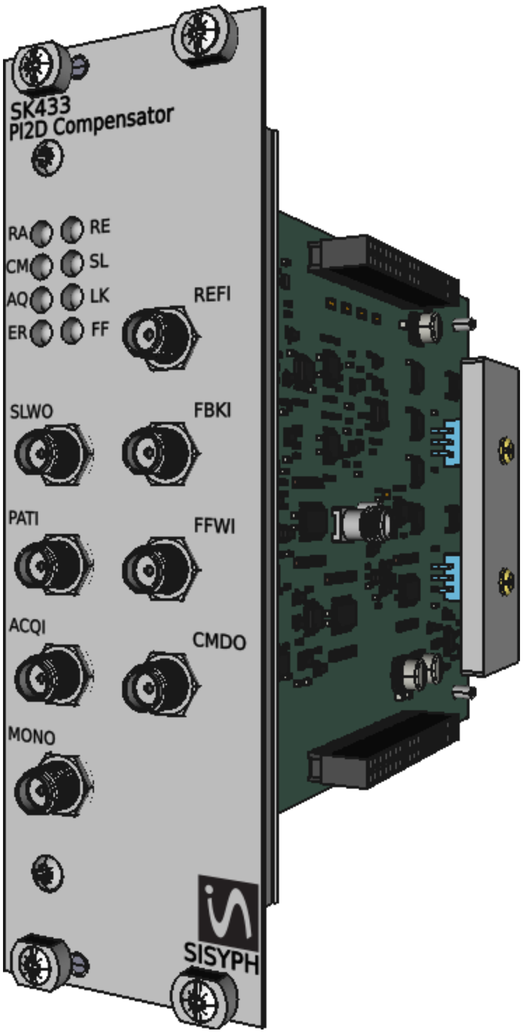
User's Guide

SK433*Velay*
PI2D Compensator

SK-Series Modules



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General Information

Scope

This document provides the user with information on how to operate the SK433 *PI2D Compensator* module.

Safety and Preparation for Use

Because of the variety of uses for the SK433 *PI2D Compensator*, those responsible for the application and use of this control equipment must satisfy themselves that all necessary steps have been taken to assure that each application and use meets all performance and safety requirements, including any applicable laws, regulations, codes and standards.

The SK433 *PI2D Compensator* is not designed, intended, or sold for use in hazardous environments requiring fail-safe operation, including without limitation, operation of nuclear facilities, aircraft or spacecraft control systems, and life support or weapons systems. The user must assure that any failure or misapplication of the SK433 *PI2D Compensator* cannot lead to a consequential failure of any interconnected equipment that could lead to loss of life or limb, or property damage.

The illustrations, charts, and discussions shown in this manual are intended solely for purposes of example. Since there are many variables and requirements associated with any particular control application, *Signals and Systems for Physics* does not assume responsibility or liability for actual use based upon the examples shown in this publication.

Do not install substitute parts or perform any unauthorized modifications to this instrument.

The SK433 *PI2D Compensator* is a module designed to be used with the SPK-Series Platforms. Do not turn on the power to the platform or apply voltage inputs to the module until the module is completely inserted and locked in place. Do not exceed the specified voltages at any input or output connector.

Specifications and Related Documentation

Complete information (specifications, datasheet, programming guide, block diagram . . .) is available online. These additional documents can be downloaded from the product page at www.sisyph.com.

Contents

1 Getting Started

This section provides the user with the necessary information to get started quickly with the SK433 *PI2D Compensator*. Each part of the front-panel as well as the rear and the top sides of the module are explained in the following sections. Circled numbers beginning a paragraph help the user to locate these features on the module sides (see Figs 4 and 5).

1.1 Overview

Refer to the *Functional Block Diagram* online for a synthetic presentation of the SK433 *PI2D Compensator*'s functionalities.
The SK433 *PI2D Compensator* was primary designed for use in laser control applications involving high-speed servo loops. In order to maintain low-noise and wide bandwidth closed-loop performances, the SK433 provides a low-noise front-end differential amplifier followed by a programmable PI²D compensator. The input amplifier differences two single-ended inputs and feeds the first integrator (HFI) with this error signal (e). The integrated error signal is then multiplied by the proportional gain (K_p) and transmitted to the last PID stage (HFD and LFI). The command output signal (u) is obtained by summing the PID's output and a programmable offset voltage (V_OFS) :

$$u\,(s) = e\,(s) \times \left(1 + \frac{1}{T_\mathrm{HFI}s}\right) \times K_\mathrm{p} \times \left(1 + \frac{1}{T_\mathrm{LFI}s} + \frac{T_\mathrm{HFD}s}{1 + aT_\mathrm{HFD}s}\right) + V_\mathrm{OFS}\,(s)\ . \tag{1}$$

Alongside with this PI²D compensator, the SK433 includes a second compensator which can be used for preventing the saturation of the high-speed primary loop. Indeed, by using the additional low-speed integrator within an secondary servo loop, the PI2D's output signal can be automatically de-trended. For proper operation of such nested loop, the secondary loop must involve an orders of magnitude more powerful actuator, which is also usually orders of magnitude slower.
Like all modular instruments of the SK-Series, the SK433 can be operated stand-alone or within a platform where several modules can be assembled to configure a specific control or measurement system. For instance, SPK-Series platforms can accommodate up to eight instruments and provide power, clock synchronization, communications, and module status monitoring. For stand-alone operation, the SKN10 and SKN11 *Adapters* can be used for connecting the module to the power supplies and remote host computer.

1.2 Front-Panel Connections

1.2.1 Reference Input (REFI)

(20) Connect the external reference input signal to the **REFI** receptacle. The reference signal is applied to the differential amplifier's positive input for the generation of the error signal. Can be left open if not used.

1.2.2 Feedback Input (FBKI)

(21) Connect the feedback input signal to the **FBKI** receptacle. The feedback signal is applied to the differential amplifier's negative input to generate the error signal. Can be left open if not used.

1.2.3 Feed-Forward Input (FFWI)

(22) Connect the feed-forward input signal to the **FFWI** receptacle. This signal can be summed with the PI²D compensator's output. Can be left open if not used.

1.2.4 Search-Pattern Input (PATI)

(13) The generator used for providing specific search-pattern command signals must be connected to the **PATI** receptacle. Can be left open if not used.

1.2.5 Acquisition Input (ACQI)

(14) Connect the acquisition input to the **ACQI** receptacle. This signal can be used to drive the finite-state machine controlling the compensator operation. Can be left open if not used.

1.2.6 PI²D Command Output (CMDO)

(23) Connect the input of the fast actuator driver to the **CMDO** receptacle.

1.2.7 Slow Command Output (SLWO)

(12) Connect the slow actuator driver's input to the **SLWO** receptacle. Can be left open if not used.

1.2.8 Monitoring Output (MONO)

(15) The monitoring output can be used for test and diagnostic purposes since it provides copies of main SK433's signals. Use the `MONS` remote command to select which signal is routed to this SMA receptacle. Can be left open if not used.

1.3 Front-Panel Indicators

The front panel of the SK433 *PI2D Compensator* (Figure 5) provides minimal information about the status of the instrument.

1.3.1 Remote Interface Activity (RA)

(6) Any data coming from or going to the host interface will cause the **RA** indicator to flash green.

1.3.2 Remote Interface Error (RE)

(6) Command errors or buffer overruns will cause the the **RE** indicator to illuminate red. Because this led reflects the state of **RXQ**, **EXE** and **CMD** flags of the Event Status register (**EVTS**), the indicator can be switched off by invoking any remote commands clearing these flags. For instance, executing `CLS?` will switch the error indicator off.

1.3.3 Slow Command Saturation (SL)

(11) The **SL** indicator illuminates red when the slow command output (**SLWO**) is out-of-range (±8 V). Because this indicator reflects the state of the **SLH** and **SLL** flags in the Overload Condition register (**OVLC**), it is automatically switched off when these conditions disappear. A saturation of the slow integrator also illuminates the **SL** indicator. Here, it is the status of the related flag (**SLI**) which is used to control the indicator likewise.

1.3.4 PI²D Command Saturation (CM)

(11) The **CM** indicator illuminates red when the PI²D command output (**CMDO**) is out-of-range (±3 V). Because this indicator reflects the state of the **CMH** and **CML** flags in the Overload Condition register (**OVLC**), it is automatically switched off when these conditions disappear. A saturation of the low-frequency integrator also illuminates the **CM** indicator. Here, it is the status of the related flag (**LFI**) which is used to control the indicator likewise.

1.3.5 Acquisition Event (AQ)

(11) The **AQ** indicator illuminates green when the acquisition input (**ACQI**) is above the programmable level. In this case, an event is triggered, according to the selected operating mode, to control the compensator.

1.3.6 Lock State (LK)

(11) This green indicator is switched on when the compensator operates in the lock state. It is switched off when the compensator is in the unlock state. When the search-pattern is engaged, the **LK** indicator blinks green.

1.3.7 Error Saturation (ER)

(11) This indicator illuminates red for large error amplitudes (±1 V). It is also illuminated when the programmable amplifier saturates (±4 V). Because **ER** reflects the state of the **ERR** and **PGA** flags in the Overload Condition register (**OVLC**), it is automatically switched off when these conditions disappear.

1.3.8 Feed-Forward Enabled (FF)

(11) The **FF** indicator illuminates green when the feed-forward functionality is enabled. In this case, the voltage applied to the **FFWI** receptacle is transmitted to the PI²D command output signal.

1.4 Backplane Connector

(1) The primary connection to the SK433 module is the rear DIN41612-96C connector (see Fig.6 for its generic pin assignments). Typically, the module is mated into the backplane of an SPK-Series Platform using this connector. It is also possible to operate the SK433 directly, without any platform. In such stand-alone operation, the user has to externally wire all required signals and power supplies through the DIN41612 connector. To help the user in this operation, *Signals and Systems for Physics* provides several module adapters (see SKN-Series *Module Adapters* online). DIN41612 connector's pins are used to power the module and connect its communications lines to the remote controller. Some pins are also used for sharing signals with other slave modules plugged on the same backplane. Wiring external signals to the module from the rear-side of the backplane is also provided using dedicated terminal blocks.

1.4.1 Power Supply

The pins used for powering the SK433 module are listed in the following table. It mentions only pins that are effectively used and must be therefore connected. For detailed information on power requirements, refer to the *Datasheet* available online.

Caution - *Because the SK433 uses some power supplies without any local post-regulation circuitry, always use clean, well regulated power sources with adjustable current limitation.*

Pin	Label	Functionality	Source	Destination
A2, B2, C2	P5V	Digital +5 V	Platform	SK433
A27, B27, C27	P15V	Analog +15 V	Platform	SK433
A31, B31, C31	N15V	Analog −15 V	Platform	SK433
A3, B3, C3	DGND	Digital Ground (0 V)	Platform	SK433
A7, B7, C7				
A7, B7, C7				
A11, B11, C11				
A24, B24, C24	AGND	Analog Ground (0 V)	Platform	SK433
A28, B28, C28				
A32, B32, C32				
C14	Power Good	Monitoring	Platform	SK433
A1	Chassis	Chassis Ground - Earth	Platform	SK433

Table 1: SK433's power supplies – DIN4161 connector pin assignments.

The +5 V power supply is connected to the module through the **P5V** and **DGND** pins. This power supply is used for the digital circuits. Their analog counterparts are powered from the +15 V and −15 V sources connected through the **P15V**, **N15V** and **AGND** pins. The Earth safety line is routed to the module *via* the **Chassis Ground** pin, which is used for grounding the mechanical parts. The SK433 also uses the **Power Good** signal provided by the SPK-Platform for monitoring the power supply inputs. This signal is asserted-low by the platform whether one or more power supply is under its nominal operating value.

1.4.2 Grounding

The **AGND** and **DGND** power lines of the backplane connector are not tied together by the internal circuitry of the SK433. They are instead connected through back-to-back Schottky diodes, so the digital and analog grounds cannot be more than ±350 mV apart. When the SK433 module is assembled into an SPK-Platform, its digital and analog ground lines are tied together through the backplane to a single point (star connection).

Caution – *When the module is used stand-alone, the digital and analog ground lines should be separately wired to a single, low-impedance ground source at the power supply.*

(2A) (2B) (2C) Alternative grounding schemes can be also wired using the dedicated optional jumpers, which are accessible from the top-side of the printed circuit board.

1.4.3 Host Interface

The pins used for operating the SK433 module over the host interface are listed in the following table. It mentions only pins that are effectively used. For detailed information on serial communications settings, refer to the *Programming Guide* available online.

Pin	Label	Functionality	Source	Destination
B1, C1, B4, C4	ID[3-0]	Slot identification	Platform	SK433
A20	/STATUS	Master Summary Status	SK433	Platform
A23	/SLOT	Occupied slot	SK433	Platform
A9	UART-TX	Async data	Platform	SK433
A16	UART-RX	Async data	SK433	Platform

Table 2: SK433's host interface – DIN41612 connector pin assignments.

The SK433 communicates with the host through **TX-** and **RX-UART** lines without any hardware handshaking. The **Slot Identification** lines are used by the module to retrieve the number of the slot (0 to 15) where the module is mated. Because these lines are coded by the platform hardware, no such identification can be provided for a stand-alone operation. In this case, the identification pins are automatically asserted-high by the internal module hardware to detect a stand-alone operation, which corresponds to the virtual slot number 255. The **/STATUS** line is driven by the module to indicate whether one or more of the enabled status messages in the Master Summary Status (**MSTS**) register are true. The signal is then asserted-low and remains in this state until the register has been queried by the `MSTS?` remote command. When the SK433 is used with an SPK-Platform, the **/STATUS** signal is monitored and reported to the host controller *via* the communications link. The **/SLOT** line, which is driven-low by the module, is used by the platform circuitry to detect whether or not a module occupies this slot.

1.4.4 Shared Lines

Some pins of the DIN41612 connector are reserved for sharing signals with others modules through the backplane. *Always contact us before using this functionality.*

This functionality is not currently in use in SK433.

1.4.5 User's Terminal Blocks

SPK-Series Platforms feature a backplane where each slot is provided with 16 additional User's Terminal Blocks (**UTB**). These connectors, located at the rear-side of the backplane, are wired to the module through dedicated pins of its DIN41612 connector. They can be used for specific module wiring, *e.g.* for connecting some signals to the rear-panel of the platform. *Always contact us before using this functionality.* The SK433's pins routed to the terminal blocks are listed in the following table.

Pin	Label	Functionality	Direction
B18	/STATUS	Status monitoring	Digital Output
B19	DGND	Digital ground (0 V)	
B22	CMDO	PI^2D command	Analog Output
B23	AGND	Analog ground (0 V)	
C16	PATI	Search pattern	Analog Input
C17	ACQI	Acquisition	Analog Input
C18	FBKI	Feedback	Analog Input
C19	REFI	Reference	Analog Input
C20	FFWI	Feed-forward	Analog Input
C21	MONO	Monitoring	Analog Output
C22	SLWO	Slow command	Analog Output
C23	AGND	Analog ground (0 V)	
Not listed pins are used for factory test and diagnostic.			

Table 3: SK433 User's terminal blocks – DIN41612 connector pin assignments.

1.4.6 Synchronization

The SPK-Platform distributes a **Synchronization timebase** of 10 MHz to the modular instruments *via* the (**SYN-P**, **SYN-N**) backplane lines. The SK433 uses this differential pair to synchronize the clock of its microcontroller. When operating stand-alone, the SK433 module automatically switches the 10-MHz clock to an internal source. Whether the module is synchronized or not is reported by the **IKS** bit in the Instrument Status register (**INSS**).

Pin	Label	Functionality	Source	Destination
A14	SYNC-N	Negative synchronization	Platform	SK433
B14	SYNC-N	Positive synchronization	Platform	SK433

Table 4: SK433 Synchronization – DIN41612 connector pin assignments.

1.5 Expansion Connectors

These connectors (3A) and (3B) are reserved for customization or factory testing purposes. *Always contact us before using these connectors for own purpose.*

1.5.1 Analog I/O Expansion

(3B) The following table provides the pin assignments of the Analog I/O Expansion connector. Refer to the Section 3.2 for more information.

Pin	Label	Functionality	Direction
1	FBKI	Feedback signal	Input
3	REFI	Reference signal	Input
5	FFWI	Feed-forward signal	Input
7	PATI	Search-pattern signal	Input
13	ACQI	Acquisition signal	Input
15	/STATUS	Status summary signal	Output
16	SLWO	Slow command signal	Output
20	MONO	Monitoring	Output
22	CMDO	PI^2D command signal	Output
35, 36	P15V	+15 V power supply	Output
37, 38	N15V	−15 V power supply	Output
9, 10, 19, 20, 39, 40	AGND	Analog ground (0 V)	
Not listed pins are used for factory test and diagnostic.			

Table 5: SK433 Analog I/O Expansion connector – Pin assignments.

1.5.2 Digital I/O Expansion

(3A) The following table provides the pin assignments of the Digital I/O Expansion connector.

Pin	Label	Functionality	Direction
16	DBG0	Debugging / reserved	Not defined.
27	DBG1	Debugging / reserved	Not defined.
37, 38	P5V	+5 V power supply	Output
9, 10, 19, 20, 39, 40	DGND	Digital ground (0 V)	Output
Not listed pins are used for factory test and diagnostic.			

Table 6: SK433 Digital I/O Expansion connector – Pin assignments.

1.6 On-Board Settings and Connectors

Some functionalities of the SK433 are controlled or configured using switches located on its printed circuit board. Connectors can be also installed on the component-side of the board when they are rarely used, *e.g.*

for test or calibration purposes.

1.6.1 Analog Ground

(24) The **AGND** receptacle provides a clean ground reference voltage (0 V). It is mainly used for factory test and diagnostic.

1.6.2 Configuration Switches

(4) This 4-position switch array (**CFG**) is not used in this version of the module. Nevertheless, it is populated for future use or software customization purpose.

1.6.3 Grounding Jumpers

Three jumpers are provided to modify the initial arrangement for connecting the ground lines. By default, these jumpers are not mounted. They must be left open if not used.

(2A) Mounting the **OPT-DGND** jumper will tie the digital ground to the chassis ground (power earth).

(2B) Mounting the **OPT-AGND** jumper will tie the analog ground to the chassis ground (power earth).

(2C) Mounting the **OPT-GND** jumper can be used to tie the digital and analog ground lines together since they are connected only through back-to-back Schottky diodes. When the SK433 is mounted into a platform, the digital and analog ground lines are tied together through the backplane to a single point.

1.6.4 High-Frequency Integrator Customization

(29B) In order to allow the user to set specific unity-gain frequencies (UGF) for the high-frequency integrator, component locations **(C19, C20, C21)** are provided to set 3 custom UGFs.

1.6.5 Low-Frequency Integrator Customization

(29C) In order to allow the user to set specific unity-gain frequencies (UGF) for the low-frequency integrator, component locations **(C34, C35, C36)** are provided to set 3 custom UGFs.

1.6.6 High-Frequency Differentiator Customization

(29A) In order to allow the user to set specific unity-gain frequencies (UGF) for the high-frequency differentiator, component locations **(C57, C58, C59)** are provided 3 custom UGFs.

1.7 Module Interfacing

The primary connection to the SK433 *PI2D Compensator* is the backplane connector. Typically, the SK433 is mounted into a platform, but it is also possible to operate the SK433 directly, without using any platform. This section provides details on the interface.

1.7.1 Interfacing through SPK-Series Platform

The SKP-Series Platform is designed to assemble a system based on SK-Series modules. The platform carries all the power and communications lines to the mounted modules through the internal backplane. The platform also provides an USB interface for communications with the host controller (see SK810 *Interfaces Controller* module online). The power supply voltages are provided to the platform by external sources *via* a rear panel DSUB-7W2 connector. This should reduce the exposition of the modules to the power supplies' EMI.

1.7.2 Direct Interfacing for Stand-Alone Operation

It is also possible to operate the SK433 module directly, without using any platform.

CAUTION – *Misapplication of power may cause circuit damage.* Signals and Systems for Physics *recommends using the SK433 together with the SPK-Platform for most applications.*

The mating connector needed is a standard 96-pin DIN41612 female receptacle. Clean, well-regulated power supplies must be provided. Refer to the Grounding section for appropriate connection of the different ground lines. The communication is possible by directly connecting the appropriate interface lines to an USB-to-UART bridge as explained in the related section. *Signals and Systems for Physics* also provides the user with several module adapters to wire the required signals and power supplies. Among them, the SKN10 features an USB-to-UART bridge and several spring clamping terminal blocks.

2 Operation

Refer to the *Functional Block Diagram* online for graphical information and to the *Datasheet* for detailed specifications.

2.1 PI²D Compensator

2.1.1 Error Signal

The PI²D compensator operates from the error signal for delivering the command output according to Eq1. Here, the error voltage e is provided by the input differential amplifier, which compares the feedback signal FBKI to the reference REF signal.
Both external feedback and reference signals can be connected to the differential amplifier *via* several interfaces : either front-panel SMA, user terminal blocks or expansion connector can be used. The feedback signal FBKI can be discarded from the error signal

$$e(s) = \mathrm{REF}(s) - \mu_{\mathrm{FBKE}}\mathrm{FBKI}(s), \tag{2}$$

via the scalar $\mu_{\mathrm{FBKE}} \in \{0, 1\}$, which is controlled by the remote command `FBKE`. This functionality may be useful for diagnostic and calibration purposes. Several options are provided for the reference signal : the related input of the differential amplifier can be either i) routed to the **REFI** external input, ii) driven by the internal setpoint DAC or, iii) tied to the analog ground voltage. Two remote commands are provided for configuring the reference input : `REFS` allows the user to select which reference signal source is used for the error voltage, while `STPS` is used to program the internal setpoint voltage.
Because the polarity of the process response to the controller output is arbitrary and system dependent, it may be necessary to switch the loop polarity to restore negative feedback. A dedicated remote command is

provided for inverting the error signal :

$$e(s) = -1^{\mu_{\mathrm{ERRN}}}\left[\mathrm{REF}(s) - \mu_{\mathrm{FBKE}}\mathrm{FBKI}(s)\right], \tag{3}$$

where the scalar $\mu_{\mathrm{ERRN}} \in \{0, 1\}$ is controlled by the remote command `ERRN`.
In order to slightly change the setpoint, a second internal DAC can be used to add a small bipolar offset voltage, V_{ERRC}, after the error signal inverter :

$$e(s) = -1^{\mu_{\mathrm{ERRN}}}\left[\mathrm{REF}(s) - \mu_{\mathrm{FBKE}}\mathrm{FBKI}(s)\right] + V_{\mathrm{ERRC}}(s). \tag{4}$$

The error offset voltage is programmed between $-25\,\mathrm{mV}$ to $+25\,\mathrm{mV}$ using the remote command `ERRC`. This functionality can be useful for fine adjustments of the locking point or to compensate small offset voltages due to the previous circuitry.

2.1.2 High-Frequency Integrator

The error voltage provided by the differential amplifier is first processed by the high-frequency integrator (HFI) as stated in Eq.1. The HFI's parameter is its unity-gain frequency, which is related to the programmed time constant as $1/f_{\mathrm{HFI}}(n) = 2\pi T_{\mathrm{HFI}}(n)$. With the index n ranging from 1 to 16, the remote command `HFIF` allows the user to program up to sixteen UGFs. In order to provide the user with custom UGFs, only the first 13 time constants are wired, the last 3 component locations are not populated and reserved for specific values. Factory set UGFs for the high-frequency integrator range from 100 Hz to 1 MHz.
Because the HFI's output voltage range is limited to $\pm 1\,\mathrm{V}$, it may not be able to provide alone the required DC-voltage level for the output command signal. In this case, the low-frequency integrator (LFI) or the offset DAC must be used to extend the locking range.
The HFI was installed before the programmable gain amplifier (PGA) to preserve the low-noise specifications of the input difference amplifier. Indeed, without this integrator, operating the PGA at negative gains (*i.e.* attenuations) will degrade the input referred noise and offset voltages.
The contribution of the HFI's output voltage to the command signal is also configurable :

$$u(s) = e(s) \times \left(1 + \mu_{\mathrm{HFI}}\frac{1}{T_{\mathrm{HFI}}(n)s}\right), \tag{5}$$

where the parameter $\mu_{\mathrm{HFI}} \in \{0, 1\}$ is controlled using the remote command `INTS`.

2.1.3 High-Frequency Differentiator

The high-frequency differentiator (HFD) completes the action of the programmable gain amplifier (PGA) and high-frequency integrator (HFI) stages to form a high-speed PID compensator (*cf* Eq.1). The HFD transfer function's parameters - the time constant T_{HFD} and the HF-gain $1/a$ are programmable :

$$HFD(s) = \mu_{\mathrm{HFD}}\frac{T_{\mathrm{HFD}}(n)s}{1 + a(m)T_{\mathrm{HFD}}(n)s}. \tag{6}$$

The index n is passed to the command `HFDF` for programming up to 16 unity-gain frequencies, which are related to the time constants by $1/f_{\mathrm{HFD}}(n) = 2\pi T_{\mathrm{HFD}}(n)$. The remote command `HFDG` allows the user to select two different values (+12 dB or +20 dB) for the HF-gain $1/a(m)$. The parameter $\mu_{\mathrm{HFD}} \in \{0, 1\}$ is used to enable the differentiator. It is programmed using the remote command `DIFS`.
In order to provide the user with custom UGFs, only the first 13 time constants are wired, the last 3 component locations are not populated and reserved for specific values. Factory set UGFs for the high-frequency differentiator range from 500 Hz to 5 MHz.

2.1.4 Low-Frequency Integrator

The low-frequency integrator (LFI) provides the second integral action (*cf* Eq.1) of the PI²D compensator. The LFI's unity-gain frequency, which is related to the programmed time constant by $1/f_{\mathrm{LFI}}(n) = 2\pi T_{\mathrm{LFI}}(n)$, is programmed using the `LFIF` remote command. With the index n ranging from 1 to 16, up to sixteen UGFs are available. In order to provide the user with custom UGFs, only the first 13 time constants are wired, the last 3 component locations are not populated and reserved for specific values. Factory set UGFs for the low-frequency integrator range from 10 Hz to 100 kHz.
Due to its wider output voltage range (±4.5 V), the LFI is able to provide the required DC-voltage level to maintain the system locked. It should be always used where command signals are subject to drift. Nevertheless, disabling the LFI is allowed by invoking the `INTS` to program the parameter $\mu_{\mathrm{LFI}} \in \{0, 1\}$:

$$LFI\,(s) = \mu_{\mathrm{LFI}} \frac{1}{T_{\mathrm{LFI}}(n)s}. \tag{7}$$

2.1.5 Offset

An offset voltage (denoted by V_{OFS} in Eq.1) can be added to the PI²D controller's output (**CMDO**) using the `OFSE` and `OFSS` remote commands. This feature is useful when the actuator must be biased in order to bring the open-loop plant into a specific operating range, *e.g.* to bring the manipulated variable within the sensor range. Whether the offset voltage is applied to the command does not depend of the current lock state, only the `OFSE` command is able to switch the offset voltage on (off).

2.1.6 Feed-Forward

The feed-forward signal applied to the **FFWI** input can be manually added to the PI²D output by invoking the `FFWE` remote command. Its transmission is controlled (amplitude and polarity) by the `FFWG` command. The **ACQI** input signal can be also used to externally control whether the feed-forward is enabled. For this purpose, the input must be configured using the `ACQM` command.

2.2 Slow Compensator

The PI²D compensator is able to provide tight and fast control when it is used to drive a fast actuator. Unfortunately, high-speed actuators are usually much lower powerful than their slower counterparts and a saturation of the command signal may occurs when the PI²D compensator has to compensate large drifts. In order to maintain the loop locked over a wider range, a second loop can be used to automatically remove the large DC-components of the command signal. For this purpose, the SK433 features a third integrator whose output can be used to drive a much more powerful actuator, forming a secondary slow-loop able to prevent the saturation the main command signal.

2.2.1 Integrator

The integrator of the slow-loop (SLI) operates from the output of the low-frequency integrator to drive the slow actuator :

$$SLWO\,(s) = \mu_{\mathrm{SLI}} \left[-1^{\mu_{\mathrm{SLEN}}} \frac{1}{T_{\mathrm{SLI}}(n)s} \right] u_{\mathrm{LFI}}\,(s) + V_{\mathrm{SLOS}}, \tag{8}$$

where u_{LFI} is the LFI's output and $SLWO$ the command signal provided by the slow-loop. The time constant $T_{\mathrm{SLI}}(n)$ is set using the `SLIF` remote command. Up to 9 unity-gain frequencies $f_{\mathrm{SLI}}(n) = 1/(2\pi T_{\mathrm{SLI}}(n))$, ranging from 0.1 Hz to 1 kHz, are available.

The parameter $\mu_{\text{SLI}} \in \{0, 1\}$ is used to control whether the slow-loop integrator is engaged. It is programmed through the remote command INTS, which also controls the operation of the HFI and LFI integrators. When the SLI integrator is disabled, only the offset voltage V_{SLOS} contributes to the command output signal.

2.2.2 Feedback Polarity

In order to restore the negative feedback of the slow-loop, the signal inverter (*cf* Eq.8) may be engaged by using the command SLEN, which programs the scalar $\mu_{\text{SLEN}} \in \{0, 1\}$.

2.2.3 Offset

An offset voltage can be added to the slow controller's output using the SLOE and SLOS remote commands. This feature is useful when the actuator must be biased in order to bring the open-loop plant into a specific operating range, *e.g.* to bring the manipulated variable within the sensor range. Whether the offset voltage is applied to the command does not depend of the current lock state, only the SLOE command is able to switch the offset voltage on (off).

2.3 Search Pattern Signals

It may be quite useful to apply a specific command signal to an actuator when operating open-loop. For instance, a ramping voltage applied to slow-actuator can be used to sweep the manipulated variable over the desired locking point for system optimization purposes.
Search pattern signals are specific open-loop command signals used to acquire lock for open-loop systems featuring a narrow sensor range. In order to recover a relevant feedback signal, a search pattern generator is used to drive the actuator in charge to bring the manipulated variable inside the sensor range. During this acquisition phase, the search pattern signal is routed to the command output. Locking is then obtained by switching the command from the pattern signal generator to the compensator's output. Switching from the acquisition phase to lock can be provided by an external out-of-range detector, which continuously analyzes the sensor's output signal and drives the ACQI input to engage the servo controller.

2.3.1 Internal Search Pattern

The SK433 module features an internal triangle waveform generator whose output can be used as search pattern signal. Both period and amplitude are set using dedicated remote commands : 8 periods, ranging from 3 ms to 10 s, can be selected in 1-3 steps using the PATP command, while PATA can be used to select the amplitude among 8 values (0.9 V_{pp} to 10 V_{pp}).

2.3.2 External Search Pattern

Arbitrary waveforms are also allowed for search pattern signals. In this case, the **PATI** input connector is used to connect the external function generator. The PATA remote command provides now both amplification or attenuation (from 5 V/V to 0.45 V/V) of the external search pattern signal.

2.3.3 Using the Search Pattern

Whether the search pattern signal is routed to PI²D or slow compensator output is selected through the remote command PATD. Before selecting the output destination, the source (internal or external generator) must be selected using the PATS command. Applying the search pattern signal to the selected output is then controlled by the LOCK command. Using the appropriate input argument with the LOCK command, the search pattern signal can be either engaged manually or externally *via* the **ACQI** input.

2.4 Locking

2.4.1 Configuring the Compensators

Since both PI^2D and slow compensators are configurable, the related commands must be invoked before attempting lock. For instance, the `INTS` command allows the user to select which integrators will be engaged when locking. Likewise, the `DIFS` command is used to select the differentiator in the PI^2D output signal. Depending on the arguments passed to the `LOCK` and `ACQM` commands, the **ACQI** input can be used to switch between the unlock and lock states, or acquiring lock automatically as described below.

2.4.2 Acquiring Lock Manually

The `LOCK` command is provided to control the state of the SK433 PI2D Compensator. This command is used to place the compensator in the unlock state where only offset voltages can be added to the command signals. `LOCK` can be also invoked to manually engage the compensators according to the current configuration.

2.4.3 Acquiring Lock Automatically

The servo loops can be closed manually using the `LOCK` command. If this provides a simple way for locking, the search pattern signal can be also used to automatically acquire lock. In such operating mode, the search pattern signal is applied to one of the two actuators until the external detector asserts the **ACQI** input. At this time, the loop is closed by switching the command signal from the search pattern to the compensator output. For this purpose, the **ACQI** input must be prior configured using the `ACQM` command.

2.5 Monitoring

The signal actually routed to the monitoring output (**MONO**) is selected *via* the `MONS` remote command. Some PI^2D and slow compensator signals are available, both in raw or filtered version. The `STMS` command also allows monitoring from the host computer : specified signals can be sampled (one sample per second) and sent over the remote interface.

2.6 Restoring the Default Configuration

To reset the SK433 module to its factory defaults, execute the remote command `*RST`. The reset values of the parameters are shown in bold in the *Programming Guide* available online.

3 Description of Operation

This chapter provides the user with a number of additional details of the operation of the SK433 *PI2D Compensator* module.

3.1 Setting Custom Unity-Gain Frequencies

Three component locations are provided to customize the unity-gain frequencies of the PI^2D compensator's differentiator and integrators. *Contact us before using this functionality.*

3.2 Expansion Connectors

The SK433 module provides the user with two expansion connectors for mounting an additional board (see Fig.7). Indeed, specific functionalities can be obtained by mounting a dedicated board on these connectors. This feature can be useful for customization purposes. The expansion connectors' pins are identified on the *Functional Block Diagram* using the **EXP** label. Analog signals and power supplies of the SK433 are routed to the Analog I/O Expansion connector while their digital counterparts are available through the Digital I/O connector. Some pins are reserved for programming the microcontroller and should not be used. Refer to the Section 1.5 for information on which pins are actually used in the SK433.

CAUTION – *Because the power lines are fed from the internal module circuitry and not directly from the backplane, only low-consumption circuits should be powered from the expansion connectors. Contact us prior using this functionality.*

The parts used for the expansion connectors are compatible with the standard 2x20-pin PC/104 non-stackthrough J2-connector, *e.g.* M20-6112045 from Harwin.

3.3 Shared Backplane Lines

Some lines of the backplane are dedicated for sharing analog and digital signals between modules. They correspond to the AIO, PWR-AIO, DIO and PWR-DIO lines listed in the generic pin assignments. This functionality can be useful for customizing a system where the number of front-panel connections has to be reduced by using these backplane lines instead. Refer to the Section 1.4.4 for information on which SK433's signals can be routed to the shared lines of the backplane.

CAUTION – *The SK433 has no internal protection against short-circuits on the shared lines. Contact us before using this functionality.*

3.4 User Terminals Blocks

The SK433 is primary designed to be assembled into a platform. Some pins of the mating connector are not connected to the bus, they are instead directly routed to 16 terminal blocks located at the rear-side of the backplane. This arrangement provides the user with specific wiring schemes. Indeed, acting as many independent connectors, the user terminal blocks can be used to wire some SK433's signals regardless of the backplane operation.

The SK433's signals routed to the user terminal blocks are identified on the *Functional Block Diagram* using **UTB** labels. See Figure 6 for their generic pin assignments and Section 1.4.5 for information about which signals of the SK433 are routed to the the terminal blocks.

Caution – *By design, an SK433 module can be plugged anywhere into the platform since there is no assigned slot. The only reserved location (the rightmost slot) is dedicated to the master module, which is in fact a part of the platform. Therefore, using the user terminal blocks functionality of a specific slot will, in practice, assign the module to this slot. Contact us before using this functionality.*

4 Remote Operation

This chapter describes how to operate the SK433 *PI2D Compensator* over the host interface.

4.1 Commands

For a complete and detailed information, please refer to the *Programming Guide* available online at the product page.

4.2 Status Model

The *Status Model Diagram* of the SK433's is available online at the product page. The *Programming Guide* also provides the user with detailed information about the Status registers.

5 Accessories and Related Products

This chapter describes related products and accessories that are available for use with the SK433 *PI2D Compensator*. These optional parts must be ordered separately.

5.1 Optional Module Adapters

Like all SK-Series modular instruments, the SK433 module is primary designed to be assembled into a platform. But stand-alone operation of the SK433 *PI2D Compensator* is also possible (see section 1.7.2). In this case, the user has to wire all required power supplies and remote control lines to the DIN41612 connector. In order to help the user in this operation, *Signals and Systems for Physics* provides several module adapters, namely the SKN10 and SKN11. For instance, the SKN10 *Module Adapter* features a mating DIN41612 connector, an USB-to-UART bridge and several spring clamp terminals blocks. Refer to the adapters' pages online for detailed information.

6 Figures

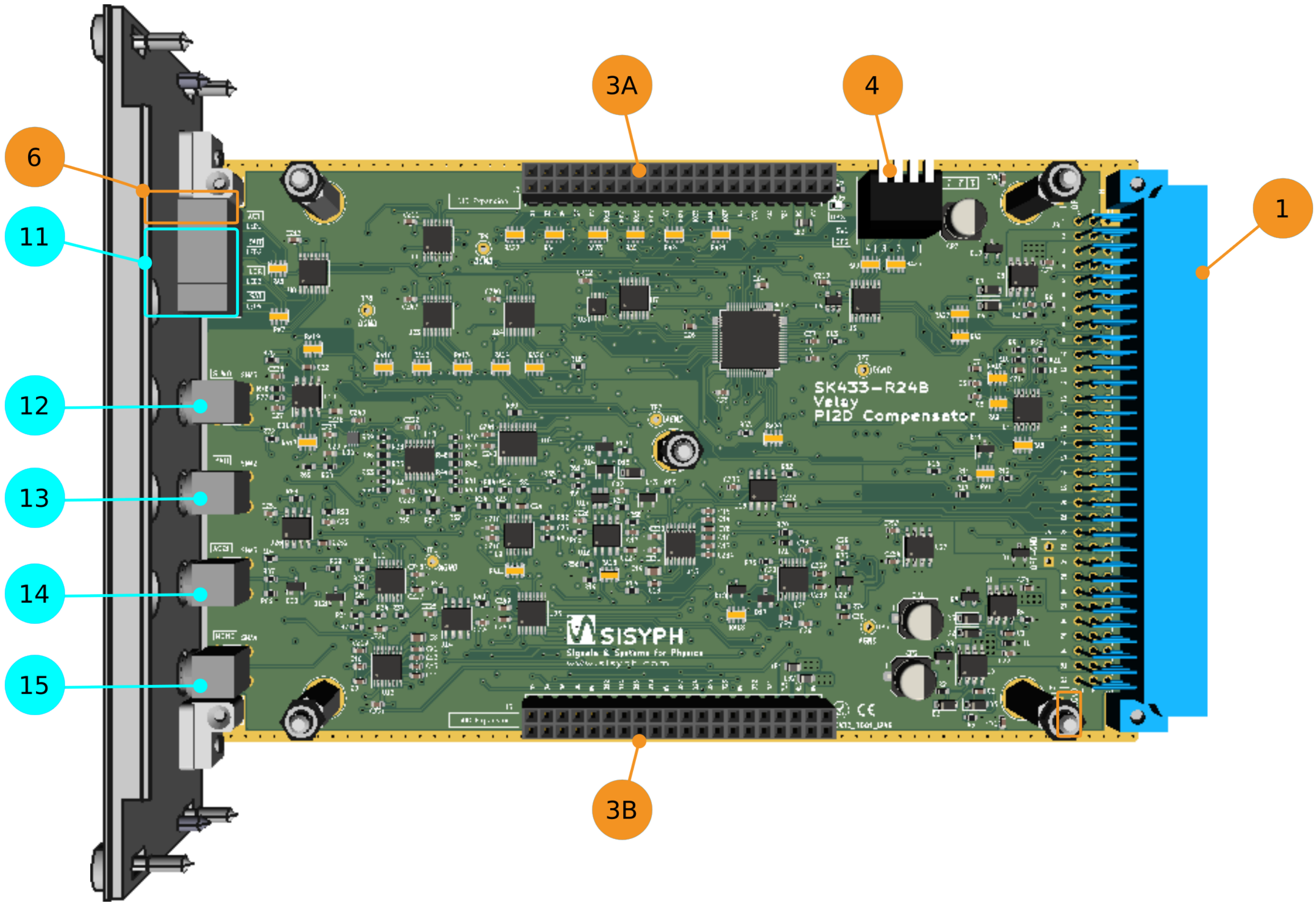


Figure 1: View of the SK433's top side. The secondary board has been removed to only show the main (carrier) board. Circled numbers refer to features detailed in the Section 1. While the orange colored numbers denote generic parts of the SK-Series modules, their blue-color counterparts refer to specific features of the SK433.

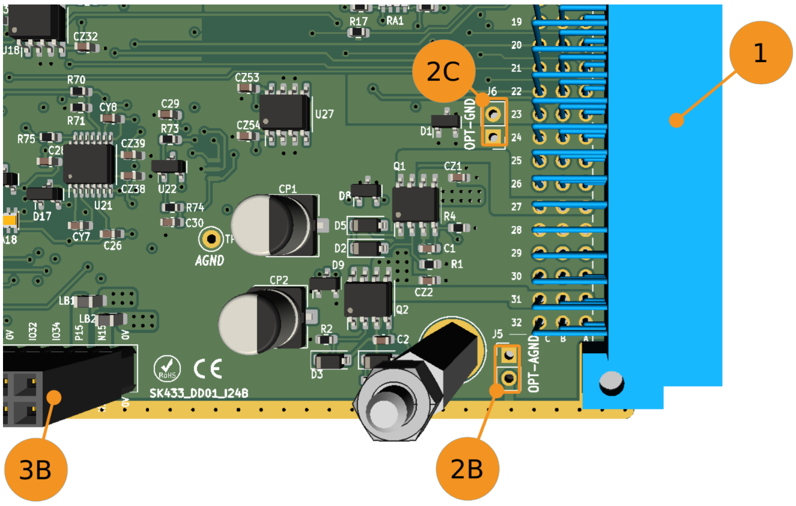


Figure 2: View of the SK433's top side - Details. The secondary board has been removed to show the main (carrier) board only. Circled numbers refer to features detailed in the Section 1.

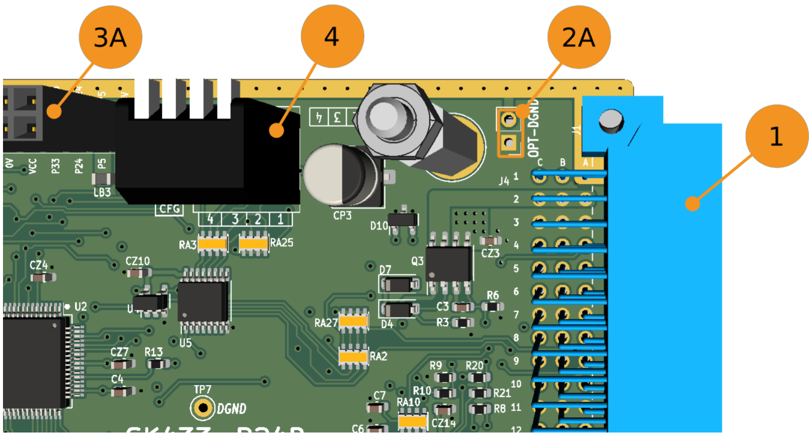


Figure 3: View of the SK433's top side - Details . The secondary board has been removed to show the main (carrier) board only. Circled numbers refer to features detailed in the Section 1.

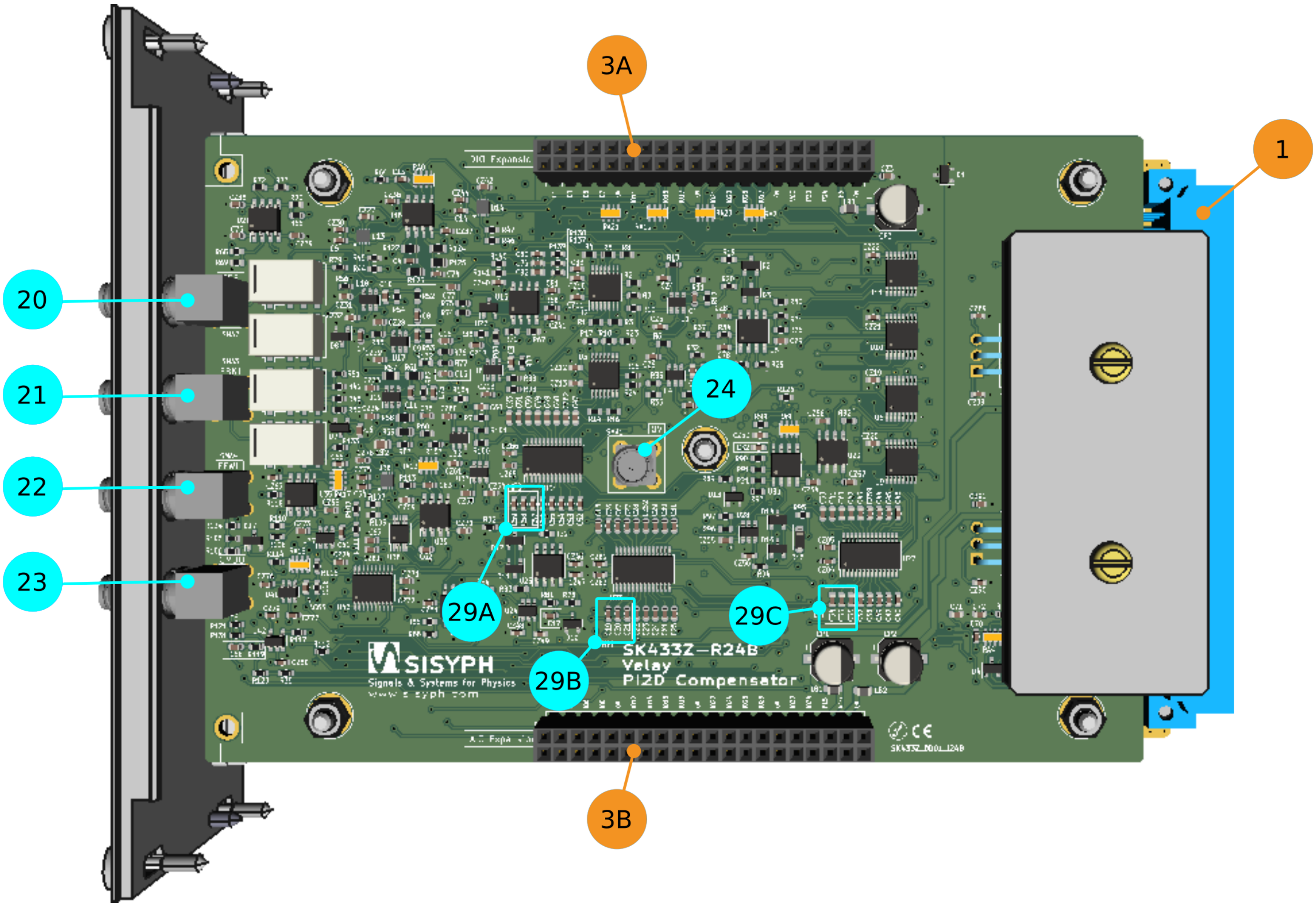


Figure 4: View of the SK433's top side. Circled numbers refer to features detailed in the Section 1. While the orange colored numbers denote generic parts of the SK-Series modules, their blue-color counterparts refer to specific features of the SK433.

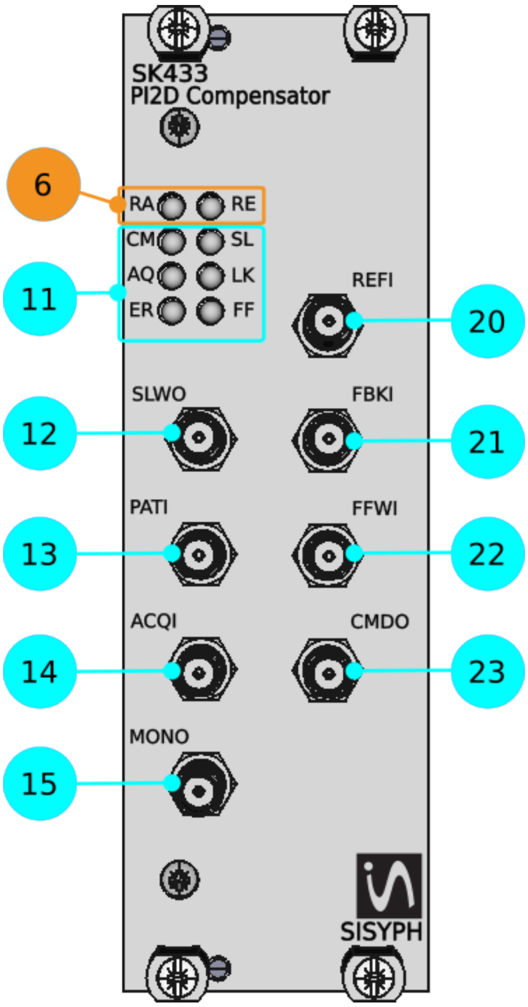
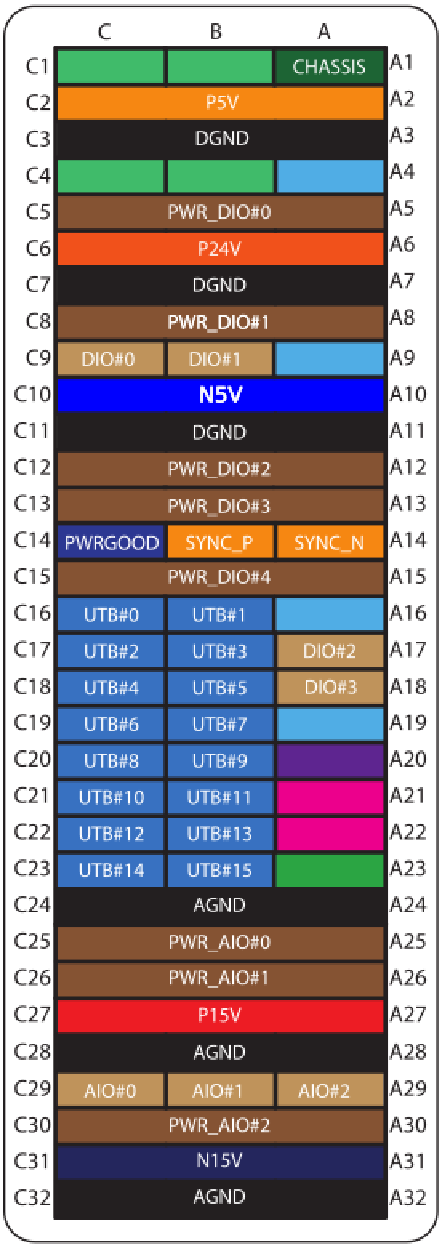


Figure 5: The SK433's front view. Circled numbers refer to features detailed in the Section 1. While the orange colored numbers denote generic characteristics shared by all SK-Series modules, their blue-color counterparts refer to specific features of the SK433.



DIN41612-C96

Figure 6: Generic pin assignments of the DIN41612 connector. The DIN41612-96C connector carries all the power and communication lines to the module. Additional lines are provided for i) sharing signals with other slave modules plugged on the same backplane, ii) reception of the 10-MHz synchronization signals and iii) module status information. The presence of a slave module on the backplane is detected by the platform controller using a dedicated line.

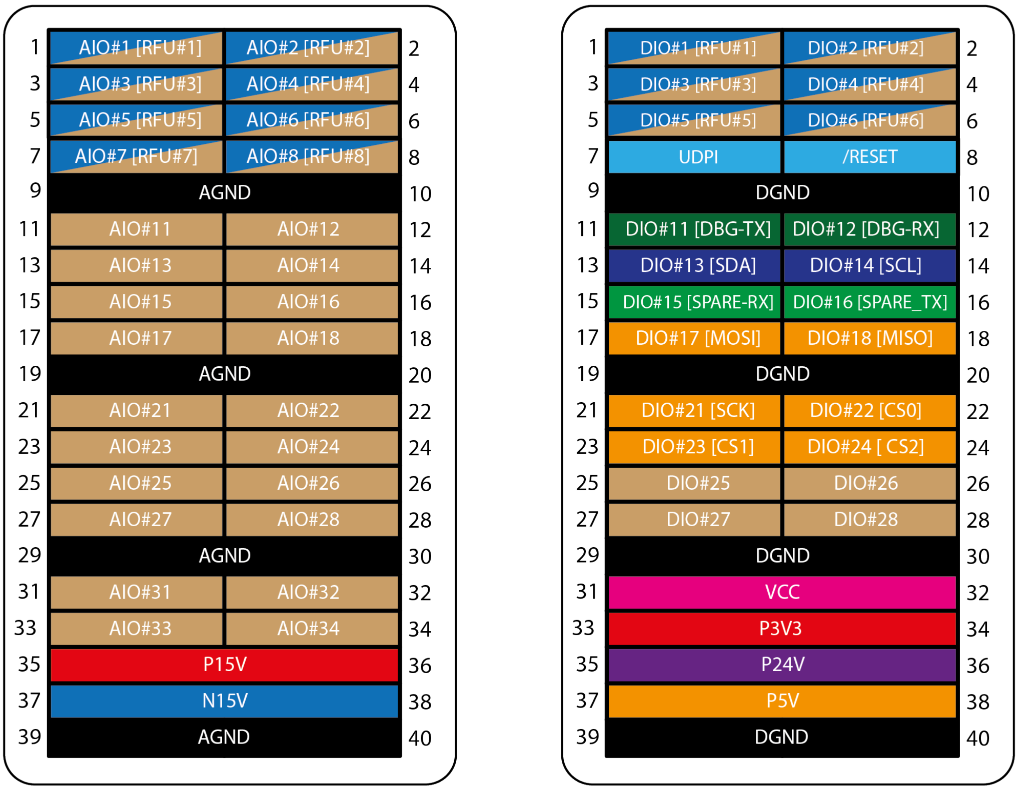


Figure 7: Generic pin assignments of the Expansion connectors. Analog power supplies and signals are routed to the AIO Expansion connector (left). Their digital counterparts are routed to the DIO Expansion connector (right). Refer to the Section 1.5 for information on the pin assignments used in SK433.

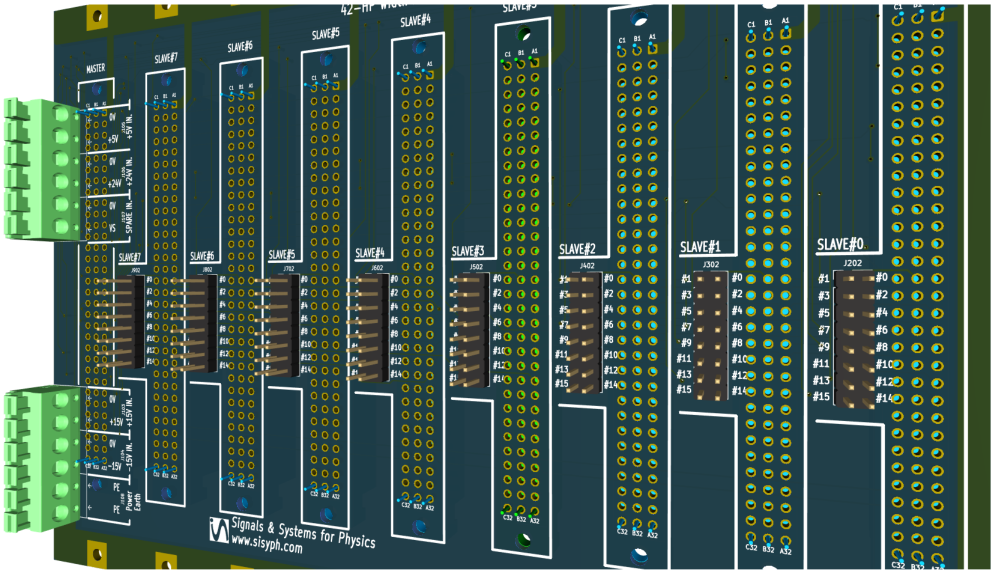


Figure 8: User's terminal blocks viewed from the rear of the backplane. Each slot of the SPK-Platform is associated with 16 independent terminals providing the user with specific wiring schemes. These connectors are accessible from the rear-side of the backplane. Note that if a 16-pin header has been used here as an exemplifying interface, the backplane is shipped without any populated parts to increase versatility.

7 Document Revision History

7.1 Version Number

This document is identified by SK433-SU02-P24A.

7.2 Revision History

P24A (2024-03-19)

Initial version.