SuM Hardware Manual

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Applicable Hardware Revision	SuM HAT rev. 1.1 HifiBerry DAC+ADC Pro Raspberry Pi 4B+

1 Hardware Description

The main hardware features of the SuM HAT are highlighted in Fig. 1:

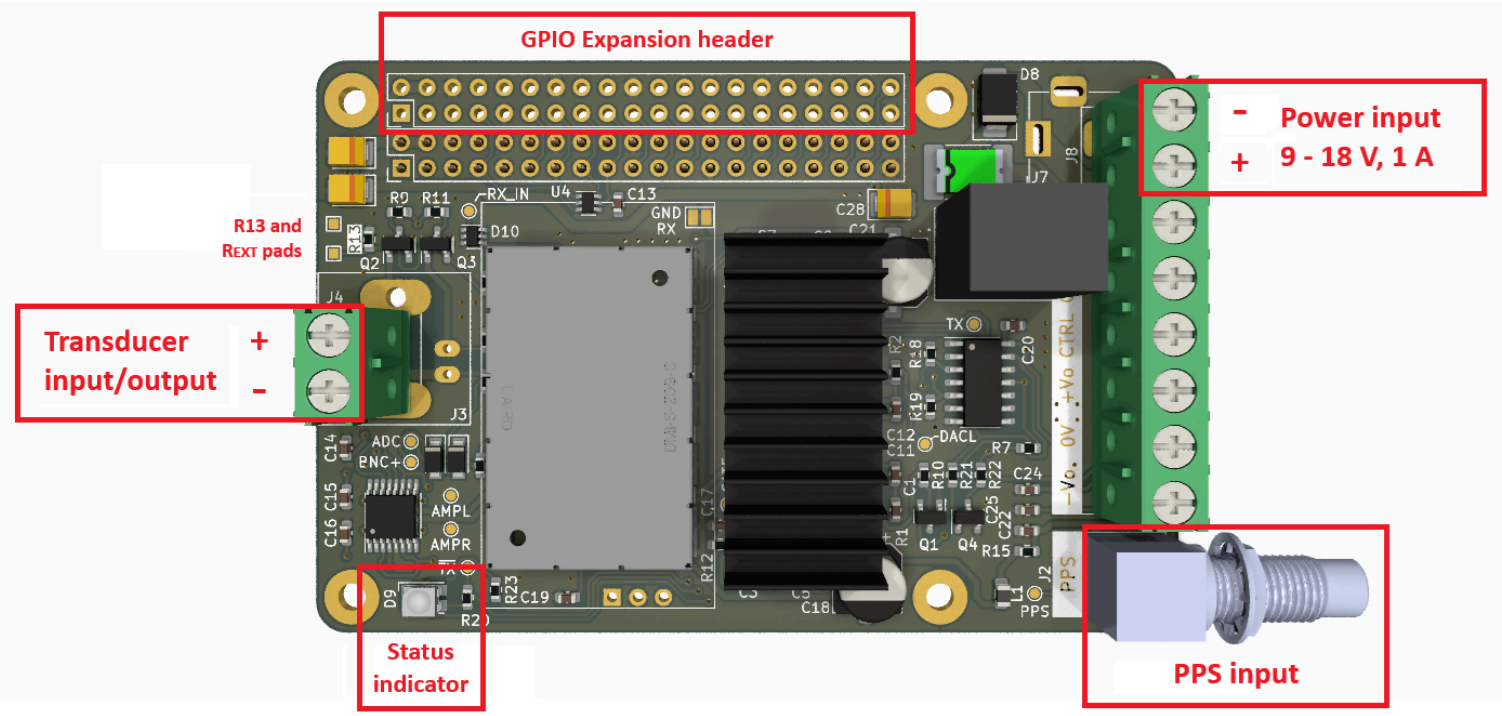

Figure 1: SuM HAT render and main hardware features.

It is recommended to not disassemble the board stack to avoid damaging the components. Should disassembly be necessary, proper ESD precautions must be in place and care should be taken to avoid flexing the boards when unplugging.

1.1 Power Supply

The SuM accepts a wide input voltage range of approximately 9 to 18V through either a 2.1mm center-positive DC barrel jack or screw terminal, located on the top right of the board. The input is fused and reverse-polarity-protected and can tolerate high surge currents, allowing the SuM to be powered by the most common battery technologies (3S Li-Ion or LiPo, Lead acid etc.).

From the main power supply are then derived the +5V supply for the Raspberry Pi and the ±24V supply for the analog frontend (the latter only when the SuM HAT is enabled). If additional hardware is connected to the GPIO expansion header, the user must ensure compliance with the maximum load reported in Section 2 “Electrical Specifications” table.

To power the SuM, simply connect a 9 to 18 V voltage source either with a 2.1mm DC jack or through the screw terminals with the polarity shown. Make sure that the external source can supply at least 1 A of current to avoid unexpected reboots of the Raspberry Pi.

1.2 GPIO expansion connector

A GPIO expansion connector is available to connect additional hardware to the Raspberry Pi. It can be fitted with any 2.54mm 20x2 pin header or socket and the pinout is compatible with the standard 40-pin Raspberry Pi connector. However, GPIOs 18-19-20-21, 22-27 and the I2C bus are used by either the sound card or SuM HAT and thus are not available to the user.

1.3 PPS Input

An input is prepared to accept 1 PPS timing signals for synchronization with external equipment through a right-angle SMA connector located on the edge of the board. This input is directly routed to GPIO 4 of the Raspberry Pi, so the user should make sure that the signal has valid 3.3V CMOS logic levels and the voltage at this input is never higher than 3.3V or below ground.

1.4 LED Indicators

LED D9 (located on the bottom left of the board) provides the main indication of the modem status as follows:

- **LED Off:** the SuM HAT is disabled and the analog frontend is powered down. The +5V supply is always on, so the Raspberry Pi and sound card may still be used in this state;
- **Green:** the ±24V supply and receiver are active and the TX/RX switch is configured for reception. The modem will automatically switch to this state upon completing a packet transmission and begins listening for incoming packets;
- **Red:** the ±24V supply and TX amplifiers are active and the TX/RX switch is configured for transmission. The modem will automatically switch to this state when a transmission is issued, and voltages up to ±48V may be present between the output terminals and up to ±24V between each terminal and system ground. The receive amplifier is still active in this state (although not connected to the output), and will output an attenuated replica of the transmitted waveform to the ADC.

Additionally, the user should check that when D9 is on (either green or red) the green indicator LED on the external ±24V supply module is also on. If not, a hardware fault or damaged connection may be present and the SuM will not be operating correctly.

1.5 Transducer Input/Output

Warning: do not connect any output terminal (including the BNC shield) to the input ground to avoid damaging the transmitter or switch. The transducer is intended to be left electrically floating with respect to system ground.

The transducer output connector can be fitted with either a standard right-angle BNC connector or a two-terminal screw connector. To avoid unwanted noise and potential damage, the piezoelectric element terminals should be connected directly to the input terminals and be isolated from any other circuit voltage and protective earth. If using a transducer with coaxial cable output, the shield should be connected to the negative terminal in Fig. 1.

The transmit amplifiers are thermally protected: if the internal temperature rises to above 160 °C the output will shut down. This may be due to overload, output short circuit or insufficient cooling. Operating above 125 °C may however degrade reliability, so if during operation the heatsink temperature rises above this value (and the output current is below the maximum allowed value), better cooling solutions should be investigated.

When configured for reception, the switch connects the output terminal to the receive preamplifier. The input is protected against ESD and overvoltage due to mechanical shock to the transducer. The maximum differential voltage at the input to avoid saturating the ADC is approximately ±10 mV.

1.5.1 Power output to the transducer

The transmitter employs a constant voltage driver technique. This means that the amplifiers try to impose a constant voltage derived from the DAC output to the transducer, within their maximum current and power limit. The typical output voltage swing can be found using the following equation, with **0 ≤ TX_GAIN ≤ 1**:

$$\left|V_{OUT,MAX}\right| \leq 40\,V \cdot TX\_GAIN$$

The output current will thus depend on the transducer's impedance at the operating frequency. For piezoelectric transducers driven at mechanical resonance, knowledge of the conductance **G [S = Ω $^{-1}$]** and susceptance **B [S = Ω $^{-1}$]** at the working frequency is sufficient to determine the output current and power. The RMS amplitude of the output current (for a sine wave excitation) is given by the following equation:

$$I_{OUT,RMS} = \frac{V_{OUT,MAX}}{\sqrt{2}}\sqrt{G^2 + B^2} \leq 200\text{ mA}$$

The user should ensure that this value is below the maximum continuous current of 200 mA. If this is not the case, lower the **TX_GAIN** parameter until satisfied. The average active output power (proportional to the radiated power) can then be computed as follows:

$$P_{OUT,MAX} = \frac{G\,V^2_{OUT,MAX}}{2} \leq 10\text{ W}$$

Finally, the output source level can be computed:

$$SPL = TVR + 20log_{10}(V_{OUT,MAX}) - 3 \qquad \text{[dB re 1μPa @ 1m]}$$

1.5.2 Manually setting the TX/RX switch

It is possible to manually control the status of the TX/RX switch and analog frontend power supply by acting on appropriate GPIOs. This is useful for example to perform recordings of sounds received by the hydrophone or play custom waveforms through the ADC/DAC. To set up the SuM for reception, execute the following commands:

```
sudo gpioset gpiochip0 22=1
sudo gpioset gpiochip0 27=0
```

The amplified signal is then available for recording on the left ADC input (ALSA mixer input **VINL1[SE]**). For playback, execute the following commands:

```
sudo gpioset gpiochip0 22=1
sudo gpioset gpiochip0 27=1
```

When not in use, the analog power supply can be disabled to save power with the command:

```
sudo gpioset gpiochip0 22=0
```

1.5.3 Changing the input impedance

> **Warning:** this section details a hardware modification that should be performed only by users experienced in electronics and soldering, to avoid unwanted damage to the board.

By default, when the SuM is configured for reception, the transducer is shunted by a resistor R_{IN} = 10 kΩ. This is to create a high-pass frequency response, whose -3dB cutoff frequency can be found using the following equation:

$$f_L = \frac{1}{2\pi R_{IN} C_T}$$

Where C_T is the low-frequency capacitance of the transducer. With the AS1 hydrophone, this results in a nominal cutoff frequency of 2.6 kHz, which provides sufficient attenuation of low-frequency environmental noise while not impacting the communication. However, the user may wish to change this behavior, for example when using high-capacitance transducers or recording environmental noises. If a higher cutoff frequency is desired, it is sufficient to solder an external resistor R_{EXT} to the pads highlighted in Fig. 1; the new frequency value is found using the following equation:

$$f_L = \frac{1}{2\pi \frac{R_{EXT} R_{IN}}{R_{EXT} + R_{IN}} C_T}$$

If a lower cutoff frequency is desired, it is also necessary to remove resistor R13 and then perform the same modification as above. If $C_T \ll C_{IN}$, the new value of the cutoff frequency can be approximated using the following equation:

$$f_L = \frac{1}{2\pi \frac{R_{EXT} \times 1.8M\Omega}{R_{EXT} + 1.8M\Omega} C_T}$$

The lowest cutoff frequency can be obtained by removing R13 and leaving R_{EXT} open, and the nominal value is approximately 14.3 Hz using an AS1 hydrophone. As a final note, all the equations above are only valid if the transducer is operated below its resonance frequency and without impedance matching; if that is not the case, more careful analysis and simulations should be performed.

2 Electrical Specifications

Parameter	Description/Test conditions	Min	Typ	Max	Unit
POWER SUPPLY					
Supply voltage (V_S)		9		18	V
Input current	JANUS transmission with AS1, V_S = 12 V		440		mA
	JANUS transmission with AS1, V_S = 9 V		600		mA
	FlexFrame transmission with AS1, V_S = 12 V		400		mA
	FlexFrame transmission with AS1, V_S = 9 V		520		mA
	Reception, V_S = 12 V		300		mA
	Reception, V_S = 9 V		400		mA
	Idle (SuM HAT disabled), V_S = 12 V		150		mA
	Idle (SuM HAT disabled), V_S = 9 V		190		mA
	Shutdown, V_S = 12 V		120		mA
5V Supply current	Maximum load on the +5V power supply (**Note 1**)			2	A
±24V Supply current	Maximum load on ±24V power supply	0		± 208	mA
Input PPTC fuse rating	T = 23°		1.85		A
Voltage on PPS input		0		3.3	V
RECEIVER					
Gain	Source impedance $\ll Z_{IN}$		50		dB
Input resistance (R_{IN})	Default configuration, see (**Note 2**)		10		kΩ
Input AC coupling capacitance (C_{IN})			100		nF
Low-frequency -3dB cutoff (f_L)	Source capacitance as per AS1 specifications. Default configuration, see (**Note 2**)	2.2	2.6	2.9	kHz
High-frequency -3dB cutoff (f_H)	Source impedance $\ll Z_{IN}$		83		kHz
Linear input range	Maximum differential voltage without ADC saturation	-10		+10	mV
Input-referred noise	RMS voltage noise integrated over -3dB bandwidth, 10nF input shunt capacitance (from simulation)		2.2		μV_{RMS}
TRANSMITTER					
Output voltage swing	AS1 Hydrophone, TX_GAIN = 1.00		± 40		V
Output current	Maximum continuous output current (**Note 3**)			± 200	mA
Output power	Maximum power output to transducer (**Note 3**)			10	W

Note 1 This load includes the Raspberry Pi, sound card and additional user hardware. When using external hardware, the user must make sure that this load is not exceeded, otherwise low-voltage throttling or unexpected shutdowns may occur on the Raspberry Pi.

Note 2 This is the default configuration, intended to be used with the AS1 hydrophone for most general-purpose communication applications. The user can change this behavior by performing a small hardware modification detailed in section 1.5.3 “Changing the input impedance”.

Note 3 The actual current and power output to the transducer depends strongly on its impedance at the operating frequency, as highlighted in Section 1.5.1 “Power output to the transducer”, and on the cooling efficiency. Additionally, for package temperatures above 85 °C, some derating of the specifications applies.