User's Guide

SMA91 – Autolock Controller

A-Series Modules – Laser Frequency Stabilization

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Contents

1 Important Notice

The information given in this guide applies to the SMA91-R16B module and its related documents or hardware

Related document	Release number
SMA91 Printed circuit board	SMA91-DD01-R16B
SMA91 Datasheet	SMA91-SS01-R16A

2 Overview

In RF-optical heterodyne lock (also known as Pound-Drever-Hall lock), the non-linear frequency discriminator range is given by the frequency of the phase modulating signal. Thus, if the detuning frequency between the laser and the resonator is greater than this modulation frequency, which typically lies in the megahertz range, the error signal is null and the closed-loop cannot operate. Furthermore, for a frequency control loop using some integrators, an out-of-range error signal leads to the saturation of the actuators. In such operation, the laser remains unlocked until a proper action from the user has been carried out. This behaviour becomes problematic with high-finesse cavities because the resulting sensor range is reduced to the resonator bandwidth.

The SMA91 module is able to automatically acquire lock for frequency control systems featuring ultra narrow linewidth cavities. Neither computer nor user actions are required since the module includes its own algorithm. The autolock controller is designed to operate with the high-speed (SMB20) and piezo (SMB30) compensators. It features a thermo-electric cooler (TEC) compensator to provide a third nested loop in order to prevent saturation of the piezo actuator.

Several operating modes are provided to help the user during the tuning phase: for example, it is possible to choose which actuators are engaged when the loop is closed. This feature can be useful to find the right polarity of the error signal.

Like all SM-Series modules, the SMA91 is shipped with the schematic diagrams of its electronic circuitry providing all required information for advanced users. In addition, all C source files of the microcontroller firmware are available for our customers on simple request.

2.1 Acquiring lock

The SMA91 autolock controller implements a state-machine to achieve locked operation without any action from the user. The simplified acquisition procedure is the following: while the sensor signal is out-of-range, the laser frequency is swept to bring the laser frequency within the sensor range. Once an in-range error signal has been detected, the search pattern generator is stopped and the compensators are sequentially engaged to acquire lock. For this purpose, a photodetector (not included) is used to monitor continuously the transmitted power through the resonator. An out-of-range sensor operation is declared when the transmitted light is under a preset level. Above this level, a locked condition is detected and the autolock controller performs all required actions to acquire lock.

The search pattern used during the acquisition is selected between an increase of the crystal temperature and a ramp voltage applied to the piezo actuator. No external signal source is required since these signals are internally generated. The rotary selector located on board edge allows the user to select which actuator, from TEC or piezo, is used to sweep the laser during the acquisition phase. When the laser is swept, the command signals are preset to a voltage level, which is selected using dedicated on-board switches.

2.2 Tracking

If the state-machine succeeds in acquiring lock, the 3 compensators are engaged in order to maintain lock. In case of lose of lock, the state-machine enters a new acquiring lock procedure: the command signals are preset a their predefined levels and the search pattern generator is started.

2.3 Sweeping

Since a piezo actuator is almost available in such frequency control loops, this actuator is used to check the error signal before trying lock. For this purpose, a low-frequency ramp signal is applied to piezo actuator. When the ramp voltage is large enough to sweep the laser over several free-spectral-ranges, the resulting error signal can be monitored and adjustments can be carried out if necessary. The amplitude of the ramp voltage is selected using a switch located on the printed circuit board. When the autolock controller is switched from Sweep to Autolock operation, the ramp generator is stopped and the acquiring procedure is engaged.

2.4 Temperature Compensator

In 3-path control systems, the temperature loop is used to remove the DC components or drifts from the piezo command signal. This is required when the piezo actuator range is not sufficient to hold lock over large variations. Such low-frequency disturbances are easily compensated by a temperature actuator, usually thanks to a thermoelectric cooler (TEC) bounded to the laser crystal. When used as frequency actuators, TECs can offer several order of magnitude greater gain than piezos.

In order to avoid saturation of the piezo control path, the TEC compensator operates from the measurement of the PID output of the SMB30 compensator. The piezo command is compared to a local reference voltage and the resulting error signal is fed to the integrator through an attenuator stage. The polarity of the loop can be changed using either the local on-board switch or the dedicated digital input. Using the Laplace transform, the temperature command signal is given by

$$U_{\mathrm{TEC}}(s) = \frac{\alpha\left(U_{\mathrm{PZT}}(s) - R_{\mathrm{PZT}}(s)\right)}{T_{\mathrm{i}} s} \tag{1}$$

where α is the attenuation, T_{i} the integrator time constant, U_{PZT} and R_{PZT} are respectively the piezo command measured from the SMB30 module and the local setpoint voltage.

2.5 Microcontroller Programming Interfaces

The autolock controller includes a microcontroller (MCU) that implements the state-machine. The firmware running on the MCU should operate in most of the cases but, if special functions or adjustments are required, two headers are provided for programming and debugging. Program updates and bugs corrections are carried out using these connectors.

3 Operation

3.1 Front Panel

There are a total of three BNCs, two switches and three leds on the front panel, they are described in this section.

3.1.1 Controller Switch

In left position, the controller is off. By default, when the controller is off, the command signals are preset. When the switch is on (right position), the controller operates according to the **Autolock Switch** status.

3.1.2 Autolock Switch

The **Controller Switch** must be on, otherwise the **Autolock Switch** has no action on the state-machine. When the **Autolock Switch** is in left position, the controller operates in sweeping mode: the ramp voltage is applied to the piezo actuator and all compensators are preset. In this mode, the green led blinks. When the switch is in right position, the controller operates in autolock mode: the compensators are preset and the state machine enters the acquiring procedure. Once lock is acquired, the state-machine performs the required actions to hold lock. The state-machine behavior is controlled by the rotary **Mode Operation Selector** located on the printed circuit board. During autolock mode operation the green led is on.

3.1.3 TEC Output BNC

This is the command signal of the temperature path. Connect the temperature laser input to this signal using a coaxial cable. Left open if not used.

3.1.4 TEC Monitor BNC

The **TEC Monitor BNC** carries a copy of the **TEC Output** command signal. Can be left open if not used.

3.1.5 Photodetector Input BNC

Connect the transmission photodetector signal to this input using a coaxial cable. The **Photodetector Input** is used to provide a logical locked/unlocked discriminator for the state-machine. For this purpose, an internal voltage comparator is used whose threshold is set by a switch located on board. A lock condition is declared when the transmission voltage exceeds the threshold level, which set by the **Trigger Source Selector**.

3.1.6 Green Led

This led indicates the controller status. When the controller is on, the green led blinks during sweeping operation, *i.e.* the ramp voltage is applied to the piezo actuator. In autolock mode, the led is switched on. The green led is off when the controller is set off.

3.1.7 Yellow Led

This led shows whether the **Photodetector Input** signal is above the threshold or not. It is switched on when the transmission level is sufficient to declare a locked condition.

3.1.8 Red Led

This led blinks when the state-machine enters an internal reset state.

Green Led	Yellow Led	Red Led	Status
off	x	x	Controller disabled
blinking	x	x	sweeping mode
on	x	x	autolock mode
x	blinking	x	triggered
x	on	x	locked
x	off	x	unlocked
x	x	blinking	state-machine reset

3.2 AIO and DIO Interfaces

Like all SMA-Series modules, the SMA91 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 SMA91 operation is described.

For information purposes, the signals of the SMB20 and SMB30 compensators controlled by the Autolock module are also listed.

3.2.1 TEC Servo (AIO A91 SERVO)

This signal carries a copy of the **TEC Actuator Output**. Left open if not used.

3.2.2 Signal Ground (AIO A91 GND)

A clean signal ground **GND** is provided as a reference for measurement purposes. *Do not connect this pin to a ground signal*, use a differential sense circuit. Left open if not used.

3.2.3 Acquire Input (DIO A91 ACQ/TRK)

Use this input to provide for the state-machine a digital signal indicating a locked/unlocked condition. A low-level signal indicates an unlocked condition. For proper operation, any connection at the **Photodetector Input** located on front panel should be removed. Left open if not used.

3.2.4 Controller Mode Enable (DIO A91/CNTRL)

Use this active-low input to switch the controller on. The front panel **Controller Switch** must be in left position to allow remote control. Left open if not used.

3.2.5 Autolock Mode Enable (DIO A91/AUTO)

Use this active-low input to enable the autolock operation. The front panel **Autolock Switch** must be in left position to allow remote control. Left open if not used.

3.2.6 Locked Output (DIO A91/LOCKED)

This active-low digital output indicates a locked operation. Left open if not used.

3.2.7 Negative Polarity Enable (DIO A91/NEG)

This active-low input controls the polarity of the temperature loop. When is set low, the polarity is negative. The switch **S302-2** must be off to allow remote control. Left open if not used.

3.2.8 Spare DIO (A91 DIO0 and DIO1)

Reserved.

3.2.9 High-Speed Compensator Analog Signals (AIO SMB20)

These signals are internally connected to the Autolock controller through the AIO bus connector. See the *SMB20 User's Guide* for more information.

- Tracking (B20 TRK). This input is used to preset the command signal of the SMB20 compensator. The setpoint voltage level is set using the switch **S502-4**.

3.2.10 High-Speed Compensator Digital Signals (DIO SMB20)

These active-low signals are internally connected to the Autolock controller through the DIO bus connector. See the *SMB20 User's Guide* for more information. *For proper operation of the Autolock controller, ensure that signals are not driven by another module.*

- Error Enable (B20/ERR).
- Gain Boost Enable (B20/GB).
- Gain Boost1 Enable (B20/GB1).
- Gain Boost2 Enable (B20/GB2).
- Integrator Enable (B20/INT).
- Servo Enable (B20/SERVO).
- Tracking Enable (B20/TRK).

3.2.11 Piezo Compensator Analog Signals (AIO B30)

These signals are internally connected to the Autolock controller through the AIO bus connector. See the *SMB30 User's Guide* for more information.

- Reference (B30 REF). When the SMB30 compensator operates in nested-loop configuration, this signal is used by the piezo loop as a setpoint in order to regulate the mean value of the B20's command.
- PID (B30 PID). This signal is used as an error signal by the temperature path.
- Tracking (B30 TRK). The piezo command signal is preset through this input.

3.2.12 Piezo Compensator Digital Signals (DIO SMB30)

These active-low signals are internally connected to the Autolock controller through the DIO bus connector. See the *SMB30 User's Guide* for more information. *For proper operation of the Autolock controller, ensure that signals are not driven by another module.*

- Error Enable (B30/ERR).
- Integrator Enable (B30/INT).
- Reference Enable (B30/REF).

- Servo Enable (B30/SERVO).
- Tracking Enable (B30/TRK).
- Servo Enable (B20/SERVO).
- Tracking Enable (B20/TRK).

3.2.13 Power Supply

The module needs analog ±15 V and digital +5 V power supplies. It is recommended to use the SMB00 module to connect these sources.

3.2.14 Pin Assignments of the Analog Bus Connector

Only the specific pins of the Autolock controller module are listed (A91 prefix).

Signal label	Pin assignment	Direction
A91 SERVO	AIO.46	output
A91 GND	AIO.48	output
−15 V	AIO.45	input
+15 V	AIO.47	input
AGND	AIO.49	input

3.2.15 Pin Assignments of the Digital Bus Connector

Only the specific pins of the Autolock controller module are listed (A91 prefix).

Signal label	Pin assignment	Direction
A91 /SS	DIO.4	input/output
A91 ACQ/TRK	DIO.6	input
A91 /NEG	DIO.3	input
A91 /LOCKED	DIO.5	output
A91 /AUTO	DIO.7	input
A91 /CNTRL	DIO.9	input
A91 DIO0	DIO.8	input/output
A91 DIO1	DIO.10	input/output
+5 V	DIO.47	power input
+5 V	DIO.48	power input
DGND	DIO.49	power input
DGND	DIO.50	power input

3.3 On-Board Settings

Several switches located on the printed circuit board are provided for configuration purposes.

3.3.1 Trigger Threshold Source Selector (S302-1)

S302-1	Threshold	Source
off	1.1 V	internal reference
on	(1)	user defined level

Note

(1) level set using the resistors **R302** and **R303**.

3.3.2 TEC Error Polarity Selector (S302-2)

Use this switch to control the polarity of the temperature control path. Remote control of the polarity is achieved using the digital input **A91/NEG**.

S302-2	A91/NEG	Error Polarity
on	x	negative
off	left open	positive
off	high	positive
off	low	negative

3.3.3 Booster Gain Stages (S302-3,4)

The gain-booster sections of the high-speed compensator (SMB20) are controlled using these switches.

S302-3	S302-4	Section	Status
off	x	Gain-Booster#1	disabled
on	x	Gain-Booster#1	enabled
x	off	Gain-Booster#2	disabled
x	on	Gain-Booster#2	enabled

3.3.4 Open-Loop Temperature Command Setpoint (S501-1)

The preset voltage applied to the TEC actuator is set using this switch.

S501-1	Setpoint Voltage
off	0 V
on	+2.5 V (1)

Note

(1) other value can be programmed using the resistors **R403** and **R409**.

3.3.5 Closed-Loop Piezo Command Setpoint (S501-3)

Use this switch to select the desired mean value of the piezo command signal. When the temperature control path is engaged, the temperature is adjusted to maintain the piezo command around this level.

S501-3	Setpoint Voltage
off	0 V
on	+5 V (1)

Note

(1) other value can be programmed using the resistors **R418** and **R420**.

3.3.6 Open-Loop Piezo Command Setpoint (S502-1)

The setpoint voltage applied to the piezo actuator is set using this switch.

S502-1	Setpoint Voltage
off	0 V
on	+5 V

Note

(1) other value can be programmed using the resistors **R501** and **R501**.

3.3.7 Ramp Amplitude Selector (S502-2)

The amplitude of the ramp voltage applied to the piezo actuator is set using this switch.

S502-2	Ramp Amplitude
off	±2.5 V
on	±10 V

3.3.8 Open-Loop High-Speed Command Setpoint (S502-4)

The setpoint voltage applied to the high-speed actuator is set using this switch.

S502-4	Setpoint Voltage
off	0 V
on	+2.5 V (1)

Note
(1) other value can be programmed using the resistors **R604** and **R607**.

3.3.9 Closed-Loop High-Speed Command Setpoint (S502-3)

Use this switch to select the desired mean value of the high-speed compensator (B20) command signal. When the piezo control path is engaged, the command is adjusted to maintain the high-speed compensator command around this level. *This applies to nested-loop topology only.*

S502-3	Setpoint Voltage
off	0 V
on	+2.5 V (1)

Note
(1) other value can be programmed using the resistors **R609** and **R613**.

3.3.10 Mode Operation Selector (SW303)

When the controller operates in autolock mode, the behavior of the state-machine is controlled by this rotary encoder located on the edge of the printed circuit board. Hence, the user can select which actuator is used to sweep the laser and which compensators are engaged to acquire lock.

Coder Position	SMB20 Compensator	SMB30 Compensator	SMA91 Compensator	Acquisition Actuator
0	preset	preset	preset	none
1	preset/engaged	preset	search/hold	TEC
2	preset/engaged	preset/engaged	search/hold	TEC
3	preset/engaged	preset/engaged	search/engaged	TEC
4	preset	preset	preset	none
5	preset	preset	preset	none
6	preset/engaged	search/hold	preset	Piezo
7	preset/engaged	search/engaged	preset	Piezo
8	preset/engaged	search/engaged	preset/engaged	Piezo

4 Circuitry

4.1 Circuit Description

The finite-state-machine (FSM) is implemented using a microcontroller (U301A). The internal clock generator of the microcontroller (MCU) is used as 1-MHz clock source. The FSM's outputs are fed to the output pins of the MCU. When these pins are connected to the DIO bus, a 1-kΩ limitation resistor is inserted between the the bus connection and the MCU output. The 4-way switch (S302) is connected to the input ports of the MCU to provide configuration switches for the user. The rotary switch SW303 is also fed to the MCU's input ports in order to control the behavior of the FSM among 16 operating modes. Three leds (L301-A,B,C) and two switches (SW301 and SW302) are provided as a user control interface. Two headers (J301 and J302) allow firmware updating and debugging.

The input of the temperature control loop comes from the command of the piezo compensator. This input signal is applied to the differential amplifier (U403-C) where high-frequency components are removed. The desired closed-loop value (U403-A) is compared to this input signal in order to provide the error signal for the temperature loop. The polarity of the error is controlled using the conditional inverter (U403-E). Once attenuated (R404 and R405), the error signal is fed to the integrator (U403-D) whose the time constant, given by R408 and C401, is about 20 s. Discrete components (Q401, Q402, D401, D402) limit the output range of the integrator while maintaining low-bias currents. An instrumentation amplifier (U401-A) acts as a buffer featuring differential-sense connections in order to avoid ground-loops. Presetting the temperature command to the desired open-loop setpoint value (S501-1) is achieved using the local feedback loop (U402-D) around the integrator. When the temperature actuator is used to sweep the laser, a negative offset current (U404-B, R406 and R417) is integrated in order to increase the command signal. A copy of the actuator signal is fed to the front panel BNC (J402). In addition, a copy of this signal is also sent (U402-C) to the analog bus connector.

During open-loop operation, the piezo command voltage of the SMB30 compensator is controlled through its tracking input. The setpoint voltage is buffered (U501-C) and added (U501-E) to the ramp generator voltage using two analog switches (U502-B,D).

The FSM is triggered by the photodetector input. This incoming signal is first filtered and buffered (U601). Then, it is applied to the non-inverting input of the MCU's analog comparator. A locked condition is detected when the photodetector level is above the threshold voltage (S302.1). By default, the internal voltage source (1.1 V) is selected but other level can be programmed using the dedicated resistors (R302 and R303). The open-loop setpoint value of the high-speed compensator (SMB20) is buffered (U602-C) and applied to the SMB20's tracking input. The desired closed-loop command setpoint of the high-speed compensator is also buffered (U602-A) and fed to the piezo compensator (SMB30) reference input.

4.2 Printed Circuit Board Legend

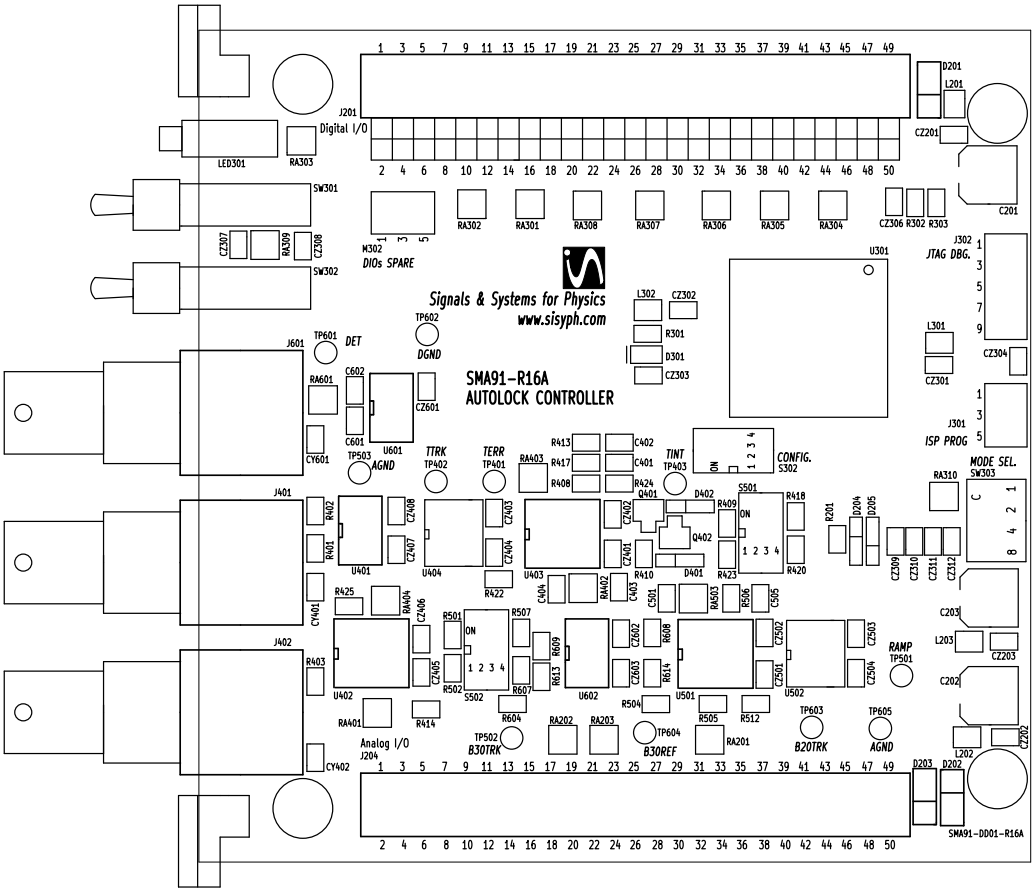

Figure 1: SMA91 printed circuit board legend

Document Revision History

Release	Comments
SMA91-SN01-R16A	first release