

# LCLS II- Experiment Systems Vacuum Controls Architecture

ICALEPCS2023

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Margaret Ghaly  
Controls Engineer  
LCLS Experiment Control Systems

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# LCLS-II Vacuum Controls Systems

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## Vacuum Controls Requirements

- Physics Requirement Documents
  - Preserve vacuum
  - Preserve vacuum components
  - Ability to controls and monitor vacuum systems/devices remotely
- Controls FRS-ESD
  - Maintain high availability
  - Modular PLC code and SCADA code libraries
  - Standard hardware and interfaces
  - Include testing and troubleshooting through all phases of the system's life cycle
  - Enable straightforward and timely upgrades and deployment
  - Record vacuum events

# LCLS-II Vacuum Controls System - Architecture

Time for an upgrade.

- Experiment system vacuum controls architecture:
  - Informs all phases of a vacuum system **lifecycle**
  - With a **full stack** of integrated software and hardware
  - Complement of software and hardware **tools**
  - Enables a **straightforward** delivery of vacuum controls system
    - Development and Deployment
    - Testing and Checkout
  - **Beyond the LCLS-II project**

Functional Requirements Specification Document	
Document Title: ECS LCLS-II Vacuum Control System FRS	Page 1 of 5
Document Number: LCLS-FR-001	

**Document Approval:**

Originator: Margaret Ghady	
Approver: Alex Wallace, Platform architect	
Approver: Jing Yu, ECS Vacuum SME	
Approver: David Fuhs, ECS Decision Manager	
Approver: Mike Nelson, ECS Delivery Manager	
Reviewer: Brady Robinson	Signature Not Required
Reviewer: Tyler Johnson	Signature Not Required
Reviewer: William Schletter	Signature Not Required

**Revision History:**

R02	1.0.0/10/2022
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**Table of Contents**

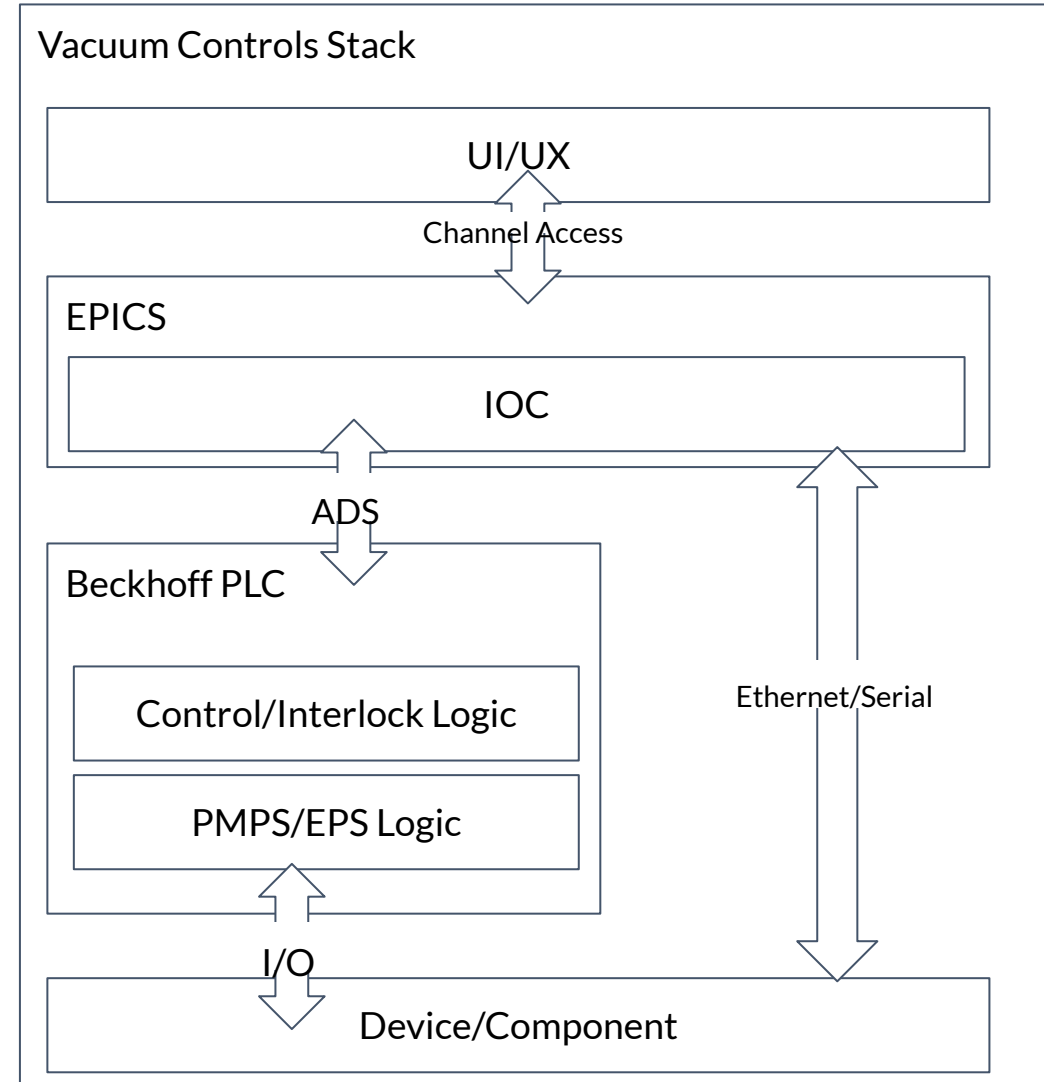
1	Purpose	2
2	Scope	2
3	Definitions	2
4	Overview	2
5	Functional Requirements	2
5.1	Vacuum Component Interlock	2
5.2	Fail Safe Requirements	3
5.3	Interface Requirements	3
5.3.1	User Interface Requirements	3
5.3.2	Other Interface Requirements	4
5.4	General Safety Requirements	4
5.5	Vacuum Equipment and Instrumentation	4
5.6	Vacuum Process Automation Requirements	5
5.7	Operations/Development Requirements	5

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# LCLS-II Vacuum Controls Systems - Architecture

Experiment Controls full stack integration.

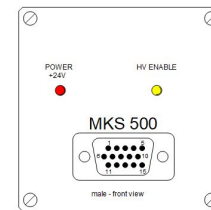
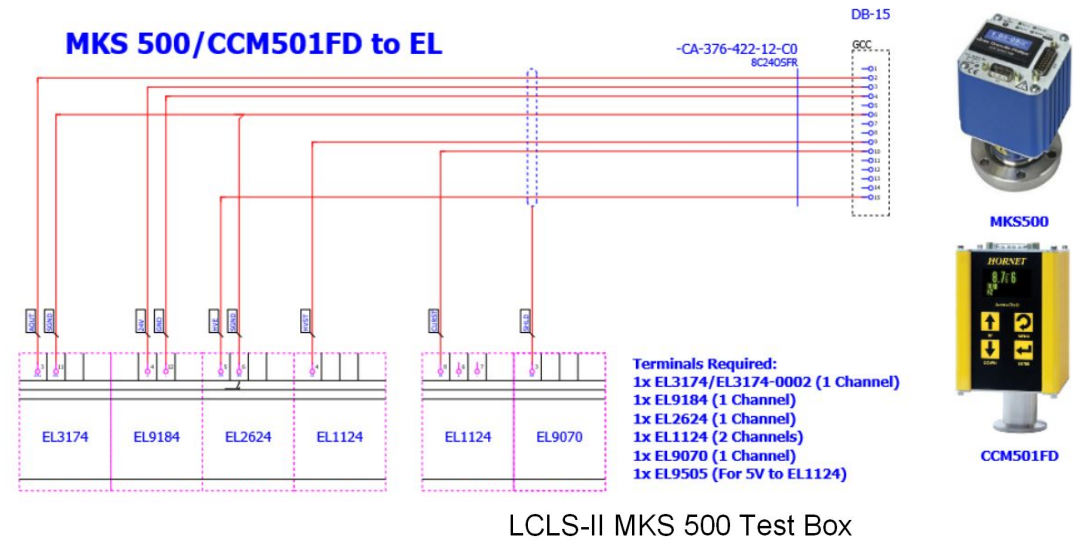
- UI/UX screens
- Ophyd devices
- EPICS interface
- Beckhoff Communication interface with EPICS (ADS)
- Beckhoff PLC – Software libraries
- Device/Controller interface I/Os



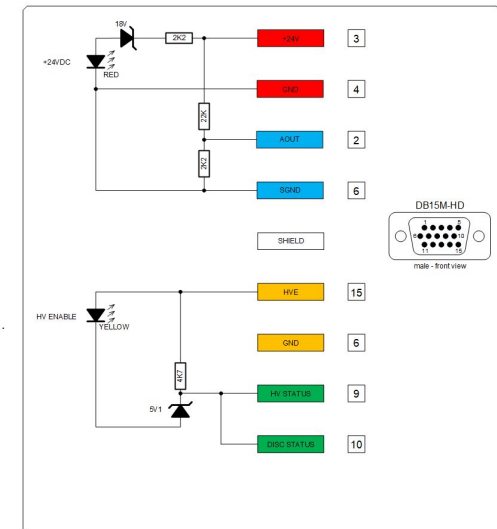
# Device Component - IO

It all starts at the connector.

- Cable design
  - Cable type
  - Connector
  - Pinouts
  - Fabrication information
- Standard CAD Macro
  - Cable number
  - Signals
  - Termination
  - I/O terminals
- Test Box
  - Verify cables fabrication
  - Verify termination



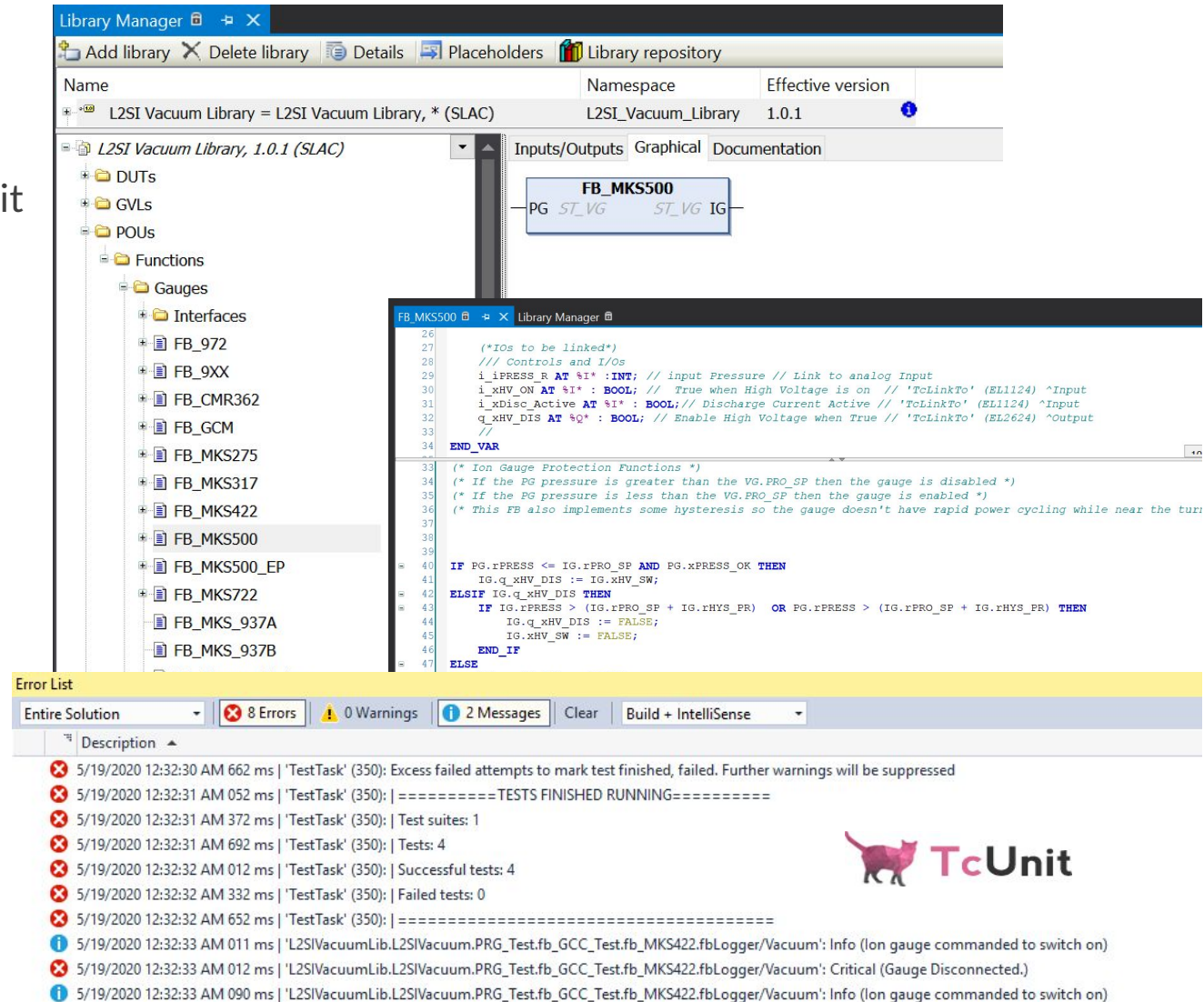
- Test procedure:
- Connect the cable in the Test Box.
  - +24V LED should be lit.
  - Enable HV from PLC.
  - HV STATUS and DISC STATUS should read HIGH.
  - Analog Pressure should read +2.4 VDC.



# Vacuum Library

## Complete TcLibraries code with unit tests.

- Basic operational functionality and Interlocks are implemented in the PLC
  - Bundling data and logic together as a single unit
  - Structure includes all device PV/data
  - All I/Os definitions
  - Protection/Run Logic, MPS
  - PLC variable tagging
  - Logging.
- Unit Testing
  - Ensures any modifications to existing device didn't break basic functionality and interlocks
  - Reduce deployment time for future library releases



The screenshot displays the Siemens Library Manager interface. The left pane shows the project structure for the 'L2SI Vacuum Library, 1.0.1 (SLAC)', including folders for DUTs, GVLs, POU, Functions, Gauges, and Interfaces. The 'Functions' folder is expanded to show 'Gauges', which contains several function blocks, with 'FB\_MKS500' selected. The right pane shows the ladder logic for 'FB\_MKS500', including input/output definitions and control logic. The 'Error List' at the bottom shows 8 errors, 0 warnings, and 2 messages. The messages include test results and status updates for the 'TestTask' and 'Vacuum' components.

```
(* I/Os to be linked*)
// Controls and I/Os
i_iPRESS_R AT %I* :INT; // input Pressure // Link to analog Input
i_xHV_ON AT %I* :BOOL; // True when High Voltage is on // 'ToLinkTo' (EL1124) ^Input
i_xDisc_Active AT %I* :BOOL; // Discharge Current Active // 'ToLinkTo' (EL1124) ^Input
q_xHV_DIS AT %Q* :BOOL; // Enable High Voltage when True // 'ToLinkTo' (EL2624) ^Output
//
END_VAR

(* Ion Gauge Protection Functions *)
(* If the PG pressure is greater than the VG.PRO_SP then the gauge is disabled *)
(* If the PG pressure is less than the VG.PRO_SP then the gauge is enabled *)
(* This FB also implements some hysteresis so the gauge doesn't have rapid power cycling while near the turn

IF PG.rPRESS <= IG.rPRO_SP AND PG.xPRESS_OK THEN
  IG.q_XHV_DIS := IG.xHV_SW;
ELSIF IG.q_XHV_DIS THEN
  IF IG.rPRESS > (IG.rPRO_SP + IG.rHYS_PR) OR PG.rPRESS > (IG.rPRO_SP + IG.rHYS_PR) THEN
    IG.q_XHV_DIS := FALSE;
  ELSE
    IG.q_XHV_SW := FALSE;
  END_IF
ELSE
```

Error List

Entire Solution	8 Errors	0 Warnings	2 Messages	Clear	Build + IntelliSense
Description					
5/19/2020 12:32:30 AM 662 ms	'TestTask' (350):	Excess failed attempts to mark test finished, failed. Further warnings will be suppressed			
5/19/2020 12:32:31 AM 052 ms	'TestTask' (350):	=====TESTS FINISHED RUNNING=====			
5/19/2020 12:32:31 AM 372 ms	'TestTask' (350):	Test suites: 1			
5/19/2020 12:32:31 AM 692 ms	'TestTask' (350):	Tests: 4			
5/19/2020 12:32:32 AM 012 ms	'TestTask' (350):	Successful tests: 4			
5/19/2020 12:32:32 AM 332 ms	'TestTask' (350):	Failed tests: 0			
5/19/2020 12:32:32 AM 652 ms	'TestTask' (350):	=====			
5/19/2020 12:32:33 AM 011 ms	'L2SIVacuumLib.L2SIVacuum.PRG_Test.fb_GCC_Test.fb_MKS422.fbLogger/Vacuum':	Info (Ion gauge commanded to switch on)			
5/19/2020 12:32:33 AM 012 ms	'L2SIVacuumLib.L2SIVacuum.PRG_Test.fb_GCC_Test.fb_MKS422.fbLogger/Vacuum':	Critical (Gauge Disconnected.)			
5/19/2020 12:32:33 AM 090 ms	'L2SIVacuumLib.L2SIVacuum.PRG_Test.fb_GCC_Test.fb_MKS422.fbLogger/Vacuum':	Info (Ion gauge commanded to switch on)			



# Vacuum Library- Logging

Vacuum and device state events are recorded.

- Logging functionality is fully integrated in the library code
  - Messages can be logged every PLC cycle
  - Device state changes
  - Actions
  - Interlock events

```

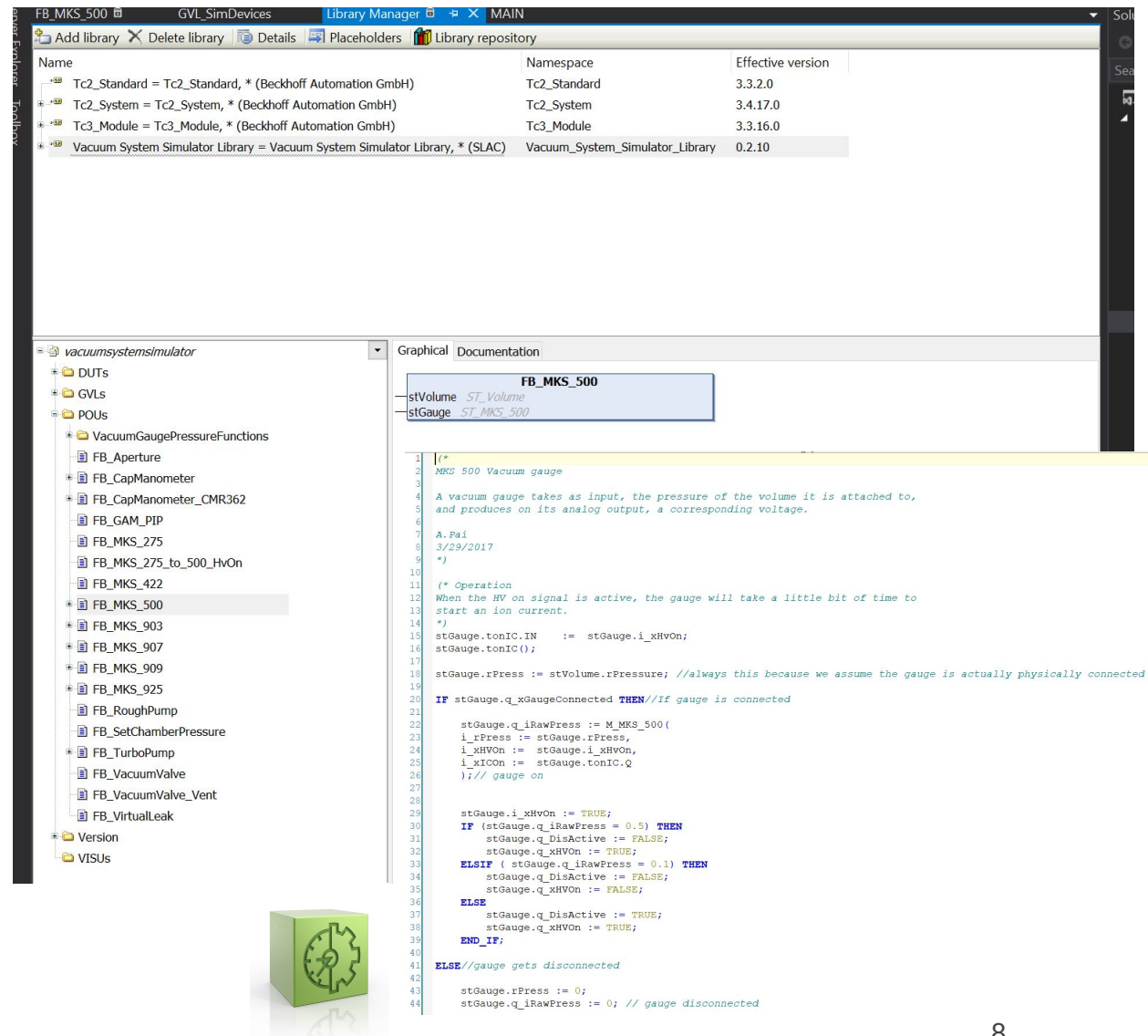
FB_MKS909  FB_MKS422.ACT_Logger*  FB_MKS500  FB_901_ECAT.ACT_Logger
1 // ILK logger
2 IF (IG.xLog) THEN
3     IF NOT IG.xILKok AND NOT IG.q_xHV_DIS THEN
4         fbLogger(sMsg:='Lost external interlock while gauge was on.', eSevr:
5     END_IF
6     // Log Action
7     tAction(CLK:= IG.xHV_SW);
8     IF tAction.Q THEN fbLogger(sMsg:='Ion gauge commanded to switch on', eSevr:
9
10    //STATE Logger
11    IF ePrevState <> IG.eState THEN
12        CASE IG.eState OF
13            ValidHi:
14                fbLogger(sMsg:='Gauge pressure valid high.', eSevr:=TcEventSeve
15            ValidLo:
16                fbLogger(sMsg:='Gauge pressure valid low.', eSevr:=TcEventSever
17            Valid:
18                fbLogger(sMsg:='Gauge pressure valid.', eSevr:=TcEventSeverity.
    
```

Severity Level	Event Class Name	Event Id	Event Text	Source Name	Time Raised	Time Cleared	Time Confir
Info	Log event	3	Info (Valve set to Close.)	plc_kfe_xgmd_vac.plc_kfe_xgmd_vac.GVL_Devices.VGP_50.fbLogger/Vacuum	10/5/2021 6:39:04.958 AM		
Info	Log event	3	Info (Valve commanded to move)	plc_kfe_xgmd_vac.plc_kfe_xgmd_vac.GVL_Devices.VGP_50.fbLogger/Vacuum	10/5/2021 6:39:04.957 AM		
Critical	Log event	0	Critical (Pump stopped.)	plc_kfe_xgmd_vac.plc_kfe_xgmd_vac.GVL_GMD.fb_EM2K0_XGMD_PTM_30.fbLogger/Vacuum	10/4/2021 12:47:04.527 PM		
Critical	Log event	0	Critical (Pump Fault.)	plc_kfe_xgmd_vac.plc_kfe_xgmd_vac.GVL_GMD.fb_EM2K0_XGMD_PTM_30.fbLogger/Vacuum	10/4/2021 12:47:04.327 PM		
Critical	Log event	0	Critical (Pump Lost Alarm OK bit)	plc_kfe_xgmd_vac.plc_kfe_xgmd_vac.GVL_GMD.fb_EM2K0_XGMD_PTM_30.fbLogger/Vacuum	10/4/2021 12:47:04.317 PM		
Info	Log event	3	Info (Pump starting.)	plc_kfe_xgmd_vac.plc_kfe_xgmd_vac.GVL_GMD.fb_EM2K0_XGMD_PTM_30.fbLogger/Vacuum	10/4/2021 12:47:04.127 PM		
Info	Log event	3	Info (Pump running.)	plc_kfe_xgmd_vac.plc_kfe_xgmd_vac.GVL_GMD.fb_EM2K0_XGMD_PTM_30.fbLogger/Vacuum	10/4/2021 12:43:36.969 PM		
		2023-06-24 10:29:12	Info (Gauge pressure valid.)	plc_kfe_gatt.plc_kfe_gatt.GVL_Devices.fb_AT1K0_GAS_GCC_140.fbLogger			1
		2023-06-24 10:29:10	Info (Gauge pressure valid.)	plc_kfe_gatt.plc_kfe_gatt.GVL_Devices.fb_AT1K0_GAS_GCC_130.fbLogger			1
		2023-06-24 10:29:09	Info (Ion gauge commanded to switch on)	plc_kfe_gatt.plc_kfe_gatt.GVL_Devices.fb_AT1K0_GAS_GCC_140.fbLogger			1

# Vacuum Library- Simulator

## Testing, testing, testing.

- Simulation Library
  - Each vacuum device has its own simulation function block
    - All I/Os definitions (inverted)
    - Simulate the device functions
    - Simulates vacuum volumes
- EtherCAT Simulation
  - Connect the PLC to a simulation computer.
  - EtherCAT features on the simulation computer are modeled.
  - No additional reconfiguration needed



The screenshot displays the Siemens SIMATIC Manager Library Manager interface. The top window shows the 'Library repository' with a table of installed libraries:

Name	Namespace	Effective version
Tc2_Standard = Tc2_Standard, * (Beckhoff Automation GmbH)	Tc2_Standard	3.3.2.0
Tc2_System = Tc2_System, * (Beckhoff Automation GmbH)	Tc2_System	3.4.17.0
Tc3_Module = Tc3_Module, * (Beckhoff Automation GmbH)	Tc3_Module	3.3.16.0
Vacuum System Simulator Library = Vacuum System Simulator Library, * (SLAC)	Vacuum_System_Simulator_Library	0.2.10

The bottom window shows the 'vacuumsystemsimulator' library structure in the left pane, with 'FB\_MKS\_500' selected. The right pane displays the graphical documentation for 'FB\_MKS\_500', showing a block diagram with inputs 'stVolume ST\_Volume' and 'stGauge ST\_MKS\_500'. Below the diagram is the ladder logic code for the function block:

```
1 | (*  
2 | MKS 500 Vacuum gauge  
3 |  
4 | A vacuum gauge takes as input, the pressure of the volume it is attached to,  
5 | and produces on its analog output, a corresponding voltage.  
6 |  
7 | A.Pai  
8 | 3/29/2017  
9 | *)  
10 |  
11 | (* Operation  
12 | When the HV on signal is active, the gauge will take a little bit of time to  
13 | start an ion current.  
14 | *)  
15 | stGauge.tonIC.IN := stGauge.i_xHvOn;  
16 | stGauge.tonIC();  
17 |  
18 | stGauge.rPress := stVolume.rPressure; //always this because we assume the gauge is actually physically connected  
19 |  
20 | IF stGauge.q_xGaugeConnected THEN //If gauge is connected  
21 |  
22 |   stGauge.q_iRawPress := M_MKS_500(  
23 |     i_rPress := stGauge.rPress,  
24 |     i_xHvOn := stGauge.i_xHvOn,  
25 |     i_xICOn := stGauge.tonIC.Q  
26 |   ); // gauge on  
27 |  
28 |  
29 |   stGauge.i_xHvOn := TRUE;  
30 |   IF (stGauge.q_iRawPress = 0.5) THEN  
31 |     stGauge.q_DisActive := FALSE;  
32 |     stGauge.q_xHvOn := TRUE;  
33 |   ELSEIF ( stGauge.q_iRawPress = 0.1) THEN  
34 |     stGauge.q_DisActive := FALSE;  
35 |     stGauge.q_xHvOn := FALSE;  
36 |   ELSE  
37 |     stGauge.q_DisActive := TRUE;  
38 |     stGauge.q_xHvOn := TRUE;  
39 |   END_IF;  
40 |  
41 | ELSE //gauge gets disconnected  
42 |  
43 |   stGauge.rPress := 0;  
44 |   stGauge.q_iRawPress := 0; // gauge disconnected
```



# EPICS Interface

## Automatic generation of db files from PLC.

- ADS deploy and Pytmc
  - SLAC-defined Pytmc pragmas to tag variables and data structures of the PLC code
  - Automates and simplifies accessing PLC variables through EPICS
  - EPICS DB records are generated automatically
  - ads-deploy wraps the above tool to generate a templated IOC and ready it for usage
- EPICS device drivers
  - Stream Device and Modbus
  - Configuration variables
  - Device meta-info
  - Long-term device status variables

```
15 {attribute 'pytmc' := '  
16 pv: AT_VAC;  
17 io: i;  
18 field: ENAM FALSE;  
19 field: ONAM TRUE;  
20 }  
21 xAT_VAC: BOOL;  
22 {attribute 'pytmc' := '  
23 pv: PRESS_OK;  
24 field: ENAM OFF;  
25 field: ONAM ON;  
26 io: i;  
27 }  
28 xPRESS_OK: BOOL;  
29 {attribute 'pytmc' := '  
30 pv: STATE;  
31 field: ERST Off;  
32 field: ONST GaugeDisconnected;  
33 field: TWST CoR;  
34 field: THST PressInvalid;  
35 field: FRST Starting;  
36 field: FVST Valid;  
37 field: SVST ValidHi;  
38 field: SVST ValidLo;  
39 io: i;  
40 }  
41 eState : E_PressureState;  
42 (* EPICS Controls *)  
43 {attribute 'pytmc' := '  
44
```

```
(* EPICS Controls *)  
{attribute 'pytmc' := 'pv: OPN_SW field: ZNAM CLOSE field: ONAM OPEN io: io '}  
pv_xOPN_SW : BOOL;  
{attribute 'pytmc' := '  
pv: ALM_RST  
io: o  
'}  
pv_xAlmRst : BOOL;
```

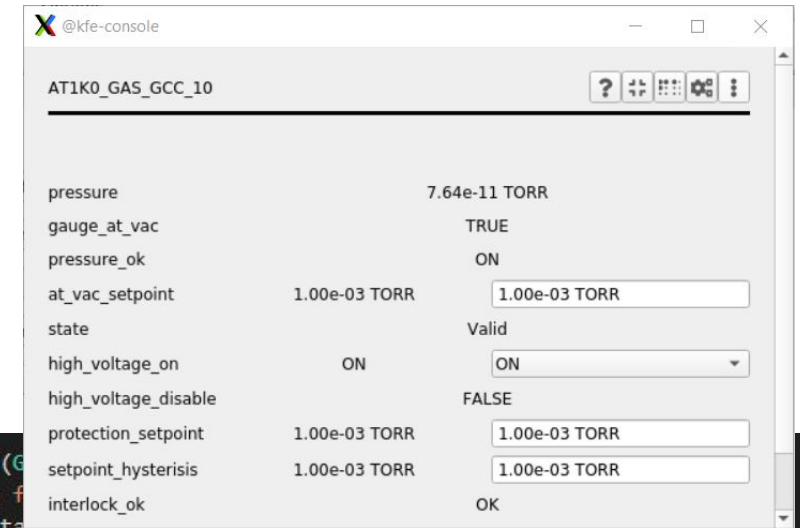
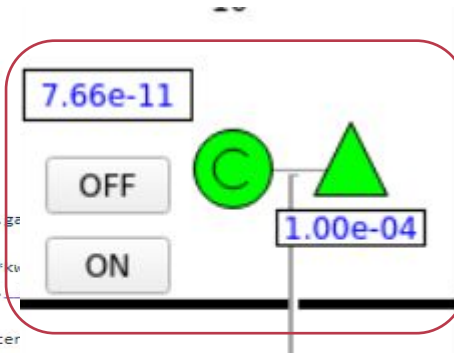
```
record(bo, "EM1L0:GEM:VGC:10:OPN_SW"){  
  field(ZNAM, "CLOSE")  
  field(ONAM, "OPEN")  
  field(DTYP, "asynInt32")  
  field(OUT, "@asyn($ (PORT),0,1)ADSPORT=851/GVL_Devices.GEM1_VGC_10.iq_stValve.pv_xOPN_SW=")  
}
```

# UI/UX - Ophyd and PyDM

Automatic generation of detailed engineering screens.

- Ophyd
  - Typhos uses ophyd objects to auto-generate device engineering screens
- PyDM Widgets
  - Widget stylesheet customizing the appearance of the widget based on the values of a number of PVs

```
227 """
228 _interlock_suffix = ":ILK_OK_RBV"
229 _state_suffix = ":STATE_RBV"
230 _readback_suffix = ":PRESS_RBV"
231 _command_suffix = ":HV_SW"
232
233 NAME = "Cold Cathode Gauge"
234 EXPERT_OPHYD_CLASS = "pcdsdevices.g...
235
236 def __init__(self, parent=None, **kw
237     super(ColdCathodeGauge, self).
238     parent=parent,
239     interlock_suffix=self._inter
240     state_suffix=self._state_suffix,
241     command_suffix=self._command_suffix,
242     readback_suffix=self._readback_suffix,
243     readback_name='pressure',
244     **kwargs)
245 self.icon = ColdCathodeGaugeSymbolIcon(parent=self)
246 self.readback_label.displayFormat = DisplayFormat.Exponential
247
```



```
class GCCPLC(GCCPLC)
    """Class for GCCPLC"""
    high_voltage_on = Cpt(EpicsSignalWithRBV, ':HV_SW', kind='normal',
        doc='command to switch the high voltage on')
    high_voltage_disable = Cpt(EpicsSignalRO, ':HV_DIS_DO_RBV', kind='normal',
        doc=('enables the high voltage on the cold '
            'cathode gauge'))
    protection_setpoint = Cpt(EpicsSignalWithRBV, ':PRO_SP', kind='normal',
        doc=('Protection setpoint for ion gauges at '
            'which the gauge turns off'))
    setpoint_hysteresis = Cpt(EpicsSignalWithRBV, ':SP_HYS', kind='config',
        doc='Protection setpoint hysteresis')
    interlock_ok = Cpt(EpicsSignalRO, ':ILK_OK_RBV', kind='normal',
        doc='Interlock is ok')
    auto_on = Cpt(EpicsSignalWithRBV, ':Auto_On', kind='config',
        doc=('Setting to automatically turn on the gauge when the '
            'reference gauge pressure is below protection '
            'setpoint'))
    autoOn_countdown = Cpt(EpicsSignalRO, ':AutoOn_timer_RBV', kind='normal',
        doc='timer count down to turn on the gauge')
```

# LCLS-II Vacuum Controls Systems - Architecture

## Standardisation.

- Supported Device List (SDL)
  - Extensive list of vacuum devices
  - Fully integrated across the stack
  - Configuration Scripts
- Vacuum Design templates



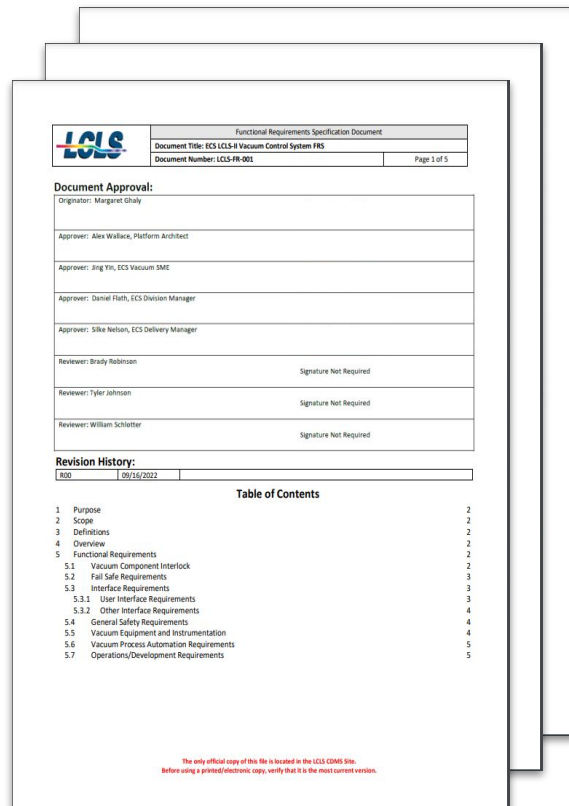
Valves	Pumps / Controllers	Gauges / Controllers
<ul style="list-style-type: none"><li>MKS 179A</li><li>MKS 248A/B/C</li><li>MKS 1179A</li><li>MKS 2179A</li><li>Pfeiffer EVR-116</li><li>Pfeiffer RVC-300</li><li>VAT Series 14</li><li>VAT Series 108</li><li>VAT Series 482</li><li>VAT Series 590</li></ul>	<ul style="list-style-type: none"><li>Agilent 4UHV Ion Pump C</li><li>DCU Rack-Mount Power S</li><li>DCU Wall-Mount Power S</li><li>Digital MPCe</li><li>Ebara ETC010M (new)</li><li>Ebara ETC011M</li><li>Ebara EV-S series</li><li>Gamma Ion Pump</li><li>HiPace (Hybrid Bearing)</li><li>HiPace M (Mag Lev)</li><li>HPU 001 - Hand-held Pro</li><li>Leybold MAG W 300/400</li><li>Leybold MAG W 2800 CT</li><li>Leybold TD20 Controller</li><li>Oerlikon Leybold Mag Dri</li><li>Oerlikon Leybold Mag Dri</li><li>OPS 400 Onboard Power</li><li>Pfeiffer TC110 Onboard D</li><li>Pfeiffer TC400 Onboard D</li><li>Pfeiffer TM700 Onboard C</li><li>QPC</li><li>TPS 110-400 Wall Mount</li><li>TPS 110 Rack Mount Pow</li><li>Turbo-V 2K-G Navigator</li><li>Turbo-V 81-M</li><li>Turbo-V 301 Navigator &amp;</li><li>Turbo-V 701</li><li>Turbo-V 1001 Navigator</li><li>TwisTorr 304 FS on board</li><li>Varian 9290022 Ion pump</li></ul>	<ul style="list-style-type: none"><li>InstruTech CCM501</li><li>InstruTech CVM201</li><li>Leybold IE 514</li><li>Leybold IM 540</li><li>MKS 275</li><li>MKS 317</li><li>MKS 392</li><li>MKS 422</li><li>MKS 500</li><li>MKS 622B/623B/62</li><li>MKS 622C/626C</li><li>MKS 627B</li><li>MKS 670B</li><li>MKS 722B</li><li>MKS 901P</li><li>MKS 903</li><li>MKS 907</li><li>MKS 909</li><li>MKS 925</li><li>MKS 937A</li><li>MKS 937B</li><li>MKS 937 Serial Con</li><li>MKS 972B</li><li>MKS Issues and Inst</li><li>MKS MIG</li><li>MKS PDR 200</li><li>Pfeiffer CMR 362</li></ul>

The screenshot shows a Confluence page with the SLAC logo and navigation options. The main heading is 'Vacuum System Architecture Design Templates', created by Alex Wallace. A list of links includes: Turbo pump stack, Vent Package example, Gas injection chamber overview, Beam transport overview, and Treaty Interfaces Between Two Vacuum Systems. Below the list is a schematic diagram of a vacuum system. The diagram shows a horizontal line representing a main pipe with a 'Gate Valve' at the bottom. Two vertical lines branch off from the main pipe, each leading to a box labeled '500 VG' and '275 VG' respectively. A callout box points to the diagram with the text: 'Cold Cathode gauge - Switches on when the attached pirani gauge reads a pressure less than a predefined setpoint. - Switches off when its internal reading rises about the predefined setpoint.'

The screenshot shows a Confluence page for 'Cold Cathode Vacuum Pressure Transducers'. It includes an image of a blue and silver gauge, a 'Website' link, and a 'Datasheets and Manuals' section with links to 'Brochure.pdf' and 'Manual.pdf'. A red box highlights the 'Manual.pdf' link, and a red arrow points from it to the 'MKS 500' entry in the adjacent table.

# LCLS-II Vacuum Controls Systems - Architecture

## Beyond LCLS-II.



LCLS		Functional Requirements Specification Document	
Document Title: ECS LCLS-II Vacuum Control System FRS		Page: 1 of 5	
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**Document Approval:**

Originator: Margaret Ghaly	
Approver: Alex Wallace, Platform Architect	
Approver: Jing Yin, ECS Vacuum SME	
Approver: Daniel Flath, ECS Division Manager	
Approver: Silke Nelson, ECS Delivery Manager	
Reviewer: Brady Robinson	Signature Not Required
Reviewer: Tyler Johnson	Signature Not Required
Reviewer: William Schlotter	Signature Not Required

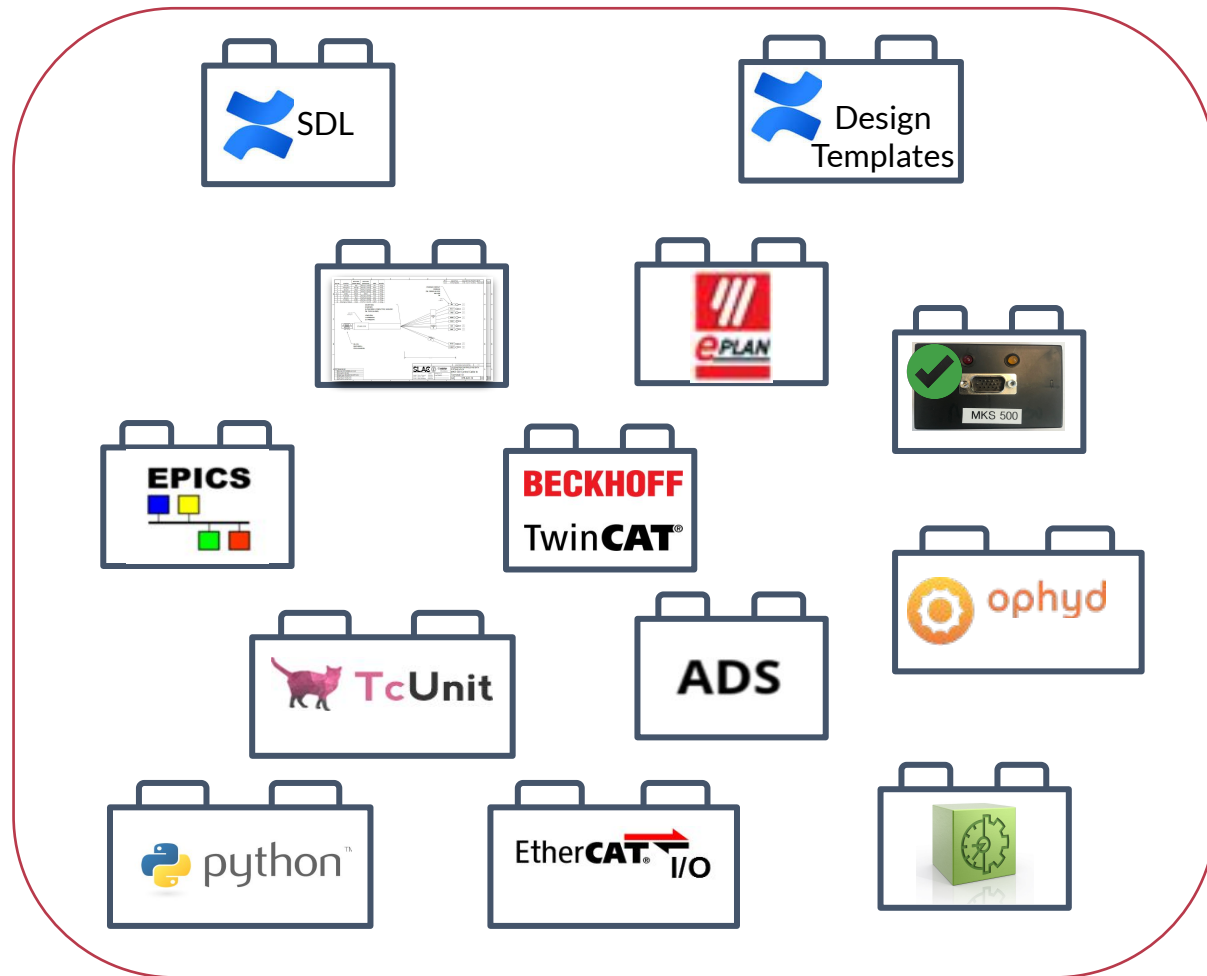
**Revision History:**

Rev	Date	Description
000	09/16/2022	

**Table of Contents**

1	Purpose	2
2	Scope	2
3	Definitions	2
4	Overview	2
5	Functional Requirements	2
5.1	Vacuum Component Interlock	2
5.2	Fail Safe Requirements	3
5.3	Interface Requirements	3
5.3.1	User Interface Requirements	3
5.3.2	Other Interface Requirements	4
5.4	General Safety Requirements	4
5.5	Vacuum Equipment and Instrumentation	4
5.6	Vacuum Process Automation Requirements	5
5.7	Operations/Development Requirements	5

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Questions?

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