User's Guide

SMC20 – *Cézallier* –Temperature Controller

C-Series Modules – Laser Diode Controller

SISYPH
Signals & Systems for Physics

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1 General Information

1.1 Important notice

The information given in this guide is subject to change without notice.

1.2 Scope

This manual provides the user with a description of the operation for the Temperature Controller module SMC20-R19A.

1.3 Related documents

All documents listed below are available online. See the product page.

Document	Release Number
Datasheet	SMC20-SS01-R19A
PCB legend	SMC20-AG01-R19A
Block diagram	SMC20-SG01-R16A
Front-panel	SMC20-DD02-R16A

1.4 Certification

Signals and Systems for Physics certifies that this product met its published specifications at the time of shipment.

1.5 Warranty

This Signals and Systems for Physics product is warranted against defects in materials and workmanship for a period of one (1) year from the date of shipment.

1.6 Absolute maximum ratings

All SMC-Series modules are designed to be operated in laboratory environment.

Parameter	Rating
Environmental Temperature	$> 15°$ C and $< 30°$ C
Environmental Humidity	$< 60\,\%$

1.7 Specifications

All specifications regarding the product are reported in the datasheet available online. See section 1.3.

Contents

2 Overview

The SMC-Series modules are the ideal instruments for controlling the current and the temperature of diodes laser for AMO physics. With an ultra-low current noise density $\leq 20\,\mathrm{pA}/\sqrt{\mathrm{Hz}}$ (SMC11) and sub-mK thermal control stability (SMC20 & SMC31), the SMC-Series is the right choice for the most demanding applications.

Because SMC-Series was first designed for frequency stabilization and OPLL applications, the SMC20 temperature controller provides both high-stability and analog setpoint control features to maintain a laser locked continuously. The SMC20 presents a typical stability less than 1 mK/°C with respect to room temperature, and has a temperature control range from 17 °C to 31 °C.

When the temperature controller is used with the SMC31 TEC Linear Driver, two modes of operation are supported: constant temperature mode (CT) and constant current mode (CC). A laser frequency control application normally operates in CT mode. In this case, the laser temperature is tight controlled using a high-resolution thermistor bridge and an analog PID controller. The CC mode operates the TEC at fixed current, which is set using a front-panel trimmer or an analog control voltage. Because laser diodes usually come with integrated TEC and such sensor, only 10-kΩ NTC thermistors are supported.

Like all SM-Series modules, the SMC20 is shipped with the schematic diagrams of its electronic circuitry providing all required information for advanced users.

2.1 Description

The SMC20 module delivers high performance temperature control for thermally stabilizing the laser diode. Two modes of operation are allowed. In constant temperature (CT) mode, the temperature of the laser, which is measured using a thermistor, is maintained at the desired setpoint value. For this purpose, an analog proportional-integral-differential (PID) controller, operating from the laser temperature, is used to adjust the current of the thermoelectric cooler (TEC) actuator. *An external power stage must be used to drive the TEC.* The SMC31 Linear TEC Driver module was designed for this purpose. It features a clean ±1 A current source free of digital noise encountered in switching-mode amplifiers. The second operating mode is allowed for an open-loop characterization of the thermal path, where the PID controller and the power driver act as a voltage controller constant-current (CC) source.

The block diagram of the SMC20 of the temperature controller is available online (see section 1.3). Referring to this diagram, the 10-kΩ thermistor of the laser head is used in a linearized-bridge amplifier to provided the temperature measurement. For the purpose of the CT mode operation, the temperature error signal is derived from this measurement and two user-controlled signals: a setpoint input allows the user to set the desired temperature precisely while a servo input makes possible small variations of the temperature. This input is intended to laser frequency stabilization in order to maintain lock over long period.

The temperature error signal is fed to a three-path analog PID controller. Both integral and derivative time constants are selected using switches located on the printed circuit bord (PCB) while the loop-gain is adjusted using a front-panel trimmer. In order to prevent the integrator wind-up, which can make the temperature lock difficult with excessive settling times, an internal loop is used to control the integrator output.

Operation in CC mode is allowed by presetting the integrator output of the PID controller using an internal closed-loop. The TEC current setpoint is adjusted using either a front-panel trimmer or a DC voltage input. This closed-loop operation of the integrator in CC mode results in a smooth or bump-less transient when switching from CC to CT mode.

Safe operation of the diode laser is assured through continuous fault monitoring. The temperature controller is disabled if either the laser temperature is out of the allowed range or the connections of the thermistor are defective. In this case, the TEC current is set to zero and a digital output is fed to the current source module to shut the laser off.

The controller command signal is connected to power amplifier through the analog interface. A fault signal resulting from a failure from the current driver is also connected *via* the interface to disable the temperature controller. Three leds are used to indicate whether the laser temperature is locked to the setpoint or not. These indications are also available through the digital interface.

2.2 Connections to the power driver

The temperature controller was designed to operate with a power driver through the analog and digital interfaces. The SMC31 TEC Linear Driver module should be used for this purpose. Contact us to use a different driver.

2.3 TEC and thermistor connections

The connections between the temperature controller and the thermistor of the laser head are made using the analog interface connector. *None of these terminals is allowed to contact ground or any other signal.* When the SMC31 TEC Linear Driver is used, these connections are available on the front-panel of the power driver through a D-SUB9 connector. In this case, the connections between the TEC and the driver are also made using this front-panel connector.

2.4 Connections to the current source

The temperature controller was designed to operate with the SMC10 Low-Noise Current Source module. Because the laser diode should not operate without thermalization, the temperature controller is able to shut the laser down if a failure in the thermal control path is detected. The control of the current source is made through the analog and digital interface connectors.

3 Operation

3.1 Front-panel

There are a total three trimmers, six leds and one BNC on the front-panel, they are described in this section. Refer to the section 1.3 for more information on the front-panel.

3.1.1 Temperature Setpoint Trimmer

If the setpoint temperature of the CT mode results from the **Temperature Setpoint Switches** settings, accurate adjustments of the desired temperature are also allowed using the **Temperature Setpoint Trimmer**. The range covered (−5 K to 0 K) by the trimmer is sufficient to set the temperature anywhere between two positions of the switch. Turn the trimmer counterclockwise to decrease the setpoint, full clockwise to leave the desired temperature unchanged. The digital /**Setpoint Input** must be left open or driven high to enable the trimmer.

3.1.2 Manual Steering Trimmer

The current setpoint used in CC mode is adjusted with the **Manual Steering Trimmer**. When the trimmer is enabled, the controller output voltage can be set from −10 V (full counterclockwise) to +10 V (full clockwise). In the case where the SMC31 TEC Linear Driver is used as power stage, the TEC current

can be adjusted from from −1 A (full counterclockwise) to +1 A (full clockwise). To enable the trimmer, the digital /**Remote Tracking Input** must be left open or driven high.

3.1.3 Loop-Gain Trimmer

The P-coefficient of the PID is adjusted from 0 dB (full counterclockwise) to +40 dB using the **Loop-Gain Trimmer**.

3.1.4 Servo BNC Connector

This input is intended to laser frequency stabilization where a feedback on the laser temperature is required to maintain lock. For this purpose, very small variations of the desired temperature (±50 K) in CT mode are allowed by applying a DC voltage (±10 V) through the **Servo BNC Connector**. To enable this input, the digital /**Servo Input** must be driven low. When the **Servo BNC Connector** is used to provide the input servo signal, the terminals **Temperature Servo Input** of analog interface must be left open.

3.1.5 Temperature Status Leds

These three leds are intended to display the temperature status in CT mode operation. They refer to the magnitude of the temperature error ϵ between the setpoint and the measured value.

Led	**Temp. Error Magnitude**	**Status**
Green	$-150\,\text{mK} < \epsilon < +150\,\text{mK}$	Locked
Red	$\epsilon > +150\,\text{mK}$	Above
Yellow	$\epsilon < -150\,\text{mK}$	Below

3.1.6 Controller Status Leds

These three leds are used to display the status of the temperature controller.

- The **Red Led** is lit if a **Temperature Fault** is detected. This can result from bad connections of the thermistor (shorted or open). A fault is also detected if the temperature of the laser is either below 10 ° or above 50 °. When a **Temperature Fault** occurs, the SMC10 Current Source enters immediately in a laser shut down procedure.
- The **Yellow Led** indicates that a **Saturation** of the command output is detected. In this case, the voltage is clamped to ±10 V.
- The **Green Led** is lit if the **Command Output** of the controller is enabled. The controller is operating either in CC or CT mode.

Led	**Status**
Green	Command Enabled
Red	Temperature Fault
Yellow	Saturation

3.2 Analog I/O interface connector

Like all SMC-Series modules, the SMC20 has two 50-pin stack-through headers acting as Analog I/O and Digital I/O interfaces. In this section each pin allocated to the analog interface is described.

3.2.1 Command output

The **Command Output** is aimed at driving the power amplifier. In CC mode, this output is either controlled by the **Manual Steering Trimmer** located on the front-panel or by a DC voltage applied to the **Remote Tracking Input** through the analog interface. In CT mode operation, the **Command Output** is provided by the PID compensator. This output can drive a light load. It is directly connected to the SMC31 TEC Linear Driver module *via* the analog interface. To enable the **Command Output**, the digital **Controller Enable Input** must be driven low.

3.2.2 Error Monitor output

A copy of the error signal is available on the **Error Monitor Output**. The error signal is defined as the difference between the desired temperature and the laser one. This monitoring signal is provided for diagnostic purposes, such as PID tuning. It can drive a light load. Can be left open if not used. In order to access the **Error Monitor** output through a front-panel BNC connector, consider the SMC112 module.

3.2.3 Reference Ground output

The **Reference Ground Output** provides a clean ground connection (0 V)) for analog differential measurements. *Do not tie this pin to the ground of the measuring circuitry.* Left open if not used.

3.2.4 Temperature Setpoint input

The **Temperature Setpoint Input** provides the user with remote control of the desired temperature (±500 mK) of the laser. For this purpose, a DC voltage is applied to this differential input between the two terminals labeled **Setpoint Pos** and **Setpoint Neg**. To enable this input and disables the front-panel trimmer, the digital /**Setpoint Enable Input** must be driven low. In order to access the **Temperature Setpoint Input** through a front-panel BNC connector, consider the SMC112 module.

3.2.5 Temperature Servo input

In CT mode, the **Temperature Servo Input** provides the user with remote control of the desired temperature (±50 mK) of the laser. For this purpose, a DC voltage is applied to this differential input between the two terminals labeled **Servo Pos** and **Servo Neg**. This feature is intended to laser frequency stabilization where a thermal feedback is required to maintain lock over a long period. When the analog interface terminals are used to provide the input servo signal, the Servo BNC Connector must be left open. To enable this input the digital /**Servo Enable Input** must be driven low. In order to access the **Temperature Servo Input** through a front-panel BNC connector, consider the SMC112 module

3.2.6 Remote Tracking input

The **Remote Tracking Input** is used to drive the power amplifier by an external voltage source. This input is provided for diagnostic purposes, such as the thermal response analysis. The DC voltage is applied to this differential input between the two terminals labeled **Tracking Pos** and **Tracking Neg**. To enable this input the digital /**Remote Tracking Input** must be driven low. In order to access the input through a front-panel BNC connector, consider the SMC112 module.

3.2.7 Thermistor inputs

The temperature sensor is connected to the bridge amplifier through two terminals labeled **RT+** and **RT-**. *None of these terminals is allowed to contact ground or any other signal.* The temperature controller was

designed to operate with a thermistor featuring a resistance of 10 kΩ at 25 °C and a β of 3800. When the SMC31 TEC Linear Driver is used, the thermistor connections are available on the front-panel of the driver through a D-SUB9 connector.

3.2.8 Analog Power Supply inputs

The analog circuitry of the module operates from +15 V and −15 V power supplies. It is recommended to use the SMZ00 Power Interface module to connect these sources. The digital ground **DGND** terminal must be tied to the analog ground **AGND**.

3.2.9 Pin assignments

Signal label	Pin assignment	Direction
Temp. Servo Pos.	AIO.31	input
Temp. Servo Neg.	AIO.33	input
Temp. Setpoint Pos.	AIO.27	input
Temp. Setpoint Neg.	AIO.29	input
Remote Tracking Pos.	AIO.28	input
Remote Tracking Neg.	AIO.30	input
Thermistor RT+	AIO.23	input
Thermistor RT-	AIO.25	input
Error Monitor	AIO.26	output
Command Output	AIO.32	output
Reference Ground	AIO.34	output
AGND	AIO.6	power input
−15 V	AIO.45	power input
+15 V	AIO.47	power input
AGND	AIO.49	power input
Chassis	AIO.2	chassis ground input (Earth)

3.3 Digital I/O Interface connector

Like all SMC-Series modules, the SMC20 has two 50-pin stack-through headers acting as analog I/O and digital I/O interfaces. In this section each pin allocated to the digital interface is described.

3.3.1 /Controller Enable input

To enable the controller **Command Output**, the **/Controller Enable Input** must be driven low. If no faults are detected, the controller output is delivered to the power amplifier module. Whenever the **/Controller Enable Input** goes high or a fault occurs, the command output is immediately grounded. In order to control the **/Controller Enable Input** through a front-panel switch, consider the SMC121 module.

3.3.2 Tracking/Auto input

This input is used to select the operating mode of the temperature controller. For CC mode operation, set the **Tracking/Auto Input** high, it can be also left open. To operate in CT mode, the input must be driven low. In order to control the **Tracking/Auto Input** through a front-panel switch, consider the SMC121 module.

3.3.3 /Setpoint Enable input

The /**Setpoint Enable Input** is driven low to enable the adjustment of the desired temperature *via* the **Temperature Setpoint Input**. In this case, the front-panel trimmer is disabled and the temperature is set using a DC voltage. When the /**Setpoint Enable Input** is set high or left open, the setpoint is adjusted using the trimmer. In order to control the /**Setpoint Enable Input** through a front-panel switch, consider the SMC121 module.

3.3.4 /Servo Enable input

To enable small variations of the desired temperature using the servo inputs, the /**Servo Enable Input** must be driven low. In order to control the /**Servo Enable Input** through a front-panel switch, consider the SMC121 module.

3.3.5 Manual/Remote Tracking Enable input

This input is used to select whether of the **Manual Steering Trimmer** or the **Remote Tracking Input** is used to control the TEC current in CC mode operation. To enable front-panel control, the **Manual/Remote Tracking Enable Input** is set high or left open. To enable current control through the analog interface, the input must be driven low. In order to control the **Manual/Remote Tracking Enable Input** through a front-panel switch, consider the SMC121 module.

3.3.6 /Power Fault input

This active-low input is used to disable the **Command Output** when a power supply fault is detected. The /**Power Fault Input** is driven by the SMZ00 Power Interface module, which is able to provide such a signal. Until the /**Power Fault Input** goes high, the laser remains shorted whatever the level of the /**Controller Enable Input**.

3.3.7 /Amplifier Fault input

An low digital level on the /**Amplifier Fault Input** disables the **Command Output** immediately. This input is driven by the SMC31 TEC Linear Driver module to indicate that a severe fault is detected in the power amplifier stage. Until the /**Amplifier Fault Input** goes high, the controller output remains disabled whatever the level of the /**Controller Enable Input**.

3.3.8 /Temperature Fault output

The /**Temperature Fault Output** is driven low when a fault is detected. In this case, the **Command Output** is disabled (grounded) and the SMC10 Current Source shuts the laser off immediately. A fault condition is detected when

1. The laser temperature is above +50° C.
2. The laser temperature is below +10° C.
3. The thermistor is shorted.
4. The connection of thermistor is open.

3.3.9 /Controller On output

The /**Laser On Output** is driven low when the controller **Command Output** is enabled.

3.3.10 /Above output

The /**Above Output** is driven low when the laser temperature differs from more than 150 mK above the desired one. This information is also given to the user using the **Controller Status Leds** on front-panel.

3.3.11 /Locked output

The /**Locked Output** is driven low when the laser temperature differs not more than 150 mK from the desired one. This information is also given to the user using the **Controller Status Leds** on front-panel.

3.3.12 /Saturation output

The /**Saturation Output** is driven low to indicate that the **Command Output** is clamped to ±10 V. In CT mode for example, this can happen when the closed-loop operates with a wrong polarity of the error signal. In CC mode, an excessive input control voltage can lead to limitation of the controller output.

3.3.13 Digital Power supply

The digital circuitry of the module operates from a +5 V power supply. It is recommended to use the SMZ00 Power Interface module to connect this source. The digital ground **DGND** terminal must be tied to the analog ground **AGND**.

3.3.14 Pin Assignments

Signal label	Pin assignment	Direction
/Controller Enable	DIO.33	input
Tracking/Auto Enable	DIO.29	input
/Setpoint Enable	DIO.25	input
/Servo Enable	DIO.27	input
Man./Remote Tracking Enable	DIO.31	input
/Amplifier Fault	DIO.21	input (from SMC31 module)
/Power Fault	DIO.45	input (from SMZ00 module)
/Controller On	DIO.28	output
/Saturation	DIO.30	output
/Temp. Fault	DIO.26	output
/Above	DIO.32	output
/Locked	DIO.34	output
+5 V	DIO.47	power input
+5 V	DIO.48	power input
DGND	DIO.49	power input
DGND	DIO.50	power input
Chassis	DIO.1	chassis ground input (Earth)

3.4 PCB Settings and connectors

There are five sets of switches and one header on the printed circuit board.

3.4.1 Temperature Setpoint switches

The 8-way switch labeled SW301 (RSET) on the printed circuit board is allowed to select 8 setpoint temperatures for CT operation. Since only one way of the switch must be on for proper operation, the table refers to the switch that must be selected, understood that the other elements of the set must be off.

Selected way	Setpoint Temperature
SW301-1	+17° C
SW301-2	+19° C
SW301-3	+21° C
SW301-4	+23° C
SW301-5	+25° C
SW301-6	+27° C
SW301-7	+29° C
SW301-8	+31° C

If all ways are open (off), then the resistor R312 can be used to chose an arbitrary value of the setpoint temperature. By default, this resistor is not not mounted on the printed circuit board. This allows to use a different resistance than those provided by SW301. The value of R312 value is chosen equal to the thermistor resistance at the desired temperature.

3.4.2 Integrator Time Constants switches

Seven ways of the switch SW502 (INTEGRAL label on PCB) are intended to integrator time constants (T_i) selection. In the table, the Unity Gain Frequency is defined as $UGF = \frac{1}{2\pi T_\mathrm{i}}$.

Selected way	$\mathbf{T_i}$	UGF
SW502-1	0.47 s	330 mHz
SW502-2	1 s	150 mHz
SW502-3	2.2 s	70 mHz
SW502-4	4.7 s	33 mHz
SW502-5	10 s	15 mHz
SW502-6	22 s	7 mHz
SW502-7	47 s	3.3 mHz

If all seven ways are open (off), then the capacitor C510 can be used to choose an arbitrary value for the time constant. By default, this capacitor is not not mounted on the printed circuit board. This allows to use a different capacitance than those provided by SW502.

3.4.3 Integrator Enable/Disable switch

The integrator can be disabled by opening SW502-8 (off). *Nevertheless, this operation is not recommended whatever the operating mode, CT or CC.* In both case the integrator is used, to provide high performances in CT operation or to ensure good tracking of the control voltage input in CC mode. To enable the integrator, SW502-8 must be closed (on).

3.4.4 Differentiator Time Constants switches

Seven ways of the switch SW501 (DIFFERENTIAL label on PCB) are intended to differentiator time constants (T_d) selection. In the table, the Unity Gain Frequency is defined as $UGF = \frac{1}{2\pi T_\mathrm{d}}$.

Selected way	T_d	UGF
SW501-1	0.1 s	1500 mHz
SW501-2	0.22 s	700 mHz
SW501-3	0.5 s	330 mHz
SW501-4	1 s	150 Hz
SW501-5	2.2 s	70 mHz
SW501-6	5 s	33 mHz
SW501-7	10 s	15 mHz

If all seven ways are open (off), then the capacitor C509 can be used to choose an arbitrary value for the time constant. By default, this capacitor is not not mounted on the printed circuit board. This allows to use a different capacitance than those provided by SW502.

3.4.5 Differentiator Enable/Disable switch

The differentiator can be disabled by opening SW501-8 (off) or enabled by closing SW501-8 (on).

3.4.6 Digital Voltmeter connector

The four-pin **Digital Voltmeter Connector** is intended to measure the **Error Monitor Output** using a small digital voltmeter module (DVM). To connect the voltmeter, use the following pin assignments :

J202 pin	Signal	DVM pin
1	Error Monitor	Positive Input (High), sensitivity +1 V/K at 25° C
2	+5 V	Positive Power Supply, 100 mA max
3	Analog Ground	Negative Input (Low)
4	Digital Ground	Negative Power Supply (0 V)

4 Circuitry

4.1 Circuit description

The module is powered by ±15 V from the analog interface connector (J201) and by +5 V from the digital interface connector (J401). These power supply inputs are both protected against reverse voltage and over voltage transients.

The thermistor used to measure the temperature of the laser diode is connected to the linearized bridge amplifier (U302A and U304A). A fault in the connections of the thermistor is detected by monitoring the drive voltage of the bridge amplifier (U303A and U303C). The detection of temperatures out of the allowed range relies on a measurement of the current in the thermistor bridge (U302D), which leads to an unbiased measurement of the thermistor resistance (U302E). This resistance is then compared to those admissible (U303D and U303E).

The difference between the resistance of the thermistor and the resistance of the upper branch (SW301) of the bridge is amplified by U304A. This bridge output is then compared to the optional desired temperature offset (U603A) to derive the temperature error signal (U603C). The P-gain of the PID controller is implemented in this stage.

The PID circuit is implemented using parallel paths. The differentiator (U503A) time constant is controlled by the switch SW501. An additional roll-off pole (C511 and R506) prevents noise-peaking. The integrator (U502D) time constant is selected using SW502. Two diodes (D501 and D502) act as an error limiter, which reduce the risk of large transients. The bump-less operation required when the mode is switched from CC to CT is achieved by presetting the integrator using the local feedback loop (U502C). An second internal closed-loop (U503E) prevents the wind-up of the integrator.

4.2 Printed circuit board legend

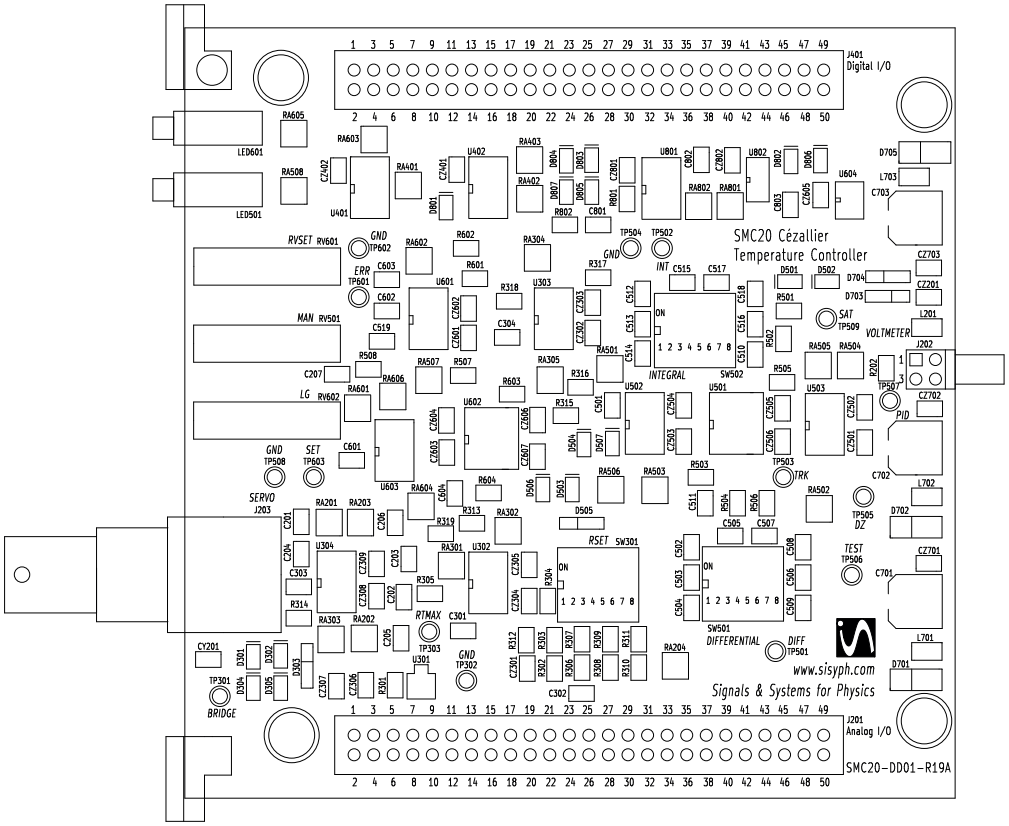

Figure 1: SMC20 Printed Circuit Board legend

Document Revision History

Release	Comments
SMC20-SN01-R19A	Updated module identifier
	Updated related files
	Added full name
	Updated current noise density of SMC11
SMC20-SN01-R17A	First release