

## Revision history:

- rev. 0.1 - 24.03.2015: this is first revision
- rev. 0.2 - 27.03.2015: add missed data
- rev. 0.3 - 30.04.2015: add missed data in CMD\_READ\_PARAMS\_EXT
- rev. 0.4 - 01.07.2015: extended CMD\_CONTROL; add MENU\_CMD\_LEVEL\_ROLL\_PITCH; FRAME\_ANGLE\_XX replaced by ROTOR\_ANGLE\_XX in the CMD\_REALTIME\_DATA\_4; updated CMD\_AHRS\_HELPER.
- rev. 0.5 - 30.07.2015: extended set PROFILE\_FLAGS1, GENERAL\_FLAGS1; extended set CMD\_EXECUTE\_MENU; deprecated FRAME\_CAM\_ANGLE\_XX.
- rev. 0.6 - 12.08.2015: new mode for CMD\_CONTROL; new commands CMD\_GETANGLES\_EXT, CMD\_SET\_ADJ\_VARS\_VAL.
- rev. 0.7 - 22.10.2015: new parameters ORDER\_OF\_AXES, EULER\_ORDER; set of PROFILE\_FLAGS1, GENERAL\_FLAGS1 extended; SKIP\_GYRO\_CALIB options extended.
- rev. 0.8 - 09.11.2015: CMD\_AHRS\_HELPER is extended.
- rev. 0.9 - 22.12.2015: new command CMD\_GYRO\_CORRECTION; new adj. var. FRAME\_HEADING\_ANGLE and GYRO\_HEADING\_CORRECTION; extended GENERAL\_FLAGS1 and PROFILE\_FLAGS1.
- rev. 0.10 - 13.02.2016: updated CMD\_AUTO\_PID; extended range of NOTCH\_GAIN.
- rev. 0.11 - 07.03.2016: new command CMD\_READ\_PARAMS\_EXT2; new parameter MOTOR\_MAG\_LINK\_FINE; new command CMD\_CALIB\_MOTOR\_MAG\_LINK; ACC\_LIMITER split to axes; extended form of CMD\_HELPER\_DATA.
- rev. 0.12 - 02.04.2016: new commands CMD\_DATA\_STREAM\_INTERVAL, CMD\_REALTIME\_DATA\_CUSTOM.
- rev. 0.13 - 05.06.2016: new command CMD\_BEEP\_SOUND; new adjustment variables.
- rev. 0.14 - 21.06.2016: CMD\_ADJ\_VARS\_STATE described.
- rev. 0.15 - 09.07.2016: extended CMD\_READ\_PARAMS\_EXT2; extended CFG\_FLAGS in CMD\_AUTO\_PID; new command CMD\_CALIB\_INFO; corrected CMD\_DATA\_STREAM\_INTERVAL.
- rev. 0.16 - 10.08.2016: added MavLink parameters in CMD\_READ\_PARAMS\_EXT2.
- rev. 0.17 - 21.10.2016: new commands CMD\_CONTROL\_CONFIG, CMD\_CALIB\_ORIENT\_CORR; extended CMD\_READ\_PARAMS\_EXT2.
- rev. 0.18 - 23.03.2017: new parameter FRAME\_HEADING in CMD\_HELPER\_DATA; new flag CONTROL\_FLAG\_AUTO\_TASK in CMD\_CONTROL; new command CMD\_CALIB\_ACC\_EXT\_REF; document structure is updated.
- rev. 0.19 - 08.09.2017: add CMD\_EVENT; updated CMD\_DATA\_STREAM\_INTERVAL.
- rev. 0.20 - 10.30.2017: updated parameter EXT\_FC\_GAIN in CMD\_READ\_PARAMS\_3; updated CMD\_READ\_PARAMS\_EXT2.
- rev. 0.21 - 10.01.2018: new parameters in CMD\_READ\_PARAMS\_EXT2;
- rev. 0.24 - 29.03.2018: updated CMD\_EXECUTE\_MENU; add AHRS\_DEBUG\_INFO and MOTOR4\_CONTROL data structures; extended CMD\_REALTIME\_DATA\_CUSTOM; add CMD\_EXT\_IMU\_DEBUG\_INFO; add CMD\_READ\_PARAMS\_EXT3, CMD\_WRITE\_PARAMS\_EXT3;
- rev. 0.25 - 27.11.2018: add protocol V2 specification.
- rev. 0.26 - 21.03.2019: add command CMD\_AUTO\_PID2.
- rev. 0.27 - 18.09.2019: add command CMD\_EXT\_IMU\_CMD.
- rev. 0.28 - 31.01.2020: extended CMD\_READ\_PARAMS\_EXT3.
- rev. 0.29 - 01.04.2020: add FLAGS description in CMD\_RESET; updated CMD\_AHRS\_HELPER (extended examples section and described additional flags).
- rev. 0.30 - 10.09.2020: add CMD\_READ\_STATE\_VARS; new flag in CMD\_AHRS\_HELPER; added Appendix D.
- rev. 0.31 - 10.11.2019: fixed CMD\_READ\_PARAMS\_EXT;
- rev. 0.32 - 11.10.2021: added command description: CMD\_CALIB\_COGGING, CMD\_CAN\_DEVICE\_SCAN, CMD\_WRITE\_PARAMS\_SET
- rev. 0.33 - 02.11.2022: added CMD\_EXT\_SENS\_CMD;
- rev. 0.40 - 13.02.2022: document structure was redesigned and added table of contents

## Overview

Serial API allows for an external application or device to communicate with the SimpleBGC controller via serial port (UART). Each controller has several UART ports that can be used to send or receive Serial API commands. All models are equipped with the USB port that is visible as Virtual Com Port (VCP) for the host machine. Depending on controller, USB may be dedicated or shared with the one of UARTs.

Commands may be used to retrieve actual system state and realtime data, change settings, control gimbal, trigger pin state, execute various actions, get access to internal EEPROM and I2C bus, and so on. Moreover, SimpleBGC GUI software uses the same Serial API protocol to communicate with the board, so all of its functions may be implemented in third-party applications.

Communications is initiated from the remote side (host) by sending *outgoing* commands. The controller may do some action and send response (for the host it is an *incoming* command).

Board can work on different serial baud rates, adjustable by the parameters, with the 115200 as default value. Host can automatically find the proper baud rate by sending the CMD\_BOARD\_INFO command in a loop, altering the speed and waiting for a response, until valid response is received, or should allow to specify a baud rate in its settings.

Additionally, board can auto-detect the "parity" parameter. EVEN and NONE parity are supported (NONE is selected by default after start, and EVEN is detected automatically). It means that beside the baud rates, host application should vary the parity setting, when connecting through an intermediate layer that can have this parameter unknown (like Bluetooth modules). For the direct UART or USB VCP connection, it is enough to set parity to "NONE".

## Throughout capacity

The controller parses incoming command queue each 8ms, so there is no reason to send commands of the same type with the higher rate. Commands of different type may be sent without delay between them. It is responsibility of the host application to prevent an overflow of the input and output buffers of the controller (255 bytes each). If new serial data comes when the input buffer is full, the whole message will be lost. If controller has to generate an answer that does not fit into the output buffer, it hangs until buffer will have enough space to accept new data. It may negatively affect the normal operation and even make whole system unstable. The only exception is the CMD\_REALTIME\_DATA\_xx and several others, that are considered as non-obligatory for delivery.

You can calculate the safe rates according to the size of incoming and outgoing commands and the configured baud rate for the serial port. Take into account the bandwidth and the buffering strategy of the intermediate transmission layer. For example, BLE modules have a very limited bandwidth and small buffers. Also, almost all radio modems have effective transmission rate less than 100Kbit/s in optimal conditions.

## Debugging

You can configure SimpleBGC32 GUI to display all incoming and outgoing commands that it receives/sends. To do it, run it in a "console" mode using the "run\_console.bat" script. Commands will be displayed in the "Debug" tab in format:

```
<local_time> <direction>: [<command_id>,<payload_length>] <payload_data_hex>
```

Note that several commands with high rate are not displayed (like CMD\_REALTIME\_DATA\_xx).

Starting from the firmware and GUI version 2.66b4, it's possible to monitor all serial API messages on all other ports, by connecting GUI to any available serial port, configured for the SBGC Serial API mode, and enabling the "Debug" – "Set as debug port" option for it. Controller will forward all incoming and outgoing Serial API commands from all other ports to this port. Commands will be displayed in the "Debug" tab in format:

```
<MCU_time> port<idx>.<direction>: [<command_id>,<payload_length>] <payload_data_hex>
```

In this case, the "in" direction means "to the board", "out" – "from the board".

Note, that only the successfully parsed commands are forwarded. All unknown data is ignored.

## Message format

Each command consists of the *header* and the *body*, both with checksum. Commands with the wrong header or body checksum, or with the body size that differs from expected, should be ignored. Parser should scan incoming datastream for the next start character and try to restore synchronization from it.

Input and output commands have the same format.

### Protocol version 1

header				body			
start character > (0x3E)	command ID, 0..255	payload size N=0..255	header checksum	payload variable size N			payload checksum
0	1	2	3	4	...	4+N-1	4+N

Header checksum is calculated as (command ID + payload\_size) modulo 256.

Payload checksum is calculated as the sum of all payload bytes modulo 256.

Operation "modulo" means least significant byte of the sum.

Example: outgoing command to read Profile2:

header				body	
0	1	2	3	4	5
0x3E	0x52	0x01	0x53	0x01	0x01

### Protocol version 2

Starting from firmware version 2.68b0, firmware additionally supports protocol version 2, that has better error rejection by replacing the old 8 bit simple checksum (over payload only) to CRC16 checksum (over header + payload).

header				payload			crc	
start character \$ (0x24)	command ID, 0..255	payload size N=0..255	header checksum	variable size N			CRC16 (header + payload)	
0	1	2	3	4	...	4+N-1	4+N	4+N+1

Compared to version 1, it has a different start character "\$" and a different checksum calculation:

payload checksum is calculated as a CRC16 over the header bytes and payload bytes, starting from index 1 to index 4+N-1. A reference implementation of CRC16 using polynomial 0x8005 is given in the [Appendix A](#).

### Protocol version 2 locking

At startup, firmware supports messages in both versions 1 and 2. But when the first valid message version 2 is received, this version is locked and all incoming messages in version 1 are not recognized anymore.

## Data type notation

- 1u – 1 byte unsigned
- 1s – 1 byte signed
- 2u – 2 byte unsigned (little-endian order)
- 2s – 2 byte signed (little-endian order)
- 4f – float (IEEE-754 standard)
- 4s – 4 bytes signed (little-endian order)
- string – ASCII character array, first byte is array size
- Nb – byte array size N

Many parameters are grouped in arrays, that is indicated by the square brackets notation: "ANGLE[3]". Parameters that are split into axes, always go in the order ROLL, PITCH, YAW for the Euler angles and corresponding motors in a normal position. For the vectors order is X, Y, Z in the coordinate system having X pointing right, Y – forward, Z – up.

**NOTE:** order of parameters in arrays is always ROLL,PITCH,YAW, but it doesn't corresponds to the order of Euler angles used to express a rotation – it is variable and defined by the parameter 'EULER\_ORDER'.

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## Device information

### Requests

#### CMD\_BOARD\_INFO (#86) – request board and firmware information

Simple format: no parameters

Extended format:

Name	Type	Min	Max	Possible values, remarks
CFG	2b			configuration for this serial driver: <ul style="list-style-type: none"> <li>for UARTs – period (in ms) between 20-bytes packets for BLE mode</li> <li>for USB – not used</li> </ul>
RESERVED	?			size is not checked

#### CMD\_BOARD\_INFO\_3 (#20) – request additional board information

No parameters

### Responses

#### CMD\_BOARD\_INFO (#86) – version and board information

Name	Type	Min	Max	Possible values, remarks
BOARD_VER	1u			Multiplied by 10: 3.0 => 30
FIRMWARE_VER	2u			Split into decimal digits X.XX.X, for example 2305 means 2.30b5  major_ver = (int)(FIRMWARE_VER/1000); minor_ver = (int)((FIRMWARE_VER%1000)/10); beta_ver = FIRMWARE_VER%10;
STATE_FLAGS1	1u			bit0: DEBUG_MODE – internal use only  <i>Starting from frw.ver. 2.66:</i> bit1: IS_FRAME_INVERTED – system is re-configured for frame inversion over the middle motor;  <i>The following flags are set at the system initialization:</i> bit2: INIT_STEP1_DONE – finished initialization of all basic sensors, frame inversion configuration is applied; bit3: INIT_STEP2_DONE – finished initialization of the RC subsystem, adjustable variables, etc. Automated positioning is started; bit4: STARTUP_AUTO_ROUTINE_DONE - positioning and calibrations at startup is finished;

BOARD_FEATURES	2u			Bit set to encode functions firmware supports: BAT_MONITORING = (1<<1) 3AXIS = (1<<0) ENCODERS = (1<<2) BODE_TEST = (1<<3) SCRIPTING = (1<<4) CURRENT_SENSOR = (1<<5) MAG_SENSOR = (1<<6) ORDER_OF_AXES_LETUS = (1<<7) IMU_EEPROM = (1<<8) FRAME_IMU_EEPROM = (1<<9) CAN_PORT = (1<<10) MOMENTUM = (1<<11) COGGING_CORRECTION = (1<<12) MOTOR4_CONTROL = (1<<13) ACC_AUTO_CALIB = (1<<14) BIG_FLASH = (1<<15) – firmware needs 256Kb of FLASH
CONNECTION_FLAG	1u			Bit set: CONNECTION_USB = 1
FRW_EXTRA_ID	4u			Used for specific builds only
BOARD_FEATURES_EXT	2u			Extends the set of BOARD_FEATURES to 16..31 bit: EXT_IMU = (1<<16) STATE_VARS = (1<<18) POWER_MANAGEMENT = (1<<19) GYRO_ADVANCED_CALIB = (1<<20) LIMITED_VERSION = (1<<21) REACTION = (1<<22) ENCODER_LUT = (1<<23)
RESERVED	3b			
BASE_FRW_VER	2u			For “experimental” versions encodes the main version which they are based on

### CMD\_BOARD\_INFO\_3 (#20) – additional board information

Name	Type	Min	Max	Possible values, remarks
DEVICE_ID	9b			Unique Id used to identify each controller in licensing system
MCU_ID	12b			MCU ID, unique
EEPROM_SIZE	4u			Size of available EEPROM in current device. Generally 32K bytes
SCRIPT_SLOT1_SIZE SCRIPT_SLOT2_SIZE SCRIPT_SLOT3_SIZE SCRIPT_SLOT4_SIZE SCRIPT_SLOT5_SIZE	2u			size of user-written scripts stored in each slot, 0 if slot is empty.
PROFILE_SET_SLOTS	1u			bit0..bit5: bit is set if the corresponding profile set is not empty. bit0 for profile set#1, bit2 for profile set#2, bit5 for profile set backup
PROFILE_SET_CUR	1u	1	6	A number of currently selected profile set
FLASH_SIZE	1u			Actual FLASH memory size (a number of 32 Kb pages)

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RESERVED	31b			
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## Configuring gimbal

### Requests

**CMD\_READ\_PARAMS (#82),**

**CMD\_READ\_PARAMS\_3 (#21) – request parameters from the board**

**CMD\_READ\_PARAMS\_EXT (#33) – request extended parameters part1**

**CMD\_READ\_PARAMS\_EXT2 (#62) – request extended parameters part2**

**CMD\_READ\_PARAMS\_EXT3 (#104) – request extended parameters part3**

(frw.ver. 2.66+)

Name	Type	Min	Max	Possible values, remarks
PROFILE_ID	1u	0	4	profile ID to load. If value >4, currently selected profile is loaded.

**CMD\_WRITE\_PARAMS (#87),**

**CMD\_WRITE\_PARAMS\_3 (#22) - write parameters to board and saves to EEPROM**

**CMD\_WRITE\_PARAMS\_EXT (#34) – write extended parameters part1**

**CMD\_WRITE\_PARAMS\_EXT2 (#63) – write extended parameters part2**

**CMD\_WRITE\_PARAMS\_EXT3 (#105) – write extended parameters part3**

(frw.ver. 2.66+)

Data structure is the same as for the corresponding CMD\_READ\_PARAMS\_xx incoming command. On success, confirmation CMD\_CONFIRM is sent in response and new values are applied. Some changes require system to be restarted, so full reset occurs in 1 second after this command, if there are no other CMD\_WRITE\_PARAMSxx have came in that time. It's recommended to send these commands in the “configuration” mode, activated by the [CMD\\_WRITE\\_PARAMS\\_SET](#).

### **CMD\_WRITE\_PARAMS\_SET (#119) – start or end of the writing parameters sequence**

(frw.ver. 2.70b4+)

Send this command before sending the sequence of CMD\_WRITE\_PARAMSxx to enter the “configuration” mode, and send it again at the end of the sequence to apply changes and switch to a normal working mode. In the configuration state motors are turned OFF and system does not try to make initialization after each CMD\_WRITE\_PARAMSxx.

Name	Type	Min	Max	Possible values, remarks
ACTION	1u			1 – start writing parameters 0 – finish writing parameters

On success, confirmation CMD\_CONFIRM is sent in response with the DATA=ACTION.

### **CMD\_USE\_DEFAULTS (#70) – reset to factory defaults**

Name	Type	Min	Max	Possible values, remarks
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PROFILE_ID	1u	0	4	profile ID to reset. Special values: 253 – erase EEPROM 254 – reset currently selected profile
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### CMD\_CALIB\_OFFSET (#79) – calibrate follow offset

No parameters

### CMD\_READ\_PROFILE\_NAMES (#28) – Request profile names stored in EEPROM

No parameters

### CMD\_WRITE\_PROFILE\_NAMES (#29) – Writes profile names to EEPROM

Name	Type	Min	Max	Possible values, remarks
PROFILE_NAME[5]	48b* 5			Each name is encoded in UTF-8 format and padded with '\0' character to 48 byte size

### CMD\_PROFILE\_SET (#95) – manage profile sets

(frw. ver. 2.65+)

Name	Type	Min	Max	Possible values, remarks
SLOT	1u	1	6	Slot to operate. 1..5: regular slots, 6 – backup slot
ACTION	1u			<b>PROFILE_SET_ACTION_SAVE = 1</b> save current configuration (including all profiles and simple calibrations) to the given slot  <b>PROFILE_SET_ACTION_CLEAR = 2</b> clear the selected slot  <b>PROFILE_SET_ACTION_LOAD = 3</b> load configuration from the given slot
RESERVED	8b			

Confirmation is sent on success.

## Responses

### CMD\_READ\_PARAMS\_3 (#21) – read/write system configuration part 1

Receive parameters for a single profile.

Name	Type	Min	Max	Possible values, remarks
PROFILE_ID	1u			profile ID to read or write. To access current (active) profile, specify 255. Possible values: 0..4
P	1u	0	255	
I	1u	0	255	divided by 100 when displayed in the GUI
D	1u	0	255	

axis = (1..3)	POWER	1u	0	255	
	INVERT	1u	0	1	
	POLES	1u	0	255	
axis = (1..3)	ACC_LIMITER_ALL	1u	0	255	Units: 5 degrees/sec <sup>2</sup> 0 – disabled. (starting from ver. 2.60 is deprecated; replaced by the ACC_LIMITER3)
	EXT_FC_GAIN[2]	1s*2	-127	127	
axis = (1..3)	RC_MIN_ANGLE	2s	-720	720	Units: degrees
	RC_MAX_ANGLE	2s	-720	720	Units: degrees
	RC_MODE	1u			0..2 bits - mode: RC_MODE_ANGLE = 0 RC_MODE_SPEED = 1 3rd bit - control is inverted, if set to 1
	RC_LPF	1u	0	15 (255)*	*Range depends on the flag “Extend LPF range” in GUI settings
	RC_SPEED	1u	0	255	
	RC_FOLLOW	1u	-127	127	ROLL, PITCH: this value specify follow rate for flight controller. YAW: if value != 0, “follow motor” mode is enabled.
	GYRO_TRUST	1u	0	255	
	USE_MODEL	1u	0	1	
	PWM_FREQ	1u			PWM_FREQ_LOW = 0 PWM_FREQ_HIGH = 1 PWM_FREQ_ULTRA_HIGH = 2
	SERIAL_SPPED	1u			Baud rate for the main UART1 port (where USB normally connects) 115200 = 0 57600 = 1 38400 = 2 19200 = 3 9600 = 4 256000 = 5
	RC_TRIM[3]	1s*3	-127	127	
	RC_DEADBAND	1u	0	255	
	RC_EXPO_RATE	1u	0	100	
	RC_VIRT_MODE	1u			The mode of the RC_ROLL input pin operation: RC_VIRT_MODE_NORMAL = 0 RC_VIRT_MODE_CPPM = 1 RC_VIRT_MODE_SBUS = 2 RC_VIRT_MODE_SPEKTRUM = 3 RC_VIRT_MODE_API = 10
	RC_MAP_ROLL RC_MAP_PITCH	1u*6			Assign input as a signal source. Bits 0..4 for channel number, bits 5..7 for a type. Value 0 means that input is not assigned.

RC_MAP_YAW RC_MAP_CMD RC_MAP_FC_ROLL RC_MAP_FC_PITCH				<b>PWM source</b> RC_INPUT_ROLL = 1 RC_INPUT_PITCH = 2 EXT_FC_INPUT_ROLL = 3 EXT_FC_INPUT_PITCH = 4 RC_INPUT_YAW = 5  <b>Analog source</b> Channel = 1..3, type = 32 (5 <sup>th</sup> bit is set) ADC1 = 33 ADC2 = 34 ADC3 = 35  <b>RC Serial source (CPPM/SBUS/SPEKTRUM):</b> Virtual channel (1..31), type = 64 (6 <sup>th</sup> bit is set)  <b>API Virtual control source</b> Virtual channel (1..31), type = 128 (7 <sup>th</sup> bit is set)  <b>Step signal source (ver. 2.66+)</b> Step signal channel 1..6, type = 160 (5 <sup>th</sup> and 7 <sup>th</sup> bits are set)
RC_MIX_FC_ROLL RC_MIX_FC_PITCH	1u 1u			Mix the value received from the FC channel, to the value received from the selected RC channels, with the given rate:  bits 0..5: mix rate. For example, 0 - no mix (100% RC) 32 - 50% RC, 50% FC, 63 - 0% RC, 100% FC bits 6,7: target RC channel 0 - no mix 1 - ROLL 2 - PITCH 3 - YAW
FOLLOW_MODE	1u			FOLLOW_MODE_DISABLED=0 FOLLOW_MODE_FC=1 FOLLOW_MODE_PITCH=2
FOLLOW_DEADBAND	1u	0	255	
FOLLOW_EXPO_RATE	1u	0	100	
FOLLOW_OFFSET[3]	1s*3	-127	127	Starting from frw. ver. 2.70+ replaced by the FOLLOW_OFFSET_EXT[3]
AXIS_TOP AXIS_RIGHT FRAME_AXIS_TOP FRAME_AXIS_RIGHT	1s 1s 1s 1s			Main IMU and frame IMU orientation: X = 1 Y = 2 Z = 3 -X = -1 -Y = -2 -Z = -3
FRAME_IMU_POS	1u			Location of the frame IMU: FRAME_IMU_DISABLED = 0 FRAME_IMU_BELOW_YAW = 1 FRAME_IMU_ABOVE_YAW = 2 FRAME_IMU_BELOW_YAW_PID_SOURCE = 3
GYRO_DEADBAND	1u	0	255	<i>Units: 0.1 of gyro sensor's units.</i>
GYRO_SENS	1u			deprecated




I2C_SPEED_FAST	1u	0	1	If set, use 800kHz ultra-fast speed mode, otherwise use 400kHz speed
SKIP_GYRO_CALIB	1u			Skip calibration of gyroscope. 0 - do not skip 1 - skip always 2 - try to calibrate but skip if motion is detected
RC_CMD_LOW RC_CMD_MID RC_CMD_HIGH  MENU_BTN_CMD_1 MENU_BTN_CMD_2 MENU_BTN_CMD_3 MENU_BTN_CMD_4 MENU_BTN_CMD_5 MENU_BTN_CMD_LONG	1u*9			Assign action to various event sources. See CMD_EXECUTE_MENU for available actions
MOTOR_OUTPUT[3]	1u*3			Motor output mapping DISABLED = 0 ROLL = 1 PITCH = 2 YAW = 3 I2C_DRV#1 = 4 I2C_DRV#2 = 5 I2C_DRV#3 = 6 I2C_DRV#4 = 7
BAT_THRESHOLD_ALARM	2s	-3000	3000	Negative means means alarm is disabled <i>Units: 0.01V</i>
BAT_THRESHOLD_MOTOR S	2s	-3000	3000	Negative value means function is disabled <i>Units: 0.01V</i>
BAT_COMP_REF	2s	-3000	3000	Negative value means compensation is disabled. <i>Units: 0.01V</i>
BEEPER_MODES	1u			BEEPER_MODE_CALIBRATE=1 BEEPER_MODE_CONFIRM=2 BEEPER_MODE_ERROR=4 BEEPER_MODE_ALARM=8  BEEP_BY_MOTORS=128 (if this flag is set, motors emit sound instead of internal buzzer)
FOLLOW_ROLL_MIX_START	1u	0	90	
FOLLOW_ROLL_MIX_RANGE	1u	0	90	
BOOSTER_POWER[3]	1u*3	0	255	Additional power to correct lost synchronization
FOLLOW_SPEED[3]	1u*3	0	255	
FRAME_ANGLE_FROM_MOTORS	1u	0	1	
RC_MEMORY[3]	2s*3	-36767	32767	Initial angle that is set at system start-up, in 14bit resolution <i>Units: 0,02197265625 degree</i>
SERVO1_OUT	1u*4			Disabled = 0

SERVO2_OUT SERVO3_OUT SERVO4_OUT				1..32 - Virtual channel number as source of data to be output
SERVO_RATE	1u	5	40	PWM frequency, 10 Hz per unit.
ADAPTIVE_PID_ENABLED	1u			Set of bits (0 - disable all): EN_ROLL = 1 EN_PITCH = 2 EN_YAW = 4
ADAPTIVE_PID_THRESHOLD	1u	0	255	
ADAPTIVE_PID_RATE	1u	1	255	
ADAPTIVE_PID_RECOVERY_FACTOR	1u	0	10	
FOLLOW_LPF[3]	1u*3	0	15	
GENERAL_FLAGS1	2u			REMEMBER_LAST_USED_PROFILE = (1<<0) UPSIDE_DOWN_AUTO = (1<<1) SWAP_FRAME_MAIN_IMU = (1<<2) BLINK_PROFILE = (1<<3) EMERGENCY_STOP = (1<<4) MAGNETOMETER_POS_FRAME = (1<<5) FRAME_IMU_FF = (1<<6) OVERHEAT_STOP_MOTORS = (1<<7) CENTER_YAW_AT_STARTUP = (1<<8) SWAP_RC_SERIAL_UART_B = (1<<9) UART_B_SERIAL_API = (1<<10) BLINK_BAT_LEVEL = (1<<11) ADAPTIVE_GYRO_TRUST = (1<<12)  (frw. ver. 2.66+) IS_UPSIDE_DOWN = (1<<13)
PROFILE_FLAGS1	2u			ADC1_AUTO_DETECTION = (1<<0) ADC2_AUTO_DETECTION = (1<<1) ADC3_AUTO_DETECTION = (1<<2) FOLLOW_USE_FRAME_IMU = (1<<4) BRIEFCASE_AUTO_DETECTION = (1<<5) UPSIDE_DOWN_AUTO_ROTATE = (1<<6) FOLLOW_LOCK_OFFSET_CORRECTION = (1<<7) START_NEUTRAL_POSITION = (1<<8) MENU_BUTTON_DISABLE_FOLLOW = (1<<9) TIMELAPSE_FRAME_FIXED = (1<<10) RC_KEEP_MIX_RATE = (1<<11) RC_KEEP_CUR_POS_ON_INIT = (1<<12) (frw. ver. 2.66+) OUTER_MOTOR_LIMIT_FREE_ROTATION = (1<<13) (frw. ver. 2.69b3+) GIMBAL_LOCK_SMOOTH_TRANSITION = (1<<14) (frw. ver. 2.69b0+) CAM_UPSIDE_DOWN_WORKING = (1<<15)
SPEKTRUM_MODE	1u			0 Auto-detection (default) 1 DSM2/11ms/10bit 2 DSM2/11ms/11bit 3 DSM2/22ms/10bit 4 DSM2/22ms/11bit 5 DSMX/11ms/10bit

				6 DSMX/11ms/11bit 7 DSMX/22ms/10bit 8 DSMX/22ms/11bit
ORDER_OF_AXES	1u			Order of hardware axes, counting from a camera:  PITCH_ROLL_YAW = 0 YAW_ROLL_PITCH = 1 ROLL_YAW_PITCH* = 2 ROLL_PITCH_YAW = 3  * implemented in special builds of firmware only
EULER_ORDER	1u			Order of Euler angles to represent the current orientation of a camera and the target of stabilization:  PITCH_ROLL_YAW = 0 ROLL_PITCH_YAW = 1 LOCAL_ROLL* = 2 ROLL_LOCAL* = 3 YAW_ROLL_PITCH = 4 YAW_PITCH_ROLL = 5  * used for 2-axis systems only
CUR_IMU	1u			currently selected IMU IMU_TYPE_MAIN=1 IMU_TYPE_FRAME=2
CUR_PROFILE_ID	1u			profile ID which is currently active in the controller, 0...4

### CMD\_READ\_PARAMS\_EXT (#33) – read/write system configuration part 2

Name	Type	Min	Max	Possible values, remarks
PROFILE_ID	1u			profile ID to read or write. To access current (active) profile, specify 255. Possible values: 0..4
 NOTCH_FREQ[3]	1u*3	0	255	Center frequency, x2 Hz (value 10 means 20Hz), for each axis R,P,Y
	1u*3	0	255	Width of -3dB gain band, Hz, for each axis R,P,Y
LPF_FREQ[3]	2u*3	0	1000	Low-pass filter -3dB cut-off frequency, Hz
FILTERS_EN[3]	1u*3			Set of bits (0 – disable all): EN_NOTCH1 = 1 EN_NOTCH2 = 2 EN_NOTCH3 = 4 EN_LPF = 8
ENCODER_OFFSET[3]	2s*3			Units: 0,02197265625 degree
ENCODER_FLD_OFFSET[3]	2s*3			Units: 0,02197265625 degree
ENCODER_MANUAL_SET_TIME[3]	1u*3	0	255	Units: 10ms
MOTOR_HEATING_FACTOR[3]	1u*3	0	255	

MOTOR_COOLING_FACTOR[3]	1u*3	0	255	
RESERVED	2b			
FOLLOW_INSIDE_DEADBAND	1u	0	255	
MOTOR_MAG_LINK[3]	1u*3	0	255	Deprecated, replaced by the MOTOR_MAG_LINK_FINE
MOTOR_GEARING[3]	2u*3			Real number encoded as 8.8 fixed point (1.0f → 256)
ENCODER_LIMIT_MIN[3] ENCODER_LIMIT_MAX[3]	1s*3 1s*3	-127	127	<i>Units: 3 degree</i> Startig from ver. 2.61 is deprecated, replaced by the FRAME_CAM_ANGLE_MIN.
NOTCH1_GAIN[3] NOTCH2_GAIN[3] NOTCH3_GAIN[3]	1s*3 1s*3 1s*3	-100	100	Notch gain, in dB (positive – notch, negative – peak filter)
BEEPER_VOLUME	1u	0	255	
ENCODER_GEAR_RATIO[3]	2u*3			<i>Units: 0.001</i>
ENCODER_TYPE[3]	1u*3			Bits 0..3: ENC_TYPE_AS5048A = 1 ENC_TYPE_AS5048B = 2 ENC_TYPE_AS5048_PWM = 3 ENC_TYPE_AMT203 = 4 ENC_TYPE_MA3_10BIT = 5 ENC_TYPE_MA3_12BIT = 6 ENC_TYPE_ANALOG = 7 ENC_TYPE_I2C_DRV1 = 8 ENC_TYPE_I2C_DRV2 = 9 ENC_TYPE_I2C_DRV3 = 10 ENC_TYPE_I2C_DRV4 = 11 ENC_TYPE_AS5600_PWM = 12 ENC_TYPE_AS5600_I2C = 13 ENC_TYPE_RLS_ORBIS = 14 TYPE_RLS_ORBIS_PWM = 15 Bit 4: SKIP_DETECTION = 1 Bit 7: ENCODER_IS_GEARED = 1
ENCODER_CFG[3]	1u*3			For SPI encoders: SPI_SPEED_1MHz = 0 SPI_SPEED_2MHz = 1 SPI_SPEED_4MHz = 2 SPI_SPEED_500kHz = 3 For I2C_DRV: internal encoder type
OUTER_P[3]	1u*3	0	255	
OUTER_I[3]	1u*3	0	255	
MAG_AXIS_TOP MAG_AXIS_RIGHT	1s 1s			X = 1 Y = 2 Z = 3 -X = -1 -Y = -2 -Z = -3

MAG_TRUST	1u	0	255	
MAG_DECLINATION	1s	-90	90	Units: 1 degree
ACC_LPF_FREQ	2u	0	1000	Units: 0.01Hz
D_TERM_LPF_FREQ[3]	1u*3	0	60	Units: 10Hz

### CMD\_READ\_PARAMS\_EXT2 (#62) – read/write system configuration part 3

Name	Type	Min	Max	Possible values, remarks
PROFILE_ID	1u			profile ID to read or write. To access current (active) profile, specify 255. Possible values: 0..4
channel = (1..2)	MAV_SRC	1u		Disabled=0 UART1=1 RC_SERIAL=2 UART2=3 USB VCP=4
	MAV_SYS_ID	1u	0	255
	MAV_COMP_ID	1u	0	255
	MAV_CFG_FLAGS	1u		FLAG_BAUD_MASK = ((1<<0)   (1<<1)   (1<<2)) // baud rate idx 0..5 FLAG_PARITY_EVEN = (1<<3) // even parity FLAG_HEARTBEAT = (1<<4) // send heartbeat FLAG_DEBUG = (1<<5) // send debug to GUI FLAG_RC = (1<<6) // use RC values
	MAV_RESERVED	4b		
MOTOR_MAG_LINK_FINE[3]	2u*3	0	65000	Units: 0.01
ACC_LIMITER[3]	1u*3	0	200	Units: 5 degrees/sec <sup>2</sup>
PID_GAIN[3]	1u*3	0	255	pid_gain_float[axis] = 0.1 + PID_GAIN[axis]*0.02
FRAME_IMU_LPF_FREQ	1u	0	200	Units: Hz
AUTO_PID_CFG	1u			See 'CFG_FLAGS' in the CMD_AUTO_PID
AUTO_PID_GAIN	1u	0	255	See 'GAIN_VS_STABILITY' in the CMD_AUTO_PID
FRAME_CAM_ANGLE_MIN[3] FRAME_CAM_ANGLE_MAX[3]	2s*3 2s*3			Software limits for motor's angles (frw. ver. 2.61+) Units: 1 degree
GENERAL_FLAGS2	2u			(frw. ver. 2.61+) SEARCH_LIMIT_ROLL = (1<<0) SEARCH_LIMIT_PITCH = (1<<1) SEARCH_LIMIT_YAW = (1<<2)  (frw. ver. 2.62b7+) AUTO_CALIBRATE_MOMENTUM = (1<<3)

				USE_MOMENTUM_FEED_FORWARD = (1<<4) MOTORS_OFF_AT_STARTUP = (1<<5) FC_BELOW_OUTER = (1<<6)  (frw. ver. 2.66+) DO_NOT_CHECK_ENCODER_LIMITS = (1<<7) AUTO_SAVE_BACKUP_SLOT = (1<<8) FC_BELOW_MIDDLE = (1<<9) Note: if both flags FC_BELOW_OUTER and FC_BELOW_MIDDLE are set, it means FC position on the camera platform (frw. ver. 2.67b2+) ENVIRONMENT_TEMP_UNKNOWN = (1<<10) LPF_EXTENDED_RANGE = (1<<11) SAVE_SYSTEM_STAT = (1<<12) FLAG2_DISABLE_ACC = (1<<13) FLAG2_DISABLE_POWER_MANAGER = (1<<14) ALLOW_FRAME_IMU_AS_MAIN = (1<<15)
AUTO_SPEED	1u	1	255	(frw. ver. 2.61+) Speed used in automated tasks. The same range as for the RC_SPEED parameter
AUTO_ACC_LIMITER	1u	1	255	(frw. ver. 2.61+) Acceleration limiter used in automated tasks. The same range as for ACC_LIMITER parameter <i>Units: 5 degrees/sec<sup>2</sup></i>
IMU_ORIENTATION_CORR[3]	2s*3			(frw. ver. 2.61+) The rotation angle of correction of main IMU sensor misalignment over its local X,Y,Z axis. <i>Units: 0.01 degrees</i>
TIMELAPSE_TIME	2u			(frw. ver. 2.60+) Time for the time-lapse motion sequence <i>Units: seconds</i>
EMERGENCY_STOP_REST ART_DELAY	2u			<i>Units: ms</i>
TIMELAPSE_ACC_PART	1u	0	250	<i>Units: 0.2%</i>
MOMENTUM[3]	2u*3			(frw.ver. 2.62b7+)
MOMENTUM_CALIB_STIM ULUS[3]	1u*3	1	255	(frw.ver. 2.62b7+)
MOMENTUM_ELITPICITY[3]	1u*3	1	255	(frw.ver. 2.62b7+) <i>Units: 0.05</i>
FOLLOW_RANGE[3]	1u*3	1	180	(frw.ver. 2.62b7+) <i>Units: degrees</i>
STAB_AXIS[3]	1u*3			(frw.ver. 2.62b7+) Bits0..1: axis assigned for each motor: 0 - default 1 - ROLL 2 - PITCH 3 - YAW  Bits2..4: enable automatic selection of best matching axis: bit2: ROLL bit3: PITCH bit4: YAW
OUTER_MOT_TILT_ANGLE	1s	-90	90	<i>Units: degrees</i>

The following parameters are applied for the firmware ver. 2.66+				
STARTUP_ACTION[4]	1u*4			bits 0..6: action, as listed in the CMD_EXECUTE_MENU.CMD_ID bit 7: if set, menu button should be pressed
STARTUP_ACTION_SRC[2] [4]	1u*8			Signal source, as listed in the RC_MAP_ROLL parameter
STARTUP_ACTION_THRES HOLD[2][4]	1s*8			Threshold for RC signal on a given source, multiplied by 10.
FORCE_POSITION_CFG[3]	1u*3			bits 0..2: snap angle, one of the 0, 45, 90, 180 bits 4..7: flags: FORCE_POSITION_FLAG_BUTTON_PRESS = (1<<4) FORCE_POSITION_FLAG_STARTUP = (1<<5) FORCE_POSITION_FLAG_IGNORE_LIMITS = (1<<6) FORCE_POSITION_FLAG_FINE_ADJUST = (1<<7)
N=1..6	STEP_SIGNAL_SRC	1u		Signal source, as listed in the RC_MAP_ROLL parameter
	STEP_SIGNAL_CFG	1u		bits 0..2: number of steps, one of the [2, 3, 5, 10, 15, 25, 50, 100] bit 3: if set, menu button should be pressed bit 5: if set, initial value is zero bits 6..7: mode MODE_LEVEL_LOW = 0 MODE_LEVEL_HIGH = 1 MODE_LEVEL_LOW_HIGH = 2
N=1..5	RC_CALIB_SRC	1u		Signal source to apply calibration, as listed in the RC_MAP_ROLL parameter
	RC_CALIB_OFFSET	1s		
	RC_CALIB_NEG_SCALE	1u		Calibration is applied by the rule: val = val + RC_CALIB_OFFSET*(RC_RANGE/2/128); if(val > 0) val = val * (80 + RC_CALIB_POS_SCALE) / 100; else val = val * (80 + RC_CALIB_NEG_SCALE) / 100;
	RC_CALIB_POS_SCALE	1u		
PARKING_POS_CFG	1u			ROLL: bit 0 – negative border, bit 1 – positive border PITCH: bit 2 – negative border, bit 3 – positive border YAW: bit 4 – negative border, bit 5 – positive border
EXT_LED_PIN_ID	1u			Use this pin to duplicate the on-board LED function. Values are listed in the CMD_TRIGGER_PIN.PIN_ID
INTERRUPT_CFG	2u			bits 0..4: pin ID as listed in the CMD_TRIGGER_PIN.PIN_ID bit 5: generate interrupt on emergency stop bit 6: generate interrupt on entering parking position
OVERLOAD_TIME	1u			Units: 100ms
AUTO_PID_MOMENTUM	1u	0	255	
JERK_SLOPE[3]	1u*3			Units: 40ms
MAV_CTRL_MODE	1u	0	2	0 – disabled 1 – ROLL and PITCH axes 2 – all axes
RC_SERIAL_SPEED	1u*2			See the SERIAL_SPEED parameter definition



UART2_SPEED				
MOTOR_RES[3]	1u*3	0	255	Motor resistance (one phase) <i>Units: 100 mOhm</i>
CURRENT_LIMIT	2u	0	65535	<i>Units: 10mA</i>
MIDDLE_MOT_TILT_ANGLE	1s	-90	90	( <i>frw. ver. 2.67+</i> ) <i>Units: degrees</i>

### CMD\_READ\_PARAMS\_EXT3 (#104) – read/write system configuration part 3

(*frw.ver. 2.66+*)

Name	Type	Min	Max	Possible values, remarks
PROFILE_ID	1u			profile ID to read or write. To access current (active) profile, specify 255. Possible values: 0..4
RESERVED	21b			
EXT_IMU_TYPE	1u			MavLink1 = 1 MavLink2 = 2 Vectornav VN200 = 3 Inertialsense uAHRS = 4
EXT_IMU_PORT	1u			Disabled = 0 UART1 = 1 RC_SERIAL = 2 UART2 = 3 USB VCP = 4
EXT_IMU_POSITION	1u			BELOW_OUTER = 1 ABOVE_OUTER = 2 BELOW_MIDDLE = 8 MAIN_IMU = 9
EXT_IMU_ORIENTATION	1u			index in array [X, Y, Z, -X, -Y, -Z] bit0..2 for the TOP axis bit3..5 for the RIGHT axis
EXT_IMU_FLAGS	2u			EXT_IMU_FLAG_ACC_COMP_ONLY = 2 EXT_IMU_FLAG_REPLACE = 4 EXT_IMU_FLAG_Z = 8 EXT_IMU_FLAG_H = 16 EXT_IMU_FLAG_FRAME_UPSIDE_DOWN_UPDATE = 32 EXT_IMU_FLAG_AS_FRAME_IMU = 64 EXT_IMU_FLAG_GYRO_CORR = 128 ( <i>frw.ver. 2.68b7+</i> )
EXT_IMU_ALIGN_CORRECTION[3]	2s*3			Rotation over X,Y,Z axes <i>Units: 0.001 degrees</i>
EXT_IMU_STARTUP_DELAY	1u			<i>Units: 50ms</i>
EXT_IMU_GYRO_CORRATE	1u			Strength of the gyroscope correction by ext. IMU in the “online calibration” algorithm.
EXT_IMU_RESERVED	4b			
SOFT_LIMIT_WIDTH[3]	1u*3	1	255	Width of the software limits defined by the FRAME_CAM_ANGLE_MIN, FRAME_CAM_ANGLE_MAX <i>Units: 0.1 degrees</i>

ADC_REPLACE_SRC[3]	1u*3			See RC_MAP_ROLL description for possible values
GLOCK_MID_MOT_POS_C ORR_RATE	1u	0	255	
EXTRA_BTN_CFG[5]	5b			Extra buttons connected to controller's pins. Bits0..4: MCU pin source, see PIN_ID in CMD_TRIGGER_PIN Bit6: latching mode if set Bit7: invert action if set
POWER_CTRL_CFG	8b			1u: overcurrent_protection, units: 0.5A 1u: power_on_delay, units: 100ms 1u: power_off_delay, units: 100ms 1u: power_on_limiter, 0..255 4b: reserved
RESERVED	3b			
CAN_IMU_EXT_SENS_TYP E	1u			0 disabled 1 KVH 1725 2 KVH 1750 (ACC 2G) 3 KVH 1750 (ACC 10G) 4 KVH 1750 (ACC 30G) 5 KVH 1775 (ACC 10G) 6 KVH 1775 (ACC 25G) 7 KVH 1760 8 ADXRS453 9 ADIS16460 10 STIM210 11 STIM300 12 SCHA63X 64 Vectornav VN100/200 (UART) 65 Vectornav VN100/200 (SPI)
PROFILE_FLAGS2	2u			FOLLOW_PITCH_DISABLED = (1<<0) LOW_ANGLE_PRIOR_ROLL = (1<<1) LOW_ANGLE_PRIOR_PITCH = (1<<2) LOW_ANGLE_PRIOR_YAW = (1<<3) HEADING_TRIPOD_MODE = (1<<4)
RESERVED	3b			
GENERAL_FLAGS3	4u			ENC_LUT_EN_ROLL = (1<<0) ENC_LUT_EN_PITCH = (1<<1) ENC_LUT_EN_YAW = (1<<2) MAVLINK_YAW_ABSOLUTE = (1<<3)
FOLLOW_OFFSET_EXT[3]	2s*3	-16384	16384	Frw. ver. 2.70+: replaces old 8-bit FOLLOW_OFFSET[3] Units: 0,02197265625 degree
MOTOR_STARTUP_DELAY	2u			Units: ms
RESERVED	140b			

### CMD\_READ\_PROFILE\_NAMES (#28) – receive profile names from EEPROM

Name	Type	Min	Max	Possible values, remarks
PROFILE_NAME[5]	48b* 5			Each name is encoded in UTF-8 format and padded with '\0' character to 48 byte size

## Calibrating

### Requests

**CMD\_CALIB\_ACC (#65) – calibrate accelerometer**

**CMD\_CALIB\_GYRO (#103) – calibrate gyroscope**

**CMD\_CALIB\_MAG (#59) – calibrate magnetometer**

Simple format: no parameters. Starts regular calibration of currently active IMU, selected by the CMD\_SELECT\_IMU\_3 command.

Extended format:

Name	Type	Min	Max	Possible values, remarks
IMU_IDX	1u			(0 – currently active IMU, 1 – main IMU, 2 – frame IMU)
ACTION	1u			1 – do regular calibration 2 – reset all calibrations and restart 3 – do temperature calibration 4 – enable temp. calib. data, if present, and restart 5 – disable temp. calib. data (but keep in memory), and restart 6 – copy calibration from the sensor's EEPROM to the main EEPROM ("restore factory calibration" option) 7 – copy calibration from the main EEPROM to the sensor's EEPROM
TIME_MS	2u	0	65535	Time for gyroscope calibration, in milliseconds. If set to 0, default time is used (~4 seconds), which is good balance between precision and speed.
RESERVED	8b			

If all parameters are valid, confirmation is sent immediately on reception and in the end of calibration.

**CMD\_CALIB\_EXT\_GAIN (#71) – calibrate EXT\_FC gains**

No parameters

**CMD\_CALIB\_POLES (#80) – calibrate poles and direction**

No parameters

**CMD\_CALIB\_BAT (#66) - calibrate internal voltage sensor**

Name	Type	Min	Max	Possible values, remarks
ACTUAL_VOLTAGE	2u			<i>Units: 0.01V</i>

Confirmation is sent.

**CMD\_ENCODERS\_CALIB\_OFFSET\_4 (#26) - calibrate offset of encoders**

No parameters.



(*frw. ver. 2.68b7+*) optional parameter FOR\_MOTOR (1u): value 0..2 to calibrate offset only for the given motor ROLL, PITCH or YAW. Value 255 – for all motors.

### CMD\_ENCODERS\_CALIB\_FLD\_OFFSET\_4 (#27) - start field offset calibration of encoders

All parameters are optional. Note the version of the firmware where they started to be supported.

Name	Type	Min	Max	Possible values, remarks
CALIB_ANGLE[3] ( <i>optional, frw. ver. 2.62b6+</i> )	2s*3	1	-	Angle range to move during calibration. If omitted, default is 40°. Units: 0,02197265625 degree.
CALIB_SPEED[3] ( <i>optional, frw.ver. 2.71b1+</i> )	2s*3	1	-	Speed of movement during the calibration. If omitted, default is 100. Units: 0,06103701895 deg./sec.

### CMD\_CALIB\_ORIENT\_CORR (#91) – start the calibration of sensor misalignment correction

(*frw. ver. 2.61+*)

Name	Type	Min	Max	Possible values, remarks
RESERVED	16b			

Confirmation is sent immediately. After calibration is finished, CMD\_READ\_PARAMS\_EXT2 is sent with new values in the IMU\_ORIENTATION\_CORR[3].

### CMD\_CALIB\_ACC\_EXT\_REF (#94) – refine the accelerometer calibration of the main IMU sensor

(*frw. ver. 2.62b7+, encoders*)

Use this command to refine the ACC calibration in the main IMU sensor by providing the reference ACC vector from the external well-calibrated IMU in the frame's coordinates. By using three encoders, gimbal controller is able to convert it to the main IMU's local coordinates, compare to measured ACC vector and use it to refine existing calibration: zero offset for two horizontal axes and scale factor for the vertical axis.

Name	Type	Min	Max	Possible values, remarks
ACC_REF[3]	2s*3			Reference ACC vector [X,Y,Z] in gimbal frame's coordinates (X-axis points right, Y-axis points forward, Z-axis points down relative to frame). Units: 1g/512 ≈ 0,019160156 m/s <sup>2</sup>
RESERVED	14b			

Conditions:

- One of the sensor's axis should be aligned to a gravity vector with the 20-degree tolerance
- Existing ACC calibration should be good enough

Possible usage scenario:

1. Rotate gimbal to a leveled position by the CMD\_CONTROL and run this command – X,Y-axis offset will be refined
2. Tilt gimbal 90-degree down and run it again – Z-axis offset and Y-axis scale will be refined.
3. Return gimbal back to leveled position and run it again – Z-axis scale will be refined. This is enough to have correct ACC readings inside the working range ROLL=0, PITCH = [0..90].

Calibration takes about 0.5 seconds (controller averages multiple data samples to reduce noise). Confirmation is sent only if all conditions are satisfied.

### CMD\_CALIB\_COGGING (#93) – starts the motor non-linearities calibration

Name		Type	Min	Max	Possible values, remarks
ACTION		1u			1 – Calibrate 2 – Delete calibration data
AXIS_TO_CALIBRATE		1u			Bit0: ROLL Bit1: PITCH Bit2: YAW
for axis = (1..3)	ANGLE	2u	20	360	Angle to move, in degrees
	SMOOTH	1u	0	100	Smooth the resulting curve, in %
	SPEED	1u			Speed of rotation, in relative units
	PERIOD	2u			Expected period of non-linearity curve, in degrees. Leave 0 for auto-detection.
	RESERVED	9b			
ITERATIONS_NUM		1u	2	-	
RESERVED		9b			

Command CMD\_CONFIRM is sent in response with the DATA = 1 or 2 on success, 254 on error. Another command CMD\_CONFIRM with the DATA = 255 is sent when calibration finishes.

## Real-time state monitoring and diagnostics

### Requests

#### CMD\_REALTIME\_DATA\_CUSTOM (#88) – request configurable realtime data

(frw. ver. 2.60+)

Name	Type	Min	Max	Possible values, remarks
FLAGS	4u			<p>Each bit specify which data to include in response</p> <p>bit0: IMU_ANGLES[3]  bit1: TARGET_ANGLES[3]  bit2: TARGET_SPEED[3]  bit3: FRAME_CAM_ANGLE[3]  bit4: GYRO_DATA[3]  bit5: RC_DATA[6]  bit6: Z_VECTOR[3], H_VECTOR[3]  bit7: RC_CHANNELS[18]  bit8: ACC_DATA[3]  bit9: <a href="#">MOTOR4_CONTROL</a> data structure  bit10: <a href="#">AHRS_DEBUG_INFO</a> data structure  bit11: ENCODER_RAW24[3]  bit12: IMU_ANGLES_RAD[3]  bit13: SCRIPT_VARS_FLOAT[10]  bit14: SCRIPT_VARS_INT16[10]  bit15: <a href="#">SYSTEM_POWER_STATE</a> data structure  bit16: FRAME_CAM_RATE[3]  bit17: IMU_ANGLES_20[3]  bit18: TARGET_ANGLES_20[3]</p> <p><i>A detailed description of the data structure is provided in the CMD_REALTIME_DATA_CUSTOM response specification</i></p>
RESERVED	6b			

#### CMD\_REALTIME\_DATA (#68),

#### CMD\_REALTIME\_DATA\_3 (#23) – request real-time data, response is CMD\_REALTIME\_DATA\_3

No parameters

#### CMD\_REALTIME\_DATA\_4 (#25) – request extended real-time data, response is CMD\_REALTIME\_DATA\_4

No parameters

#### CMD\_DATA\_STREAM\_INTERVAL (#85) – register or update *data stream* – a commands sent by the controller with the fixed rate without request

(frw. ver. 2.60+) or based on events (2.65+)

For each serial interface, only one unique combination of CMD\_ID + CONFIG bytes may be registered. If the data stream is already registered, it will be updated. To unregister it, specify INTERVAL\_MS=0. The total number of data streams over all serial interfaces is limited to 10.

Take care of the serial bandwidth: if data flow exceeds bandwidth, particular messages may be skipped. The interval is maintained with the  $\pm 1$ ms tolerance for the individual sample, but the averaged sample rate exactly matches to the specified.

Name	Type	Min	Max	Possible values, remarks
CMD_ID	1u			Command ID to be sent by this data stream. All supported commands are listed for the "CONFIG" parameter below.
INTERVAL_MS	2u			<p><b>SYNC_TO_DATA = 0:</b> Interval between messages, in milliseconds. Value 1 means each cycle (0.8ms)</p> <p><b>SYNC_TO_DATA != 0:</b> Sample rate divider</p> <p>Set value = 0 to unregister this data stream identified by the [CMD_ID, CONFIG] bytes.</p>
CONFIG	8b			<p>Configuration specific to each command:</p> <p><b>CMD_REALTIME_DATA_3</b> <b>CMD_REALTIME_DATA_4</b> no parameters</p> <p><b>CMD_REALTIME_DATA_CUSTOM</b></p> <ul style="list-style-type: none"> <li><b>flags</b> – 4u, see command specification.</li> </ul> <p><b>CMD_AHRS_HELPER</b></p> <ul style="list-style-type: none"> <li><b>imu_type</b> – 1u (0 – main IMU, 1 – frame IMU).</li> </ul> <p><b>CMD_EVENT</b> (ver. 2.65b7+)</p> <ul style="list-style-type: none"> <li><b>event_id</b> – 1u - One of the EVENT_ID_xx, see the CMD_EVENT command specification</li> <li><b>event_type</b> – 1u - a bitwise combination of the EVENT_TYPE_xx flags, see the CMD_EVENT command specification</li> </ul>
SYNC_TO_DATA (frw.ver 2.70b1)	1u			<p>If set, message is sent immediately after the specified type of data is updated. The parameter INTERVAL_MS=N specifies the sample rate divider (message is sent on each N-th update event).</p> <p>Data types:</p> <p><b>IMU_ATTITUDE = 1</b> – IMU attitude (Euler angles and DCM), updated each 8ms</p>
RESERVED	9b			

If the data stream is successfully registered or updated, the CMD\_CONFIRM is sent in answer.

For the command **CMD\_EVENT**, the behavior is different. This message is sent only once when the event is triggered, so the parameter INTERVAL\_MS does not matter and should be set to any non-zero value. But it is still used for the "continuous" events like EVENT\_TYPE\_HOLD. The "event\_type" parameter can be used to select which events to report.

Examples:

- Send CMD\_REALTIME\_DATA\_4 with the rate 20Hz:  
19 32 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00
- Send CMD\_REALTIME\_DATA\_CUSTOM (IMU angles + RC target angles) with the rate 10Hz:  
58 64 00 03 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00



- Send CMD\_EVENT when the mode button is pressed and released (once), and held (at 10Hz):  
66 64 00 01 07 00 00 00 00 00 00 00 00 00 00 00 00 00 00

### CMD\_READ\_RC\_INPUTS (#100) - read values for the selected RC inputs

Name	Type	Min	Max	Possible values, remarks
CFG_FLAGS	2u			bit0: try to initialize input, if it was not used by the controller and was not initialized.
RC_SRC[N]	1u*N			List of signal sources. Possible values are listed in the RC_MAP_ROLL parameter.

In response, CMD\_READ\_RC\_INPUTS is returned with the values for the requested RC sources.

### CMD\_GET\_ANGLES (#73), CMD\_GET\_ANGLES\_EXT (#61) - Request information related to IMU angles and RC control state

No parameters.

### CMD\_SELECT\_IMU\_3 (#24) – Select which IMU to calibrate or send realtime data

(for commands that don't specify IMU type explicitly)

Name	Type	Min	Max	Possible values, remarks
IMU_TYPE	1u			IMU_TYPE_MAIN=1 IMU_TYPE_FRAME=2

If the selected IMU is not connected, command is ignored.

### CMD\_DEBUG\_VARS\_INFO\_3 (#253) – request information about debug variables

No parameters.

### CMD\_DEBUG\_VARS\_3 (#254) – request values of debug variables

No parameters.

### CMD\_CALIB\_INFO (#49) – request information required for the "Calibration helper" dialog window

Name	Type	Min	Max	Possible values, remarks
IMU_TYPE	1u			1 – main IMU, 2 – frame IMU
RESERVED	11b			

On success, CMD\_CALIB\_INFO is sent in response.

## CMD\_READ\_STATE\_VARS (#111) – request reading system persistent state variables, cumulative statistics and maintenance data

(min. frw.ver. 2.68b7, “Extended” family only)

No parameters. CMD\_READ\_STATE\_VARS message is sent in response.

## CMD\_WRITE\_STATE\_VARS (#112) – write system persistent state variables, cumulative statistics and maintenance data

Data structure is the same as in the [CMD\\_READ\\_STATE\\_VARS](#).

CMD\_CONFIRM is sent in response on success.

## CMD\_SET\_DEBUG\_PORT (#249) – use this port for debugging

Forward all incoming and outgoing commands in other serial API ports to the current port. Only one port in the system may be configured for this role.

Name	Type	Min	Max	Possible values, remarks
ACTION	1u			0 – Stop using this port for debugging 1 – Start using this port for debugging
CMD_FILTER “plus” version only	4u			Set the following bits to prevent sending heavy-duty commands to the debug port: 0: CMD_REALTIME_DATA_3, 1: CMD_REALTIME_DATA_4, 2: CMD_REALTIME_DATA_CUSTOM, 3: CMD_DEBUG_VARS_3, 4: CMD_MAVLINK_DEBUG, 5: CMD_GET_ANGLES, 6: CMD_GET_ANGLES_EXT, 7: CMD_BODE_TEST_DATA, 8: CMD_HELPER_DATA, 9: CMD_AHRS_HELPER, 10: CMD_GYRO_CORRECTION, 11: CMD_CONTROL, 12: CMD_SET_ADJ_VARS_VAL, 13: CMD_API_VIRT_CH_CONTROL, 14: CMD_API_VIRT_CH_HIGH_RES
RESERVED	11b			

Command CMD\_CONFIRM is sent in response. All in and out commands from other ports that were passed the filter, are sent in [CMD\\_SET\\_DEBUG\\_PORT](#) incoming command. If there are no enough room in TX buffer, command will be dropped.

## Responses

### CMD\_REALTIME\_DATA\_CUSTOM (#88) – configurable realtime data

(frw. ver. 2.60+)

Name	Type	Min	Max	Possible values, remarks
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TIMESTAMP_MS	2u			Timestamp in milliseconds	
The set of variables below depends on requested data, see the CMD_REALTIME_DATA_CUSTOM request specifications					
IMU_ANGLES[3]	2s*3			Main IMU angles (Euler) <i>Units: 0,02197265625 degree.</i>	
TARGET_ANGLES[3]	2s*3			Target angles that gimbal should keep (Euler) <i>Units: 0,02197265625 degree.</i>	
TARGET_SPEED[3]	2s*3			Target speed that gimbal should keep, over Euler axes <i>Units: 0,06103701895 degree/sec</i>	
FRAME_CAM_ANGLE[3]	2s*3			Relative angle of joints (motors) <i>Units: 0,02197265625 degree.</i>	
GYRO_DATA[3]	2s*3			Data from the gyroscope sensor with the calibrations applied. <i>Units: 0,06103701895 degree/sec.</i>	
RC_DATA[6]	2s*6			RC data in high resolution, assigned to the ROLL, PITCH, YAW, CMD, FC_ROLL, FC_PITCH inputs. <i>Units: normal range is -16384..16384, -32768 is for 'undefined' signal</i>	
Z_VECTOR[3] H_VECTOR[3]	4f*6	-1.0f	1.0f	IMU attitude in a form of rotation matrix (2 rows as gravity and heading vectors, 3 <sup>rd</sup> row can be calculated as cross-product of them). See <a href="#">Appendix D: Coordinate system conversions</a>	
RC_CHANNELS[18]	2s*18			All RC channels captured from s-bus, spektrum or Sum-PPM inputs. <i>Mapped to -16384..16384, -32768 is for 'undefined' signal</i>	
ACC_DATA[3]	2s*3			Data from the accelerometer sensor with the calibrations applied, expressed in END coordinate system, sign is inverted. <i>Units: 1/512 G</i>	
AHRS_DEBUG_INFO	26b			See the <a href="#">AHRS_DEBUG_INFO</a> specification	
MOTOR4_CONTROL	8b			See the <a href="#">MOTOR4_CONTROL</a> specification	
ENCODER_RAW24[3]	3b*3			Encoder raw angles in a high resolution (24bit per full turn), 3 bytes for each encoder in a sequence for ROLL, PITCH, YAW motors, lower byte first. Total 9 bytes. <i>(frw. ver. 2.68+)</i>	
IMU_ANGLES_RAD[3]	4f*3	-Pi	Pi	Main IMU Euler angles in radians <i>(frw. ver. 2.68b7+)</i>	
SCRIPT_VARS_FLOAT[3]	4f*3			Script variables in floats	
SCRIPT_VARS_INT16[3]	2s*3			Script variables in 16-byte signed integers	
SYSTEM_POWER_STATE <i>(frw. ver. 2.70b6+) WARNING: specification is not final, may be changed in future!</i>					
motor=(1..3)	MOT_POWER	2s	-10000	10000	Effective power that produces torque, 10000 for 100% Encoder firmware: sign corresponds to the torque direction
	MOT_CURRENT	2u	0	65535	Estimated or measured current consumption per motor <i>Units: mA</i>
	MOT_TEMP	1s			Motor temperature estimated by heating model (if configured) or measured by the hardware sensors (if present) <i>Units: °C</i>
	MOT_FLAGS	2u			bit0: software limit in motor is violated bit1: current exceeds the limit bit2: motor driver is enabled (motor energized)

	MOT_RESERVED	6b			
	SYSTEM_POWER_STATE	1b			POWER_STATE_ON_FROM_BACKUP = -2 // internal use POWER_STATE_STARTUP = -1 // internal use POWER_STATE_OFF = 0 // motors are OFF POWER_STATE_ON = 1 // motors are ON POWER_STATE_OFF_TEMPORARY = 2 // motors are temporarily OFF for calibration POWER_STATE_OFF_PARKING = 3 // motors are temporarily OFF when entering parking position POWER_STATE_ON_SAFE_STOP = 4 // motors are energized to softly drop the unbalanced payload before going OFF
	BATTERY_VOLTAGE	2u			Voltage measured by the hardware voltage sensor <i>Units: 0.01V</i>
	TOTAL_CURRENT	2u	0	65535	Overall system current consumption measured by the hardware current sensor (if present) <i>Units: mA</i>
	SYSTEM_FLAGS	2u			bit0: software limit is violated in any motor bit1: overheat warning (estimated or measured temperature exceeds 80°C)
	FRAME_CAM_RATE[3]	2s*3			Rate of rotation of frame-to-camera joints (motors) (frw. ver. 2.70b6+) <i>Units: 0,06103701895 degree/sec.</i>
	IMU_ANGLES_20[3]	4s*3			Main IMU angles in 20bit resolution (frw. ver. 2.70b8+) <i>Units: 0,00034332275390625 degrees</i>
	TARGET_ANGLES_20[3]	4s*3			Target angles in 20bit resolution (frw. ver. 2.70b8+) <i>Units: 0,00034332275390625 degrees</i>

### CMD\_REALTIME\_DATA\_3 (#23) - receive real-time data

Name	Type	Min	Max	Possible values, remarks
axis = (1..3)	ACC_DATA	2s		Data from the accelerometer sensor with the calibrations applied, expressed in END coordinate system, sign is inverted. <i>Units: 1/512 G</i>
	GYRO_DATA	2s		Data from the gyroscope sensor with the calibrations applied. <i>Units: 0,06103701895 degree/sec.</i>
SERIAL_ERR_CNT	2u	0	65535	
SYSTEM_ERROR	2u			Set of bits ( 0 – no error): ERR_NO_SENSOR (1<<0) ERR_CALIB_ACC (1<<1) ERR_SET_POWER (1<<2) ERR_CALIB_POLES (1<<3) ERR_PROTECTION (1<<4) ERR_SERIAL (1<<5) <i>Beside that, extended error contains bits:</i> ERR_LOW_BAT1 (1<<6) ERR_LOW_BAT2 (1<<7) ERR_GUI_VERSION (1<<8) ERR_MISS_STEPS (1<<9) ERR_SYSTEM (1<<10) ERR_EMERGENCY_STOP (1<<11)

SYSTEM_SUB_ERROR	1u			See <a href="#">Appendix E: "Emergency stop" error codes</a>
RESERVED	3b			
RC_ROLL RC_PITCH RC_YAW	2s 2s 2s	1000	2000	RC control channels values (PWM or normalized analog)
RC_CMD	2s	1000	2000	RC command channel value (PWM or normalized analog)
EXT_FC_ROLL EXT_FC_PITCH	2s 2s	1000	2000	External FC PWM values. May be zero if their inputs are mapped to RC control or command.
IMU_ANGLE[3]	2s*3	-32768	32767	IMU angles in 14-bit resolution per full turn  <i>Units: 0,02197265625 degree</i>
FRAME_IMU_ANGLE[3]	2s*3	-32768	32767	Angles measured by the second IMU (if present), in 14-bit resolution.  <i>Units: 0,02197265625 degree</i>
TARGET_ANGLE[3]	2s*3	-32768	32767	Target angles, in 14-bit resolution  <i>Units: 0,02197265625 degree</i>
CYCLE_TIME	2u			<i>Units: microseconds</i>
I2C_ERROR_COUNT	2u			Number of registered errors on I2C bus
ERROR_CODE	1u			deprecated, replaced by the SYSTEM_ERROR variable
BAT_LEVEL	2u			Battery voltage <i>Units: 0.01 volt</i>
RT_DATA_FLAGS	1u			bit0 set - motors are turned ON
CUR_IMU	1u			Currently selected IMU that provides angles and raw sensor data IMU_TYPE_MAIN=1 IMU_TYPE_FRAME=2
CUR_PROFILE	1u	0	4	Currently selected profile
MOTOR_POWER[3]	1u*3	0	255	

### CMD\_REALTIME\_DATA\_4 (#25) - receive extended version of real-time data

Name	Type	Min	Max	Possible values, remarks
...The beginning of the message includes all data from the CMD_REALTIME_DATA_3				
FRAME_CAM_ANGLE[3]	2s*3			Relative angle of joints between two arms of gimbal structure, measured by encoder (with offset and gearing calibration is applied), by 2 <sup>nd</sup> IMU or by other algorithms. Value 0 corresponds to normal position (each arms forms 90 degrees with the next order arm). <i>Units: 0,02197265625 degree</i>
RESERVED	1b			

BALANCE_ERROR[3]	2s*3	-512	512	Error in balance (0 – perfect balance, 512 - 100% of the motor power is required to hold a camera)
CURRENT	2u			Actual current consumption. <i>Units: mA</i>
MAG_DATA[3]	2s*3	-1000	1000	Raw data from magnetometer <i>Units: relative, calibrated for current environment to give ±1000 for each axis.</i>
IMU_TEMPERATURE FRAME_IMU_TEMPERATU RE	1s 1s	-127	127	Temperature of IMU sensors. <i>Units: Celsius</i>
IMU_G_ERR	1u	0	255	Error between estimated gravity vector and reference vector for currently active IMU <i>Units: 0.1 degree</i>
IMU_H_ERR	1u	0	255	Error between estimated heading vector and reference vector for currently active IMU <i>Units: 0.1 degree</i>
MOTOR_OUT[3]	2s*3	-10000	10000	Motor effective output, proportional to torque. Max. value of ±10000 equals to applying full power. <i>(encoder firmware ver. 2.61+)</i>
CALIB_MODE	1u	0		If not 0, calibration or automatic task is performed: CALIB_MODE_EXT_GAIN 1 CALIB_MODE_SET_ANGLE_AND_SAVE 2 CALIB_MODE_POLES 3 CALIB_MODE_ACC 4 CALIB_MODE_GYRO 5 CALIB_MODE_ENCODER_OFFSET 6 CALIB_MODE_ENCODER_FLD_OFFSET 7 CALIB_MODE_AUTO_PID 8 CALIB_MODE_BODE_TEST 9 CALIB_MODE_GYRO_TEMP 10 CALIB_MODE_ACC_TEMP 11 CALIB_MODE_MAG 12 CALIB_MODE_SET_ANGLE 13 CALIB_MODE_SYSTEM_IDENT 14 CALIB_MODE_MOTOR_MAG_LINK 15 CALIB_MODE_SEARCH_LIMITS 16 CALIB_MODE_SET_OPERATION_POS 17 CALIB_MODE_IMU_ORIENTATION_CORR 18 CALIB_MODE_TIMELAPSE 19 CALIB_MODE_MOMENTUM 20 CALIB_MODE_MOMENTUM_AUTO 21 CALIB_MODE_COGGING 22 CALIB_MODE_ACC_EXT_REF 23 CALIB_MODE_SAFE_STOP 24 CALIB_MODE_ACC_SPHERE 25 CALIB_MODE_GYRO_AXES_ALIGNMENT 26 CALIB_MODE_EXT_IMU_GYRO 27 CALIB_MODE_EXT_IMU_ALIGN 28 CALIB_MODE_ACC_GYRO_MULTIPPOINT 34
CAN_IMU_EXT_SENS_ERR	1u			Error code from the external sensor connected to the CAN_IMU (codes are specific to sensors).
RESERVED	28b			

### CMD\_GET\_ANGLES (#73) - Information about actual gimbal control state

Name	Type	Min	Max	Possible values, remarks
IMU_ANGLE	2s			IMU angles in 14-bit resolution per full turn <i>Units: 0,02197265625 degree</i>

axis = (1..3)	TARGET_ANGLE	2s			Target angles, in 14-bit resolution <i>Units: 0,02197265625 degree</i>
	TARGET_SPEED	2s			Target speed that gimbal should keep, over Euler axes <i>Units: 0,1220740379 degree/sec</i>

### CMD\_GET\_ANGLES\_EXT (#61) - Information about angles in different format

Name	Type	Min	Max	Possible values, remarks
axis = (1..3)	IMU_ANGLE	2s		IMU angles in 14-bit resolution per full turn <i>Units: 0,02197265625 degree</i>
	TARGET_ANGLE	2s		Target angles, in 14-bit resolution <i>Units: 0,02197265625 degree</i>
	FRAME_CAM_ANGLE	4s		Relative angle of joints between two arms of gimbal structure, measured by encoder or 2 <sup>nd</sup> IMU. Value 0 corresponds to normal position of a gimbal. This angle does not overflow after multiple turns. <i>Units: 0,02197265625 degree</i>
	RESERVED	10b		

### CMD\_DEBUG\_VARS\_INFO\_3 (#253) – receive a specification of the debug variables

Name	Type	Min	Max	Possible values, remarks
DEBUG_VARS_NUM	1u	1	255	Number of variables in this messages
var = (1...DEBUG_VARS_NUM)	VAR_NAME	string		1 <sup>st</sup> byte is size, following by the ASCII characters. Note that '\0' character is not required at the end of the string.
	VAR_TYPE	1u		0..3bits - type: VAR_TYPE_UINT8 = 1 VAR_TYPE_INT8 = 2 VAR_TYPE_UINT16 = 3 VAR_TYPE_INT16 = 4 VAR_TYPE_UINT32 = 5 VAR_TYPE_INT32 = 6 VAR_TYPE_FLOAT = 7 (IEEE-754)  4..7bits - flags: VAR_FLAG_ROLL = 16 its belong to ROLL axis VAR_FLAG_PITCH = 32 its belong to PITCH axis VAR_FLAG_YAW = 48 its belong to YAW axis VAR_FLAG_ANGLE14 = 64 its an angle (14bit per turn)
	RESERVED	2b		

### CMD\_DEBUG\_VARS\_3 (#254) – values of debug variables reflecting a state of the system.

The number of variables and their types are not strictly defined and may vary depending on the firmware version. Use CMD\_DEBUG\_VARS\_INFO\_3 to obtain a specification of the variables in run-time.

Name	Type	Min	Max	Possible values, remarks
VAR_VALUE[N]	?			size and type of each variable is encoded by the



				CMD_DEBUG_VARS_INFO_3 structure
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### CMD\_CALIB\_INFO (#49) – receive information required for the "Calibration helper" dialog window.

Name	Type	Min	Max	Possible values, remarks
PROGRESS	1u	0	100	Progress of operation in percents
IMU_TYPE	1u			1 – main IMU, 2 – frame IMU
ACC_DATA[3]	2s*3			Data from the accelerometer sensor with the calibrations applied, expressed in END coordinate system, sign is inverted. <i>Units: 1/512 G</i>
GYRO_ABS_VAL	2u			Amplitude of gyro signal
ACC_CUR_AXIS	1u	0	2	ACC axis to be calibrated
ACC_LIMITS_INFO	1u			Bit set of calibrated limits, where bits 0...5 corresponds to the index in array [+X,-X,+Y,-Y,+Z,-Z]
IMU_TEMP_CELS	1s	-127	127	IMU temperature, Celsius
TEMP_CALIB_GYRO_ENAB LED	1u	0	1	Set to 1 if gyro temperature calibration is enabled
TEMP_CALIB_GYRO_T_MIN_CELS TEMP_CALIB_GYRO_T_MAX_CELS	1s 1s	-127	127	Range of temperature calibration <i>Units: Celsius</i>
TEMP_CALIB_ACC_ENABLED				Set to 1 if ACC temperature calibration is enabled
TEMP_CALIB_ACC_SLOT_NUM[6]	1u*6	0	3	The number of calibrated temperature slots for accelerometer for each limit, in order [+X,+Y,+Z,-X,-Y,-Z]
TEMP_CALIB_ACC_T_MIN_CELS TEMP_CALIB_ACC_T_MAX_CELS	1s 1s			Range of temperature calibration <i>Units: Celsius</i>
H_ERR_LENGTH	1u	0	255	The length of error vector between estimated and referenced heading vectors. <i>Unit vector=100</i>
RESERVED	7b			

### CMD\_SCRIPT\_DEBUG (#58) – state of execution of user-written script

Name	Type	Min	Max	Possible values, remarks
CMD_COUNT	2u			current command counter
ERR_CODE	1u			see error definitions in the CMD_WRITE_FILE command

### CMD\_ADJ\_VARS\_STATE (#46) – receive the state of adjustable variables

Name	Type	Min	Max	Possible values, remarks
------	------	-----	-----	--------------------------

<i>Firmware ver. prior to 2.62b5</i>				
TRIGGER_RC_DATA	2s	-500	500	RC signal for the "trigger" variable slot
TRIGGER_ACTION	1u	0	255	ID of the triggered action. The full set of actions is given in the specification of MENU_BTN_CMD_1..5 parameters
ANALOG_RC_DATA	2s	-500	500	RC signal for the "analog" variable slot
ANALOG_VALUE	4s			Current value of the variable after all calculations
RESERVED	6b			
<i>Firmware ver. 2.62b5+</i>				
TRIGGER_RC_DATA	2s	-16384	16384	RC signal for the "trigger" variable slot
TRIGGER_ACTION	1u	0	255	ID of the triggered action. The full set of actions is given in the specification of MENU_BTN_CMD_1..5 parameters
ANALOG_SRC_VALUE	2s	-16384	16384	Signal value requested in the ANALOG_SRC_ID
ANALOG_VAR_VALUE	4f			Value of variable requested in the ANALOG_VAR_ID
LUT_SRC_VALUE	2s	-16384	16384	Signal value requested in the LUT_SRC_ID. Always encoded in a range -16384..16384.
LUT_VAR_VALUE	4f			Current value of variable requested in the LUT_VAR_ID

### CMD\_READ\_RC\_INPUTS (#100) - answer to the requested RC sources

Name	Type	Min	Max	Possible values, remarks
RC_VAL[N]	2s*N	-16384	16384	Values for each RC source in order as requested in the incoming CMD_READ_RC_INPUTS command. A special value RC_UNDEF=-32768 returned if signal is absent.

### CMD\_READ\_STATE\_VARS (#111) – result of reading system persistent state variables, cumulative statistics and maintenance data

(min. frw.ver. 2.68b7, "Extended" family only)

Name	Type	Min	Max	Possible values, remarks
STEP_SIGNAL_VAL[6]	6*1u			Step signal current value
SUB_ERROR	1u			Last code of EMERGENCY_STOP error
MAX_ACC	1u			Max. registered acceleration <i>Units: 1/16G</i>
WORK_TIME	4u			Total working time <i>Units: seconds</i>
STARTUP_CNT	2u			Counter of system starts
MAX_CURRENT	2u			Max. registered instant current consumption <i>Units: mA</i>
IMU_TEMP_MIN IMU_TEMP_MAX	1u 1u			IMU temperature <i>Units: C</i>
MCU_TEMP_MIN MCU_TEMP_MAX	1u 1u			Main MCU temperature <i>Units: C</i>

SHOCK_CNT[4]	4*1u			shock detector counter for specified thresholds
ENEGRY_TIME	4u			Time collecting consumed energy statistics <i>Units: seconds</i>
ENERGY	1f			Total consumed energy <i>Units: Watt*hour</i>
AVG_CURRENT_TIME	4u			Time collecting average current statistics <i>Units: seconds</i>
AVG_CURRENT	1f			Average current <i>Units: A</i>
RESERVED	152b			Zero bytes to keep payload size exactly 192 bytes

### CMD\_SET\_DEBUG\_PORT (#249) – receive serial API commands from all other ports for a debugging

This is for debug mode initiated by the [CMD\\_SET\\_DEBUG\\_PORT](#) outgoing command.

Name	Type	Min	Max	Possible values, remarks
TIME_MS	2u			Time since system start, in milliseconds
PORT_AND_DIR	1u			bits0..6: port index bit7: direction
CMD_ID	1u			Command id
PAYLOAD	...			Payload, variable length

## Run-time gimbal parameters

### Requests

#### CMD\_SET\_ADJ\_VARS\_VAL (#31) – Update the value of selected parameter(s).

This command is intended to change parameters on-the-fly during system operation, and does not save parameters to EEPROM.

To save updated parameters permanently, use the CMD\_SAVE\_PARAMS\_3 command.

The same command is also used as an outgoing command to read the value of adjustable variable(s).

Name	Type	Min	Max	Possible values, remarks
NUM_PARAMS	1u	1	40	Number of parameters in command
for N = (1..NUM_PARAMS)	PARAM<N>_ID	1u		ID of parameter. See the <a href="#">Appendix B: Run-time parameters definition (adjustable variables)</a> for a list of available variables.
	PARAM<N>_VALUE ...	4b		Value depends on type of parameter.  Values are packed according to C-language memory model, little-endian order. 1- or 2-byte types converted to 4-byte using C-language type conversions. Floats are packed according to IEEE-754.

On success, confirmation is sent in response.

#### CMD\_GET\_ADJ\_VARS\_VAL (#64) – Query the actual value of selected parameter(s).

This command requests actual values of adjustable parameters.

On success, [CMD\\_SET\\_ADJ\\_VARS\\_VAL](#) is sent in response.

Name	Type	Min	Max	Possible values, remarks
NUM_PARAMS	1u	1	40	Number of parameters in command
for N = (1..NUM_PARAMS)	PARAM<N>_ID	1u		ID of parameter. See the <a href="#">Appendix B: Run-time parameters definition (adjustable variables)</a> for a list of available variables.

#### CMD\_READ\_ADJ\_VARS\_CFG (#43) – request configuration of mapping of control inputs to adjustable variables

CMD\_READ\_ADJ\_VARS\_CFG incoming command is sent in response.

### CMD\_WRITE\_ADJ\_VARS\_CFG (#44) – writes configuration of mapping of control inputs to adjustable variables

Data format is the same as in corresponding CMD\_READ\_ADJ\_VARS\_CFG incoming command. On success, confirmation is sent in response.

### CMD\_SAVE\_PARAMS\_3 (#32) – Saves current values of parameters linked to adjustable variables, to EEPROM

Use this command to save parameters updated by the "Adjustable Variables", permanently to EEPROM. For parameters that are split to profiles, only the current profile slot is updated.

Name	Type	Min	Max	Possible values, remarks
ADJ_VAR_ID_1 ADJ_VAR_ID_2 ... ADJ_VAR_ID_N	1u*N			<i>frw.ver. 2.68b9+</i> Optional array of IDs of adjustable variables to save. If not specified, save all active adjustable variables.

### CMD\_ADJ\_VARS\_STATE (#46) – request the state of adjustable variable in the given trigger and analog slots.

*Firmware ver. prior to 2.62b5:*

Name	Type	Min	Max	Possible values, remarks
TRIGGER_SLOT	1u	0	9	
ANALOG_SLOT	1u	0	14	

*Firmware ver. 2.62b5+:*

Name	Type	Min	Max	Possible values, remarks
TRIGGER_SLOT	1u	0	9	"Trigger" slot number to show its state
ANALOG_SRC_ID	2u			Signal source to show its value
ANALOG_VAR_ID	1u			Variable ID to show its value
LUT_SRC_ID	2u			Signal source to show its value
LUT_VAR_ID	1u			Variable ID to show its value

## Responses

### CMD\_SET\_ADJ\_VARS\_VAL (#31) – receive the values of adjustable variables.

Sent as an answer on [CMD\\_GET\\_ADJ\\_VARS\\_VAL](#). See corresponding outgoing command for format description: [CMD\\_SET\\_ADJ\\_VARS\\_VAL](#)

### CMD\_READ\_ADJ\_VARS\_CFG (#43) – receive the configuration for adjustable variables

There are 10 "trigger" slots and 15 "analog" slots. "Trigger" type is used to execute action depending on the

RC signal level, where full range is split into 5 levels. "Analog" type is used to adjust parameter by RC signal. MIN\_VAL and MAX\_VAL specify a working range, that is mapped to a native range of particular parameter.

Name		Type	Min	Max	Possible values, remarks
slot = (1..10)	TRIGGER_SRC_CH	1u			See the <i>RC_MAP_ROLL</i> parameter definition
	TRIGGER_ACTION[5]	1u*5			See the <i>CMD_EXECUTE_MENU</i> command for a list of available actions
slot = (1..15)	ANALOG_SRC_CH	1u			See the <i>RC_MAP_ROLL</i> parameter definition
	VAR_ID	1u			bits0..6: the ID of variable. Full list of adjustable variables is given in the Appendix B  bit7: if set, the value is processed as a "multiplier" for a given variable. ( <i>frw. ver. 2.62b6+</i> )
	MIN_VAL	1u			
	MAX_VAL	1u			
RESERVED		8b			

## IMU correction and diagnostic

### Requests

#### CMD\_HELPER\_DATA (#72) – provide helper data for AHRS system

Use this command to increase precision of attitude estimation under certain conditions like curved or accelerated motion. More information in the [Appendix C: Providing external reference attitude/heading information from UAV](#)

*Legacy format (prior to frw. ver. 2.60):*

Name	Type	Min	Max	Possible values, remarks
FRAME_ACC[3]	2s*3	-	-	Linear acceleration of the frame, [X,Y,Z] components in a coordinate system <b>COORD_SYS_GROUND_YAW_ROTATED</b> (see description below).  <i>Units: <math>1g/512 \approx 0,019160156 \text{ m/s}^2</math></i>
FRAME_ANGLE_ROLL FRAME_ANGLE_PITCH	2s 2s	-32768	32767	Inclination of the outer frame in a given coordinate system. Pass zero values to not use this information.  <i>Units: <math>0,02197265625 \text{ degree}</math>.</i>

*Extended format (frw. ver. 2.60+):*

Name	Type	Min	Max	Possible values, remarks
FRAME_ACC[3]	2s*3	-	-	Linear acceleration of the frame with the inverted sign. Vector with the [X,Y,Z] components in a given coordinate system (see FLAGS below).  <i>Units: <math>1g/512 \approx 0,019160156 \text{ m/s}^2</math></i>
FRAME_ANGLE_ROLL FRAME_ANGLE_PITCH	2s 2s	-32768	32767	Inclination of the outer frame in the <b>COORD_SYS_GROUND_YAW_ROTATED</b> . These angles are used only in encoders or 2 <sup>nd</sup> IMU are not installed to roughly estimate the motor angles. Pass zero values to not use this information.  <i>Units: <math>0,02197265625 \text{ degree}</math>.</i>
FLAGS	1u			<b>bits 0..2:</b> coordinate system where FRAME_ACC and FRAME_SPEED vectors are defined. <b>COORD_SYS_GROUND_YAW_ROTATED = 1</b> Global system rotated with the camera over Z axis: Y-axis is aligned with the main IMU's Y-axis (points forward), X-axis points right, Z-axis points down (nadir)  <b>COORD_SYS_GROUND = 2</b> END Global system: X-axis matches true East, Y-axis matches true North, Z-axis matches nadir. <b>Notes:</b> END system differs from commonly used NED system. To convert, swap X and Y values in vectors. A magnetometer sensor should be installed and calibrated to give global reference for the main IMU. If no magnetometer present, Y-axis points arbitrary direction, so it is required to additionally provide the FRAME_HEADING parameter and use encoders to allow synchronization of the local coordinate system to earth-related system.  <b>COORD_SYS_FRAME = 3</b>

				<p>Coordinate system linked to the gimbal's outer frame: Y-axis matches frame's "forward", X-axis matches frame's "right", Z-axis matches frame's "down". For example, having an accelerometer-measured vector <code>acc_raw</code> in NED system in units m/s/s, compensate it for the gravity <code>acc = acc_raw - acc_1g</code> and convert it the following way:</p> <pre> FRAME_ACC[0] = -acc.y*52.19164 FRAME_ACC[1] = -acc.x*52.19164 FRAME_ACC[2] = -acc.z*52.19164 </pre> <p><b>Note:</b> one of the following conditions should be satisfied: - a 2<sup>nd</sup> frame-mounted IMU and YAW encoder in the regular firmware</p> <p><b>bits 3..5:</b> reserved</p> <p><b>bit6:</b> if set, the FRAME_HEADING is assumed to be computed in Euler order "ROLL-PITCH-YAW" rather than default "PITCH-ROLL-YAW" (frw. ver. 2.70b7+)</p> <p><b>bit7:</b> Use FRAME_HEADING parameter as a heading reference to align the IMU's local coordinate system to earth-related system, or to compensate gyro drift by the YAW axis if frame is fixed. If bit is not set, FRAME_HEADING is ignored (frw. ver. 2.62b7+)</p>
FRAME_SPEED[3]	2s*3	-	-	<p>Angular speed of the frame, [X,Y,Z] components in a given coordinate system. Helps to increase a precision of stabilization in systems w/out encoders or 2<sup>nd</sup> IMU. Pass zero values to not use this information.</p> <p><i>Units: 0,06103701895 degree/sec</i></p>
FRAME_HEADING (frw. ver. 2.62b7+)	2s	-16384	16384	<p>Angle of the frame relative to the North by the YAW axis. On first occurrence, YAW angle will be updated, taking into account the position of the main IMU relative to a frame. Then it will be used only as a reference for a gyro drift correction. If frame is fixed, it's enough to set this value once. But if frame is moving, it should be measured and update with the high enough rate (10-50Hz) to reflect the frame rotation.</p> <p>Remarks:  *bit7 in the FLAGS parameter should be set to use this value.  *Provided angle may be wrapped to +-180 degrees or 0..360 degrees.  *Special value of 32767 stops the use of this reference and makes IMU heading unreferenced.  *"Heading angle" is YAW angle expressed in Euler order PITCH-ROLL-YAW. Starting from firmware 2.70b7+, the FLAGS : bit6 can change it to "ROLL-PITCH-YAW".  * This correction has a priority compared to the correction received from the external IMU, if it's connected.</p> <p><i>Units: 0,02197265625 degree.</i></p>
RESERVED	1b			

For the lateral acceleration compensation, it is enough to provide only the FRAME\_ACC data, leaving all other fields empty. Feed fresh ACC and angles data with the pretty low rate 10-20 Hz, because strong low-pass filter is applied internally. If the FRAME\_SPEED data need to be provided, data rate should be much higher, up to 125 Hz.



How to ensure that the ACC correction is applied properly, on the bench:

1. Temporarily set the "ACC LPF" filter parameter in the GUI to 5-10Hz – it will remove noise but keep fast reaction of the "IMU\_G\_ERR" variable in the "Monitoring" tab of the GUI. This variable shows the distance between the estimated gravity vector and vector, measured by accelerometer.
2. Without motion, when you tilt the frame, the FRAME\_ACC vector should have all components close to zero. The IMU\_G\_ERR variable should be near zero, too.
3. Without correction, when you shake gimbal, you see that the IMU\_G\_ERR changes significantly. With the correction applied, when you shake gimbal, IMU\_G\_ERR always stays near zero - it means that the external accelerations are compensated.
4. When you rotate frame relative to earth in all directions, or rotate camera relative to frame, the 3<sup>rd</sup> test is still passed correctly – it means that the ACC correction vector is translated to the main IMU sensor properly.

### CMD\_AHRS\_HELPER (#56) – send or request attitude of the IMU sensor.

Use this command to provide a reference or replace the attitude estimated by the internal IMU sensor, by the attitude from a high-grade external IMU. The reasonable rate of sending this command is 20-50 Hz, maximum is 125 Hz. More information in the [Appendix C: Providing external reference attitude/heading information from UAV](#)

Name	Type	Min	Max	Possible values, remarks
MODE	1u or 2u**			<p><b>bit0:</b> 0 – get, 1 – set.  <b>bit1:</b> location of the source IMU: 0 – camera platform, 1 – frame (modified by bits 8,9)  <b>bit2:</b> if set, use as a reference only (any internal reference, if present, will be disabled). If not set, replaces the attitude and heading estimated by the internal sensor (both Z1 and H1 must be provided).  <b>bit3:</b> if set, translate from camera to frame (or back) and use as a reference.  <b>bit4,5:</b> selectively apply the correction by the provided Z and H vectors:              00 or 11 - use both Z and H vectors              01 - use Z vector only.              10 - use H vector only</p> <p><i>for frw.ver. 2.69b5+:</i>  <b>bit6,7:</b> selectively translate the correction (<b>bit3</b> should be set):              00 or 11 - translate both vectors              01 - translate Z vector only              10 - translate H vector only.</p> <p><i>for 2-byte MODE (optional in frw.ver. 2.69b5+):**:</i>  <b>bits8,9:</b> position of the reference system for the frame IMU correction:              00 – the same as frame IMU              01 – “on the frame”              10 – “below outer” (next to the outer motor in motor order counting from the frame)  <b>bit10</b> (<i>frw.ver.2.70b1+</i>): disable external correction for the given IMU and vectors (specified in bits 1,4,5). Restore internal correction, if possible (using accelerometer for Z1, magnetometer for H1).</p> <p>REMARKS ON FLAGS</p> <p><i>Bit1 encodes the position of the external source of attitude/heading information. When flag is set and frame IMU is not enabled, it counts “on the frame”. If frame IMU is enabled, it counts “in the frame IMU position”, but can be modified by flags</i></p>

				<p>8,9.</p> <p><i>If Bit2 is set, attitude/heading is applied as a reference and the strength of correction depends on the parameters "Gyro trust" (inverted rule) and "Heading correction factor". The provided attitude and heading data replace the internal accelerometer and magnetometer sensor data, respectively.</i></p> <p><i>Bit3 is taken into account only if all motor angles are known from encoders or may be estimated using other ways. Bit 3 should be set if reference IMU is located on the frame and you need to correct main IMU located on the stabilized platform.</i></p> <p><i>Bits 4,5 may be used to selectively correct/replace only H (heading) or Z (attitude) vectors. For example, you can leave Z corrected by the internal accelerometer, and correct only H (heading).</i></p> <p><i>Bits 8,9 may be useful if system has the frame IMU enabled and the source of a reference attitude is located in a different position. For example, if the frame IMU is "below outer motor" but the external IMU is mounted on the gimbal's frame, before applying the correction we convert it to the coordinate system, linked to the frame IMU.</i></p> <p>Below are some useful combinations of flags as an example:</p> <p>GET MODES</p> <p>0x00 - request the main IMU attitude 0x02 - request the frame IMU attitude</p> <p>SET MODES</p> <p>0x01 - use as a camera attitude (replaces the attitude estimated by the main IMU). 0x03 - replace the frame IMU attitude (if frame IMU is not enabled, use as gimbal's frame attitude). 0x05 - use as a reference for the main IMU. 0x07 - use as a reference for the frame IMU. 0x0B - replace the frame IMU attitude/heading (or use as a gimbal's frame attitude if frame IMU is not enabled), translate to the camera coordinates and use as a reference for the main IMU. 0x0F - use as a reference for the frame IMU, translate to the camera coordinates and use as a reference for the main IMU. 0x2F - the same as above, but correct only a heading (use H-vector only). 0x012F - external IMU is located on the frame, gimbal's frame IMU is located "below outer motor". After translation, use heading (H-vector) as a reference for the frame IMU and for the main IMU.</p>
Z_VECT[3]	4f*3	-1.0f	1.0f	Unit vector that points down in END coordinate system (North-East-Down)* with the origin linked to the camera (MODE.bit1=0) or to the frame IMU or frame (MODE.bit1=1)
H_VECT[3]	4f*3	-1.0f	1.0f	Unit vector that points towards North in END coordinate system (North-East-Down)* with the same origin

\* Note that we use system END that differs from commonly used NED. See [Appendix D: Coordinate system conversions](#)

\*\* MODE may be 1u or 2u for the extended flags supported starting from frw. ver. 2.69b5

**CMD\_GYRO\_CORRECTION (#75) – correct the gyroscope sensor's zero bias manually**

Name	Type	Min	Max	Possible values, remarks
IMU_TYPE	1u			0 – main IMU, 1 – frame IMU
GYRO_ZERO_CORR[3]	2s*3			Zero offset for each axis in order X, Y, Z <i>Units: 0.001 gyro sensor unit</i>
GYRO_ZERO_HEADING_C ORR	2s			Zero offset for global Z axis to correct a heading only. This correction is distributed to all axes automatically. <i>Units: 0.001 gyro sensor unit</i>

**Responses****CMD\_AHRS\_HELPER (#56) – current attitude in vector form.**

Name	Type	Min	Max	Possible values, remarks
Z_VECT[3]	4f*3	-1.0f	1.0f	Unit vector that points down in END coordinate system (North-East-Down)*
H_VECT[3]	4f*3	-1.0f	1.0f	Unit vector that points towards North in END coordinate system*

- Note that we use system END that differs from commonly used NED. See [Appendix D: Coordinate system conversions](#)

**AHRS\_DEBUG\_INFO - information about the AHRS state**

(frw.ver. 2.66+)

It's not a separate command. This structure is included as a part of other commands. Total size is 26 bytes.

Name	Type	Min	Max	Possible values, remarks
MAIN_IMU_REF_SRC	1u			Encodes the source of the reference information for the main IMU: bits 0..2: attitude reference source bits 3..5: heading reference source bit6: if set, internal sensor is connected and used; otherwise, AHRS information is set externally bit7: if set, the processing of this IMU is enabled  Possible values for reference sources:  REF_NO = 0 - no reference REF_INTERNAL = 1 - reference is provided by the internal sensor like accelerometer or magnetometer REF_EXTERNAL = 2 - reference is set externally by the serial API or external IMU REF_TRANSLATE = 3 - translate reference from other IMU (frame -> main, main -> frame)
FRAME_IMU_REF_SRC	1u			The same structure as for the main IMU.
MAIN_IMU_Z_REF_ERR	1u			Error between the reference defined by the MAIN_IMU_REF_SRC, and the estimated attitude

				<i>Units: 0.1°</i>
MAIN_IMU_H_REF_ERR	1u			Error between the reference defined by the MAIN_IMU_REF_SRC, and the estimated heading <i>Units: 0.1°</i>
FRAME_IMU_Z_REF_ERR	1u			Error between the reference defined by the FRAME_IMU_REF_SRC, and the estimated attitude <i>Units: 0.1°</i>
FRAME_IMU_H_REF_ERR	1u			Error between the reference defined by the FRAME_IMU_REF_SRC, and the estimated heading <i>Units: 0.1°</i>
EXT_IMU_STATUS	1u			bits 0..2 for status: STATUS_DISABLED = 0 STATUS_NOT_CONNECTED = 1 STATUS_UNKNOWN = 2 STATUS_ERROR = 3 STATUS_BAD = 4 STATUS_COARSE = 5 STATUS_GOOD = 6 STATUS_FINE = 7 (values 4..7 encode the quality of the attitude estimation)  bits 3..7 for flags: STATUS_FLAG_BAD_MAG = (1<<6) = 0x40 STATUS_FLAG_NO_GPS_SIGNAL = (1<<7) = 0x80
EXT_IMU_PACKETS_RECEIVED_CNT	2u	0	65535	
EXT_IMU_PARSE_ERR_CNT	2u	0	65535	
EXT_CORR_H_ERR	1u			Difference between the externally referenced heading and the current heading <i>Units: 0.1°</i>
EXT_CORR_Z_ERR	1u			Difference between the externally referenced attitude and the current attitude <i>Units: 0.1°</i>
RESERVED	13b			

## CMD\_EXT\_IMU\_DEBUG\_INFO (#106) – debug information for the external IMU sensor

(*frw.ver. 2.66+*)

Name	Type	Min	Max	Possible values, remarks
AHRS_DEBUG_INFO	26b			See the <a href="#">AHRS_DEBUG_INFO</a> specification
DCM	9*4f	-1.0f	1.0f	Rotation matrix (DCM) received from the external IMU and converted to the (END) (East-North-Down) coordinates.
ACC_BODY	3*4f			Linear acceleration (with the gravity vector subtracted) in sensor's local coordinates.

## Controlling gimbal movements

### Requests

#### CMD\_CONTROL (#67) – controls gimbal movement

Name	Type	Min	Max	Possible values, remarks
<i>Legacy format: mode is common for all axes</i>				
CONTROL_MODE	1u			<p>Bits 0..3 for mode, bits 4..7 for flags.</p> <p>Modes:</p> <p>MODE_NO_CONTROL=0 Finish serial control and restore normal RC control.</p> <p>MODE_IGNORE=7 (<i>frw.ver.2.70b4</i>) Ignore this axis and all parameters, keeping it in the actual state</p> <p>MODE_SPEED=1 Gimbal travels with the given speed in the Euler coordinates until the next CMD_CONTROL command comes. Given angle is ignored.</p> <p>MODE_ANGLE=2 MODE_ANGLE_SHORTEST=8 (<i>frw.ver.2.70b7</i>) Gimbal travels to the given Euler angle with the automatically calculated speed according to the acceleration limit. The nominal speed may be provided by the <b>SPEED</b> parameter. Speed is additionally attenuated near target to keep the control smooth (if CONTROL_FLAG_TARGET_PRECISE is not set).</p> <ul style="list-style-type: none"> <li>• MODE_ANGLE: gimbal travels to the new absolute setpoint angle, making multiple turns if needed, but limiting a rotation by <math>\pm 720^\circ</math> per command due to limited 16bit parameter range.</li> <li>• MODE_ANGLE_SHORTEST: gimbal travels to the point on a <math>360^\circ</math> circle by the shortest path, taking into account the software limits of encoders when choosing a direction (so it can go by the long path if the short path is blocked)</li> </ul> <p>MODE_SPEED_ANGLE=3 Gimbal travels with the given <b>SPEED</b> parameter. Additionally, controller keeps the given angle and fixes the accumulated error by adjusting the actual speed in a direction of error minimization, defined by the "Outer P" GUI parameter. This error may appear because the estimated target angle (integral of SPEED by dt) may differ from the actual target angle, because the actual target speed is internally filtered by LPF and acceleration limit, if they are enabled. This mode should be chosen when it's required to exactly repeat the rotation of the user-operated device (like joystic or wheel), precisely tracking its speed and angle.</p> <p>MODE_RC=4 The <b>ANGLE</b> parameter is used as RC signal and overrides any other signal source, assigned to this</p>

				<p>axis. Normal working range is -500..500. A special value -10000 encodes a "signal lost" condition. The flag CONTROL_FLAG_AUTO_TASK can affect this mode (see below).  <i>Prior to 2.61 frw. ver., 'SPEED' parameter is ignored.</i></p> <p>MODE_RC_HIGH_RES=6 (<i>frw. ver. 2.66b2</i>)  The same as the MODE_RC, but the range of the ANGLE parameter has better resolution: -16384..16384. A special value -32768 encodes a "signal lost" condition.</p> <p>MODE_ANGLE_REL_FRAME=5  First, the neutral point of a camera relative to a frame is found in the Euler coordinates for a given axis. Then, the given angle (in <math>\pm 360^\circ</math> range) is added to this point, and camera travels to it. Note that the given angle does not relate to a particular motor, it relates to global Euler angles!</p> <p>Flags:</p> <p>CONTROL_FLAG_AUTO_TASK=(1&lt;&lt;6)  <i>Firmware version: 2.62b7</i>  <i>Applicable for: MODE_ANGLE, MODE_ANGLE_SHORTEST, MODE_ANGLE_REL_FRAME</i>  The task is processed with the speed and acceleration configured for <i>automated tasks</i>. If the <b>SPEED</b> parameter is provided, it's used instead. When all target angles are reached with the 1-degree tolerance, confirmation is sent: CMD_CONFIRM(CMD_CONTROL, 1).  Use this flag to move gimbal to a certain position as fast as possible, and receive confirmation when the target is reached. If system can't process the planned trajectory for some reasons, motion will be interrupted after 10-second timeout.</p> <p>CONTROL_FLAG_FORCE_RC_SPEED=(1&lt;&lt;6)  <i>Firmware version: 2.62b7</i>  <i>Applicable for: MODE_RC</i>  This flag forces a control in the "SPEED" mode, with the dead-band, trimming and inversion settings are NOT applied to the provided RC signal, but the LPF, Expo curve and ACC limiter are still applied. Use this flag to control gimbal from remote applications, where signal is well-defined and you need to have a direction of rotation that does not depend on gimbal's "Inverse" and "Mode" parameters.</p> <p>CONTROL_FLAG_HIGH_RES_SPEED=(1&lt;&lt;7)  <i>Firmware version: 2.60b0</i>  <i>Applicable for: all modes</i>  Speed units changed to 0.001 deg/sec for extremely slow motion (like timelapse shooting)</p> <p>CONTROL_FLAG_TARGET_PRECISE=(1&lt;&lt;5)  <i>Firmware version: 2.70b1</i>  <i>Applicable for: MODE_ANGLE, MODE_ANGLE_SHORTEST, MODE_ANGLE_REL_FRAME</i>  If this flag is set, the speed is not decreased in a vicinity of target. It allows to get more predictive speed profile for the motion trajectory. If not set, actual speed is decreased near target to smooth over the jerks when</p>
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				<p>distance to target is small and target is updated frequently by small steps.</p> <p>CONTROL_FLAG_MIX_FOLLOW=(1&lt;&lt;4)</p> <p><i>Firmware version: 2.70b5</i></p> <p><i>Applicable for: MODE_SPEED, MODE_ANGLE, MODE_ANGLE_SHORTEST</i></p> <p>If this flag is set, the follow mode is not overridden, but is mixed with the commanded motion, like it happens for the regular RC control in SPEED or ANGLE mode. If this flag is not set, the commanded motion completely overrides the follow control for this axis.</p>
<i>Extended format (firmware ver. 2.55b5+): mode is set independently for each axes</i>				
CONTROL_MODE[3]	1u*3			see definition above
<i>The remaining part is common for all formats</i>				
axis = (1..3)	SPEED	2s	- - -	<p>Speed of rotation. Overrides the speed settings in the GUI</p> <p>Notes:</p> <ul style="list-style-type: none"> <li>If the acceleration limit is enabled in the settings, the actual speed is filtered by it for all modes</li> <li>For the modes MODE_ANGLE, MODE_RC, MODE_ANGLE_REL_FRAME, the value may be omitted (set to 0). In this case, speed is taken from the RC settings (or from the "Automated tasks" settings if CONTROL_FLAG_AUTO_TASK is set):  <math>SPEED = settings.RC\_SPEED * 16</math></li> <li>Additionally, the actual speed is decreased near target to prevent jerks, unless flag CONTROL_FLAG_TARGET_PRECISE is set.</li> </ul> <p><i>Units: 0,1220740379 deg./sec.</i>  <i>0.001 deg./sec., if CONTROL_FLAG_HIGH_RES_SPEED is set</i></p>
	ANGLE	2s	-32768 32767	<p>Depends on the MODE parameter:</p> <ul style="list-style-type: none"> <li>MODE_ANGLE, MODE_SPEED_ANGLE: encodes the absolute target angle. If CONTROL_FLAG_MIX_FOLLOW is set, angle is considered relative to the point where mode starts.</li> <li>MODE_SPEED: ignored</li> <li>MODE_RC: encodes RC signal in range -500..500</li> <li>MODE_RC_HIGH_RES: encodes RC signal in range -16384..16384</li> </ul> <p><i>Units: 0,02197265625 degree.</i></p>
<p>Notes:</p> <ul style="list-style-type: none"> <li>When CMD_CONTROL comes first time, it overrides the regular RC or Follow mode control, unless CONTROL_FLAG_MIX_FOLLOW is set. To switch back to a normal mode, send this command with the MODE=0 for all axes, and all data set to zeros. All parameters that were changed by the CMD_CONTROL_CONFIG, will be restored to their default values. Behavior is different if CONTROL_FLAG_AUTO_TASK is set: when the commanded motion is finished, system returns to a normal mode automatically.</li> <li>The optimal rate of sending this command is 50..125 Hz. If the rate of CMD_CONTROL command is lower, use a low-pass filtering to prevent step-wise response. It can be set by the command CMD_CONTROL_CONFIG separately for SPEED and ANGLE parameters, with the rule: the lower the rate, the more filtering is required.</li> <li>Confirmation is sent on each CMD_CONTROL command unless CONTROL_CONFIG_FLAG_NO_CONFIRM is set. Additional confirmation is sent when the target angle is reached, if CONTROL_FLAG_AUTO_TASK is set.</li> </ul>				

- Automated tasks has greater priority then CMD\_CONTROL. For example, executing menu command "Level ROLL to horizon" overrides CMD\_CONTROL for ROLL axis until task is finished.
- The ANGLE rage is limited by  $\pm 720^\circ$ . It's possible to get rid of this limitation by sending multiple commands in a sequence: when gimbal approaches the current setpoint, send a new setpoint with the ANGLE computed using natural C++ integer arithmetics with wrap-around overflow. Example: to make 3 full turns ( $1080^\circ$ ) the first command sends axis to  $720^\circ$  (ANGLE=32767) and the second command sends it to  $1080^\circ$  (ANGLE=-16384, which is computed as  $32767+16384$  in int16\_t variable).  
Starting from firmware 2.70b8, it's possible to send several commands in sequence immediately one after another (the only condition is that the distance between two setpoints does not exceed  $720^\circ$  or 32768), or use [CMD\\_CONTROL\\_EXT](#) were 20bit [ANGLE](#) parameter does not have such limitation and allows to command a rotation up to 4096 full turns in a single command.
- The ANGLE parameter doesn't always match the TARGET\_ANGLE variable (reported in CMD\_ANGLES, CMD\_REALTIME\_DATA and others), which means "the setpoint angle that gimbal should keep right now". Only after the motion sequence is finished, they match (excepting cases when CONTROL\_MODE and flags change the resulting setpoint before the motion starts, like "travel shortest distance" or "mix with the follow mode").
- This command is developing permanently: new modes and flags are added and behavior is improved, so old firmware versions may handle this mode differently then described in this document.
- See the [Appendix A](#) for a source code examples

## CMD\_CONTROL\_EXT (#121) – controls gimbal movement, extended version

(frw. ver. 2.68+)

An extended version of CMD\_CONTROL. It allows to omit unused fields to save the bandwidth. The content of the command depends on enabled bits in DATA\_SET parameter.

Name	Type	Min	Max	Possible values, remarks
DATA_SET	2u			Defines which data is provided in this command with a variable length. Bits are grouped by axes [0..4], [5..9], [10..14] In each group: bit0: SPEED parameter is given bit1: ANGLE parameter is given bit2: use 20 bit resolution for ANGLE bit3,4: reserved
axis=(1..3)	CONTROL_MODE	2u		See the <a href="#">CONTROL_MODE</a> parameter in CMD_CONTROL. If neither SPEED or ANGLE bits are enabled, the CONTROL_MODE parameter should be omitted for this axis
	SPEED	2s		See the <a href="#">SPEED</a> parameter in CMD_CONTROL
	ANGLE	2s 4s		See the <a href="#">ANGLE</a> parameter in CMD_CONTROL  If bit2 in corresponding DATA_SET group is set, ANGLE is encoded as 32-bit signed value with the resolution 20 bits per turn. Otherwise, it's 16-bit signed value with the resolution 14 bits per turn.  <i>Units: 0,00034332275390625 or 0,02197265625 degrees</i>

Confirmation (CMD\_CONFIRM) is sent in response, unless it's disabled in CMD\_CONTROL\_CONFIG.  
Error (CMD\_ERROR) is sent in response if format is incorrect (for example, payload size differs from





expected).

Examples (payload only):

00 1C 02 00 F4 01 00 00 30 00 – rotate YAW to 1080° (MODE\_ANGLE, 20bit), SPEED=61°/sec

00 0C 02 00 F4 01 00 10 – rotate YAW to 90° (MODE\_ANGLE, 14bit), SPEED=61°/sec

42 08 02 00 00 00 02 00 00 00 02 00 00 00 – move all axes to 0° with the default speed

## CMD\_CONTROL\_CONFIG (#90) – configure the handling of CMD\_CONTROL command

(frw. ver. 2.61+)

Name		Type	Min	Max	Possible values, remarks
TIMEOUT_MS		2u	0	65535	0 - disable timeout >0 - if no CMD_CONTROL command will come in a given time on any channel, serial control will be finished. Default value after startup is 0 (no timeout). <i>Units: ms</i>
CH1_PRIORITY CH2_PRIORITY CH3_PRIORITY CH4_PRIORITY THIS_CH_PRIORITY		1u*5	0	255	Channels are counted in order: UART1, RC_SERIAL, UART2, USB_VCP (how they are named in the User Manual). THIS_CH means current port, where command is sent. Values: 0 - do not change the priority 1..255 - set the priority of a given channel. In case of concurrent CMD_CONTROL commands, they will be accepted only on a channel that has higher or equal priority than others. <i>Default value is 0 for all channels after startup.</i>
axis = (1..3)	ANGLE_LPF	1u	0	15	LPF factor for filtering the 'ANGLE' parameter in the modes "MODE_ANGLE", "MODE_SPEED_ANGLE". Helps to keep smooth control even if update rate is slow.  <i>Default value is 0 – no filtering is applied.</i>
	SPEED_LPF	1u	0	15	LPF factor for filtering the 'SPEED' parameter in the modes "MODE_SPEED", "MODE_SPEED_ANGLE". Helps to keep smooth control even if update rate is slow.  <i>Default value is 0 – no filtering is applied.</i>
	RC_LPF	1u	0	15 (255)*	LPF factor for filtering RC signal in the mode "MODE_RC", "MODE_RC_HIGH_RES". Helps to keep smooth control even if update rate is slow. 0 – do not change.  <i>Default value is "RC_LPF" GUI parameter. This values overrides it until system will be re-initialized.</i> <i>*Range depends on the flag “Extend LPF range” in GUI settings.</i>
	ACC_LIMIT (frw.ver. 2.70b1)	2u	0	65535	Acceleration limiter filter, applied to speed profile in all control modes. 0 – do not change >0 – it overrides the default value from system settings. The default value is restored when serial control is finished by timeout, MODE_NO_CONTROL or when the <i>automated motion</i> (set by the flag CONTROL_FLAG_AUTO_TASK) is finished. Note: you have to set this value again at the start of each <i>automated motion</i> command.  <i>Units: degrees/sec<sup>2</sup></i>

JERK_SLOPE (frw.ver. 2.70b8+)	1u	0	255	<p>The rate of change of an acceleration, forming S-curve in a speed profile, increasing the smoothness of control. This parameter defines the time required to rise the acceleration from zero to a nominal value.</p> <p><i>Special values:</i>  0 – ignore this parameter (leave the value set before or default value from system configuration)  1 – disable jerk slope function</p> <p><i>Units: 20ms</i></p>
RESERVED	1b			
RC_EXPO_RATE	1u	0	100	<p>Exponential curve for filtering RC signal in the mode "MODE_RC".</p> <p>0 – do not change  Default value is taken from the "RC_EXPO_RATE" GUI parameter.</p>
FLAGS	2u			<p>CONTROL_CONFIG_FLAG_NO_CONFIRM=(1&lt;&lt;0)  (frww.ver. 2.66b2+)</p> <p>If set, controller does not send confirmation on each CMD_CONTROL command.</p>
RESERVED	10b			

Confirmation is sent on success.

*Note: all changes in control parameters are applicable only for CMD\_CONTROL and acts only while it's being active. When control finishes, the GUI-configured values are restored.*

### CMD\_API\_VIRT\_CH\_CONTROL (#45) – update a state of 32 virtual channels.

Named as "API\_VIRT\_CHxx" in the GUI; may be assigned as RC source to any task.

Name	Type	Min	Max	Possible values, remarks
API_VIRT_CH1 ... API_VIRT_CH32	2s*3 2	-500	500	<p>Value may go slightly outside these limits.  Use a special value "-10000" to mark that channel has "undefined" state (its treated as "signal lost" like with the regular RC inputs)</p>

*\* Starting from firmware 2.70b5, any number of channels (1..32) may be provided, to save bandwidth by omitting unused channels.*

### CMD\_API\_VIRT\_CH\_HIGH\_RES (#116) – update a state of 32 virtual channels

(frw.ver. 2.68b7+)

Named as "API\_VIRT\_CHxx" in the GUI; may be assigned as RC source to any task.

This command is similar to CMD\_API\_VIRT\_CH\_CONTROL, excepting it has higher resolution.

Name	Type	Min	Max	Possible values, remarks
API_VIRT_CH1 ... API_VIRT_CH32*	2s	-16384	16384	<p>Value may go slightly outside these limits.  Special value -32768 sets channel to undefined state (input is ignored)</p>

*\* Any number of channels (1..32) may be provided, to save bandwidth by omitting unused channels.*

## Miscellaneous commands

### Requests

#### CMD\_RESET (#114) – reset device

Simple format: no parameters. Resets the device without delay and confirmation

Extended format:

Name	Type	Min	Max	Possible values, remarks
FLAGS	1u			bit0 – if set, CMD_RESET will be sent to the host as a confirmation. bit1 – if set, back up some state variables and restore them after restart: <ul style="list-style-type: none"> <li>– motors ON/OFF state</li> <li>– setpoint angles</li> <li>– follow mode offset angles</li> </ul>
DELAY_MS	2u			After confirmation is sent, waits for a given time (in ms) before reset.

#### CMD\_BOOT\_MODE\_3 (#51) – enter bootloader mode to upload firmware

Simple format: no parameters. Enters boot mode without delay and confirmation

Extended format:

Name	Type	Min	Max	Possible values, remarks
CONFIRM	1u			0 – no confirmation 1 - command CMD_RESET will be sent back for confirmation
DELAY_MS	2u			After confirmation is sent, waits for a given time (in ms) before reset. External application can free up resources and properly close the serial connection before controller enters boot mode.

#### CMD\_TRIGGER\_PIN (#84) - trigger output pin

Name	Type	Min	Max	Possible values, remarks
PIN_ID	1u			Triggers pin only if it is not used for input  RC_INPUT_ROLL = 1 RC_INPUT_PITCH = 2 EXT_FC_INPUT_ROLL = 3 EXT_FC_INPUT_PITCH = 4 RC_INPUT_YAW = 5 PIN_AUX1 = 16 PIN_AUX2 = 17 PIN_AUX3 = 18 PIN_BUZZER = 32 PIN_SSAT_POWER** = 33

				** PIN_SSAT_POWER triggers 3.3V power line in the Spektrum connector (low state enables power)
STATE	1u			LOW = 0 (GND) - pin can sink up to 40mA HIGH = 1 (+3.3V) - pin can source up to 40mA FLOATING = 2 ( <i>frw. ver. 2.66+</i> )

Confirmation is sent only if pin is not occupied for other functions and was really triggered.

### CMD\_MOTORS\_ON (#77) - switch motors ON

No parameters. Confirmation is sent in response.

### CMD\_MOTORS\_OFF (#109) - switch motors OFF

Name	Type	Min	Max	Possible values, remarks
MODE ( <i>frw.ver. 2.68b7+</i> )	1u			0 – normal mode: turn motors OFF leaving driver in a high impedance; 1 – "break mode": turns motors OFF leaving driver in a low impedance; 2 – "safe stop" mode for unbalanced gimbals: reduce power and wait while all motors stop rotating, then power OFF completely.

Confirmation is sent in response.

### CMD\_EXECUTE\_MENU (#69) - execute menu command

Name	Type	Min	Max	Possible values, remarks
CMD_ID	1u			MENU_CMD_NO = 0 MENU_CMD_PROFILE1 = 1 MENU_CMD_PROFILE2 = 2 MENU_CMD_PROFILE3 = 3 MENU_CMD_SWAP_PITCH_ROLL = 4 MENU_CMD_SWAP_YAW_ROLL = 5 MENU_CMD_CALIB_ACC = 6 MENU_CMD_RESET = 7 MENU_CMD_SET_ANGLE = 8 MENU_CMD_CALIB_GYRO = 9 MENU_CMD_MOTOR_TOGGLE = 10 MENU_CMD_MOTOR_ON = 11 MENU_CMD_MOTOR_OFF = 12 MENU_CMD_FRAME_UPSIDE_DOWN = 13 MENU_CMD_PROFILE4 = 14 MENU_CMD_PROFILE5 = 15 MENU_CMD_AUTO_PID = 16 MENU_CMD_LOOK_DOWN = 17 MENU_CMD_HOME_POSITION = 18 MENU_CMD_RC_BIND = 19 MENU_CMD_CALIB_GYRO_TEMP = 20 MENU_CMD_CALIB_ACC_TEMP = 21 MENU_CMD_BUTTON_PRESS = 22 MENU_CMD_RUN_SCRIPT1 = 23 MENU_CMD_RUN_SCRIPT2 = 24

				MENU_CMD_RUN_SCRIPT3 = 25 MENU_CMD_RUN_SCRIPT4 = 26 MENU_CMD_RUN_SCRIPT5 = 27 MENU_CMD_CALIB_MAG = 33 MENU_CMD_LEVEL_ROLL_PITCH = 34 MENU_CMD_CENTER_YAW = 35 MENU_CMD_UNTWIST_CABLES = 36 MENU_CMD_SET_ANGLE_NO_SAVE = 37 MENU_HOME_POSITION_SHORTEST = 38 MENU_CENTER_YAW_SHORTEST = 39 MENU_ROTATE_YAW_180 = 40 MENU_ROTATE_YAW_180_FRAME_REL = 41 MENU_SWITCH_YAW_180_FRAME_REL = 42 MENU_SWITCH_POS_ROLL_90 = 43 MENU_START_TIMELAPSE = 44 MENU_CALIB_MOMENTUM = 45 MENU_LEVEL_ROLL = 46 MENU_REPEAT_TIMELAPSE = 47 MENU_LOAD_PROFILE_SET1 = 48 MENU_LOAD_PROFILE_SET2 = 49 MENU_LOAD_PROFILE_SET3 = 50 MENU_LOAD_PROFILE_SET4 = 51 MENU_LOAD_PROFILE_SET5 = 52 MENU_LOAD_PROFILE_SET_BACKUP = 53 MENU_INVERT_RC_ROLL = 54 MENU_INVERT_RC_PITCH = 55 MENU_INVERT_RC_YAW = 56 MENU_SNAP_TO_FIXED_POSITION = 57 MENU_CAMERA_REC_PHOTO_EVENT = 58 MENU_CAMERA_PHOTO_EVENT = 59 MENU_MOTORS_SAFE_STOP = 60 MENU_CALIB_ACC_AUTO = 61 MENU_RESET_IMU = 62 MENU_FORCED_FOLLOW_TOGGLE = 63 MENU_AUTO_PID_GAIN_ONLY = 64 MENU_LEVEL_PITCH = 65 MENU_MOTORS_SAFE_TOGGLE = 66 MENU_TIMELAPSE_STEP1 = 67 MENU_EXT_GYRO_ONLINE_CALIB = 68 MENU_DISABLE_FOLLOW_TOGGLE = 69 MENU_SET_CUR_POS_AS_HOME = 70 MENU_STOP_SCRIPT = 71 MENU_TRIPOD_MODE_OFF = 72 MENU_TRIPOD_MODE_ON = 73 MENU_SET_RC_TRIM = 74
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## CMD\_AUTO\_PID (#35) – Starts automatic PID calibration

(frw. ver. prior to 3.00)

Name	Type	Min	Max	Possible values, remarks
PROFILE_ID	1u			switch to this profile before start of the calibration and save result there
CFG_FLAGS	1u			AUTO_PID_CFG_ROLL = 1 AUTO_PID_CFG_PITCH = 2 AUTO_PID_CFG_YAW = 4 AUTO_PID_CFG_SEND_GUI = 8 - if set, sends a progress of tuning to the GUI in the CMD_AUTO_PID after each iteration AUTO_PID_CFG_KEEP_CURRENT = 16

				- if set, starts from existing settings. If not set, starts from zero AUTO_PID_CFG_TUNE_LPF_FREQ = 32 - if set, tunes LPF filters, too AUTO_PID_CFG_ALL_PROFILES = 64 - if set, updates tuned parameters in all profiles. Otherwise, updates only the selected profile.
GAIN_VS_STABILITY	1u	0	255	0 - better stability, 255 - better tracking of a reference
MOMENTUM	1u	0	255	0 - detect automatically, 1 - low weight and strong motor, 255 - big weight and weak motor
ACTION	1u			0 – start tuning
RESERVED	14b			

- On start, a confirmation is sent in the command CMD\_CONFIRM(CMD\_AUTO\_PID).
- When finished, the controller sends a full set of tuned parameters to the GUI (CMD\_READ\_PARAMS\_XX), for the selected or for all profiles.
- To interrupt currently running auto-tuning process, send this command with zero values in all fields.

### CMD\_AUTO\_PID2 (#108) – Starts automatic PID calibration ver.2

(frw. ver. 3.00+)

Name		Type	Min	Max	Possible values, remarks
ACTION		1u			ACTION_START=1 start tuning (do not update config in EEPROM) ACTION_START_SAVE=2 save config to EEPROM and start tuning ACTION_SAVE=3 save config to EEPROM ACTION_STOP=5 stop tuning ACTION_READ=6 read config from EEPROM
RESERVED		10b			
The following data is required only for ACTION_START, ACTION_START_SAVE:					
CFG_VERSION		1u			version 1
for axis = (1..3)	AXIS_FLAGS	1u			bit0: this axis is enabled bit1: tune LPF bits2..3: number of notch filters to tune, 0-3
	GAIN	1u	0	255	stability vs performance ratio
	STIMULUS	1u	0	255	stimulus signal strength
	EFFECTIVE_FREQ	1u	0	255	Effective frequency, Hz
	PROBLEM_FREQ	1u	0	255	Problematic frequency, Hz
	PROBLEM_MARGIN	1u	0	255	Problematic margin, dB*10
	RESERVED	6b			
GENERAL_FLAGS		2u			bit0: start from current values bit1: save result to all profiles

				bit2: tune gain only bit3: reserved bit4: auto-save
STARTUP_CFG	1u			Automatically run at system startup 0 - Disabled 1 - Tune gain only 2 - Tune all parameters
RESERVED	22b			

Confirmation is sent immediately in the command CMD\_CONFIRM(CMD\_AUTO\_PID2).

If error is detected in parameters, CMD\_ERROR is sent with the error code:

- 1: read from EEPROM failed (data is corrupted or empty)
- 2: can't run algorithm at this moment
- 3: write to EEPROM failed
- 4: unknown action
- 5: wrong command size

When finished, the controller sends a full set of tuned parameters to the GUI (CMD\_READ\_PARAMS\_XX), for the current profile.

### CMD\_SERVO\_OUT (#36) – Output PWM signal on the servo1..4 pins

Name	Type	Min	Max	Possible values, remarks
SERVO_TIME[4]*	2s*4	-1	2500	value < 0: free up this pin and make it floating value = 0: configure this pin as output and set it to 'Low' state value > 0: PWM pulse time, us. Should be less than PWM period, configured by the "SERVO_RATE" parameter. Regular servo accept values in range about 500..2500 us, 1500 us is neutral position, PWM period is 20000 us or less.  <i>frw.ver 2.70b8+:</i> in a special PWM duty cycle output mode, value 1000 corresponds to 0% duty cycle, value 2000 to 100% duty cycle.
RESERVED	8b			

Servo mode is available on the ports:

- Servo1 - EXT\_FC\_ROLL
- Servo2 - EXT\_FC\_PITCH
- Servo3 - RC\_PITCH 3
- Servo4 - AUX1

### CMD\_I2C\_WRITE\_REG\_BUF (#39) – writes data to any device connected to I2C line

Name	Type	Min	Max	Possible values, remarks
DEVICE_ADDR	1u			bit0: I2C port 0 for external port (IMU sensor is connected) 1 for internal port (EEPROM)  bit1..7: I2C address
REG_ADDR	1u			register to write
DATA	?			remaining bytes are counted as data

On successful writing, confirmation CMD\_CONFIRM is sent in response.

### CMD\_I2C\_READ\_REG\_BUF (#40) – requests reading from any device connected to I2C line

Name	Type	Min	Max	Possible values, remarks
DEVICE_ADDR	1u			bit0: I2C port 0 for external I2C port 1 for internal I2C port (where on-board I2C devices are connected)  bit1..7: I2C address*
REG_ADDR	1u			register to read (only 1-byte addressing is supported)
DATA_LEN	1u			length of data to read

On successful reading, CMD\_I2C\_READ\_REG\_BUF command is sent in response.

\* for example, to read from ICM-20602 on address 0x68 from 'who am I' register, payload is "D0 75 01"

### CMD\_RUN\_SCRIPT (#57) – start or stop user-written script

Name	Type	Min	Max	Possible values, remarks
MODE	1u			0 – stop 1 – start 2 – start with debug information is sent back in the CMD_SCRIPT_DEBUG
SLOT	1u	0	4	slot number, starting from 0.
RESERVED	32b			

### CMD\_BEEP\_SOUND (#89) – play melody by motors or emit standard beep sound

Name	Type	Min	Max	Possible values, remarks
MODE	2u			Pre-defined melodies: BEEPER_MODE_CALIBRATE = (1<<0) BEEPER_MODE_CONFIRM = (1<<1) BEEPER_MODE_ERROR = (1<<2) BEEPER_MODE_CLICK = (1<<4) BEEPER_MODE_COMPLETE = (1<<5) BEEPER_MODE_INTRO = (1<<6) Custom melody: BEEPER_MODE_CUSTOM_MELODY = (1<<15)
NOTE_LENGTH	1u	1	255	The duration of each note in custom melody mode. <i>Units: 8ms samples</i>
DECAY_FACTOR	1u	0	15	Set the envelope "attack-decay" after each pause, that makes sound more natural. The bigger value, the longer decay. 0 - no decay. *Note: envelope takes effect only in the encoder-enabled firmware or when motors are OFF. The same is true for the 'volume' parameter in the GUI.
RESERVED	8b			
NOTE_FREQ_HZ[N]	2u*N	554	21000	Array of 2u elements, size N = 0..50, - melody to play if



				mode=BEEPER_MODE_CUSTOM_MELODY. Special value 21000 used to restart the envelope. Value > 21000 restarts envelope and makes a pause with the duration (val – 21000) 8ms-samples. <i>Units: Hz</i>
--	--	--	--	--

Example1: simple melody with short B5, D6, G6 notes and envelope:

```
00 80 05 03 00 00 00 00 00 00 00 DB 03 DB 03 08 52 DB 03 DB 03 08 52 96 04 96 04 08
52 1F 06 1F 06 1F 06 1F 06 1F 06
```

Example2: standard "calibration" sound:

```
01 00 00 03 00 00 00 00 00 00 00 00
```

Example3: single beep 1 second at 3kHz:

```
00 80 7D 00 00 00 00 00 00 00 00 00 B8 0B
```

### CMD\_SIGN\_MESSAGE (#50) – sign message by secret keys

Name	Type	Min	Max	Possible values, remarks
SIGN_TYPE	1u			Defines a set of keys to be used
MESSAGE	32b			Message to be signed

Signed message is sent in response in the command CMD\_SIGN\_MESSAGE

### CMD\_EXT\_IMU\_CMD (#110) – forward message from the controller to the connected external IMU sensor

Name	Type	Min	Max	Possible values, remarks
CMD_ID	1u			Command ID (see GPS_IMU API specification for available commands)
DATA	...			Payload

The response from the external IMU will be sent back in the CMD\_EXT\_IMU\_CMD incoming command.

### CMD\_EXT\_SENS\_CMD (#150) – forward message to the GPS\_IMU sensor

(min. frw.ver. 2.68b7, "Extended" family only)

Forward message to the GPS\_IMU sensor connected by CAN bus and acting as a main IMU.

Name	Type	Min	Max	Possible values, remarks
FLAGS	1u			Bit0: high priority. Low priority messages may be lost or delayed during the transmission, while delivery of high priority messages is guaranteed.
COMAND_ID	1u			Command ID according to <a href="#">GPS_IMU Serial API</a>
DATA				All remaining bytes are sent as a payload. It doesn't include header and checksum.

All messages that GPS\_IMU sends in response, are wrapped by [CMD\\_EXT\\_SENS\\_CMD](#) incoming message.

### CMD\_CAN\_DEVICE\_SCAN (#96) – scan for the connected CAN devices

No parameters.

Controller scans all connected CAN devices and answers with the [CMD\\_CAN\\_DEVICE\\_SCAN](#) incoming command. CMD\_ERROR is sent in case of problems, with the ERROR\_CODE related to file operations.

## Responses

### CMD\_CONFIRM (#67) – confirmation of previous command or finished calibration

Name	Type	Min	Max	Possible values, remarks
CMD_ID	1u			Command ID to confirm
DATA	1u or 2u			DATA depends on command to be confirmed

### CMD\_ERROR (#255) – error executing previous command

Data depends on error type.

Name	Type	Min	Max	Possible values, remarks
ERROR_CODE	1u			Codes related to file operations: 0 - No error 1 - EEPROM access fault 2 - File is not found 3 - FAT records fault 4 - No free space left 5 - FAT is full 6 - File size is invalid 7 - CRC check failed 8 - Limit reached 9 - File corrupted 10 - Wrong params
ERROR_DATA	4b			

### CMD\_I2C\_READ\_REG\_BUF (#40) – result of reading from I2C device

Name	Type	Min	Max	Possible values, remarks
DATA	1..255b			Data length depends on the DATA_LEN parameter in the request.

### CMD\_AUTO\_PID (#35) – progress of PID auto tuning

This command is sent by the controller during the automatic PID tuning, if requested.

Name	Type	Min	Max	Possible values, remarks
P[3]	1u*3			
I[3]	1u*3			
D[3]	1u*3			
LPF_FREQ[3]	2u*3			
ITERATION_CNT	2u			
axis = (1..3)	TRACKING_ERROR	float		Current error between the target and actual system response
	RESERVED	6b		
RESERVED	10b			

### CMD\_RESET (#114) – notification on device reset

Device sent this command when goes to reset. There is a delay 1000ms after this command is sent and reset is actually done. External application can free up resources and properly close the serial connection.

### MOTOR4\_CONTROL - provides data for the external controller of the 4<sup>th</sup> axis motor

(frw.ver. 2.68+)

It's not a separate command. This structure is included as a part of other commands.

Name	Type	Min	Max	Possible values, remarks
FF_SPEED	2s			Feed-forward control <i>Units: 0,06103701895 degree/sec</i>
ANGLE_ERROR	2s			Distance to reach the target angle of 4 <sup>th</sup> axis <i>Units: 0,02197265625 degree</i>
PID_OUT	4f			The output of the internal PID loop running over the ANGLE_ERROR with the FF_SPEED mixed, scaled by the 'scale factor' parameter.

### CMD\_EVENT (#102) – sent when event is triggered

(frw.ver. 2.65+)

Name	Type	Min	Max	Possible values, remarks
EVENT_ID	1u			<b>EVENT_ID_MENU_BUTTON = 1</b> generated on the menu buttons press, hold or release actions. For the "hold" state, command is sent serially with the given interval. Supported types: EVENT_TYPE_OFF, EVENT_TYPE_ON, EVENT_TYPE_HOLD  <b>EVENT_ID_MOTOR_STATE = 2</b> generated on the motors ON/OFF action. Supported types: EVENT_TYPE_OFF, EVENT_TYPE_ON.  <b>EVENT_ID_EMERGENCY_STOP = 3</b> generated on the emergency stop error. Supported types: EVENT_TYPE_OFF, EVENT_TYPE_ON

				<b>EVENT_ID_CAMERA = 4</b> generated on the menu commands "Camera Rec[Photo] event" Supported types: EVENT_TYPE_REC_PHOTO, EVENT_TYPE_PHOTO  <b>EVENT_ID_SCRIPT = 5</b> ( <i>frw. ver. 2.68b8+</i> ) generated on script start (EVENT_TYPE_ON) and finish (EVENT_TYPE_OFF). PARAM1 holds the slot from where the script is executed.
EVENT_TYPE	1u			Possible value and its meaning depends on the EVENT_ID parameter.  <b>EVENT_TYPE_OFF = 1</b> state changed to OFF (button is released, motor is turned OFF)  <b>EVENT_TYPE_ON = 2</b> state is changed to ON (button is pressed, motors is turned ON)  <b>EVENT_TYPE_HOLD = 4</b> state is remaining ON (button is held).  <b>EVENT_TYPE_REC_PHOTO = 1</b> <b>EVENT_TYPE_PHOTO = 2</b> menu commands "Camera Rec/Photo event" and "Camera photo event"
PARAM1	2b			Possible value and its meaning depends on the EVENT_ID and EVENT_TYPE parameters:  <b>EVENT_ID_MENU_BUTTON</b> for the "release" and "hold" events, encodes the time period when the button was held (unsigned value in milliseconds)  <b>EVENT_ID_SCRIPT</b> slot from where the script is executed, starting from 0.
NOTE: this command may be expanded by extra parameters in future versions...				

### CMD\_SIGN\_MESSAGE (#50) – result of message signing

Name	Type	Min	Max	Possible values, remarks
SIGNATURE	32b			Signed message

### CMD\_EXT\_IMU\_CMD (#110) – forwarded message received from the connected external IMU sensor

Name	Type	Min	Max	Possible values, remarks
CMD_ID	1u			Command ID (see GPS_IMU API specification for available commands)
DATA	...			Payload

### CMD\_EXT\_SENS\_CMD (#150) – forward message from the GPS\_IMU sensor

(*min. frw.ver. 2.68b7, "Extended" family only*)

A forwarded message from the GPS\_IMU sensor connected by CAN bus and acting as a main IMU. This

message is sent in response to [CMD\\_EXT\\_SENS\\_CMD](#) outgoing message.

Name	Type	Min	Max	Possible values, remarks
COMAND_ID	1u			Command ID according to <a href="#">GPS_IMU Serial API</a>
DATA				All remaining bytes are for payload. It doesn't include header and checksum.

**CMD\_CAN\_DEVICE\_SCAN (#96) – result of scanning all connected CAN devices, with the ID assigned to them.**

Name	Type	Min	Max	Possible values, remarks
N=(1..DeviceNum)	UID	12b		Unique identifier of the device
	ID	1u		Assigned ID to this device, 0 if not assigned. 5 – CAN_IMU (main) 6 – CAN_IMU (frame) 7 – GPS_IMU (main) 17 – CAN_Drv#1 18 – CAN_Drv#2 19 – CAN_Drv#3 20 – CAN_Drv#4 21 – CAN_Drv#5 22 – CAN_Drv#6 23 – CAN_Drv#7 28 – CAN_IMU (main) (old) 29 – CAN_IMU (frame) (old) <i>On some firmware versions devices that can't be assigned, are not listed.</i>
	TYPE	1u		Bits 0..6: device type 1 – Motor driver 2 – IMU  Bit7: ID is hardware-assigned

## EEPROM and internal file system

### Requests

#### CMD\_READ\_FILE (#53) – read file from internal filesystem

This command reads a portion of data from a file with the identifier `FILE_ID`, started at `PAGE_OFFSET` pages (1page = 64byte) and to the end of file, but not more then `MAX_SIZE` bytes. Size of a portion should not exceed maximum allowed command data length (256 bytes). The result or error code is sent in the incoming command `CMD_READ_FILE`.

Name	Type	Min	Max	Possible values, remarks
FILE_ID	2u			1 <sup>st</sup> byte encodes the file type; 2 <sup>nd</sup> byte depends on type; <code>FILE_TYPE_SCRIPT</code> = 1 <code>FILE_TYPE_IMU_CALIB</code> = 3 <code>FILE_TYPE_COGGING_CORRECTION</code> = 4 <code>FILE_TYPE_ADJ_VAR_LUT</code> = 5 <code>FILE_TYPE_PROFILE_SET</code> = 6 <code>FILE_TYPE_PARAMS</code> = 7 <code>FILE_TYPE_TUNE</code> = 8 <code>FILE_TYPE_CANDRV</code> = 10
PAGE_OFFSET	2u			offset from the beginning, in pages. 1 page = 64 bytes.
MAX_SIZE	2u			
RESERVED	14b			

#### CMD\_WRITE\_FILE (#54) – write file to internal filesystem

This command writes a portion of data to a file with the identifier `FILE_ID`. If file is not exists, it is created. If `FILE_SIZE` is not equal to existing file size, file is adjusted to new size. If `DATA` is empty, file is deleted.

Name	Type	Min	Max	Possible values, remarks
FILE_ID	2u			See <code>CMD_READ_FILE.FILE_ID</code>
FILE_SIZE	2u			Full size of a file
PAGE_OFFSET	2u			offset from the beginning, in pages. 1 page = 64 bytes.
DATA	?			All remaining bytes are counted as data. Size should be less then <code>FILE_SIZE</code> parameter. If data is empty, file will be deleted.

In response `CMD_CONFIRM` is sent, with parameter `ERR_CODE`. Possible codes:

```

NO_ERROR = 0
ERR_EEPROM_FAULT = 1
ERR_FILE_NOT_FOUND = 2
ERR_FAT = 3
ERR_NO_FREE_SPACE = 4
ERR_FAT_IS_FULL = 5
ERR_FILE_SIZE = 6
ERR_CRC = 7
ERR_LIMIT_REACHED = 8
ERR_FILE_CORRUPTED = 9
ERR_WRONG_PARAMS = 10

```

**CMD\_FS\_CLEAR\_ALL (#55) – delete all files from internal filesystem**

Returns CMD\_CONFIRM with parameter ERR\_CODE (see definitions in the CMD\_WRITE\_FILE command)

**CMD\_EEPROM\_WRITE (#47) – writes a block of data to EEPROM to specified address**

Name	Type	Min	Max	Possible values, remarks
ADDR	4u	0	32767 *	address should be aligned to 64. *EEPROM size in all SBGC32 controllers is 32Kbytes.
DATA	?			All remaining bytes counted as data, arbitrary size but aligned to 64-byte pages

On success, confirmation CMD\_CONFIRM is sent with parameters CMD\_EEPROM\_WRITE, ADDR.

**CMD\_READ\_EXTERNAL\_DATA (#42) – receive user data, stored in the EEPROM**

External systems can use this area to store their configurations.

Name	Type	Min	Max	Possible values, remarks
DATA	128b			

**CMD\_EEPROM\_READ (#48) – request a reading of block of data from EEPROM at the specified address and size.**

Name	Type	Min	Max	Possible values, remarks
ADDR	4u	0	32767 *	address should be aligned to 64. *EEPROM size in all SBGC32 controllers is 32Kbytes.
SIZE	2u	64	192	size should be aligned to 64

On success, CMD\_EEPROM\_READ is sent in response.

**CMD\_WRITE\_EXTERNAL\_DATA (#41) – stores any user data to the dedicated area in the EEPROM**

Name	Type	Min	Max	Possible values, remarks
DATA	128b			

Confirmation is sent on success.

**CMD\_READ\_EXTERNAL\_DATA (#42) – request user data, stored in the EEPROM**

No parameters.

CMD\_READ\_EXTERNAL\_DATA is sent in response.

## Responses

### CMD\_READ\_FILE (#53) – result of reading file from internal filesystem

In case of success:

Name	Type	Min	Max	Possible values, remarks
FILE_SIZE	2u			total size of file, bytes
PAGE_OFFSET	2u			offset that was requested, in pages. 1 page = 64 bytes
DATA	?			size that was requested, or less if the end of file is reached

In case of errors:

Name	Type	Min	Max	Possible values, remarks
ERR_CODE	1u			see error definitions in the CMD_WRITE_FILE command

### CMD\_EEPROM\_READ (#48) – receive a portion of data read from EEPROM at the specified address.

Name	Type	Min	Max	Possible values, remarks
ADDR	4u			Address of a portion of data, 64-byte aligned
DATA	?			All remaining bytes are counted as data. Size is specified in the CMD_EEPROM_READ outgoing command.



## Appendix

### Command ID definitions

```
#define CMD_READ_PARAMS 82
#define CMD_WRITE_PARAMS 87
#define CMD_REALTIME_DATA 68
#define CMD_BOARD_INFO 86
#define CMD_CALIB_ACC 65
#define CMD_CALIB_GYRO 103
#define CMD_CALIB_EXT_GAIN 71
#define CMD_USE_DEFAULTS 70
#define CMD_CALIB_POLES 80
#define CMD_RESET 114
#define CMD_HELPER_DATA 72
#define CMD_CALIB_OFFSET 79
#define CMD_CALIB_BAT 66
#define CMD_MOTORS_ON 77
#define CMD_MOTORS_OFF 109
#define CMD_CONTROL 67
#define CMD_TRIGGER_PIN 84
#define CMD_EXECUTE_MENU 69
#define CMD_GET_ANGLES 73
#define CMD_CONFIRM 67
#define CMD_BOARD_INFO_3 20
#define CMD_READ_PARAMS_3 21
#define CMD_WRITE_PARAMS_3 22
#define CMD_REALTIME_DATA_3 23
#define CMD_REALTIME_DATA_4 25
#define CMD_SELECT_IMU_3 24
#define CMD_READ_PROFILE_NAMES 28
#define CMD_WRITE_PROFILE_NAMES 29
#define CMD_QUEUE_PARAMS_INFO_3 30
#define CMD_SET_ADJ_VARS_VAL 31
#define CMD_SAVE_PARAMS_3 32
#define CMD_READ_PARAMS_EXT 33
#define CMD_WRITE_PARAMS_EXT 34
#define CMD_AUTO_PID 35
#define CMD_SERVO_OUT 36
#define CMD_I2C_WRITE_REG_BUF 39
#define CMD_I2C_READ_REG_BUF 40
#define CMD_WRITE_EXTERNAL_DATA 41
#define CMD_READ_EXTERNAL_DATA 42
#define CMD_READ_ADJ_VARS_CFG 43
#define CMD_WRITE_ADJ_VARS_CFG 44
#define CMD_API_VIRT_CH_CONTROL 45
#define CMD_ADJ_VARS_STATE 46
#define CMD_EEPROM_WRITE 47
#define CMD_EEPROM_READ 48
#define CMD_CALIB_INFO 49
#define CMD_SIGN_MESSAGE 50
#define CMD_BOOT_MODE_3 51
#define CMD_SYSTEM_STATE 52
#define CMD_READ_FILE 53
#define CMD_WRITE_FILE 54
#define CMD_FS_CLEAR_ALL 55
#define CMD_AHRS_HELPER 56
#define CMD_RUN_SCRIPT 57
#define CMD_SCRIPT_DEBUG 58
#define CMD_CALIB_MAG 59
#define CMD_GET_ANGLES_EXT 61
```

```
#define CMD_READ_PARAMS_EXT2 62
#define CMD_WRITE_PARAMS_EXT2 63
#define CMD_GET_ADJ_VARS_VAL 64
#define CMD_CALIB_MOTOR_MAG_LINK 74
#define CMD_GYRO_CORRECTION 75
#define CMD_DATA_STREAM_INTERVAL 85
#define CMD_REALTIME_DATA_CUSTOM 88
#define CMD_BEEP_SOUND 89
#define CMD_ENCODERS_CALIB_OFFSET_4 26
#define CMD_ENCODERS_CALIB_FLD_OFFSET_4 27
#define CMD_CONTROL_CONFIG 90
#define CMD_CALIB_ORIENT_CORR 91
#define CMD_COGGING_CALIB_INFO 92
#define CMD_CALIB_COGGING 93
#define CMD_CALIB_ACC_EXT_REF 94
#define CMD_PROFILE_SET 95
#define CMD_CAN_DEVICE_SCAN 96
#define CMD_CAN_DRV_HARD_PARAMS 97
#define CMD_CAN_DRV_STATE 98
#define CMD_CAN_DRV_CALIBRATE 99
#define CMD_READ_RC_INPUTS 100
#define CMD_REALTIME_DATA_CAN_DRV 101
#define CMD_EVENT 102
#define CMD_READ_PARAMS_EXT3 104
#define CMD_WRITE_PARAMS_EXT3 105
#define CMD_EXT_IMU_DEBUG_INFO 106
#define CMD_SET_DEVICE_ADDR 107
#define CMD_AUTO_PID2 108
#define CMD_EXT_IMU_CMD 110
#define CMD_READ_STATE_VARS 111
#define CMD_WRITE_STATE_VARS 112
#define CMD_SERIAL_PROXY 113
#define CMD_IMU_ADVANCED_CALIB 115
#define CMD_API_VIRT_CH_HIGH_RES 116
#define CMD_CALIB_ENCODER_LUT 117
#define CMD_CALIB_ENCODER_LUT_RES 118
#define CMD_WRITE_PARAMS_SET 119
#define CMD_CALIB_CUR_SENS 120
#define CMD_CONTROL_EXT 121
#define CMD_EXT_SENS_CMD 150

#define CMD_SET_DEBUG_PORT 249
#define CMD_MAVLINK_INFO 250
#define CMD_MAVLINK_DEBUG 251
#define CMD_DEBUG_VARS_INFO_3 253
#define CMD_DEBUG_VARS_3 254
#define CMD_ERROR 255
```

## Appendix A: Examples and libraries

We provide a comprehensive C-language library with examples for various platforms:

<https://github.com/basecamelectronics/sbgc32-serial-api>

See README.md for details.

### CRC16 reference implementation in C

```
void crc16_update(uint16_t length, uint8_t *data, uint8_t crc[2]) {
    uint16_t counter;
    uint16_t polynom = 0x8005;
    uint16_t crc_register = (uint16_t)crc[0] | ((uint16_t)crc[1] << 8);
    uint8_t shift_register;
    uint8_t data_bit, crc_bit;

    for (counter = 0; counter < length; counter++) {
        for (shift_register = 0x01; shift_register > 0x00; shift_register <= 1) {
            data_bit = (data[counter] & shift_register) ? 1 : 0;
            crc_bit = crc_register >> 15;
            crc_register <= 1;

            if (data_bit != crc_bit) crc_register ^= polynom;
        }
    }

    crc[0] = crc_register;
    crc[1] = (crc_register >> 8);
}

void crc16_calculate(uint16_t length, uint8_t *data, uint8_t crc[2]) {
    crc[0] = 0; crc[1] = 0;
    crc16_update(length, data, crc);
}
```

Example with CRC16 for command CMD\_BOARD\_INFO:

start byte	header			payload		CRC16	
	command ID	payload size	header checksum				
0x24	0x56	0x02	0x58	0x00	0x00	0xE6	0x13

## Appendix B: Run-time parameters definition (adjustable variables)

NAME	Frw. ver.	ID	TYPE	MIN	MAX	REMARK
P_ROLL P_PITCH P_YAW		0 1 2	1u	0	255	
I_ROLL I_PITCH I_YAW		3 4 5	1u	0	255	
D_ROLL D_PITCH D_YAW		6 7 8	1u	0	255	
POWER_ROLL POWER_PITCH POWER_YAW		9 10 11	1u	0	255	
ACC_LIMITER		12	2s	0	1275	Units: degrees/sec <sup>2</sup>
FOLLOW_SPEED_ROLL FOLLOW_SPEED_PITCH FOLLOW_SPEED_YAW		13 14 15	1u	0	255	
FOLLOW_LPF_ROLL FOLLOW_LPF_PITCH FOLLOW_LPF_YAW		16 17 18	1u	0	15	
RC_SPEED_ROLL RC_SPEED_PITCH RC_SPEED_YAW		19 20 21	1u	0	255	
RC_LPF_ROLL RC_LPF_PITCH RC_LPF_YAW		22 23 24	1u	0	15 (255)*	*Range depends on the flag "Extend LPF range" in GUI settings
RC_TRIM_ROLL RC_TRIM_PITCH RC_TRIM_YAW		25 26 27	1s	-127	127	
RC_DEADBAND		28	1u	0	255	
RC_EXPO_RATE		29	1u	0	100	
FOLLOW_PITCH		30	1u	0	1	0 – disabled 1* – Follow PITCH [optionally ROLL] *frw. ver. 2.65b3
FOLLOW_YAW_PITCH		31	1u	0	2	0 – disabled 1 - Follow YAW 2* – Follow YAW, PITCH [ROLL] *frw. ver. 2.65b3
FOLLOW_DEADBAND		32	1u	0	255	
FOLLOW_EXPO_RATE		33	1u	0	100	
FOLLOW_ROLL_MIX_START		34	1u	0	90	
FOLLOW_ROLL_MIX_RANGE		35	1u	0	90	
GYRO_TRUST		36	1u	0	255	
FRAME_HEADING_ANGLE		37	2s	-1800	1800	The frame's heading (YAW) angle expressed in Euler order frame-PITCH-ROLL-YAW used as an absolute heading reference for the gyroscope sensor. Effect is similar to the

						FRAME_HEADING variable in the CMD_HELPER_DATA. <i>Units: 0.1 degrees</i> <i>Special value 0x7FFF disables the correction</i>
GYRO_HEADING_CORRECTION		38	2s	-20000	20000	Units: 0.001 of gyro sensor units
ACC_LIMITER_ROLL ACC_LIMITER_PITCH ACC_LIMITER_YAW		39 40 41	2s	0	1275	Units: degrees/sec <sup>2</sup>
PID_GAIN_ROLL PID_GAIN_PITCH PID_GAIN_YAW		42 43 44	1u	0	255	Gain is calculated as 0.1 + PID_GAIN[axis]*0.02
LPF_FREQ_ROLL LPF_FREQ_PITCH LPF_FREQ_YAW		45 46 47	2u	10	400	Units: Hz
TIMELAPSE_TIME		48	2u	1	3600	Units: sec
MAV_CTRL_MODE		49	1u	0	2	0 – disabled 1 – ROLL and PITCH only 2 – enabled for all axes
H_CORR_FACTOR	2.68b7	50	1u	0	255	Heading correction factor from external reference
SW_LIM_MIN.ROLL SW_LIM_MAX.ROLL SW_LIM_MIN.PITCH SW_LIM_MAX.PITCH SW_LIM_MIN.YAW SW_LIM_MAX.YAW	2.68b8	51 52 53 54 55 56	2s	-3600	3600	Software limits for each motor, degrees (encoder firmware only) <i>Note: set new values only in pairs, min should go prior to max!</i>
FOLLOW_RANGE.ROLL FOLLOW_RANGE.PITCH FOLLOW_RANGE.YAW	2.68b9	57 58 59	1u	0	255	Units: degrees
AUTO_PID_TARGET	2.68b9	60	1u	0	255	Stability-precision slider for automatic PID tuning algorithm
RC_MODE.ROLL RC_MODE.PITCH RC_MODE.YAW	2.69b3	61 62 63	1u			0 – ANGLE 1 – SPEED 2 – TRACKING
EULER_ORDER	2.69b3	64	1u			0 – PITCH-ROLL-YAW 1 – ROLL-PITCH-YAW 2 – PITCH(M)-ROLL-YAW(M) 3 – ROLL-PITCH(M)-YAW(M) 4 – YAW-ROLL-PITCH
FOLLOW_IN_DBAND	2.70b4	65	1u	0	255	“Follow inside deadband” parameter

## Appendix C: Providing external reference attitude/heading information from UAV

Serial API allows for flight controllers of UAVs to send attitude and heading information that can be used as a reference to correct attitude and heading of internal IMU, improving its precision. As a rule, flight controllers have more sensors on-board and can do better attitude/heading angles estimation than the IMU sensor used in the SBGC32 controller.

This kind of correction is described in detail in section 18 of the "SimpleBGC32 User Manual". Our controller supports direct connection only for several models of AHRS/IMU devices. For others, Serial API can be used.

In a few words, there are two options to apply the correction:

1. provide attitude and/or heading of the frame via command `CMD_AHRS_HELPER`
2. compensate for linear accelerations via command `CMD_HELPER_DATA`

Option 1) is better because the attitude/heading information is used directly, allowing to disable the internal accelerometer and keep using the internal gyroscope only. However, it requires knowing an exact attitude of the gimbal's frame. But a common case when the gimbal mounted on the UAV has anti-vibration dampeners, which add some degree of freedom. It makes using attitude/heading information from the UAV's flight controller not applicable for a precise attitude correction for the gimbal's IMU.

Option 2) is more tolerant in this case. You can use it to compensate the attitude drift caused by an accelerated motion and the heading drift causing by an unreferenced YAW gyroscope. Attitude/heading is still computed inside the gimbal's controller, using an internal accelerometer and gyroscope. You need to pass linear accelerations (with the gravity subtracted) in the command `CMD_HELPER_DATA`. Also, for 3-axis systems, you have to provide heading information to synchronize the camera's heading angle with the UAV's heading. "Heading" here is the Euler's YAW angle expressed in order "frame-PITCH-ROLL-YAW" (note that the order of angles does matter; the commonly used in aeronautics "ROLL-PITCH-YAW" will give different values for the same physical orientation).

As a drawback, option 2) does not help to compensate for a drift caused by the thermal instability of the gyroscope and accelerometer sensors.

### Using high-grade IMU for a correction

If a high-grade IMU is used instead of UAV, there are several options where to mount it: on the frame (above the outer motor), below the outer motor, or on the camera platform. The last option provides the best accuracy because mechanical imperfection and encoder calibration do not distort the AHRS data.

### Notes on data rates and how to interrupt the correction

The more data rate is, the better. Though, as this correction is a kind of low-pass filter, and it changes the actual attitude very slowly, it is okay to have a slow data rate and still have a good result. There are no reasons to have it higher than 125 Hz as it's the maximum processing rate of Serial API messages.

The last data received in the `CMD_AHRS_HELPER` / `CMD_HELPER_DATA` messages is considered as the actual attitude/heading until it's updated by the new portion of data. If the host controller stops sending these messages, but system actually moves, it leads to serious confusion of the IMU subsystem.

Starting from firmware ver. 2.70b1 it is possible to properly stop the correction by sending a command `CMD_AHRS_HELPER` with the flag "Disable correction" (bit10 in the `MODE` parameter). For the `CMD_HELPER_DATA` it's enough to send zero accelerations and special value 32767 for the `FRAME_HEADING` parameter.

## Appendix D: Coordinate system conversions

If not specified, it's assumed the END (East-North-Down) coordinate system, that differs from commonly used NED system: in our system, X points right (or East), Y points forward (or North), Z points down. To convert vectors to NED system, you need to swap X and Y components.

### Rotation matrix

CMD\_AHRS\_HEPER provides and takes orientation data in a form of rotation matrix (DCM), but first row is omitted to save the bandwidth. The full rotation matrix can be reconstructed from two vectors H\_VECT and Z\_VECT:

$$DCM_{END} = \begin{pmatrix} A_x & A_y & A_z \\ H_x & H_y & H_z \\ Z_x & Z_y & Z_z \end{pmatrix} = \begin{pmatrix} A_{VECT} \\ H_{VECT} \\ Z_{VECT} \end{pmatrix},$$

$$A_{VECT} = H_{VECT} \times Z_{VECT}$$

Z\_VECT and H\_VECT can be considered as unit vectors in body reference system pointing down and North directions.

To convert rotation matrix from / to commonly used NED coordinate system, just swap first two rows:

$$DCM_{NED} = \begin{pmatrix} H_x & H_y & H_z \\ A_x & A_y & A_z \\ Z_x & Z_y & Z_z \end{pmatrix}$$

Note that some systems need an alternative definition of rotation matrix: (body-to-world or world-to-body defines the same rotations but in opposite direction), so DCM may need to be transposed (i.e. rows arranged as columns).

### Quaternions

Serial API does not provide quaternions prior to firmware version 3.00x, but the rotation matrix can be converted to / from quaternion without loss of precision.

### Euler angles

Serial API provides and takes all angles in a form of *Euler angles*. Attitude/heading can be reconstructed from Euler angles, but it is important taking into account the order of Euler rotations. SBGC32 supports several orders that may be configured in system parameters. Since this order is not known in advance, it's better to avoid using Euler angles to represent the rotations in calculations. Another problem is that Euler rotations are not free from *gimbal lock* problem. Rotation matrix is free from this problem and correctly represents all possible positions.

## Appendix E: “Emergency stop” error codes

- SUB\_ERR\_I2C\_ERRORS = 1, // High rate of I2C errors
- SUB\_ERR\_DRV\_OTW = 2, // Driver over-temperature protection
- SUB\_ERR\_DRV\_FAULT = 3, // Driver fault (under-voltage, over-current, short circuit)
- SUB\_ERR\_ENCODER\_IMU\_ANGLE = 4, // Encoder/IMU angles mismatch
- SUB\_ERR\_CALIBRATION\_FAILED = 5, // Auto calibration process caused serious fault
- SUB\_ERR\_INTERNAL\_SYSTEM\_ERROR = 6, // Stack is damaged
- SUB\_ERR\_ENCODER\_CALIB\_BAD\_SCALE = 7, // estimated scale differs a lot from configured
- SUB\_ERR\_OVER\_TEMPERATURE = 8, // MCU or power board over temperature
- SUB\_ERR\_BAD\_MOTOR\_POLES\_INVERT = 9, // motor n.poles or inversion is wrong
- SUB\_ERR\_NOT\_ENOUGH\_MEMORY = 10, // static\_malloc() can't allocate memory
- SUB\_ERR\_IMU\_SENSOR\_NOT\_RESPONDING = 11, // lost connection to IMU sensor
- SUB\_ERR\_CAN\_HARD = 12, // CAN on board hardware error
- SUB\_ERR\_MOTOR\_OVERHEAT\_PROTECTION = 13, // overheat protection is triggered
- SUB\_ERR\_MOTOR\_IS\_LOCKED = 14, // motor is locked during automated task
- SUB\_ERR\_BAD\_IMU\_HEALTH = 15, // IMU gyroscope and accelerometer error is too big: sensor sends corrupted data or wrong use conditions
- SUB\_ERR\_INFINITE\_RESET = 16, // Infinite reset loop is detected
- SUB\_ERR\_WRONG\_INITIAL\_POSITION = 17, // wrong position: failed to detect encoder angle, or angle is outside soft limits
- SUB\_ERR\_MOTOR\_LOAD\_TIME\_EXCEEDED = 18, // motors are fully loaded too long time
- SUB\_ERR\_CAN\_DRV\_OVERCURRENT = 19, // hardware short-circuit protection
- SUB\_ERR\_CAN\_DRV\_UNDERVOLTAGE = 20, // hardware or software undervoltage protection
- SUB\_ERR\_CAN\_DRV\_EMERGENCY\_PIN = 21, // external emergency is triggered
- SUB\_ERR\_CAN\_DRV\_FOC\_DURATION = 22, // FOC algorithm duration error
- SUB\_ERR\_CAN\_DRV\_MCU\_OVERHEAT = 23, // driver temperature is too high
- SUB\_ERR\_CAN\_DRV\_MOTOR\_OVERHEAT = 24, // motor temperature is too high
- SUB\_ERR\_CAN\_DRV\_OVERCURRENT\_SOFT = 25, // current through motor exceed limit
- SUB\_ERR\_CAN\_DRV\_SEVERAL = 26, // several errors on driver
- SUB\_ERR\_CAN\_EXT\_BUS\_OFF = 27, // CAN bus high rate errors of slave controller
- SUB\_ERR\_CAN\_INT\_BUS\_OFF = 28, // CAN bus high rate errors of main controller
- SUB\_ERR\_ENCODER\_NOT\_FOUND = 29, // no any answer from encoder during init
- SUB\_ERR\_CAN\_DRV\_NOT\_RESPONDING = 30, // lost connection to CAN Drv
- SUB\_ERR\_CAN\_DRV\_WRONG\_PARAMS = 31, // some params of CAN Drv isn't correct
- SUB\_ERR\_OVERCURRENT = 32, // fast over current protection of main controller, or short circuit detection on startup
- SUB\_ERR\_UNSAFE\_VOLTAGE = 33, // Under voltage protection or supply protection controller fault
- SUB\_ERR\_WRONG\_FULL\_BAT\_VOLTAGE\_PARAM = 34, // battery voltage is higher than expected at startup sequence
- SUB\_ERR\_EEPROM\_PARAMS\_CORRUPTED = 35, // parameters are corrupted in EEPROM and can't be restored from backup slot
- SUB\_ERR\_ENCODER\_UNSUPPORTED\_TYPE = 36, // unsupported type of encoder
- SUB\_ERR\_EXT\_IMU\_UNSUPPORTED\_TYPE = 37, // unsupported type of external imu of CAN Imu, need update CAN Imu FW
- SUB\_ERR\_EXT\_IMU\_SENSOR\_NOT\_RESPONDING = 38, // lost connection to external imu of CAN Imu
- SUB\_ERR\_EXT\_IMU\_WRONG\_PARAMS = 39, // some errors in self test in external imu of CAN Imu, or difference of int. and ext. is too big



- SUB\_ERR\_DRIVER\_INIT = 40, // initialization of ext. motor driver failed
- SUB\_ERR\_EEPROM\_VARS\_OUT\_OF\_BORDERS = 41, // \_write\_vars() or \_read\_vars() out of borders
- SUB\_ERR\_IWDG\_RESET = 42, // system was reset by watch-dog timer
- SUB\_ERR\_ADC\_WAIT = 43, // error waiting for ADC samples
- SUB\_ERR\_CALIB\_MOTOR\_OFF = 44, // need power motor for calibration process
- SUB\_ERR\_TIMEOUT = 45,
- SUB\_ERR\_CAN\_DRV\_CALIB\_UNEXPECTED\_RES = 46, // CAN DRV RL calibration error
- SUB\_ERR\_MAG\_SENSOR\_NOT\_RESPONDING = 47, // lost connection to MAG sensor
- SUB\_ERR\_CAN\_DRV\_OVERSPEED = 48, // CAN Drv spin too fast
- SUB\_ERR\_ENC\_SELF\_CALIB\_FAILED = 49, // encoder self calibration failed