Overview of SLS 2.0 Beam Based Feedbacks and BPM System

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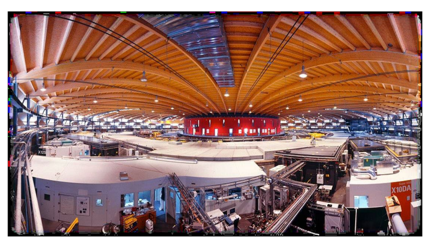
Abstract

For the ongoing upgrade of the Swiss Light Source (SLS) storage ring, the previous ageing beam-based feedbacks and beam position monitor (BPM) systems are replaced by newly developed versions, where beam commissioning is planned to start in January 2025. Feedbacks include the fast orbit feedback (FOFB), transverse and longitudinal multi-bunch feedback (MBFB), and filling pattern feedback (FPFB). In this contribution, we give an overview of the architectures and development/production status of these feedbacks and of the BPM system, including latest pre-beam test results.

SLS 2.0

SLS 1.0:

- 3rd generation synchrotron light source
- User operation since 2001



SLS 2.0:

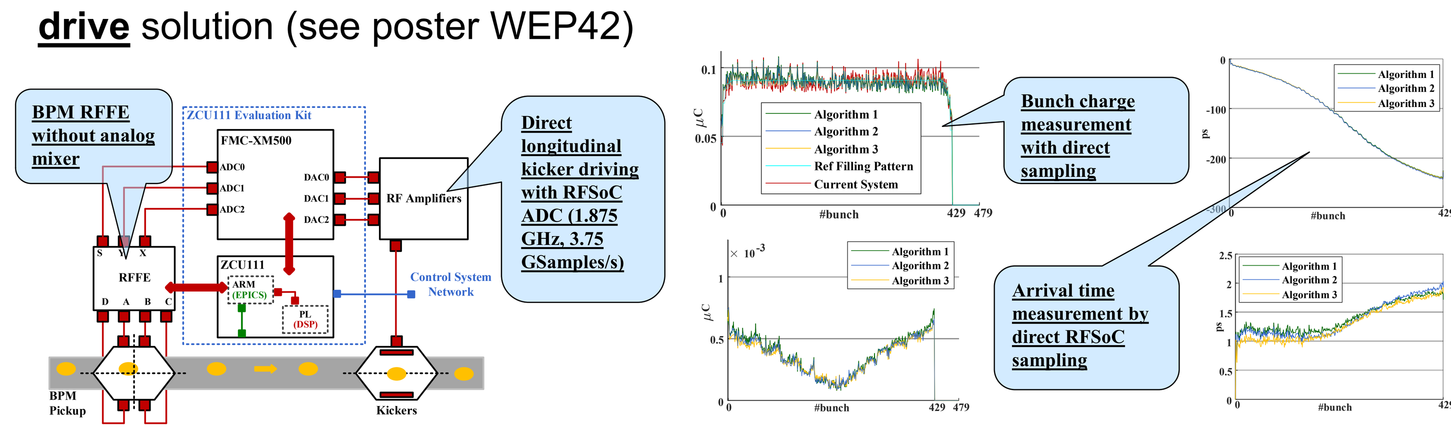
- 1st beam 1/2025
- New storage ring: >40x higher hard X-ray brilliance
- Replace ageing SLS 1.0 hardware
- Keep building & linac & booster & storage ring tunnel

Parameter	Units	SLS 1.0	SLS 2.0
Circumference	m	**288**	
Beam Current	mA	400	
Injection Charge	nC	~0.15 (1 Bunch, Top-Up @ 3 Hz)	
Beam Energy	GeV	2.4	2.7
Main RF	MHz	499.637	499.654
Harmonic No.	#	480	
Hor. Emittance	pm	**5030**	**131-158**
Vert. Emittance	pm	5-10	10
Ring BPMs (FOFB/other)	#	75/0	115/21
Ring Beam Pipe		Stainless Steel	**Copper (NEG)**
Hor./Vert. Betatr. Tune		20.43 / 8.74	39.27 / 15.22
BPM-to-BPM Betatr. Tune Phase Δ (ideal < 90°)		102° / 44°	123° / 48°
FOFB Dipole Corr. Kick	µrad	±750	±400 (600*)
Miin. beam size @ BPM	µm	5	5-10

* Temporarily for SLS 2.0 1st beam with optional extra coil windings(disconnected later).

Multi-bunch & Filling Pattern Feedback

- **MBFB** & **FPFB** both based on **RF System-on-Chip (RFSoC)** = Zynq UltraScale+ (used by BPMs/FOFB) + **8x4GSPS ADCs** & **8x6GSPS DACs**
- Replacing analog down/upconverters with **direct ADC sampling** & **direct DAC drive** solution (see poster WEP42)

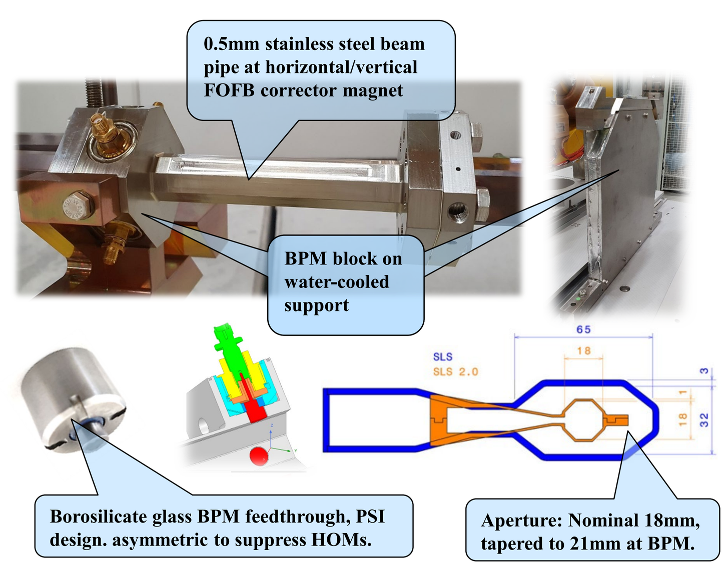


BPM Requirements and Pickups

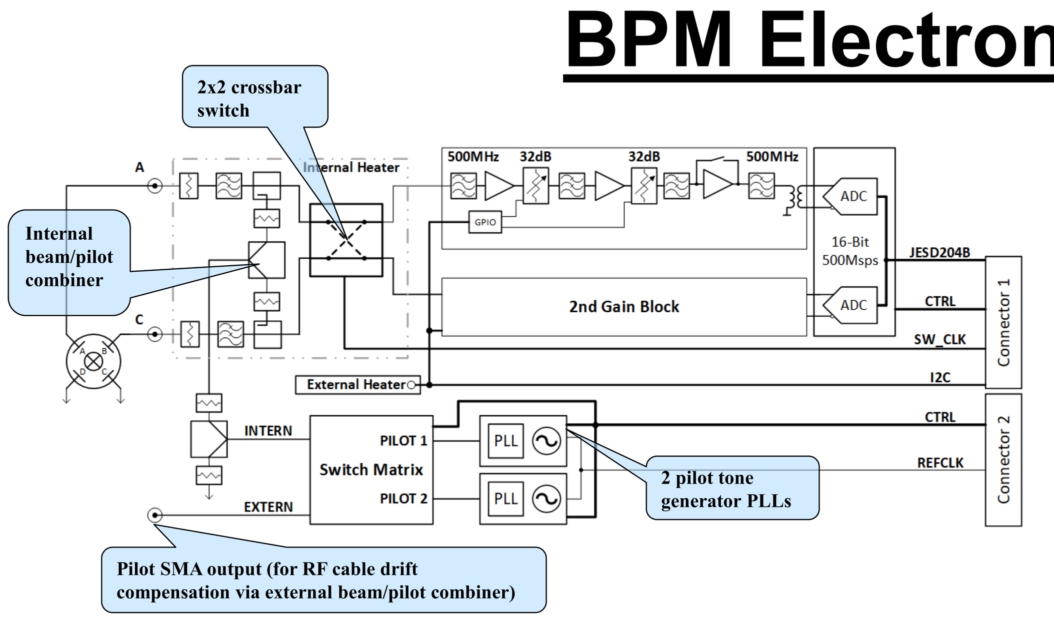
Parameter	Goal	% of σ_Y
Position Noise (0.1 Hz - 1 kHz BW), 400 mA	**<50 nm RMS**	1%
Position Noise (0.1 Hz - 0.5 MHz BW), 400 mA	<1 µm RMS	20%
Position Noise (0.5 MHz BW), 0.15nC, 1 Bunch	<50 µm RMS	-
Electronics Drift (400mA beam, constant)	<100 nm / hour	2%
	<400 nm / week	8%
	<1 µm / year	20 %
Overall Drift (Electronics + Cables + Mechanics)	<250 nm / hour	5%
	<1 µm / week	20%
	<2.5 µm / year	50%
Beam Current Dependency (Const. Fill. Patt.)	<100 nm / 4 mA	2%

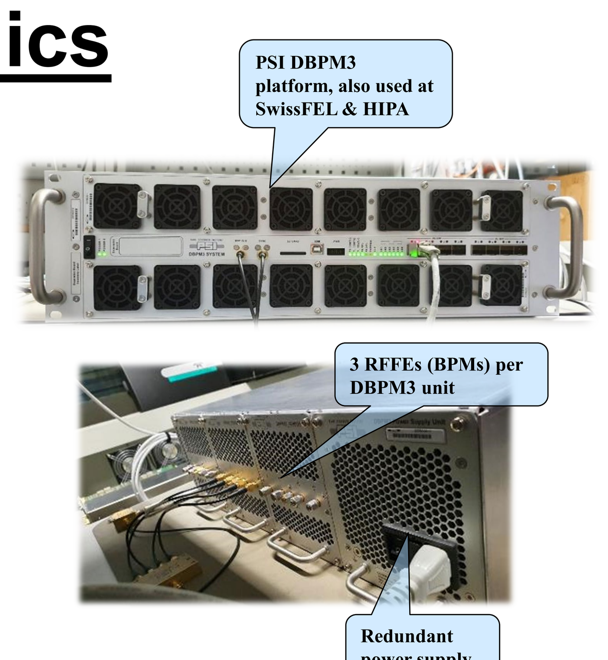
Location	BPM Type	geometry factors k_x/k_y [mm]
Linac & Transfer Lines	Resonant Stripline	various
Booster	Button	8.3/7.7
SLS 1.0 Ring	Button	16.7/14.3
SLS 2.0 Ring	Button	**7.1/7.2**

- SLS 2.0 copper beam pipe
- BPM blocks from stainless steel



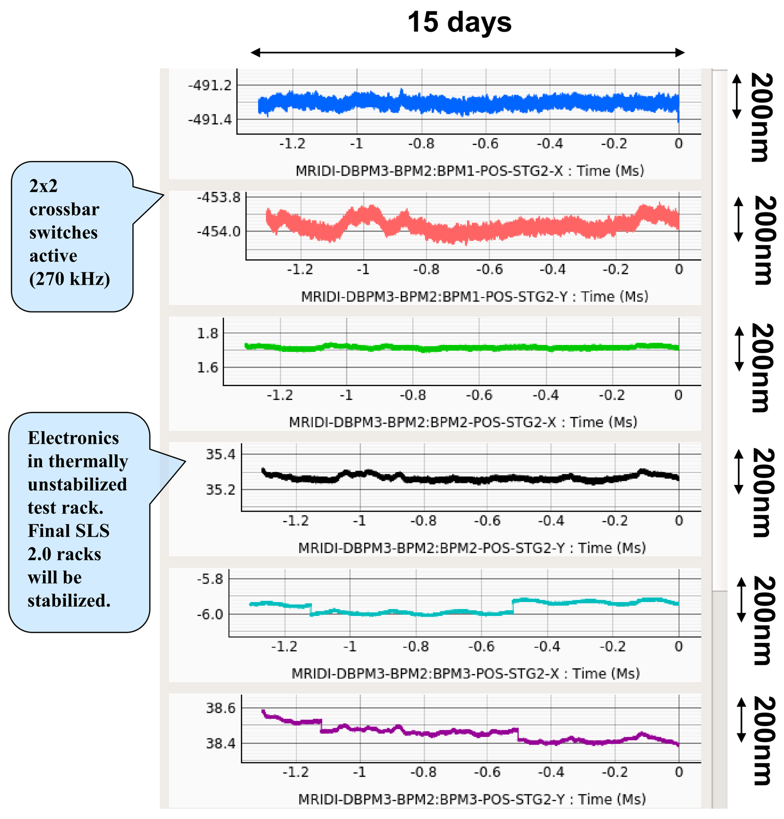
BPM Electronics



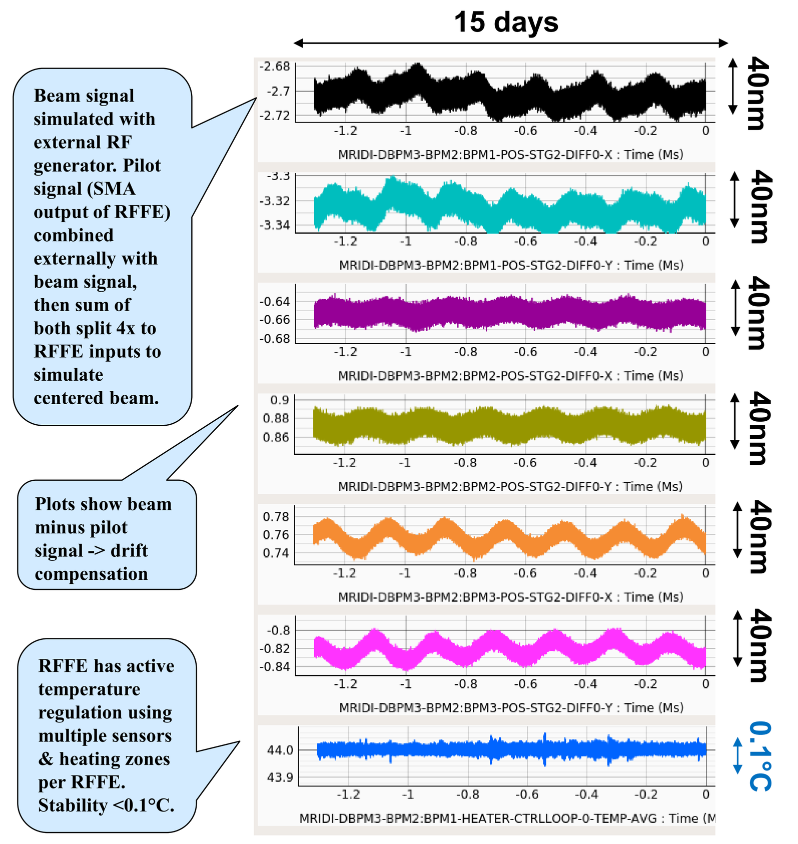


Long-Term Stability Lab Test (3 BPM Units)

Without Pilot-Tone Drift Compensation



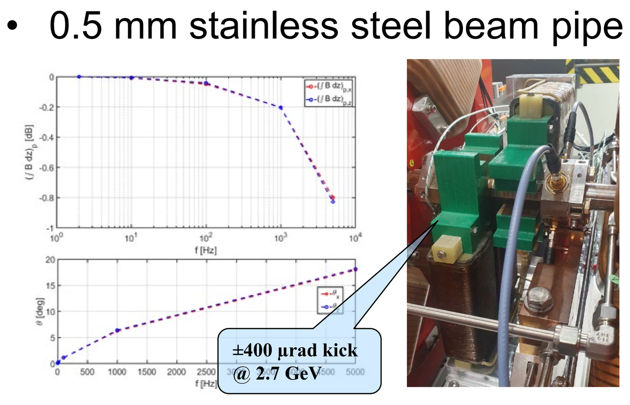
With Pilot-Tone Drift Compensation



Fast Orbit Feedback (FOFB)

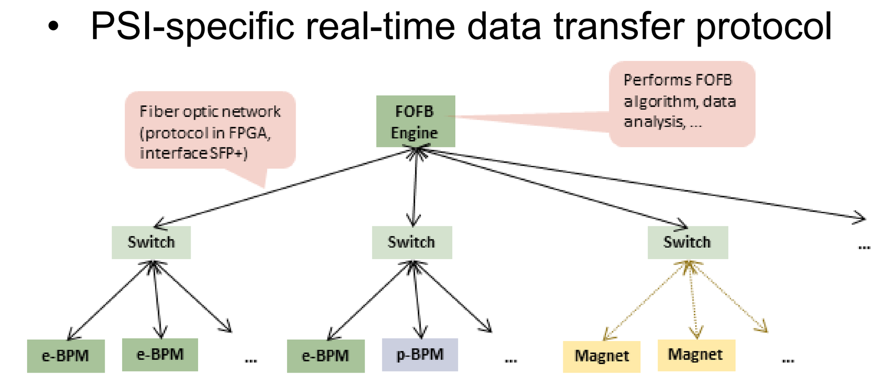
Corrector Magnets

- 0.35 mm lamination thickness
- 0.5 mm stainless steel beam pipe



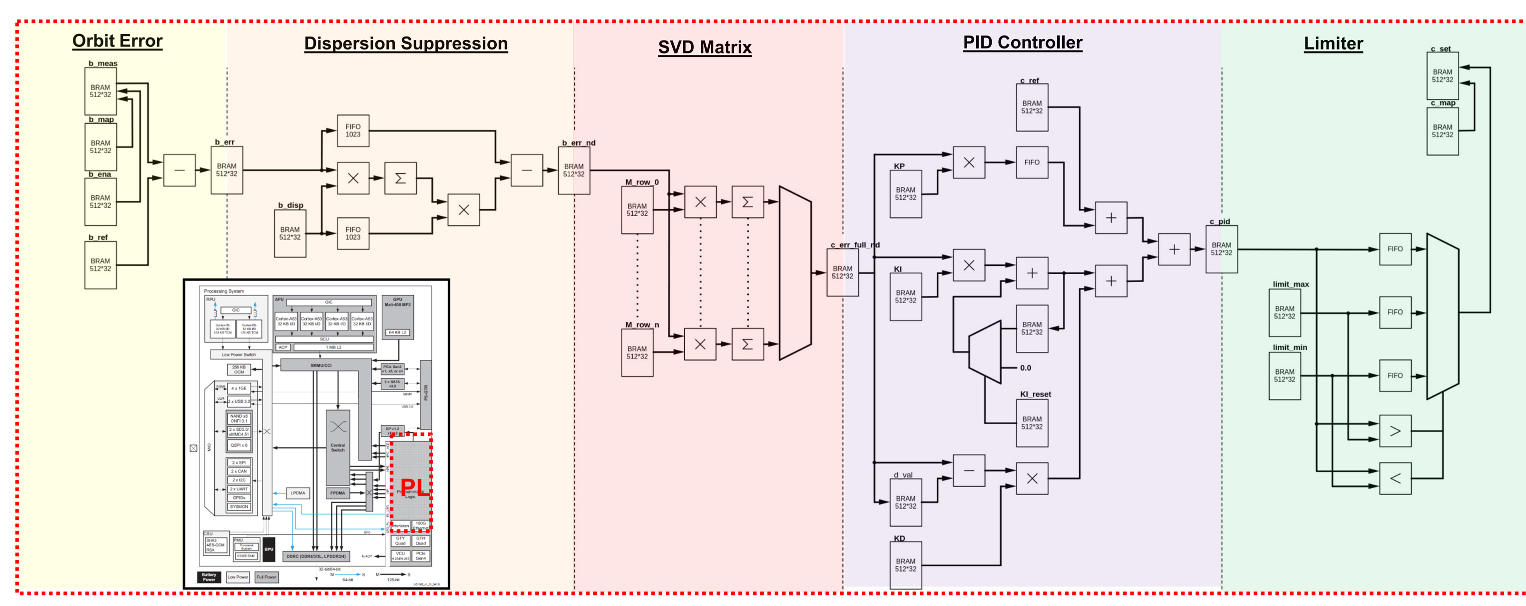
Tree Topology

- Fiber optic tree network, central FOFB engine
- PSI-specific real-time data transfer protocol



Low-Latency FOFB Algorithm Implementation in FPGA

- Algorithm first in C++ on Zynq UltraScale+ CPU, beam test @ SLS 1.0 (~4k corrections/s)
- Final version now implemented in programmable logic (PL) of Zynq U+ (~100k corrections/s)



Feedback Loop Latency & Correction Bandwidth

Component	SLS 1.0	SLS 2.0 (1st Beam)	SLS 2.0 (Final)
	Latency [µs]		
BPM RF Cable	<0.2		
BPM Electronics (ADC, …)	<1	<1	
BPM DDC Filter (Programmable)	<600	~190 (2.7 kHz)	~25 (20 kHz)
BPM → FOFB Transfer	<250	<4	
FOFB Algorithm	<250	<8	
FOFB → Magnet PS Transfer	<100	<4	
Magnet PS Internal	<50	<10	
Overall excl. DDC	<650	<28	
Overall incl. DDC	**<1250**	**<218**	**<53**

Component	Bandwidth [Hz]		
	SLS 1.0	SLS 2.0 (1st Beam)	SLS 2.0 (Final)
BPM DDC Filter(-3 dB) (Programmable)	~700	2700	20'000
Corrector Power Supply + Magnet + Beam Pipe	>1000	>1200	>3000
FOFB Closed Loop (0 dB Point)	**~100**	**~350**	**~1200**

SLS 1.0:

- 2 mm stainless steel beam pipe @ correctors (steel elsewhere)
- 4 k corrections/s
- FOFB algorithm distributed on 12 DSP boards

SLS 2.0:

- 0.5mm stainless steel pipe @ correctors (copper elsewhere)
- Up to 100 k corrections/s
- FOFB algorithm on single central Zynq UltraScale+ MPSoC

SLS 1.0 & 2.0

- Only one type of orbit corrector magnet, used for static correction and FOFB → compromise between strength, bandwidth, and noise

Dependencies

MBFB ↔ FOFB/BPMs

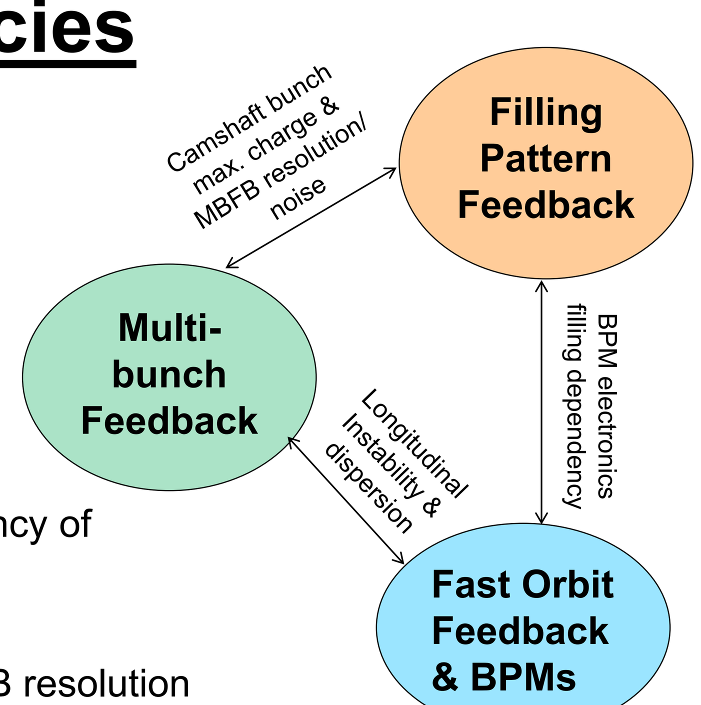
- Longitudinal ~kHz beam oscillations: FOFB sees dispersion orbit & removes it from BPM readings before correction.
- FOFB corrects RF frequency periodically → longitudinal phase changes
- FOFB stabilizes orbit at MBFB BPM, reducing common mode ADC offset.

FPFB ↔ FOFB/BPMs

- Stable filling pattern reduces systematic dependency of BPM electronics on filling pattern & beam current

FPFB ↔ MBFB

- Maximum charge in "camshaft bunch" limits MBFB resolution
- Beam stability depends on filling pattern (HOMs, ions, …)



Summary & Outlook

- The installation of the SLS 2.0 storage ring is in progress, most part of beam pipe & magnets are already installed, with external pre-assembly of most parts.
- BPM electronics series production is in progress, expecting the last production batch 1 October 2024. The pilot tone effectively suppresses beam position drift that occurs upstream of the 2x2 crossbar switch in the RFFE, including external 4x splitter for lab tests.
- After pre-beam installation and test of BPM, FOFB, MBFB and FPFB, beam commissioning is expected to start January 2025.
- The electronics of BPMs (designed by PSI), FOFB, MBFB and FPFB is all based on Xilinx/AMD Zynq UltraScale+ MPSoCs, where MBFB and FPFB have additional Multi-GSample/s ADCs and DACs on the chip ("RFSoC"). This maximizes synergies between the systems and simplifies their interfacing.