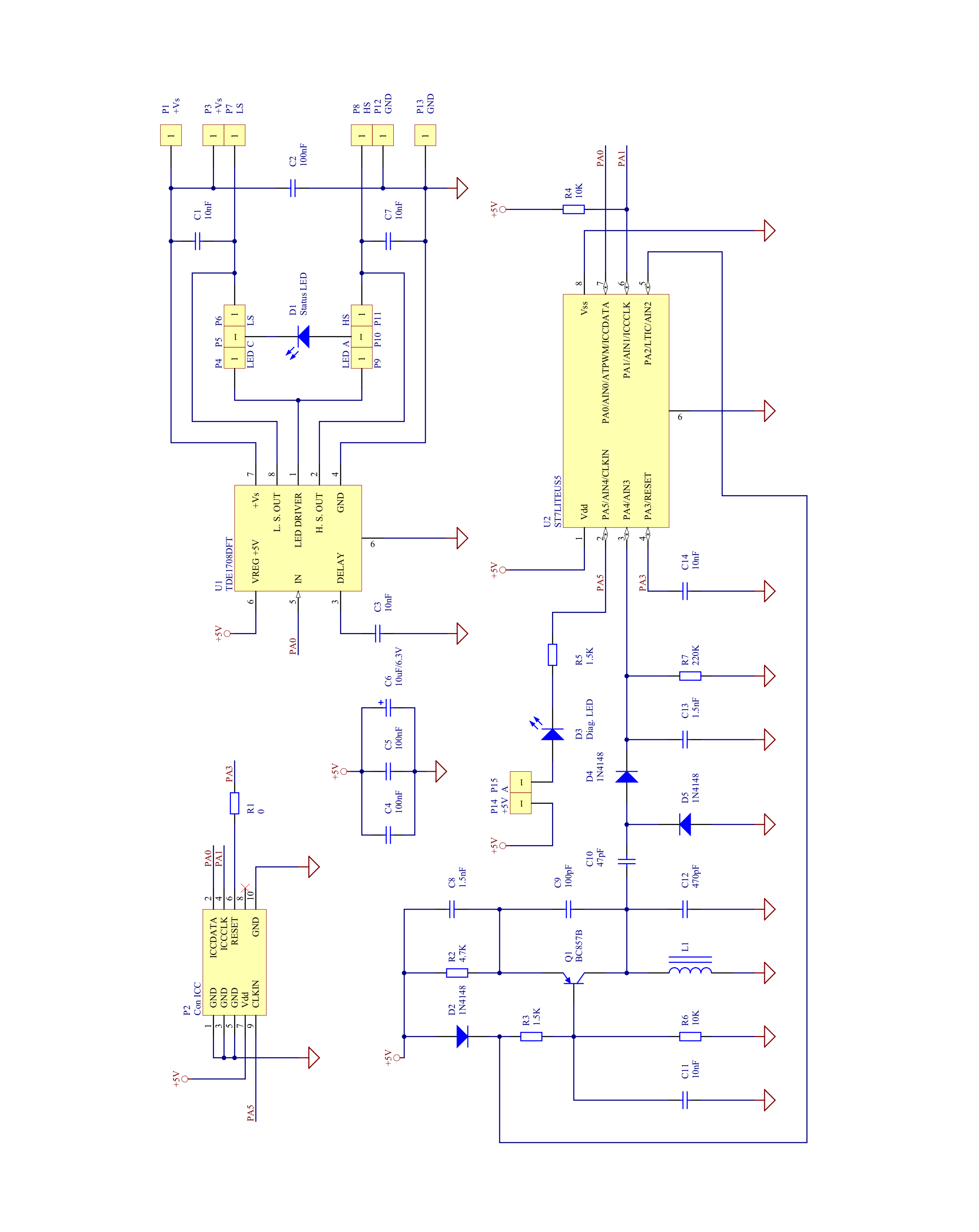
Pins	Setting
P10 - P11	A - HS
P4 - P5	LED - C
P3 - P7	+Vs - LS

Figure 5. High side (PNP) output driver configuration jumper settings



2.3 Application schematic

Figure 6. Smart inductive proximity switch schematic



2.4 Bill of materials

Table 4. Bill of materials

Reference	Value	Description	Quantity	Supplier	Order code
U1		Intelligent power switch	1	STMicroelectronics	TDE1708DFT
U2		8-bit MCU	1	STMicroelectronics	ST7FLITEUS5U3
C1, C7	10 nF	Capacitor	2	EPCOS	B37941A1103K0xx
C2	100 nF	Capacitor	1	EPCOS	B37941A5104K0xx
C3, C11, C14	10 nF	Capacitor	3	EPCOS	B37931A5103K0xx
C4, C5	100 nF	Capacitor	2	EPCOS	B37931K0104K0xx
C6	10 µF/6.3 V	Polarized capacitor	1		
C8, C13	1.5 nF	Capacitor	2	EPCOS	B37931A5152K0xx
C9	100 pF	Capacitor	1	EPCOS	B37930A5101J0xx
C10	47 pF	Capacitor	1	EPCOS	B37930A5470J0xx
C12	470 pF	Capacitor	1	EPCOS	B37930A5471J0xx
D1	Status LED	LED	1		
D2, D4, D5	1N4148	Diode	3		
D3	Diag. LED	LED	1		
L1	68 µH	PS-core inductor	1	Bohemia Electric	BES070815
		Core		EPCOS	B65933A0000X022
		Coil former		EPCOS	B65512C0000T001
P1, P3	+Vs	Header, 1-pin	2		
P2	Con ICC	ICC connector	1		
P4, P9	LED	Header, 1-pin	2		
P5	C	Header, 1-pin	1		
P6, P7	LS	Header, 1-pin	2		
P8, P11	HS	Header, 1-pin	2		
P10, P15	A	Header, 1-pin	2		
P12, P13	GND	Header, 1-pin	2		
P14	+5 V	Header, 1-pin	1		
Q1	BC857B	PNP transistor	1		
R1	0	Resistor	1		
R2	4.7 kΩ	Resistor	1		
R3, R5	1.5 kΩ	Resistor	2		
R4, R6	10 kΩ	Resistor	2		
R7	220 kΩ	Resistor	1		

2.5 ICC connector

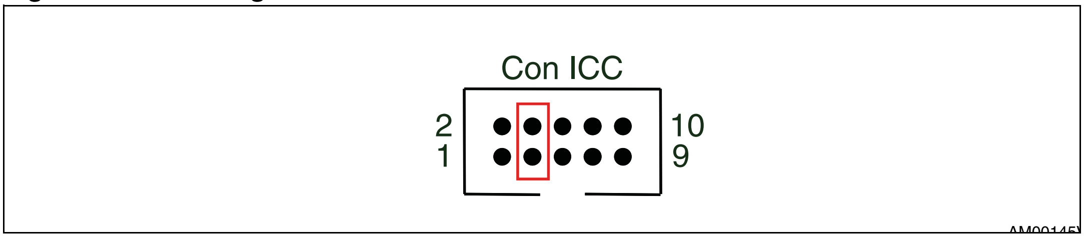
The board ICC connector offers in-circuit programming and debugging capabilities and thus simplifies the firmware development. More information about ST7 development tools is available from www.st.com/mcu.

3 Software implementation

After the first start-up following the firmware upload, the ST7 MCU performs a simple board self-test. It reads the oscillator amplitude level and voltage across the temperature-sensing diode D2 and checks whether these values are within a specific range (this state is indicated by blinking diagnostic LED D3; see *Table 5*). The oscillator amplitude level detected during this test is also considered as an initial oscillator level when no metal object approaches the sensing inductor L1, and its value is recorded to the Flash memory (address 0xfc00) using an in-application programming (IAP) method. This value is later used for amplitude reduction comparisons caused by metal objects.

Note: The initial board self-test procedure can be performed at any time by placing a jumper on pins 3 and 4 of the ICC connector (see *Figure 7*) and powering up the application.

Figure 7. Inducing the demonstration board self-test



During normal operation, the MCU then controls the sensor output based of the information about the oscillator amplitude and the actual temperature. The main sensor part of the firmware is implemented in an auto-reload timer interrupt service routine. In equidistant time intervals the oscillator amplitude is sampled and its value is compared with two system variables (ucUpperCompThreshold and ucLowerCompThreshold). One of these defines the ON to OFF transition, and the other defines the OFF to ON transition of the sensor state. The distance between them determines the hysteresis. These threshold variable values are defined as a percentage of the initial oscillator level recorded in the Flash memory and are further modified depending on the temperature by a coefficient from a lookup table.

Table 5. Diagnostic LED blinking modes (power up self-test)

LED status	Meaning
Blinking	Input values within limits
Constant	Error

Table 6. Diagnostic LED blinking modes (normal operation)

Flashing style	Meaning
* * * * * *	Under-temperature
** ** ** **	Over-temperature
*** *** ***	Ferrite approaching the coil

Figure 8. Oscillator amplitude vs. temperature (MCU pin 3)

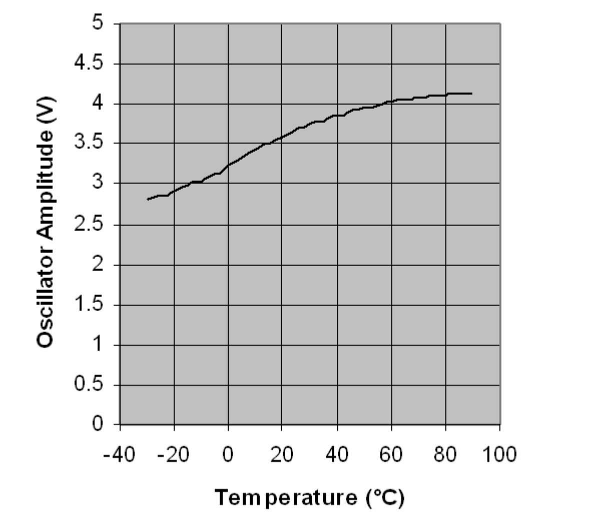
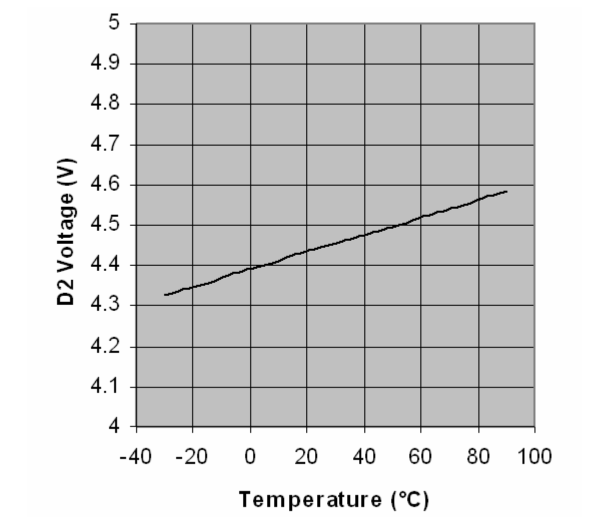


Figure 9. D2 voltage vs. temperature (MCU pin 5)



4 References

1. ST7LITEUS5 datasheet
2. TDE1708DFT datasheet
3. Application note AN495
4. EN60947-5-2: "Low-voltage switchgear and controlgear - Part 5-2: Control circuit devices and switching elements - Proximity switches"

5 Revision history

Table 7. Document revision history

Date	Revision	Changes
07-Jul-2008	1	Initial release.