中国科学院高能物理研究所

Institute of High Energy Physics, Chinese Academy of Sciences

Development a Single Cavity Regulation Based on MicroTCA.4 for SAPS-TP

Long Wei

Project group of domestic MTCA.4 platform

ICALEPCS 2021, Shanghai 2021.10

China Spallation Neutron Source

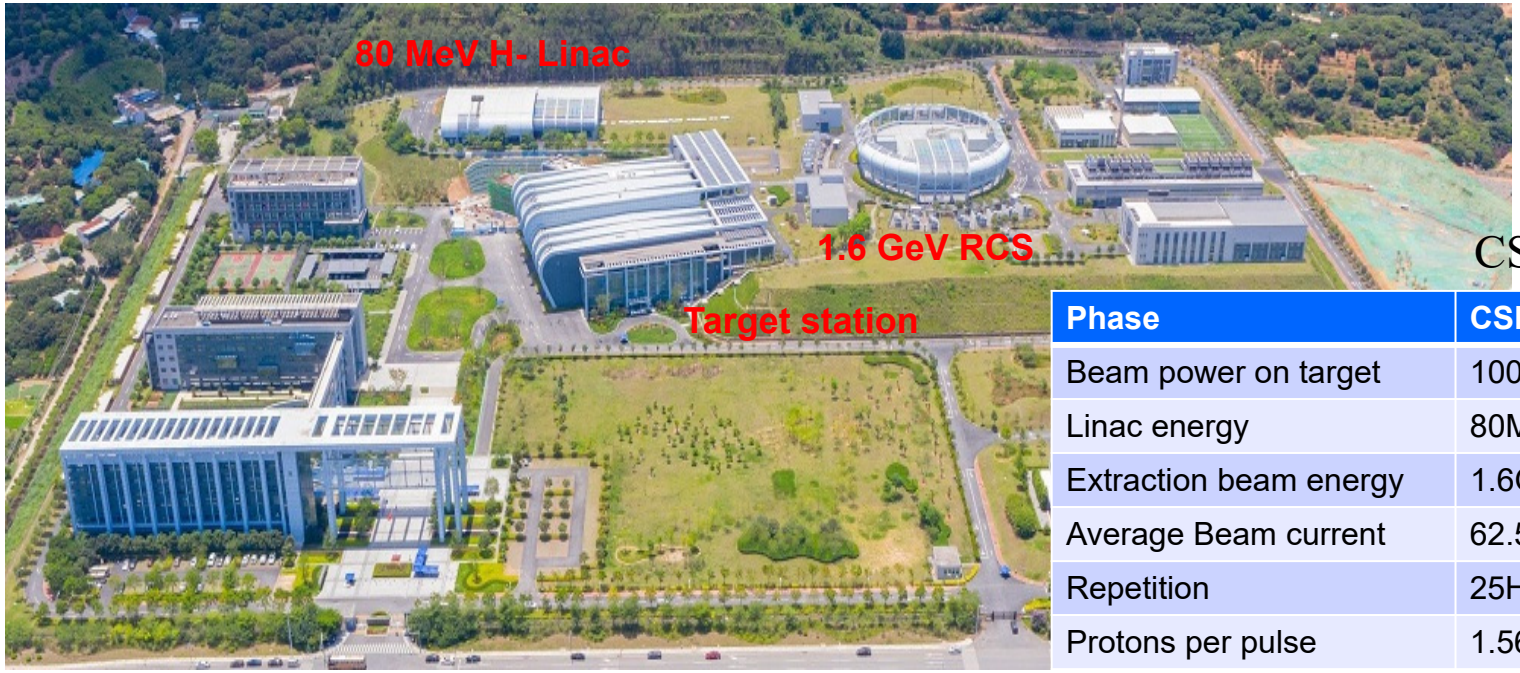
Introduction

Introduction to our facilities.

Dongguan City, Guangdong Province, China

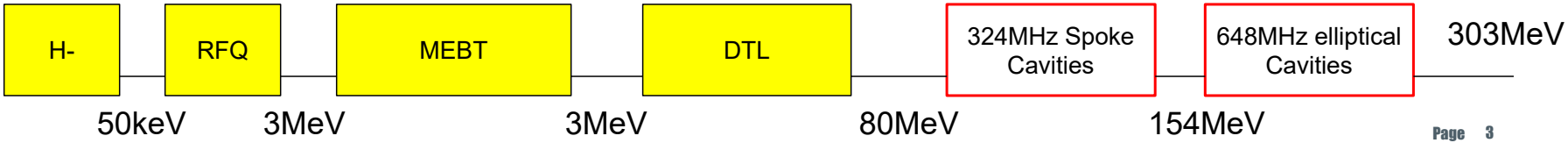
Introduction

CSNS (China Spallation Neutron Source) – China's first pulsed neutron source.



CSNS II upgrade

Phase	CSNS I	CSNS II
Beam power on target	100 kW	500 kW
Linac energy	80MeV	300MeV
Extraction beam energy	1.6GeV	1.6GeV
Average Beam current	62.5μA	312.5μA
Repetition	25Hz	25Hz
Protons per pulse	1.56E13	7.8E13



Introduction

SAPS Southern Advanced Photon Source

- 4th generation medium energy synchrotron radiation source

SAPS-TP Southern Advanced Photon Source Test platform

SAPS

Storage ring Beam energy	3.5GeV
emittance	31.7pm·rad
circumference	1080m
RF frequency	166.6MHz

SAPS-TP

- Superconducting RF Hall
- optical experiment Hall
- low temperature Hall
- High-accuracy measurement Hall
- Comprehensive laboratory

Introduction

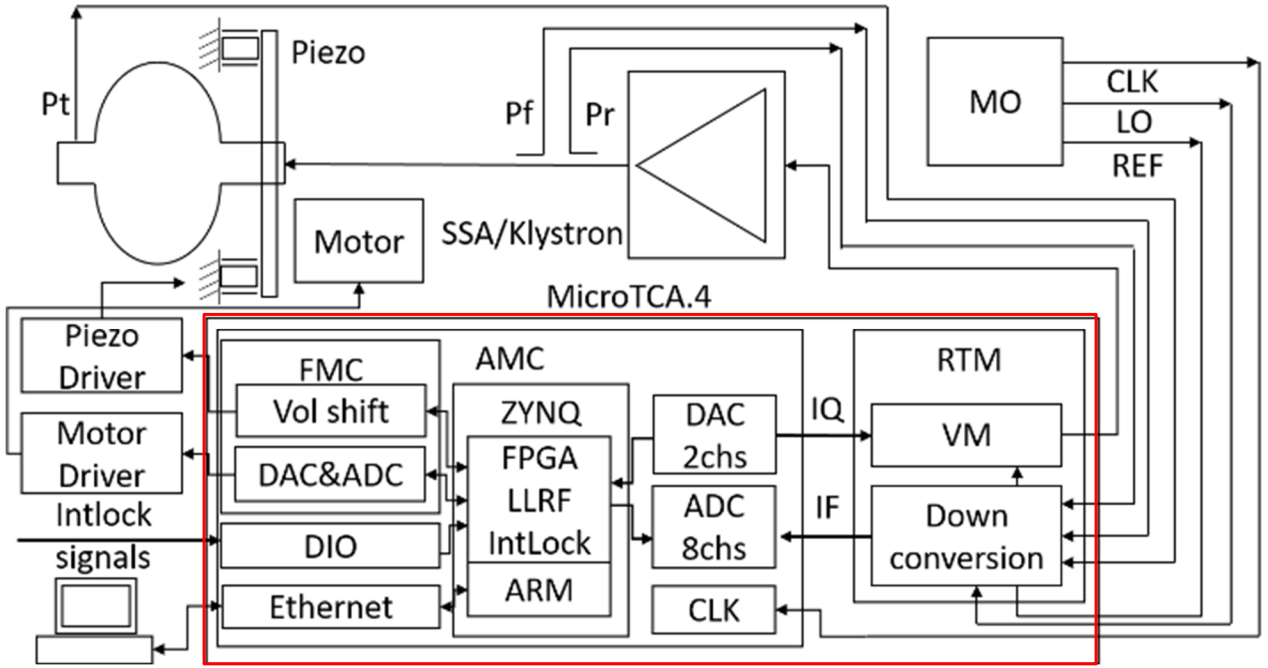
2 vertical test pits

a horizon test station

Can be applied:

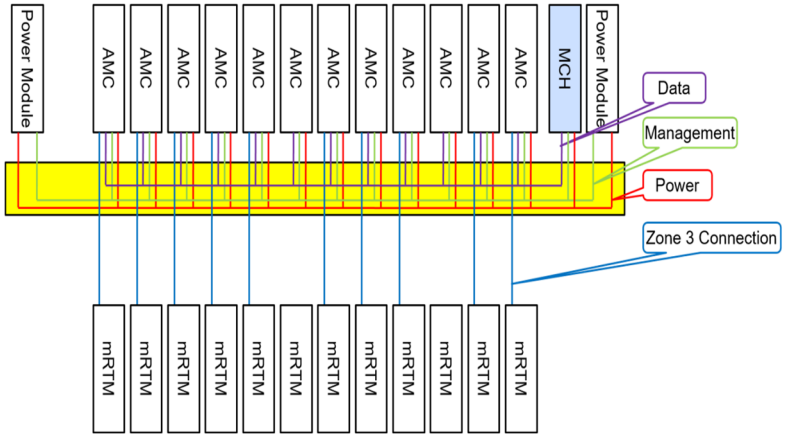
- 324 MHz spoke cavity
- 648 MHz elliptical cavity
- 500 MHz elliptical cavity
- 1.3GHz elliptical cavity
- …

single cavity regulation - system architecture



The single cavity regulation system based on MTCA.4 for SAPS-TP

Hardware platform

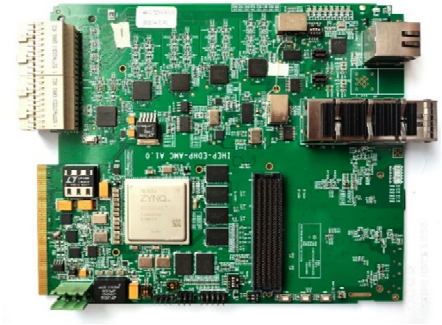


A domestic MTCA.4 chassis including:

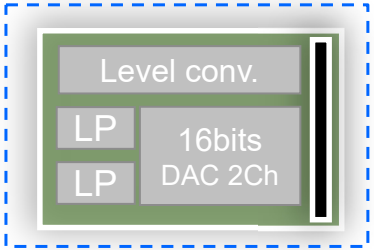
- 2 1.6kW power modules (one for redundancy)
- 2 Cooling Unit (CU) modules.

MMC mezzanine Card

A domestic multifunction digital AMC module



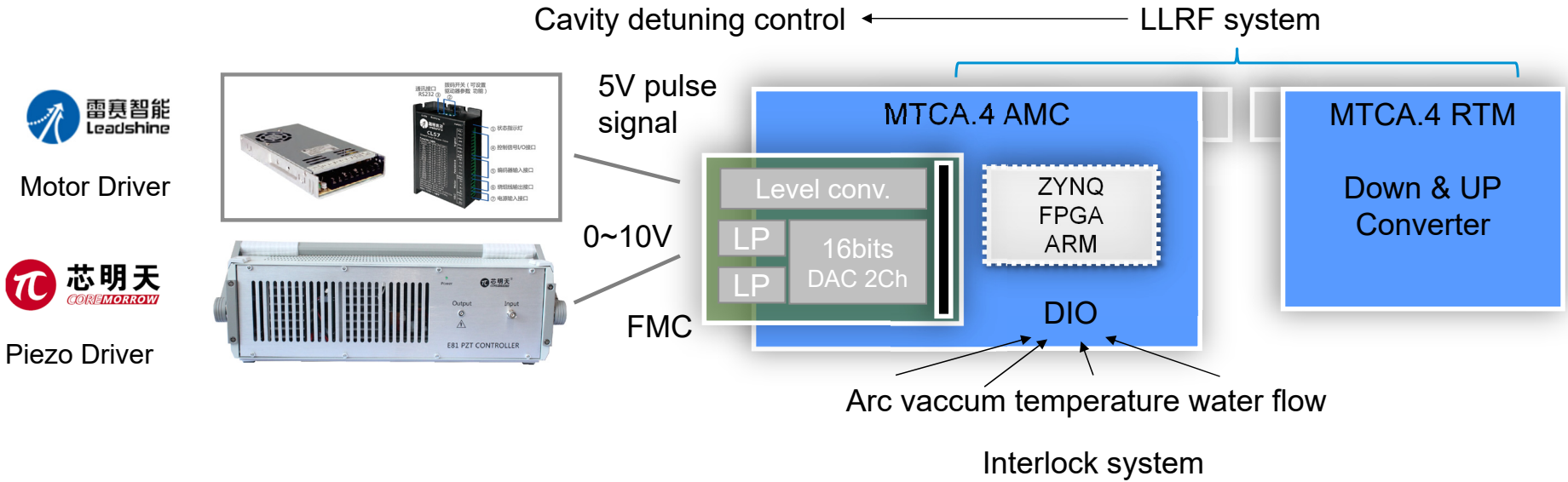
down-conversion and up-conversion RTM module.



tuning control FMC card
Under development

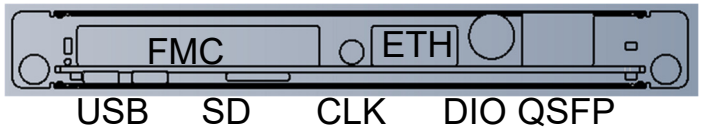
Hardware platform

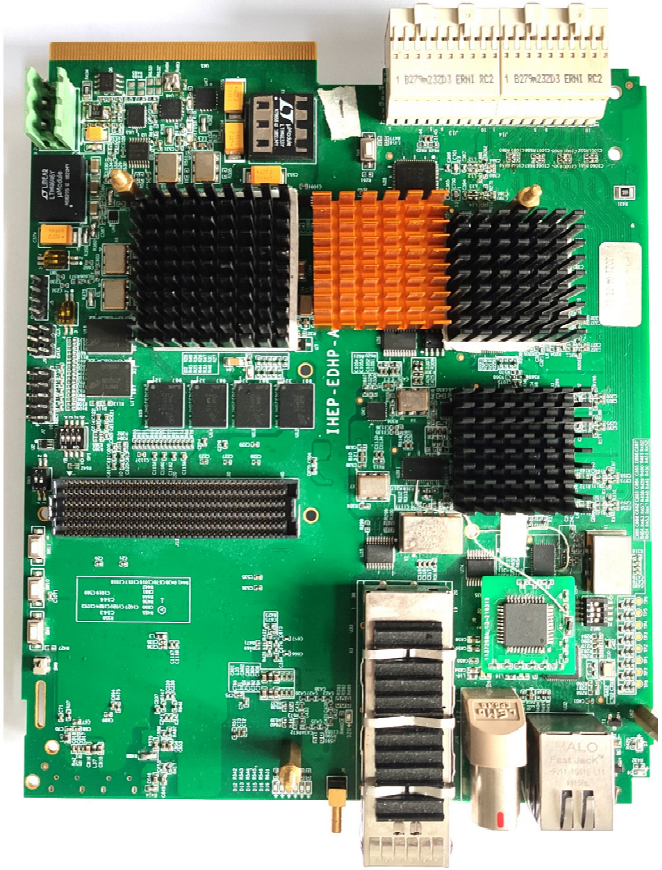
SAPS-TP 648MHz Elliptical Cavities Single Cavity Regulation based on MicroTCA.4



multifunction digital AMC module

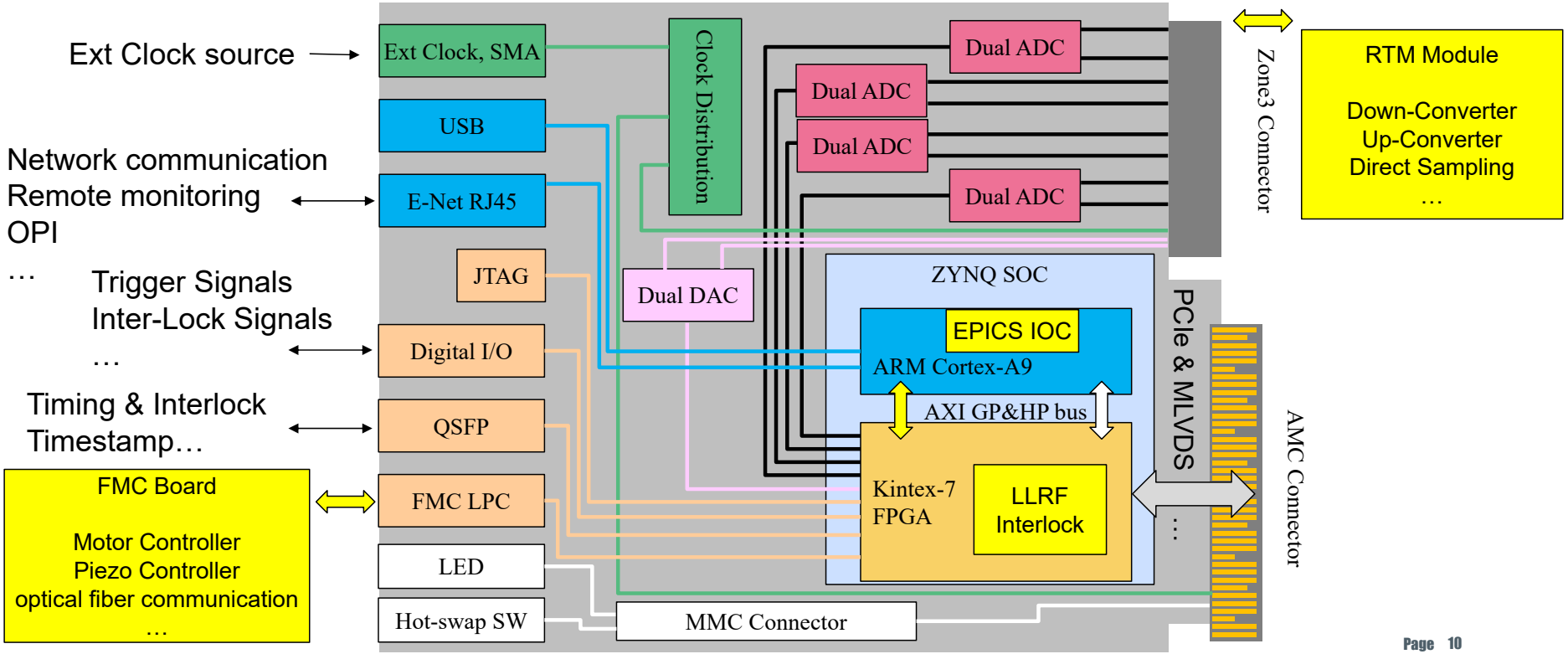
- MTCA.4 standard & µRTM ZONE3 Class A1.1CO
- Double-width mid-size
- 8 Channels 125 MSPS 16-bit ADC
- 2 Channels 500 MSPS 16-bit DAC
- XC7Z045 Zynq-7000 SoC
- 2GBytes DDR3 memory size
- 1 FMC LPC Slot (VITA 57.1)
- A 4 lanes QSFP cage
- Front panel digital I/O (10 pins LVTTL)
- A Gigabit Ethernet interface
- Front panel Clock input
- A front-panel USB provides console DisplayPort





multifunction digital AMC module

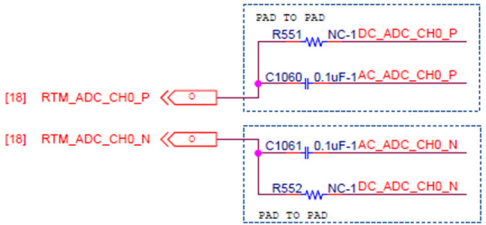
A goal: one AMC board can constitute a complete system and can implement complete project applications.



multifunction digital AMC module

- AD: Analog Devices AD9268
  - 125MSPS 16bit
  - Bandwidth: 650MHz
  - Output Interface: DDR LVDS
- DA: Analog Devices AD9783
  - 500MSPS 16bit
  - Output Interface: DDR LVDS

- Compatible analog front-end circuit design
  - Intermediate frequency range: 5-100MHz
  - Direct Sampling: 5-400MHz (650MHz? Try)
  - DC coupled

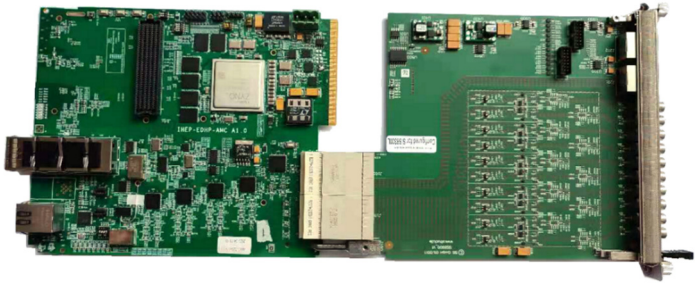


DC/AC coupled is optional

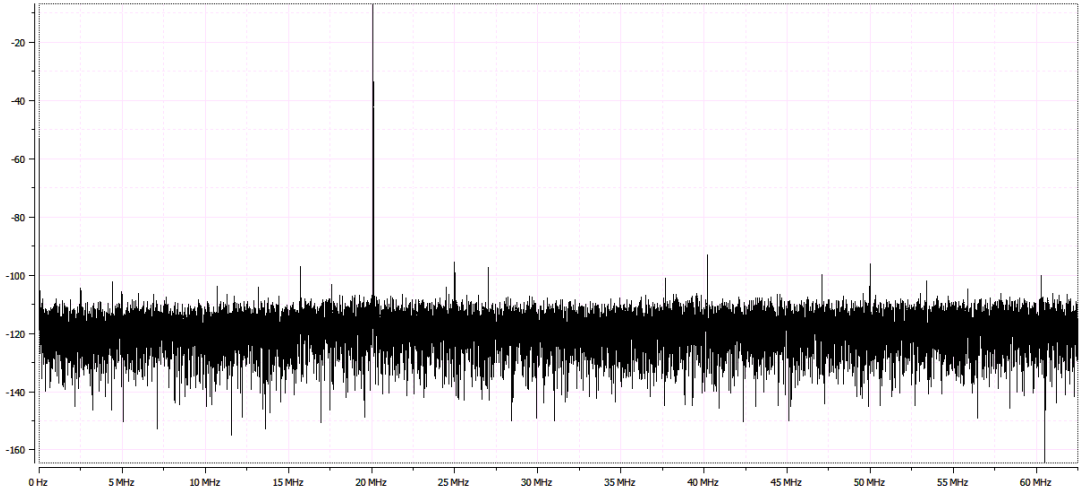
Analog signals	J31	1	CH9_PA+	CH9_PA-	DAC0+	DAC0-	CH9_TF+	CH9_TF-
		2	CH8_TF+	CH8_TF-	gnd	gnd	CH8_PA+	CH8_PA-
		3	CH7_PA+	CH7_PA-	DAC1+	DAC1-	CH7_TF+	CH7_TF-
		4	CH6_TF+	CH6_TF-	gnd	gnd	CH6_PA+	CH6_PA-
		5	CH5_PA+	CH5_PA-	DAC2+	DAC2-	CH5_TF+	CH5_TF-
		6	CH4_TF+	CH4_TF-	gnd	gnd	CH4_PA+	CH4_PA-
		7	CH3_PA+	CH3_PA-	DAC3+	DAC3-	CH3_TF+	CH3_TF-
		8	CH2_TF+	CH2_TF-	gnd	gnd	CH2_PA+	CH2_PA-
		9	CH1_PA+	CH1_PA-	DAC4+	DAC4-	CH1_TF+	CH1_TF-
		10	CH0_TF+	CH0_TF-	gnd	gnd	CH0_PA+	CH0_PA-

2 channels DA 8 channels AD

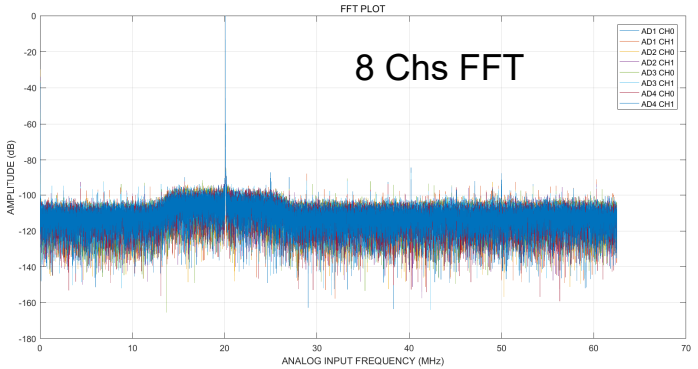
multifunction digital AMC module

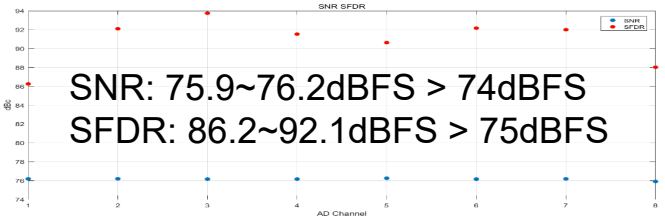


- AD Test
  - IHEP-EDHP-AMC + SIS8900 RTM
  - Signal Source: 20MHz 3dBm
  - 125MSPS



FFT



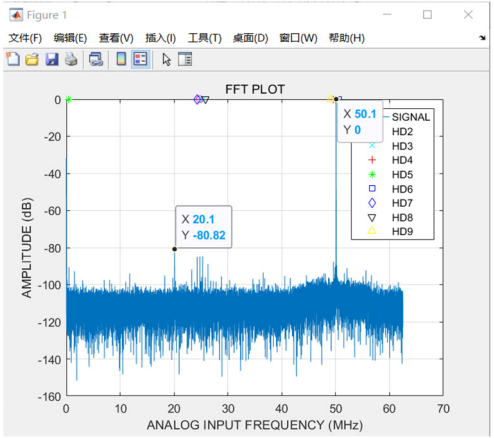


SNR: 75.9~76.2dBFS > 74dBFS
SFDR: 86.2~92.1dBFS > 75dBFS

multifunction digital AMC module

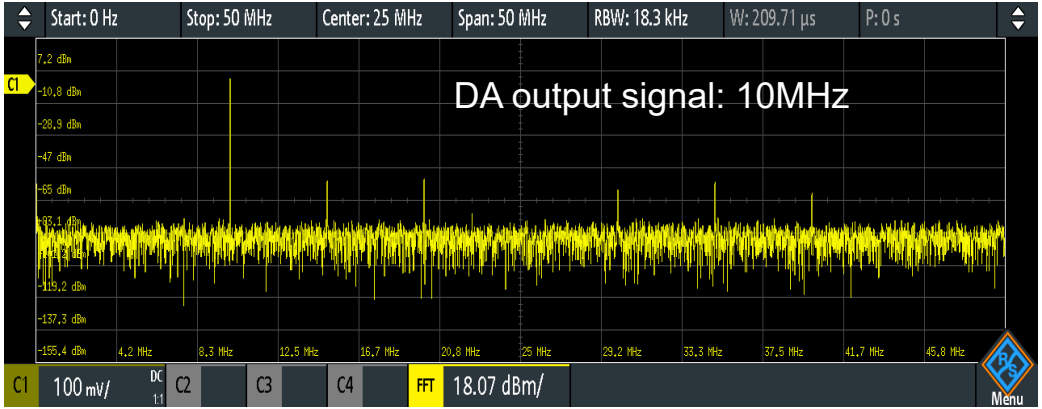
- Channel isolation

	AD1_CH0	AD1_CH1	AD2_CH0	AD2_CH1	AD3_CH0	AD3_CH1	AD4_CH0	AD4_CH1
AD1_CH0		74.95						
AD1_CH1	84.32		80.89					
AD2_CH0		75.22		77.1				
AD2_CH1			82.16		80.82			
AD3_CH0				87.3		79.46		
AD3_CH1	Isolation of adjacent channels				78.89		85.59	
AD4_CH0						94.8		85.13
AD4_CH1							78.1	



Isolation Test

- DA Spectrum



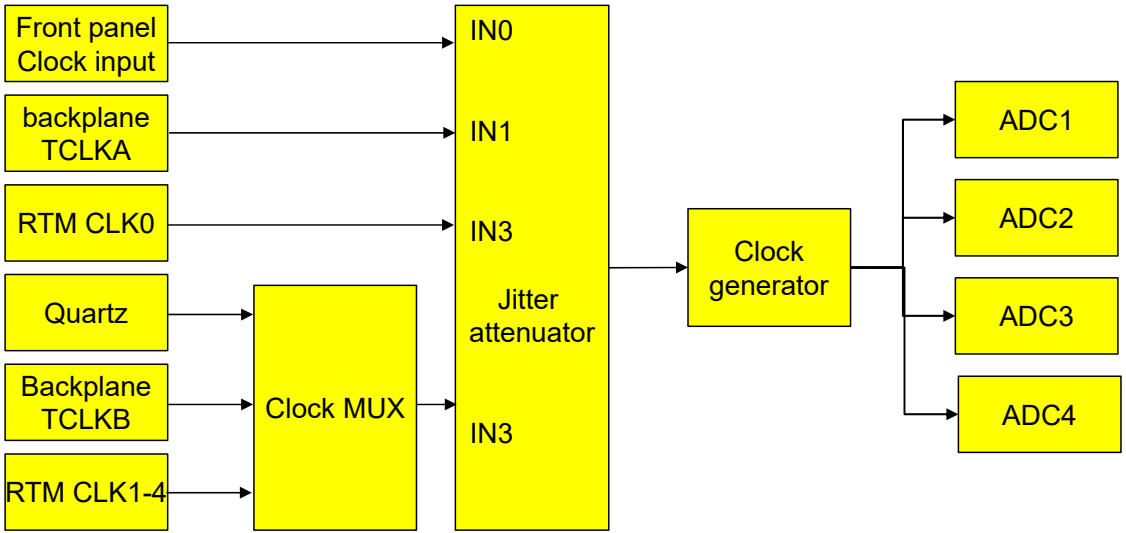
- + Adaptor RTM

SNR: 78.1 dB

some larger harmonic component

multifunction digital AMC module-Clock Distribution

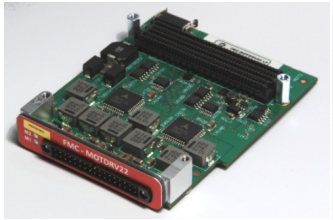
- ultra-low clock jitter
  - 648MHz direct sampling LLRF 0.1° jitter (<423fs pp)
  - Jitter attenuator + Low phase noise clock generator
  - Theoretical clock jitter ≈ 240fs pp (170fs RMS)



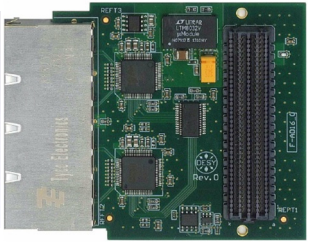
multifunction digital AMC module-FMC Slot

- Compatible with FMC LPC standard & 4 high-speed serial transceiver pairs.

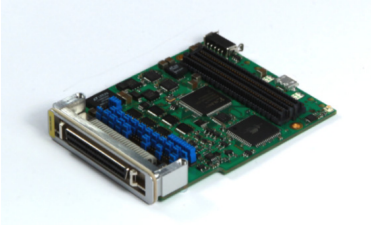
DFMC-MD22



DFMC-AD16



DFMC-UNI-IO



DFMC-SFP4

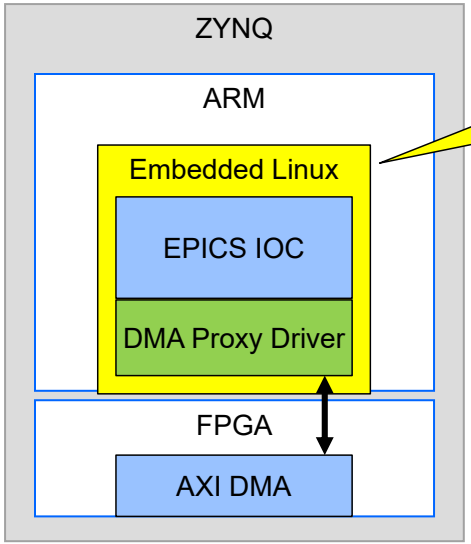
Compatible commercial FMC cards

	K	J	H	G	F	E	D	C	B	A
1	NC	NC	VREF_A_M2C	GND	NC	NC	PG_C2M	GND	NC	GND
2	NC	NC	PRSNT_M2C_L	CLK0_C2M_P	NC	NC	GND	DP0_C2M_P	NC	DP1_M2C_P
3	NC	NC	GND	CLK0_C2M_N	NC	NC	GND	DP0_C2M_N	NC	DP1_M2C_N
4	NC	NC	CLK0_M2C_P	GND	NC	NC	GBTCLK0_M2C_P	GND	NC	GND
5	NC	NC	CLK0_M2C_N	GND	NC	NC	GBTCLK0_M2C_N	GND	NC	GND
6	NC	NC	GND	LA00_P_CC	NC	NC	GND	DP0_M2C_P	NC	DP2_M2C_P
7	NC	NC	LA02_P	LA00_N_CC	NC	NC	GND	DP0_M2C_N	NC	DP2_M2C_N
8	NC	NC	LA02_N	GND	NC	NC	LA01_P_CC	GND	NC	GND
9	NC	NC	GND	LA03_P	NC	NC	LA01_N_CC	GND	NC	GND
10	NC	NC	LA04_P	LA03_N	NC	NC	GND	LA06_P	NC	DP3_M2C_P
11	NC	NC	LA04_N	GND	NC	NC	LA05_P	LA06_N	NC	DP3_M2C_N
12	NC	NC	GND	LA08_P	NC	NC	LA05_N	GND	NC	GND
13	NC	NC	LA07_P	LA08_N	NC	NC	GND	GND	NC	GND
14	NC	NC	LA07_N	GND	NC	NC	LA09_P	LA10_P	NC	NC
15	NC	NC	GND	LA12_P	NC	NC	LA09_N	LA10_N	NC	NC
16	NC	NC	LA11_P	LA12_N	NC	NC	GND	GND	NC	NC
17	NC	NC	LA11_N	GND	NC	NC	LA13_P	GND	NC	NC
18	NC	NC	GND	LA16_P	NC	NC	LA13_N	LA14_P	GND	NC
19	NC	NC	LA15_P	LA16_N	NC	NC	GND	LA14_N	GND	NC
20	NC	NC	LA15_N	GND	NC	NC	LA17_P_CC	GND	GBTCLK1_M2C_P	NC
21	NC	NC	GND	LA20_P	NC	NC	LA17_N_CC	GND	GBTCLK1_M2C_N	NC
22	NC	NC	LA19_P	LA20_N	NC	NC	GND	LA18_P_CC	GND	GND
23	NC	NC	LA19_N	GND	NC	NC	LA23_P	LA18_N_CC	GND	GND
24	NC	NC	GND	LA22_P	NC	NC	LA23_N	GND	NC	DP1_C2M_P
25	NC	NC	LA21_P	LA22_N	NC	NC	GND	GND	NC	DP1_C2M_N
26	NC	NC	LA21_N	GND	NC	NC	LA26_P	LA27_P	NC	GND
27	NC	NC	GND	LA25_P	NC	NC	LA26_N	LA27_N	NC	GND
28	NC	NC	LA24_P	LA25_N	NC	NC	GND	GND	NC	DP2_C2M_P
29	NC	NC	LA24_N	GND	NC	NC	TCK	GND	NC	DP2_C2M_N
30	NC	NC	GND	LA29_P	NC	NC	TDI	SCL	NC	GND
31	NC	NC	LA28_P	LA29_N	NC	NC	TDO	SDA	NC	GND
32	NC	NC	LA28_N	GND	NC	NC	3P3VAUX	GND	NC	DP3_C2M_P
33	NC	NC	GND	LA31_P	NC	NC	TMS	GND	NC	DP3_C2M_N
34	NC	NC	LA30_P	LA31_N	NC	NC	TRST_L	GA0	NC	GND
35	NC	NC	LA30_N	GND	NC	NC	GA1	12P0V	NC	GND
36	NC	NC	GND	LA33_P	NC	NC	3P3V	GND	NC	NC
37	NC	NC	LA32_P	LA33_N	NC	NC	GND	12P0V	NC	NC
38	NC	NC	LA32_N	GND	NC	NC	3P3V	GND	NC	NC
39	NC	NC	GND	VADJ	NC	NC	GND	3P3V	NC	NC
40	NC	NC	VADJ	GND	NC	NC	3P3V	GND	NC	NC
			LPC Connector	LPC Connector			LPC Connector	LPC Connector		

FMC LPC引脚

Software development

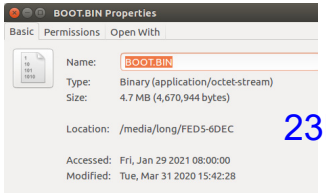
- Embedded Linux Development for ZYNQ chip



Open source Linux kernel

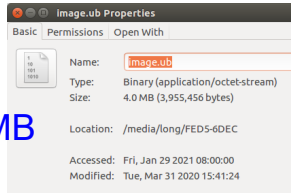
Tool: Xilinx petalinux

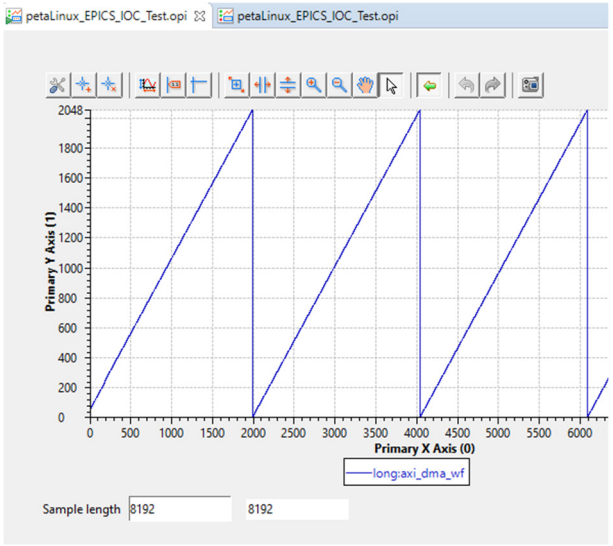
Linux Boot Image

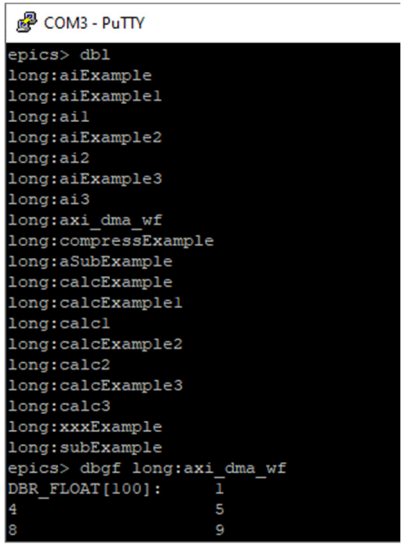


23MB

Linux Kernel Image







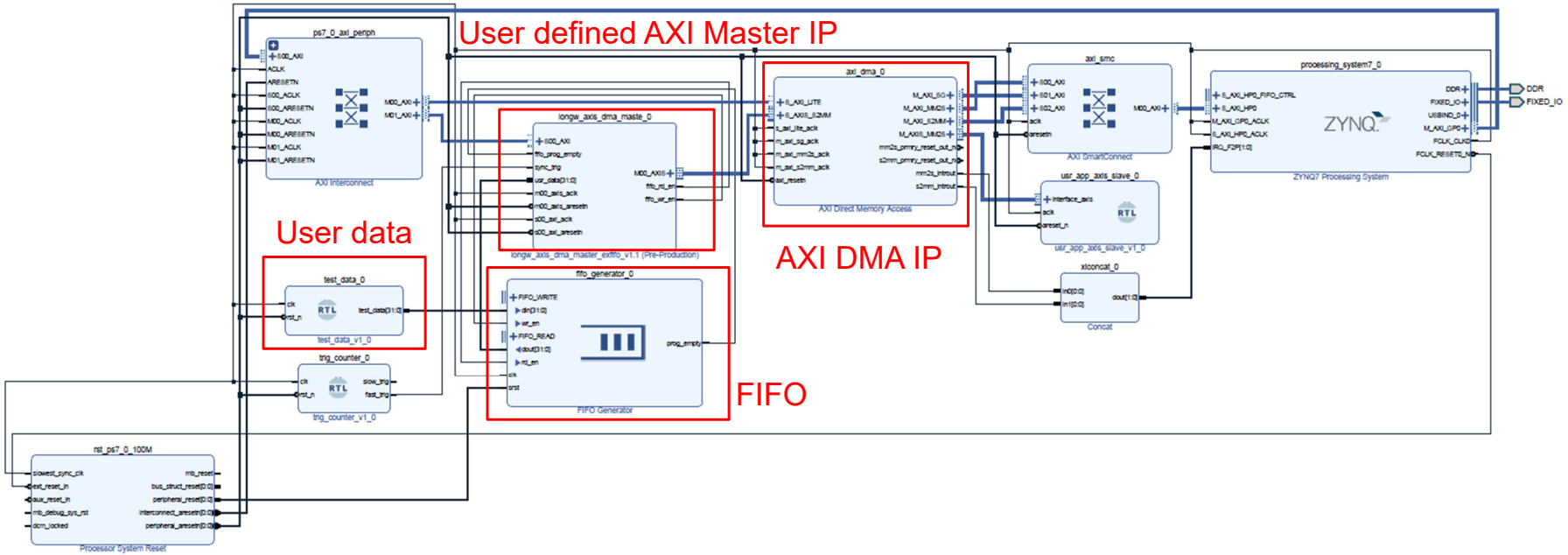
45MB

EPICS IOC Demon

PV: AI AO Waveform

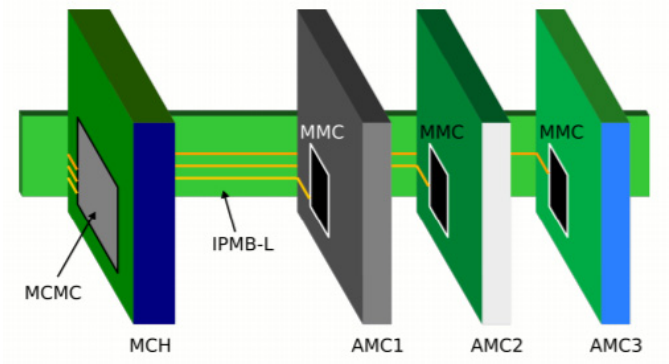
Software development

- Embedded Linux Development for ZYNQ chip



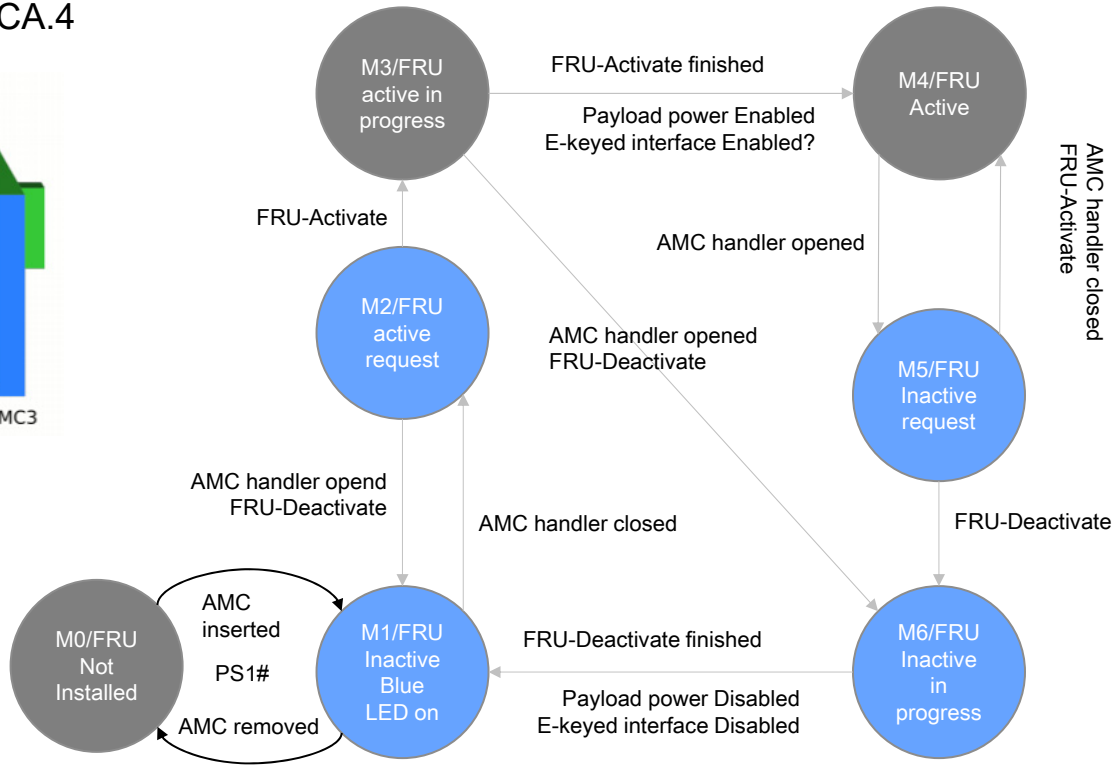
MMC controller mezzanine Card

Management subsystem of MicroTCA.4



Functions:

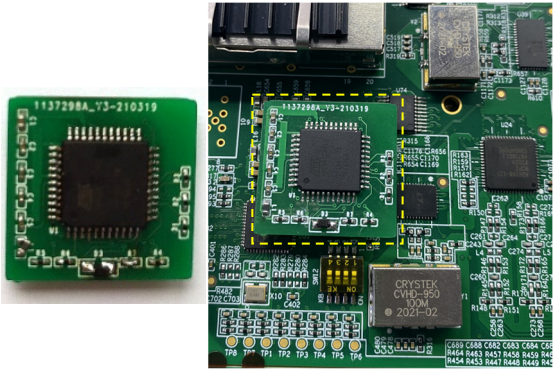
- AMC state management
- Hot swap management
- Sensor monitoring (Voltage, temperature, handler, …)
- LED management
- Threshold event management
- …



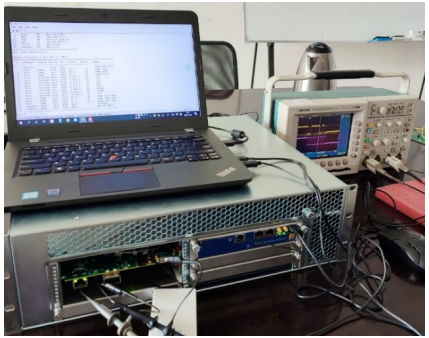
AMC state transition

MMC controller mezzanine Card

Test environment:
Commercial nVent MTCA.4 chassis
N.A.T NAT-MCH-PHYS80 MCH card

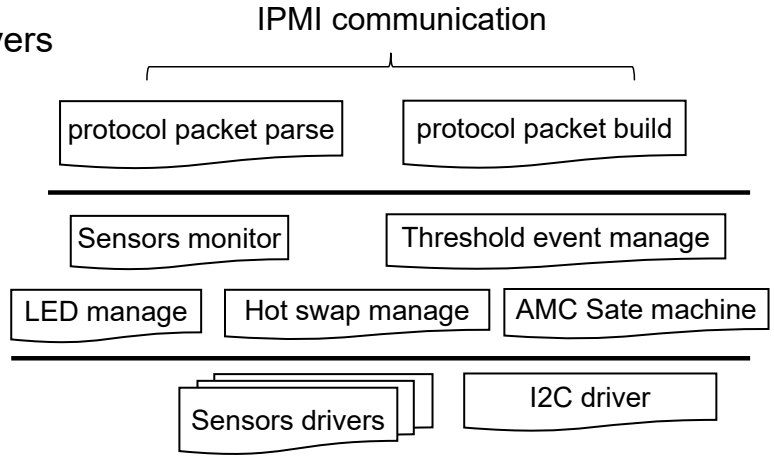


MMC Controller in AMC



MMC Controller Testbench

Software layers



FRU	Device	State	Name
0	MCH	M4	NAT-MCH-CM
3	mcmc1	M4	NAT-MCH-MCMC
9	AMC5	M4	IHEP-AMC-V1.0
40	CU1	M4	Schroff uTCA CU
51	PM2	M4	NAT-PM-AC1000
60	Clock1	M4	MCH-Clock
61	HubMod1	M4	MCH-PCIe

Module operational state management

Hot swap management works well.

Sensor Reading Test

```
nat> show_sensorinfo 9

Sensor Information for FRU 9 / AMC5
=============================================================================
  #   SDRType  Sensor Entity Inst  Value     State     Name
-----------------------------------------------------------------------------
  -   MDevLoc          0xc1  0x65                    IHEP-AMC-V1.0
  1   Full     Temp     0xc1  0x65  30 C       ok     Temp PCB1
  2   Full     Temp     0xc1  0x65  32 C       ok     Temp PCB2
  3   Full     Temp     0xc1  0x65  33 C       ok     Temp PCB3
  4   Full     Voltage  0xc1  0x65  1.00 V     ok     1V0
  5   Full     Voltage  0xc1  0x65  1.20 V     ok     1V2
  6   Full     Voltage  0xc1  0x65  1.50 V     ok     1V5
  7   Full     Voltage  0xc1  0x65  1.80 V     ok     1V8
  8   Full     Voltage  0xc1  0x65  2.50 V     ok     2V5
  9   Full     Voltage  0xc1  0x65  3.30 V     ok     3V3PP
 10   Full     Voltage  0xc1  0x65  3.45 V     ok     3V3MP
```

Temperature threshold event Test

```
[00:00:00:30:0463] LSHM(0): FRU 5 sensor 16 LUN 0 'Temp PCB1'
temperature 'upper non-critical go high' - assertion
[00:00:00:30:0473] LSHM(0): temperature exceeded - increase fan level
[00:00:00:30:0479] LSHM(0): CU0 set fan to level 100%
[00:00:00:30:0485] LSHM(0): FRU 5 sensor 16 LUN 0 'Temp PCB1'
temperature 'upper critical go high' - assertion
[00:00:00:30:0695] LSHM(0): FRU 5 sensor 16 LUN 0 'Temp PCB1'
temperature 'upper non-recoverable go high' - assertion
[00:00:00:30:0705] LSHM(0): FRU 5 sensor 16 LUN 0 'Temp PCB1'
temperature 'upper non-recoverable go high' - assertion
R(5,0,1)[00:00:00:55:0127] LSHM(0): FRU 5 sensor 16 LUN 0 'Temp PCB1'
temperature 'upper non-recoverable go low' - assertion
[00:00:00:55:0137] LSHM(0): FRU 5 sensor 16 LUN 0 'Temp PCB1'
temperature 'upper critical go low' - assertion
[00:00:00:55:0147] LSHM(0): FRU 5 sensor 16 LUN 0 'Temp PCB1'
temperature 'upper non-critical go low' - assertion
[00:00:01:10:0765] LSHM(0): temperature in range - decrease fan level
[00:00:01:10:0771] LSHM(0): CU0 set fan to level 80%
```

82℃

Fan speed increase

30℃

Fan speed decrease

Tuning control FMC

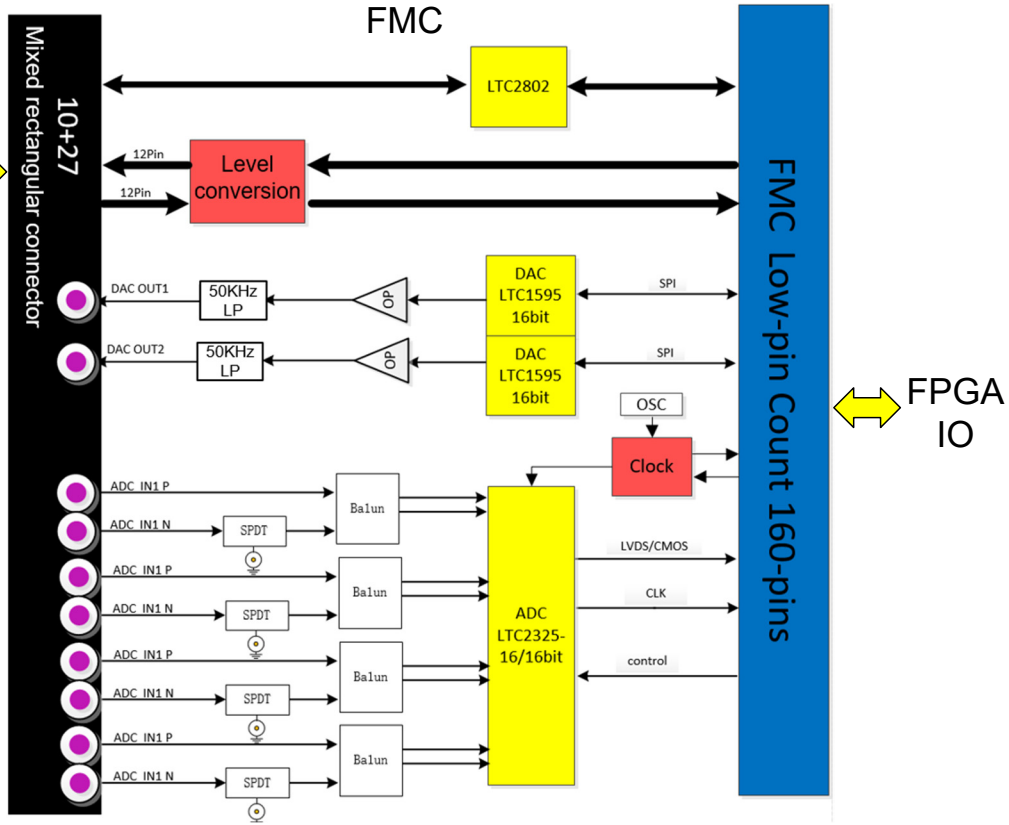
雷赛智能 Leadshine

Motor Driver

芯明天 COREMORROW

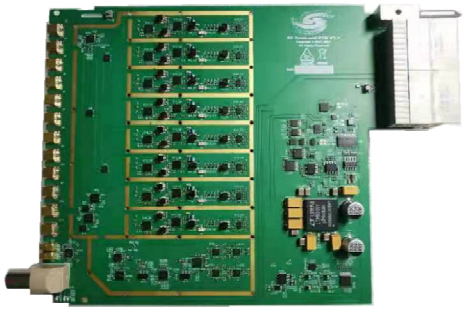
Piezo Driver

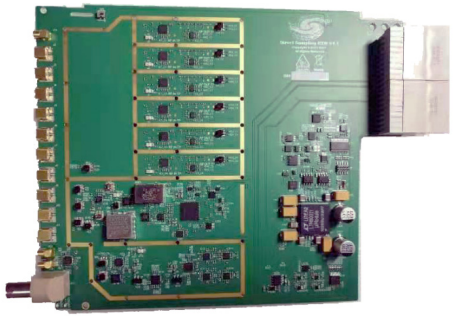
Piezo1 position sensor
Piezo2 position sensor
pressure sensor
Step motor position
（rotary transformer）



Others

- The domestic Down and up converter RTM and Direct sampling RTM is developed by the colleagues in the project group.
  - Based on the requirement of SAPS and CSNS II.
  - Down-conversion RF: 300MHz~4GHz IF: 5~100MHz Up-conversion RF 200MHz~4GHz
  - Direct sampling RTM（RF：DC~650MHz）





Provided by: Dr. Ma X P, and Dr. Gan N

Demostic MTCA.4 chassis

Provided by: Yzitech

Thanks for your attention!