ULISS DATA-SHEET

version 1.0

http://www.uliss-st.com/

Contents

1 Technologies

ULISS Cryogenic Sapphire Oscillator (CSO) offers unprecedented frequency stability performances coming from the exceptional regularity of the beat of its heart: a high-purity sapphire crystal placed at low temperature in a well-controlled environment.

Figure 1: ULISS instrument with an air-cooled compressor, a water-cooled compressor can also be provided.

The sapphire crystal has the shape of a cylinder: approximately 5 cm diameter, 3 cm high. It constitutes a Whispering Gallery Microwave Resonator in which a 10 GHz signal can propagate around the cylinder making 1 billion of cycles before undergoing noticeable attenuation. Beside low dielectric losses, the cryogenic sapphire resonator presents a low sensitivity to temperature fluctuations and to mechanical vibrations. It constitutes an ultra-stable frequency reference that show a long term frequency drift below 1×10^{-14} per day.

The sapphire resonator is maintained at 6 Kelvin into a Closed Cycle Cryocooler specially designed to limit mechanical vibrations and thermal fluctuations. The autonomy of the whole system is thus the lifetime of the cryocooler (2 years between maintenance).

The cooled sapphire resonator is the frequency-determining element of an oscillator loop whom electrical length and circulating power are stabilized thanks to specially designed numerical electronic controls.

ULISS CSO is complemented with a low noise frequency synthesis generating useful ultra-stable signals at 10 GHz and 100 MHz(standard frequency outputs). The output frequencies can be adjusted by acting on the internal Direct Digital Synthesizer enabling a relative frequency resolution of 1×10^{-16}. A Phase Comparator can be provided to lock the CSO output signals to an external 100 MHz reference.

2 Whispering Gallery Microwave Resonator

The Uliss exceptional frequency performances essentially comes from our deep expertise in the Sapphire Whispering Gallery Mode Resonator technology that has been gained through research and development activities leaded in the Femto-ST Institute since more than 15 years. Inside the sapphire resonator, the electromagnetic wave circulates around the inner cylindrical surface as the result of total internal reflection. The high degree of the electromagnetic field confinement leads to a quality factor essentially limited by the sapphire dielectric losses, which are very low near the liquid helium temperature. Moreover, low concentration paramagnetic ions inside the sapphire provide an efficient thermal compensation. At 6 K competing paramagnetic spin and Debye expansion variations compensated themselves and the resonator temperature coefficient of frequency (TCF) is nulled at first order. The sapphire resonator is enclosed in a gold plated cylindrical copper cavity, which has been designed to suppress all spurious resonances that can affect the CSO performances. The resonator coupling to the external circuit is adjusted through our own procedure that allows near unity coupling input factor, thus optimizing the power transfer as well as the sensitivity of the Pound Servo.

Figure 2: The Sapphire Resonator.

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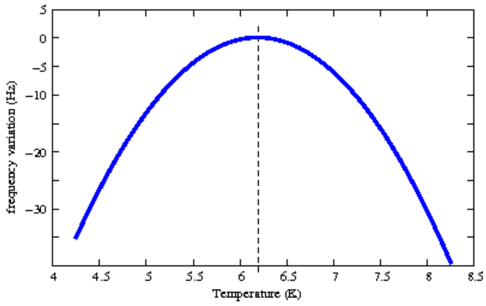

Figure 3: Turnover temperature.

3 Oscillator loop

The CSO uses a classical transmission oscillator circuit with the cryogenic sapphire resonator as frequency determining element. The sustaining loop is completed with two additional servo loops stabilizing the phase of the circulating signal and the power injected inside the resonator. The first servo loop is based on the Pound frequency discriminator principle; it ensures that the CSO oscillates at the resonator frequency by compensating any variation of the phase lag along the loop. It uses a phase modulation at a frequency of the order of few tens of kHz to probe the resonance. The phase

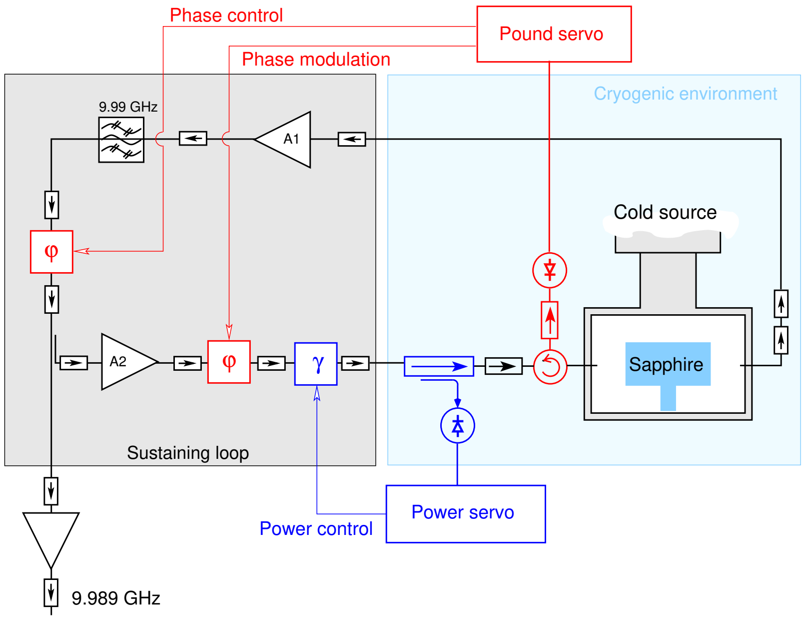

Figure 4: Oscillator loop.

modulation is applied to the microwave signal through a first voltage-controlled-phase-shifter. A lock-in amplifier demodulates the signal reflected by the resonator to generate an error signal, which is eventually added to the dc-bias of a second voltage-controlled-phase-shifter.

The power servo loop ensures that the power injected into the resonator stays constant. A tunnel diode placed as near as possible to the resonator input enables to get a voltage proportional to the signal power. This voltage is compared to a high stability voltage reference and the resulting error signal is used to control the bias of a voltage-controlled attenuator.

4 Low noise frequency synthesis

Our sapphire resonator are designed to operate on the $WGH_{15,0,0}$ whispering gallery mode at 9.99 GHz. The intentional 13-7 MHz frequency offset from the 10 GHz round frequency was chosen to permit to compensate for the resonator frequency uncertainty by using a low noise Direct Digital Synthesizer (DDS). A 2.5 GHz Dielectric Resonator

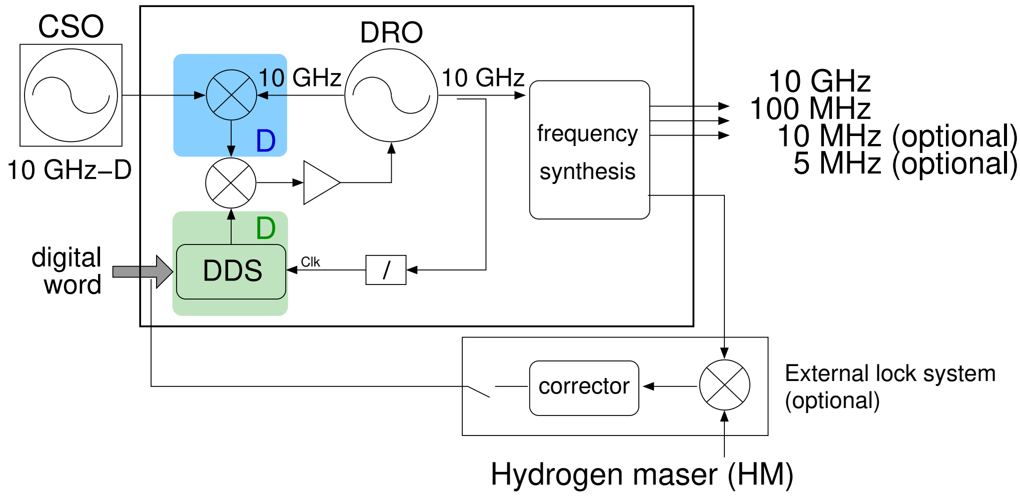

Figure 5: Low noise frequency synthesizer.

Oscillator (DRO) chosen for its low phase noise is frequency multiplied by 4 and mixed with the CSO's signal. The resultant beatnote is compared to the signal coming from a DDS. The resulting error signal is used to phase lock the DRO to the CSO. Frequency dividers complete the system to generate the 100 MHz frequencies from the 10 GHz signal.

5 Typical output performances

Resonator frequency

Allan deviation	1 s < τ < 10,000 s	$\leq 3 \times 10^{-15}$
Phase Noise	1Hz offset	-100 dBc/Hz
	10 Hz	-110 dBc/Hz
	100 Hz	-115 dBc/Hz
	1,000 Hz	-127 dBc/Hz
	10,000 Hz	-130 dBc/Hz

10 GHz

Allan deviation	1s < τ < 10,000s	$\leq 3 \times 10^{-15}$
Phase Noise	1Hz offset	-100 dBc/Hz
	10 Hz	-110 dBc/Hz
	100 Hz	-115 dBc/Hz
	1,000 Hz	-127 dBc/Hz
	10,000 Hz	-130 dBc/Hz

100 MHz

Allan deviation	τ = 1 s	4×10^{-15}
	10 s < τ < 1,000 s	$\leq 3 \times 10^{-15}$
Phase Noise	1Hz offset	-130 dBc/Hz
	10 Hz	-140 dBc/Hz
	100 Hz	-149 dBc/Hz
	≤ 1,000 Hz	-153 dBc/Hz

10 MHz (optional)

Allan deviation	1 s < τ < 10,000 s	8×10^{-15}
	10 s < τ < 10,000 s	$\leq 3 \times 10^{-15}$

5 MHz (optional)

Allan deviation	τ = 1 s	1.2×10^{-14}
	τ = 10 s	4×10^{-15}
	100 s < τ < 10,000 s	$\leq 3 \times 10^{-15}$

6 Output characteristics

Frequency outputs

1 output at the resonator frequency	10 dBm	±1 dB
1 output at 10 GHz	10 dBm	±1 dB
1 output at 100 MHz	10 dBm	±1 dB

7 Power requirements

Classic system				
	cryocooler	6 kW	380 V @ 50 Hz	3 phases
	other	1 kW	220 V @ 50 Hz	single phase
Low power system				
	cryocooler	3 kW	220 V @ 50 Hz	single phase
	other	1 kW	220 V @ 50 Hz	single phase

Power requirements for 60 Hz electrical network on demand.

8 Operating environment requirements

8.1 Temperature

Temperature shall be as stable and uniform as possible inside the operating range. Typical stability:

- Recommended $\pm$ 0.5 °C
- Allowable $\pm$ 1.0 °C

8.2 Vibration

The CSO shall be installed on a stable surface so as to avoid the propagation of vibration.

9 Experimental data

9.1 Frequency stability

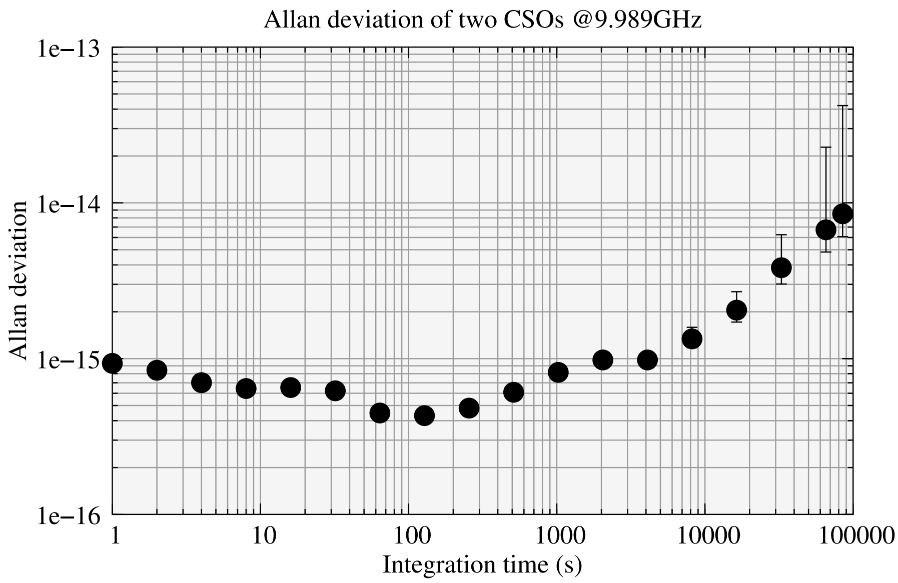

Figure 6: Stability mesured by beating the 9.99 GHz signals delivered by two identical CSOs.

9.2 Phase noise

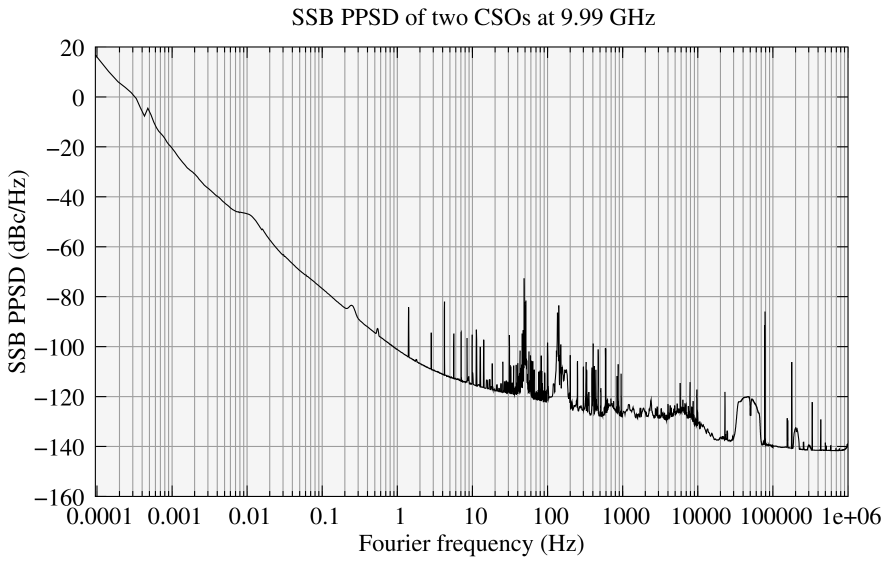

Figure 7: 9.99 GHz phase noise - two identical CSOs.

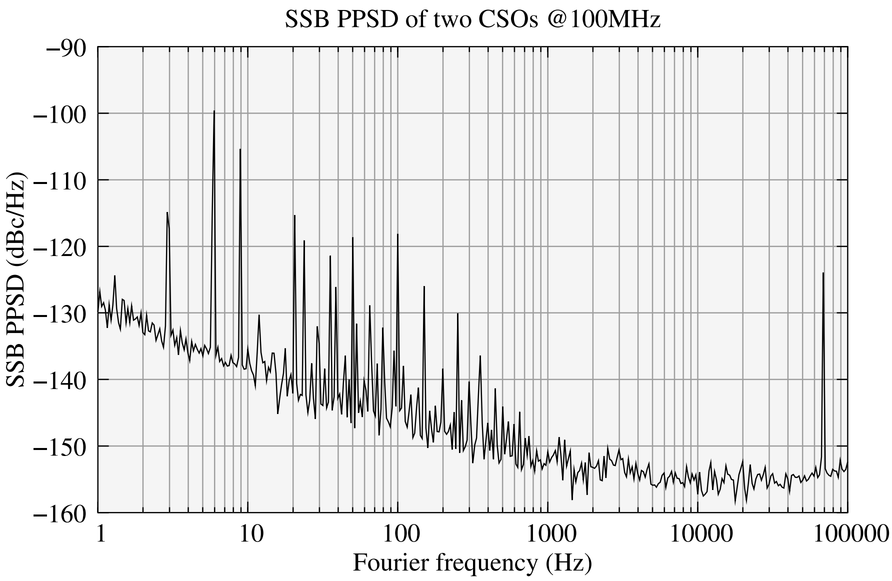

Figure 8: 100MHz phase noise - two identical CSOs.

10 ULISS - some views

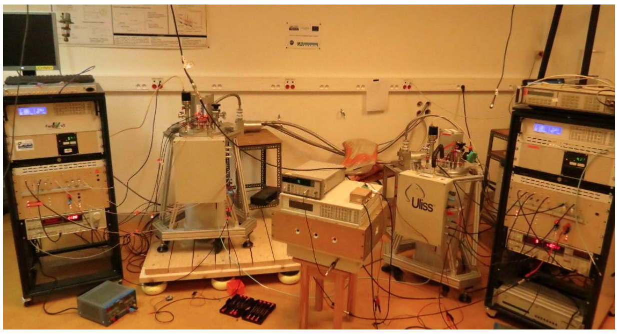

Figure 9: Tests of two CSOs in FEMTO-ST.

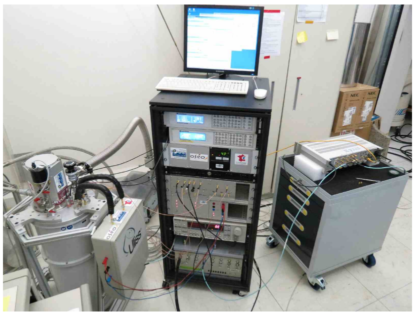

Figure 10: Uliss in CNES Toulouse (Fr)

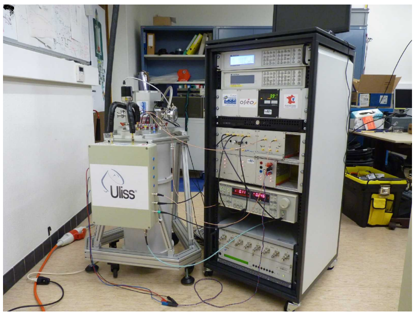

Figure 11: Uliss in LTF Neuchâtel (Ch)

Figure 12: Uliss in the Ring Laser Lab - Wettzell (De)

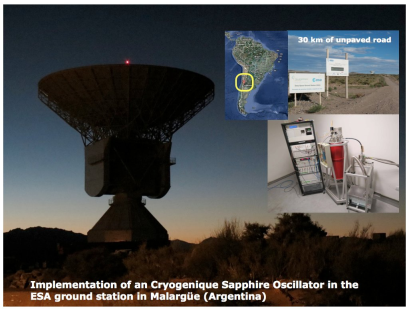

Figure 13: Implementation of our first CSO in Malargue (Ar)

11 Mechanical implementation

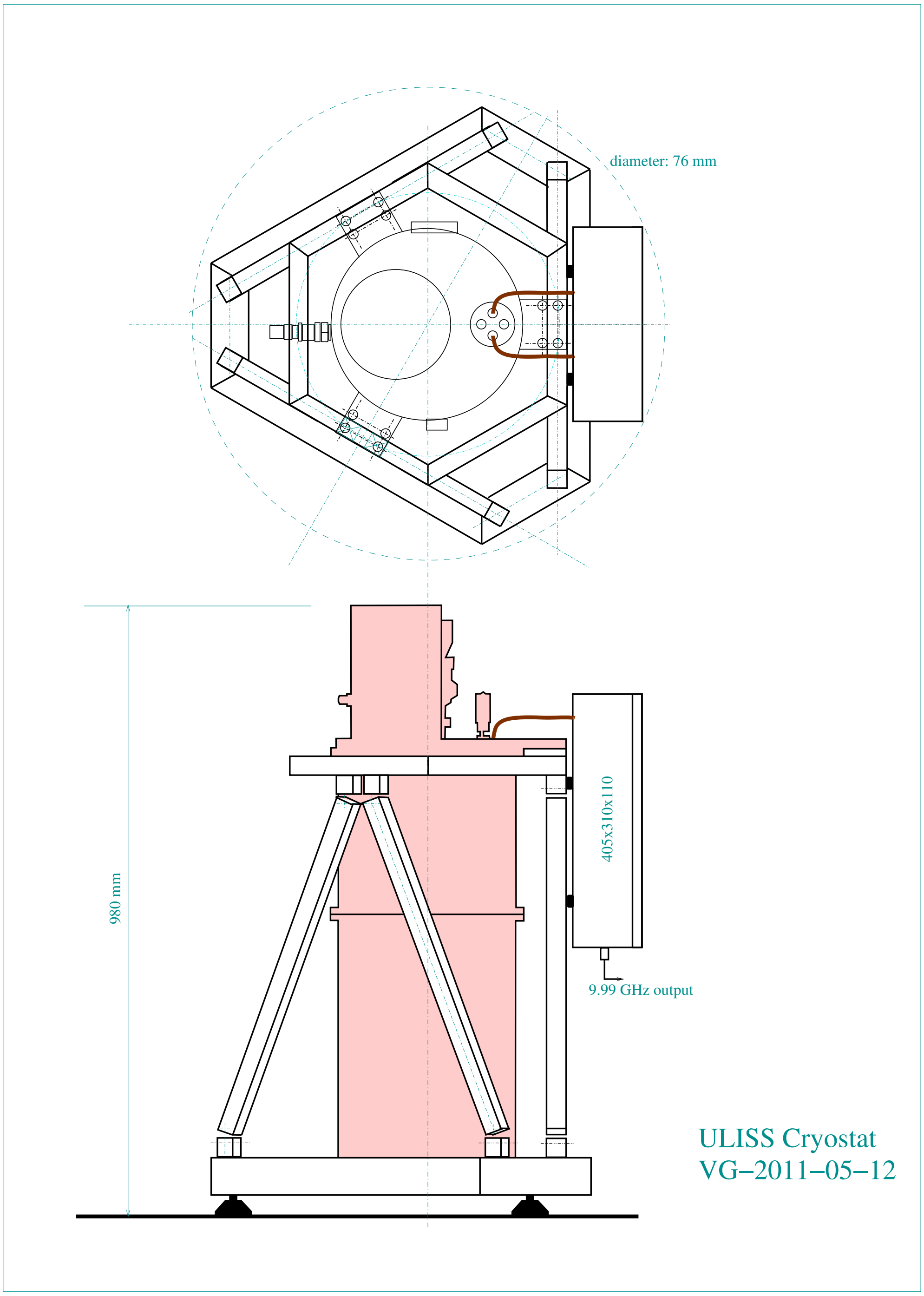

Figure 14: Cryostat implementation

12 ULISS low power version (2G)

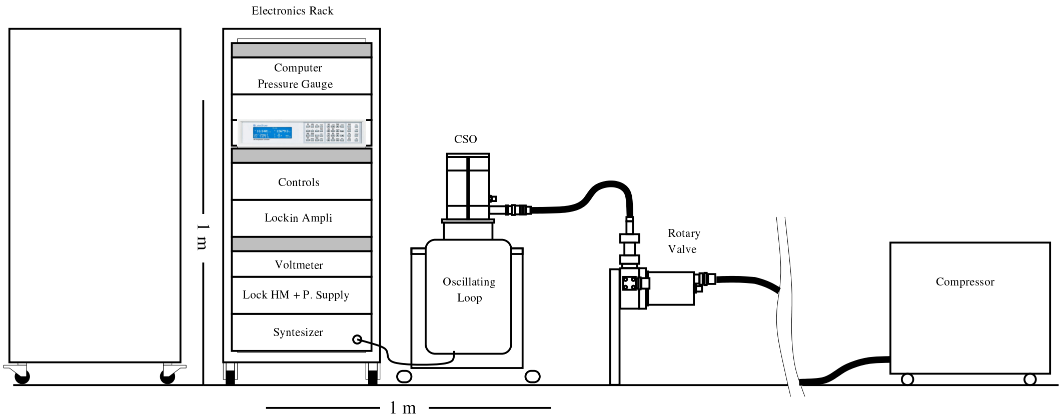

Figure 15: Uliss 2G - CSO implementation

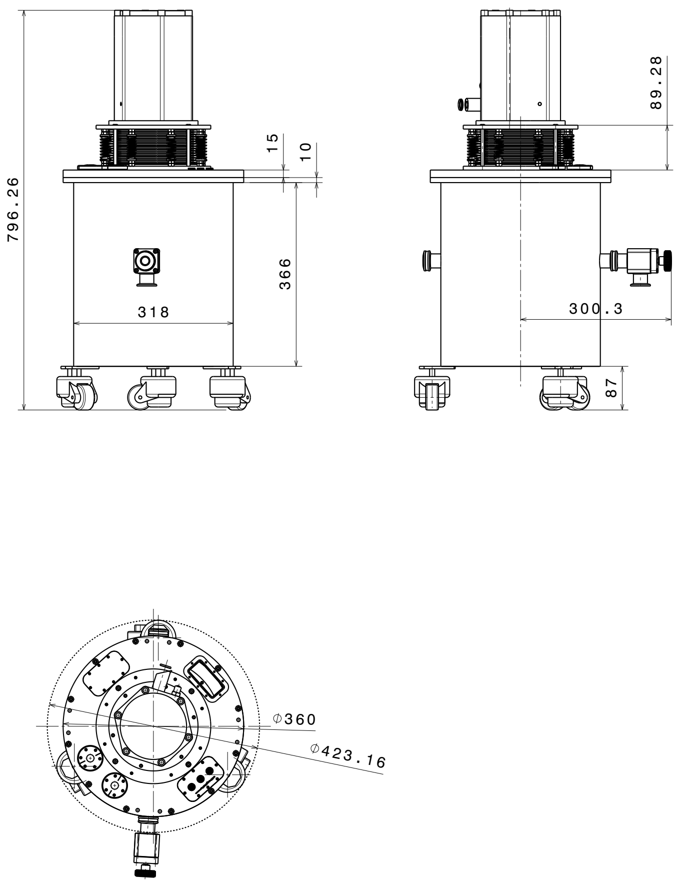

Figure 16: Uliss 2G - Cryostat implementation