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INDUSTRIAL SUMMIT 2023

SHENZHEN, CHINA | 28 SEPTEMBER

Reference designs based X-CUBE-MCSDK

Rendong Wang

Agenda

1. Reference design of dPFC+dual motors control
2. Reference design of iPFC + tri motors control
3. Reference design of single motor control
4. STM32 advanced reference design
5. Success stories for water pump, fan motor, refrigerator
6. Tips for using X-CUBE-MCSDK6

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Reference designs for air-con ODU

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Solutions for AC ODU

Complexity / energy efficiency

3xFOC Vienna

3xFOC d-IntPFC

2xFOC d-IntPFC

2xFOC d-PFC

FOC d-PFC

Central AC 3-phase 108~

RAC/Central AC 72~120

RAC 26~72

23H2

10kW commercial
STM32G4
+ ACEPACK
+ 2xSLLIMM™
Vienna topology dPFC
STM32G4
3-phase AC

7kW commercial STM32G4
+ STGIK50+ 2x STGIPQ4™
Interleaved dPFC

3.5kW AC
STM32G4 +
SLLIMM 2nd+
SLLIMM nano 2nd
Interleaved dPFC

2kW RAC
STM32G4 +
SLLIMM 2nd +
SLLIMM nano 2nd
Dual MC + dPFC

22Q3

2kW RAC
STM32G0
+SLIMM 2nd + dPFC

Completed

Ongoing and roadmap

1kW | 2kW | 4kW | 7kW | 10kW

1ph ACPS 110[V]/220[V] rms

3ph ACPS 220[V]/380[V] l-l,rms

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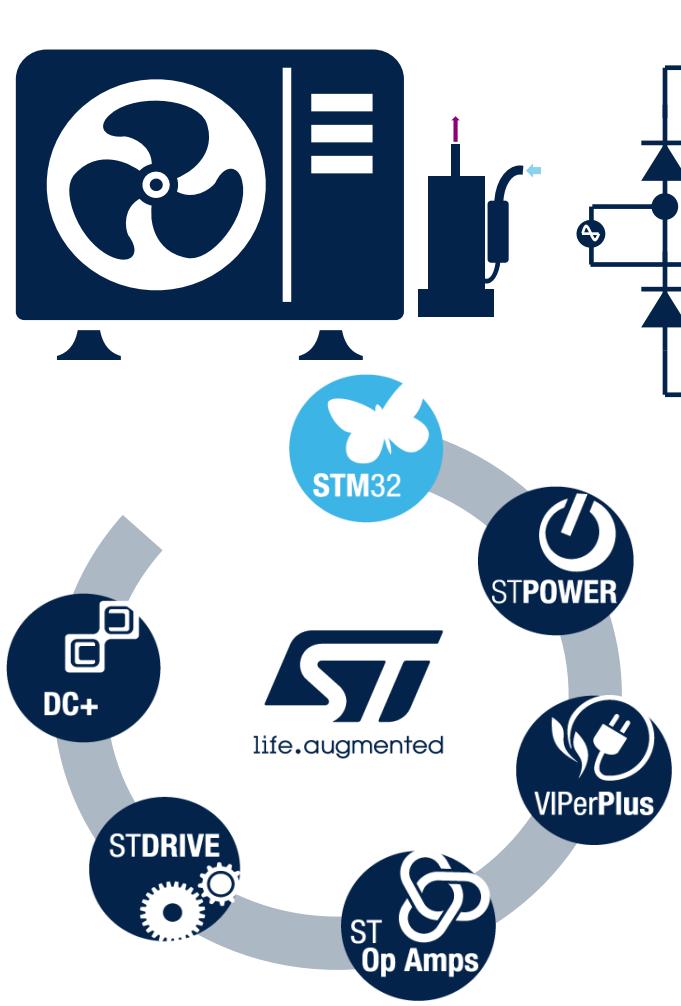
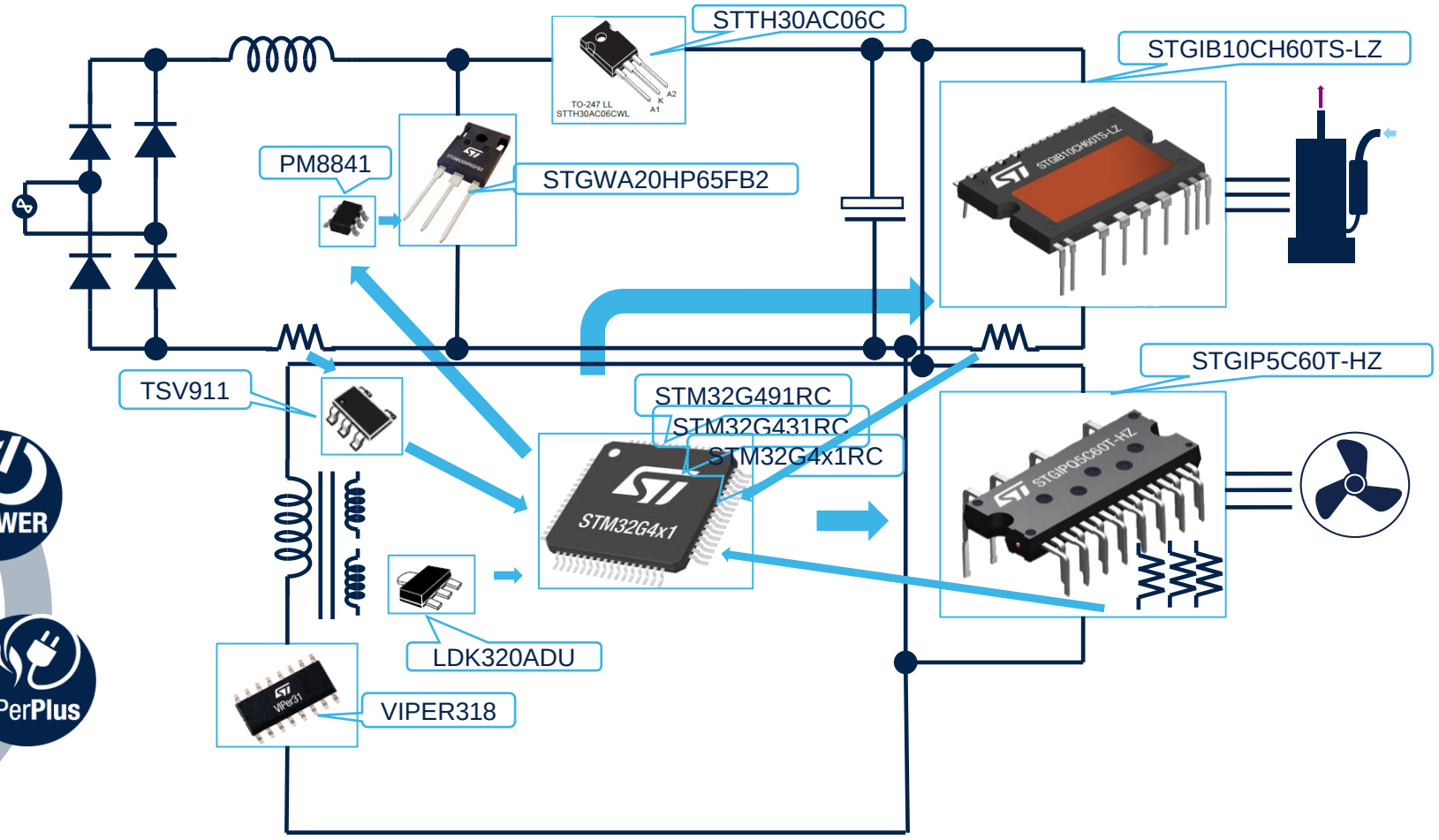
Outdoor unit controller





ST BOM adopted in turn-key solution

Modules	Product	Part No.	Features
Controller	MCU	STM32G491RC	Mainstream Arm Cortex-M4 MCU 170 MHz with 256 Kbytes of Flash memory, Math Accelerator, High Analog level integration
Booster	IGBT	STGWA30HP65FB2	I_c=30[A]@T_c=100[°C]/V_{CES}=650[V]
	FRD	STTH30AC06CPF	$I_{F(rms)}$=2 x 15[A]/V_{RPM}=600[V]/trr=40[ns]
	IGBT driver IC	PM8841D	Isnk=1.1[A]/Isrc=0.94[A]/tR=tF=20[ns]
	OP-AMP(for single shunt current detection)	TSV911ILT	Wide-bandwidth (8MHz) rail to rail input/output 5V CMOS Op-Amp, single
	OP-AMP(for AC input voltage detection)	TSV611ILT	Rail to rail input/output 5V CMOS Op-Amp, micro-power (10uA), GBP = 120kHz, single
	Comparator(for zero crossing point detection, optional)	TS391RILT	Low power, single voltage comparator
Compressor Motor drive	IPM	STGIB10CH60TS-L	I_c=15[A]@T_c=25[°C],Ic=10[A]@Tc=80[°C]/V_{CES}=600[V]
	Comparator(Demag protect)(optional)	TS391RILT	Low power, single voltage comparator
Fan motor drive	IPM(OP-AMP embedded)	STGIPQ5H60T_HZ	SLLIMM nano 2nd series IPM, 3-phase inverter, 5A, 600 V short-circuit rugged IGBTs
SMPS	Hi-voltage converter	VIPER318HDTR	Energy Saving Off-line High Voltage Converter
	LDO	LDK320ADU33R	200 mA low quiescent current and high PSRR voltage regulator
	Power Schottky diode	STPS2200U	200 V, 2 A High Voltage Power Schottky diode
	Power Schottky Rectifier	STPS1L30A	30 V, 1 A Low Drop Power Schottky Rectifier
EEPROM	EEPROM	M24C16-RMN6TP	16 Kbit serial I2C bus EEPROM
RELAY driver	Darlington Arrays	ULN2003D1013TR	Seven Darlington Arrays

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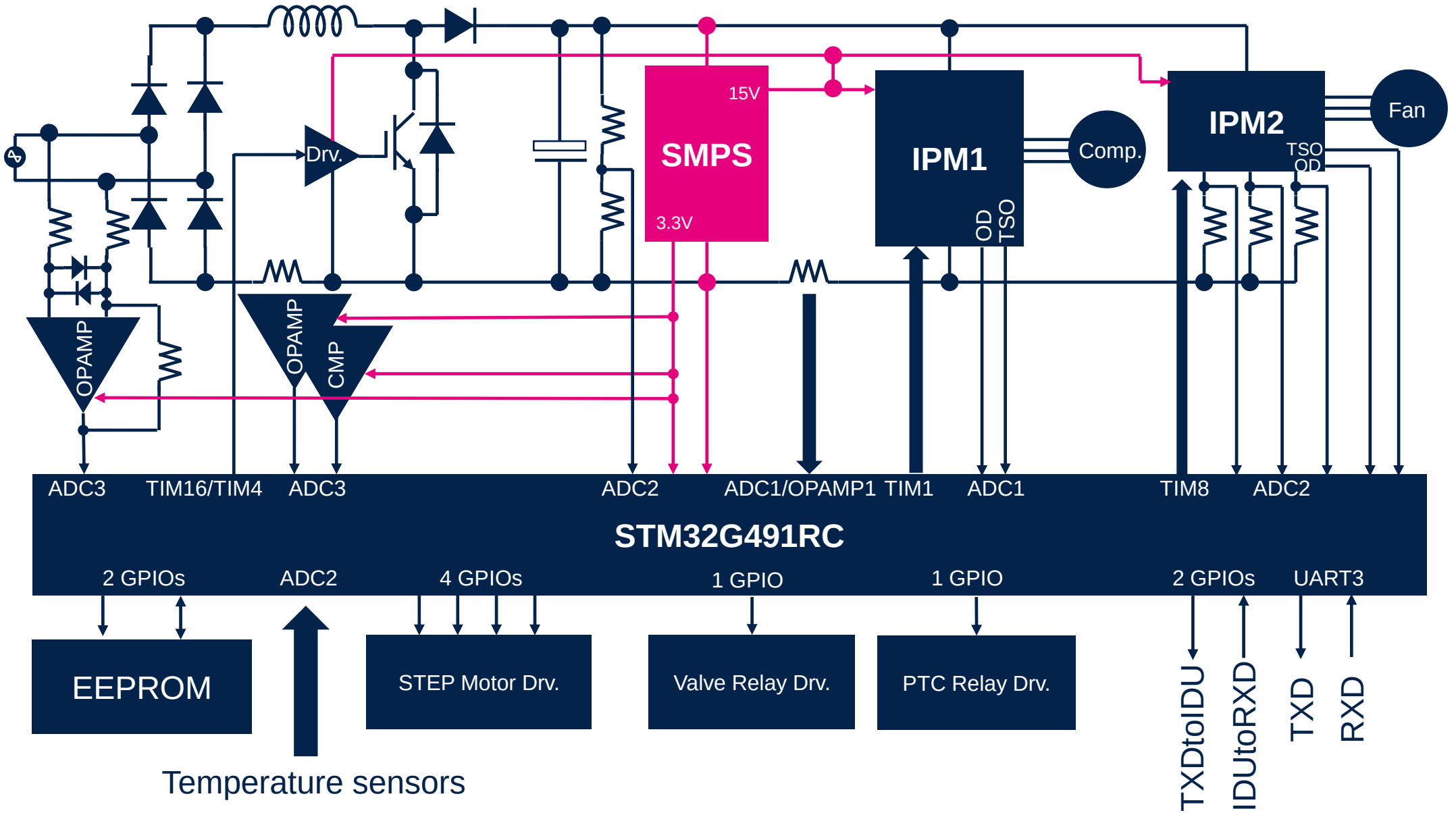
Topology


15V
SMPS
3.3V
IPM1
OD
TSO
Comp.
IPM2
TSO
OD
Fan
Drv.
OPAMP
OPAMP
CMP
ADC3
TIM16/TIM4
ADC3
ADC2
ADC1/OPAMP1
TIM1
ADC1
TIM8
ADC2
STM32G491RC
2 GPIOs
ADC2
4 GPIOs
1 GPIO
1 GPIO
2 GPIOs
UART3
EEPROM
STEP Motor Drv.
Valve Relay Drv.
PTC Relay Drv.
TXDtoIDU
IDUtoRXD
TXD
RXD
Temperature sensors

Specification

1. Input power: ~2200[kW]
2. Input voltage: single phase,150[V]rms~265[V]rms @50[Hz] or 60[Hz]
3. Cooling capacity: ~3500[W]
4. Maximum DC bus voltage: 350[V](input voltage <=240[V]rms)
5. Maximum rotor speed of compressor: 9000[rpm]
6. Maximum discharge pressure of compressor: 4.1[MPa]
7. Maximum rotor speed of fan motor: 1200[rpm]@0.57[A]rms
8. On-the-fly maximum rotor speed of fan motor: -600[rpm]~600[rpm]

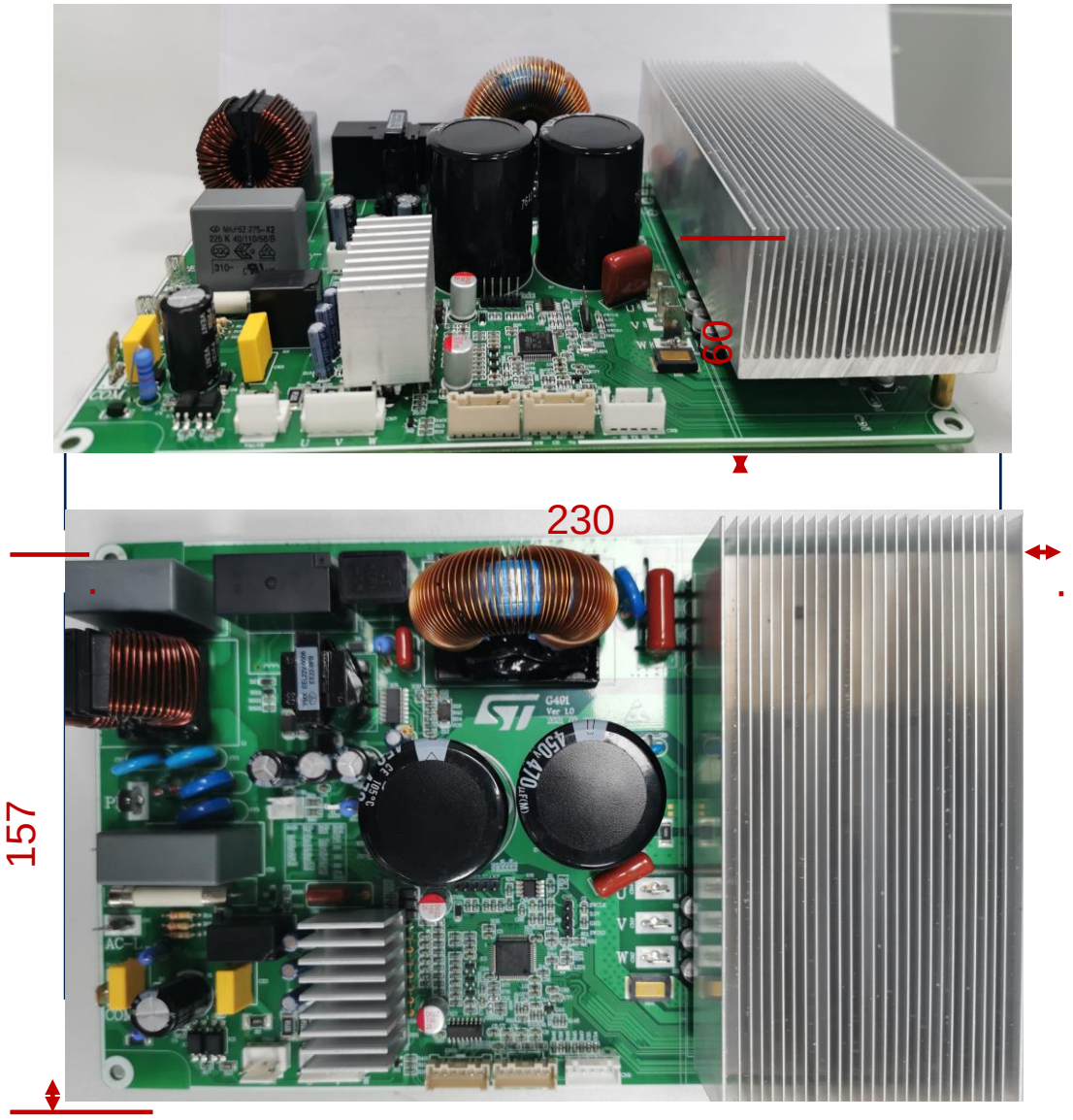
PCBA

Reference design materials are available

HW design support is available

Consulting on PCB layout is available

Ready for mandatory validation(PCBA is placed in room temperature condition)



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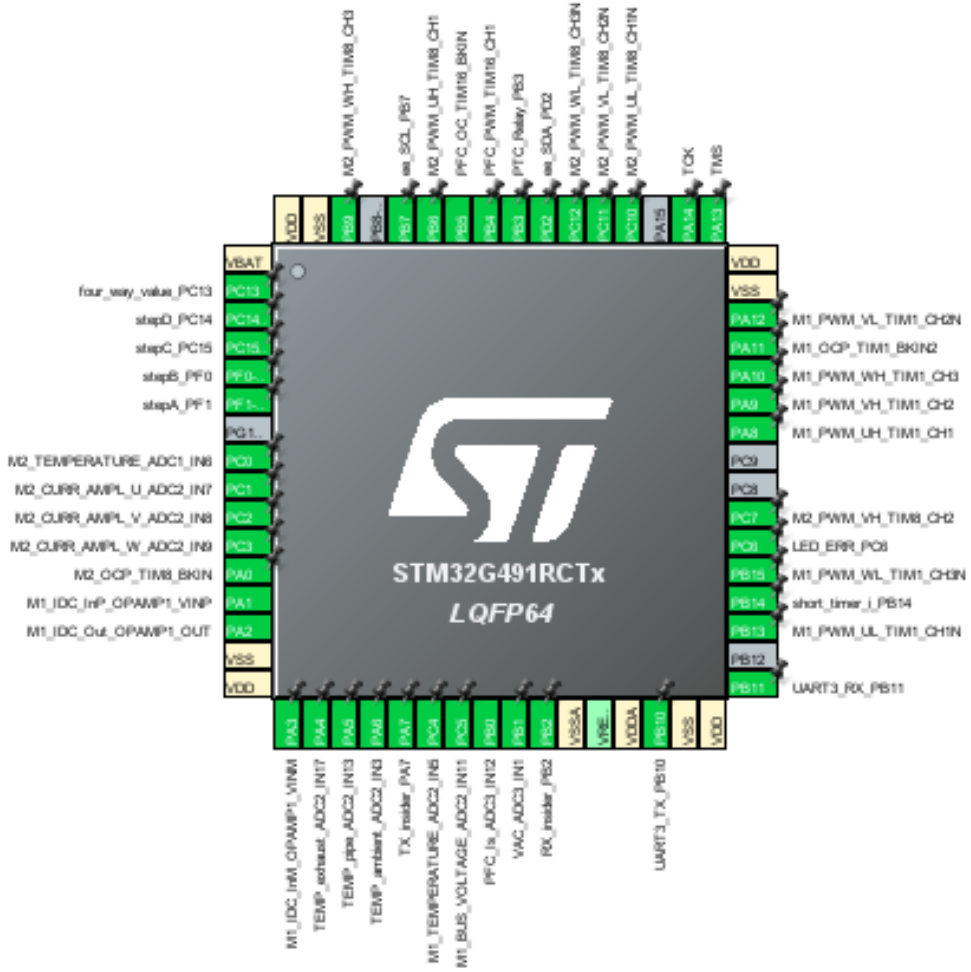
STM32G491RC Peripheral allocation



Peri.	Compressor	Fan motor	PFC	Others
TIMER	TIM1/Systick	TIM8/Systick	TIM16/TIM4/Systick	
ADC	ADC1 OPAMP1	ADC2	ADC3	
DMA1			CH2 sync. TIM16nTim4	

Interruption(4 bits for pre-emption priority, 0 bit for subpriority)	**Group Priority**	**Sub priority**	**Description**
TIM1_UP_TIM16_IRQn	0	0	PFC over current protection
TIM4_IRQn	1	0	PFC high frequency tasks
TIM8_UP_IRQn	2	0	ADC configuration for current samping
TIM3_UP_IRQn	3	0	M1 FOC high frequency tasks
ADC1_2_IRQn	3	0	M2 FOC high frequency tasks
SysTick_IRQn	4	0	Medium Frequency and safety tasks
TIM8_BRK_IRQn	5	0	M2 over current protection
TIM1_BRK_TIM15_IRQn	5	0	M1 over current protection

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Features

- Wide available speed range
- Minimized loss
- Minimized noise/vibration
- Accurate estimation
- Robust observer
- Scalable controller

- PFC
  - Variable DC bus voltage control
  - DC bus voltage ripple compensation
- Compressor control
  - Torque load ripple compensation at low/middle rotor speed
  - Model decoupling at high rotor speed
  - Adjustable flux weaken control
- Fan motor control
  - On-the-fly startup
  - Rotor stall judgement(Machine Learning)
  - Low acoustic noise using 3-shunt
- Common
  - Optimized back-emf observer for rotor speed/position estimation
  - Available to start rotor with full load from standstill and very low rotor speed(1[rpm])
  - Available to run motor at very low rotor speed(1[rpm])

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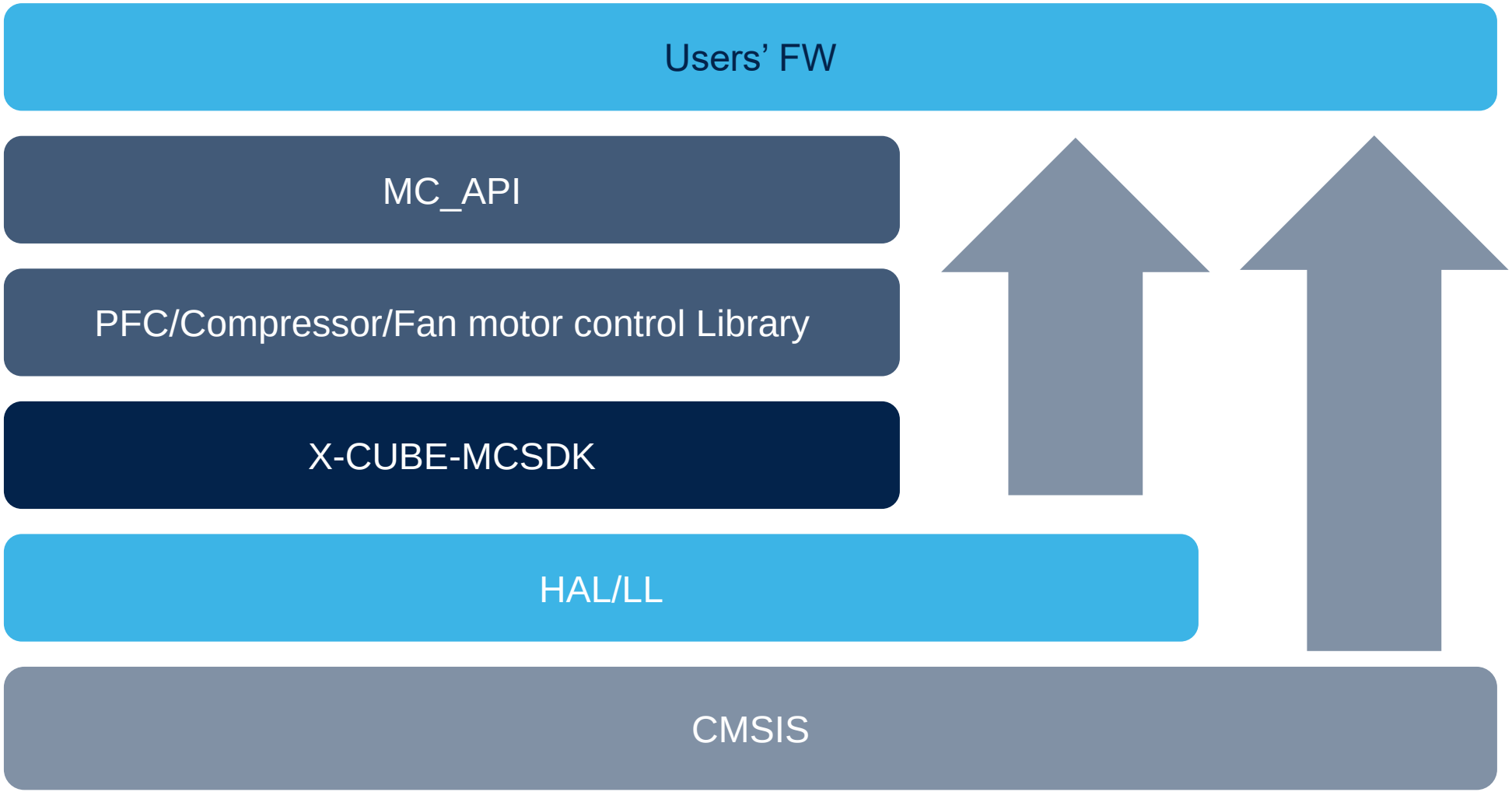
FW architecture

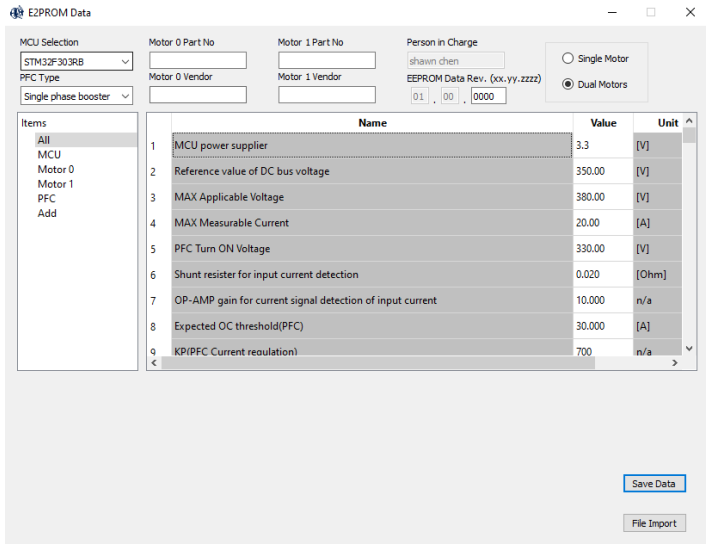


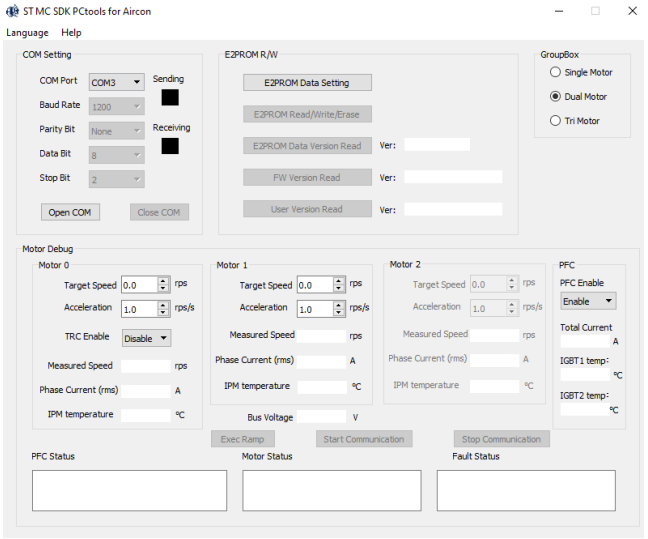
PCTools (SW)

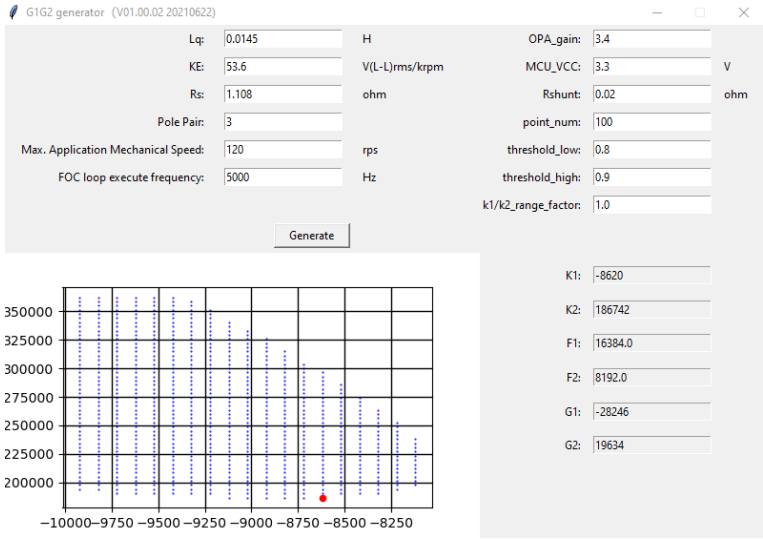
EEPROM Data Generation

Communicating with MCU

STO Gains Calculation



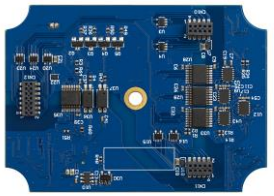




Toolchains

STM32 CubeMX

STM32 CubeIDE



CPU load

Optimize for speed(-Ofast)

module	Interrupt	Execution frequency	duration	CPU Load
PFC	TIM4_IRQHandler	40K	4.0us	16%
	MediumFrequencyTask	2K	10us	2%
Compressor	TIM1_IRQHandler（task1）	5K	24.5us	12.7%
	TIM1_IRQHandler（task2）	5K	0.8us	
	MediumFrequencyTaskM1	500	56us	2.8%
dual Fan(M2)	ADC1_2_IRQHandler	15K	13.5us	20.2%
	MediumFrequencyTaskM2	500	18us	0.9%
			Total:	**54.6%**

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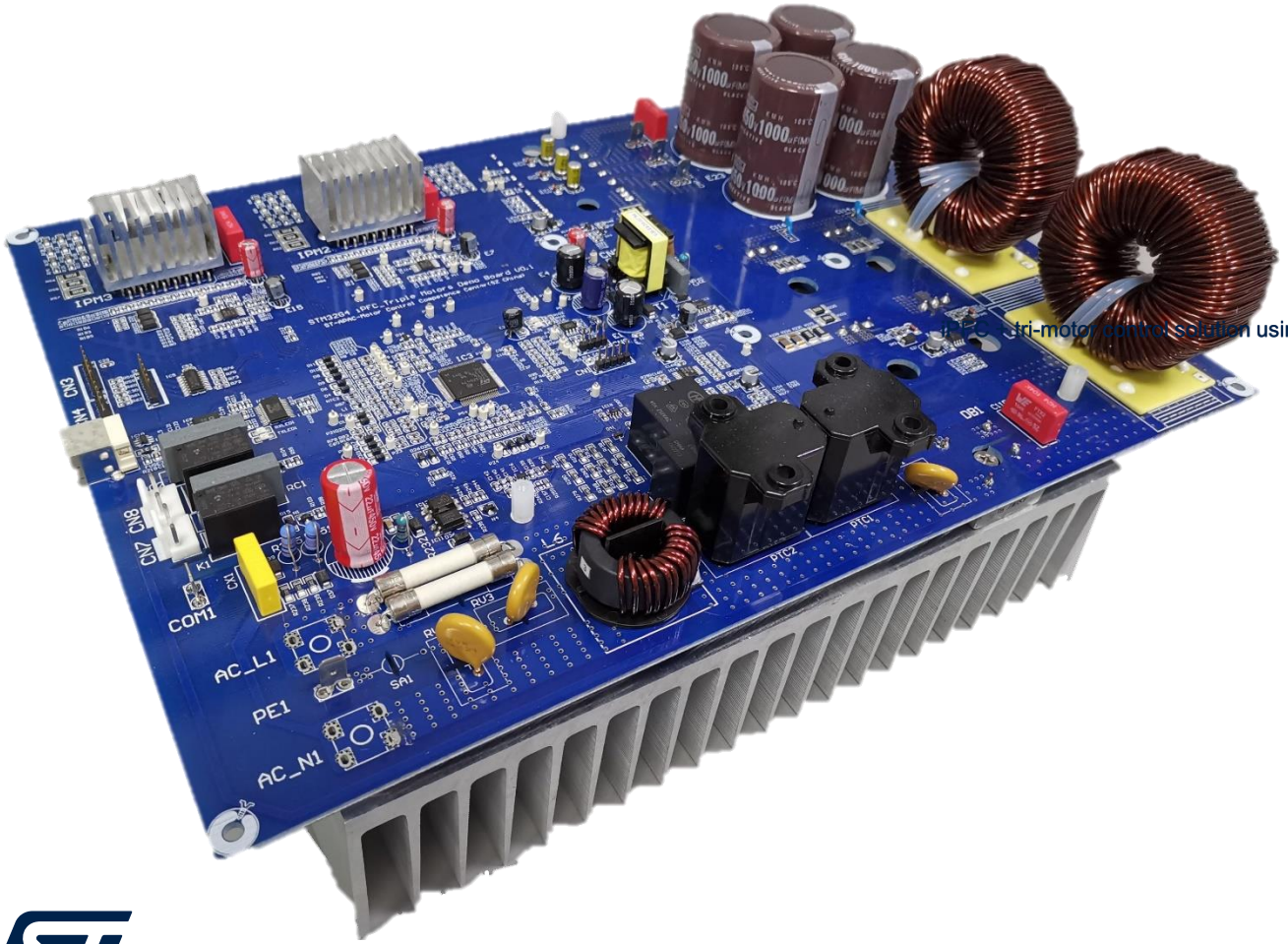
ROM, RAM size

Memory Regions	Size	Used	Free	Usage(%)
CCMRAM	16KB	11.68KB	4.32KB	73%
RAM	112KB	11.81KB	100.19KB	10.54%
Flash	256KB	87.85KB	168.15KB	34.32%

iPFC + tri-motor control solution using STM32G474



iPFC + tri-motor control solution using STM32G474

MAIN FEATURES:

- One STM32G4 MCU only to drive all functions
  - Reduced number of components
  - No need sync between controllers
  - 1 firmware workspace only
  - MC SDK v5.Y
- New ST HP SLLIMM 50A
  - High energy efficiency
- High frequency d-i-PFC
  - SJ MOSFET / IGBT
  - SiC diodes

ST products

- STM32G474VE
- STGIK50CH65T
- 2x STGIPQ4C60T-HZ
- 2x STGWA50HP65FB2
- 2x STFW40N60M2
- 2x STTH30M06S
- 2x TSV914IPT
- ULN2003D1013TR
- VIPER318HDT
- PM8834
- LMV339IDT
- TS391RILT
- LD1117S33TR
- LD1117S50TR

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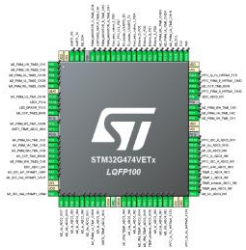
All functions inside 100-pin STM32G4 MCU + 3 IPMs

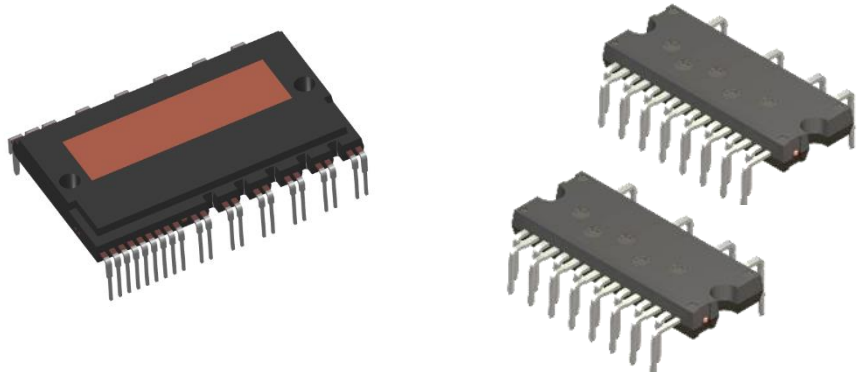


Function	Digital I/O	Analog I/O	Total
Compressor	9	5	14
Fan1	7	7	14
Fan2	7	7	14
Interleaved PFC	6	5	11
USART comm	4		4
SWD debug	2		2
I²C EEPROM	2		2
Stepper valves	6		6
Other analogs		8	8
Other digitals	3		3
MCU functional			14
unused	4	4	8
GRAND TOTAL			**100**

OCP shutdown by IPM & temperature sensing by MCU

OCP shutdown by IPM & temperature sensing by MCU

OCP shutdown by IPM & temperature sensing by MCU



Vdd, Vss, Boot, Vdda, Vssa, NRST

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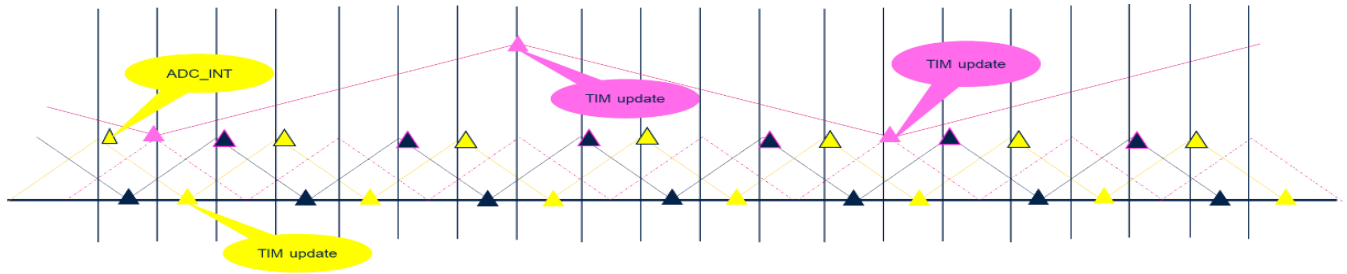
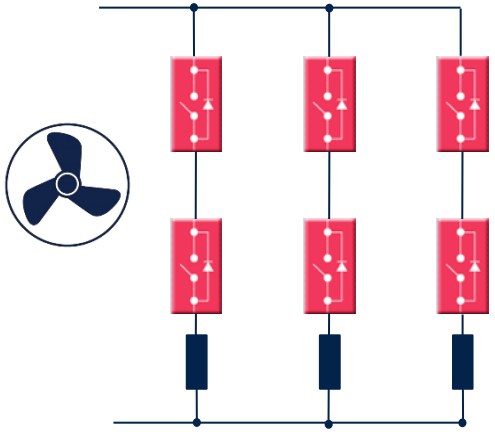
Triple FOC and current sensing topology

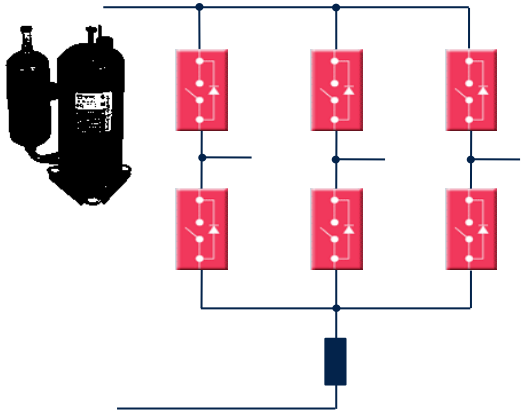
STM32G474 has up to 3 x 16-bit 8-channel advanced motor control timers

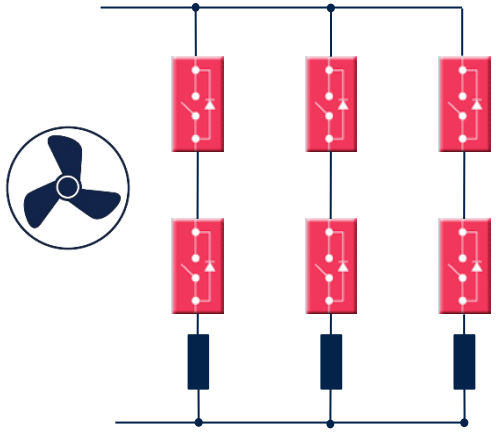
- FOC library arranges to share CPU time between the three drives, compressor, and two fans
- Two fans have same PWM frequency proportional to compressor PWM frequency





- 1 shunt for compressor to reduce BOM cost
- 2/3 shunts for fans to enhance OTF performance and startup success rate
- BEMF sensing network included to extend extreme conditions





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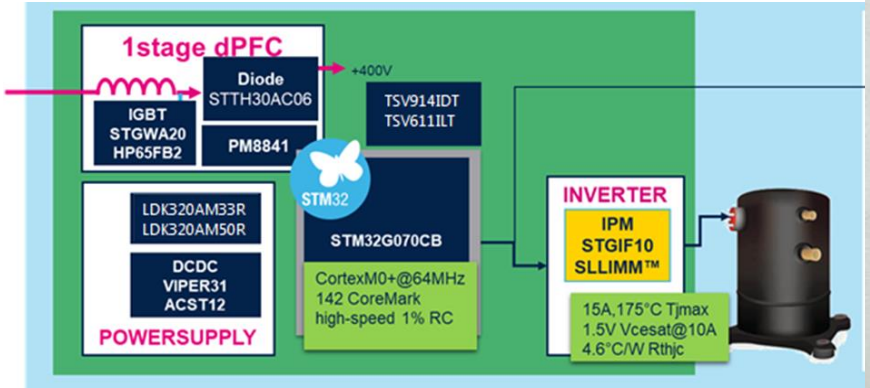
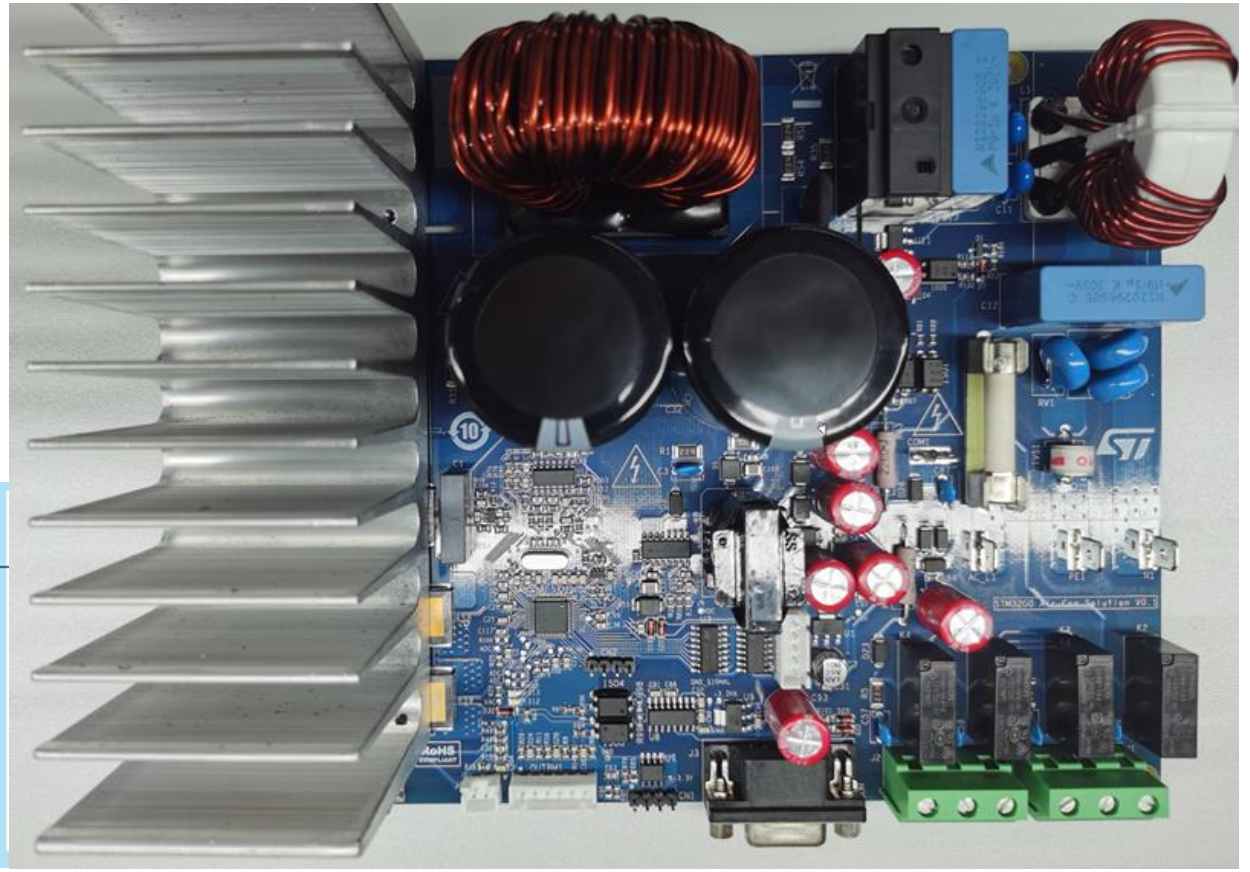
dPFC+single motor control solution using STM32G0

First STM32G0
Compressor & dPFC

Motor Control
Competence
Center





Reference design using STM32G0

Input Power：~1[kW]
Rotor speed range: 7200[rpm]
Winding Current range: ~5[A]

ST BOM

Nb.	Part Nb.	pc(s)	Description
1	LDK320ADU33R	1	LDO
2	STM32G030KxT6	1	Mainstream Value-Line Arm Cortex-M0+ MCU with 64 Kbytes of Flash memory, 8 Kbytes RAM, 64 MHz CPU, 2x USART, timers, ADC, comm. I/F, 2-3.6V
3	M24C16-RMN6TP	1	EEPROM
4	STGIPQ5C60T-HZ	1	SLLIMM nano 2nd series IPM, 3-phase inverter, 5 A, 600 V, short-circuit rugged IGBT
5	VIPER318HDTR	1	800 V avalanche-rugged power MOSFET to cover ultra-wide VAC input range
6	TSV914IPT	1	quad rail-to-rail input/output 8 MHz operational amplifiers

Deliverable

- SCH/PCB/BOM design materials
- X-CUBE-MCSDK

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Reference design for water pump

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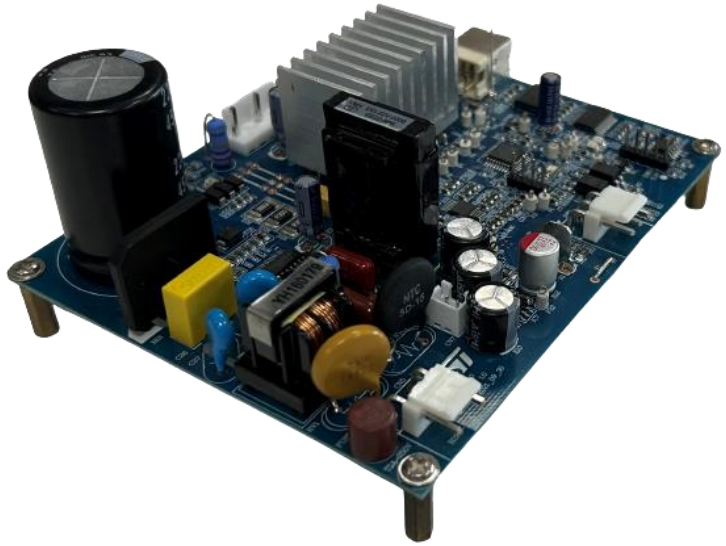
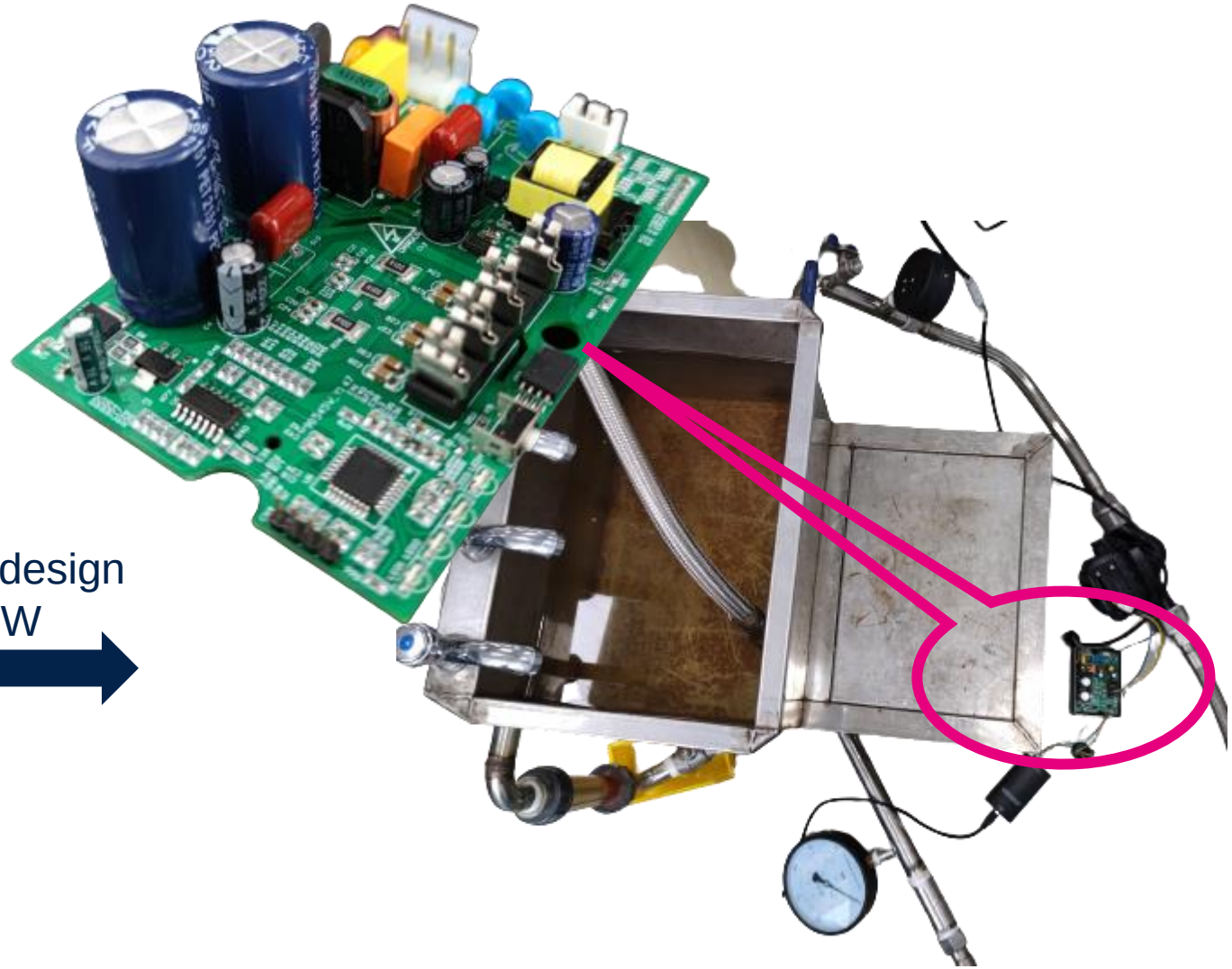
Water pump controller



From reference design
to customized HW



Reference design for fan motor

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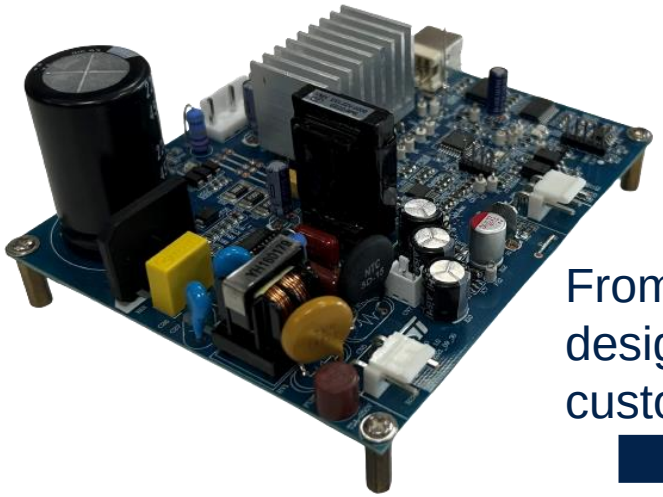
Fan motor controller



From reference design to customized HW

Reference design of refrigerator compressor control

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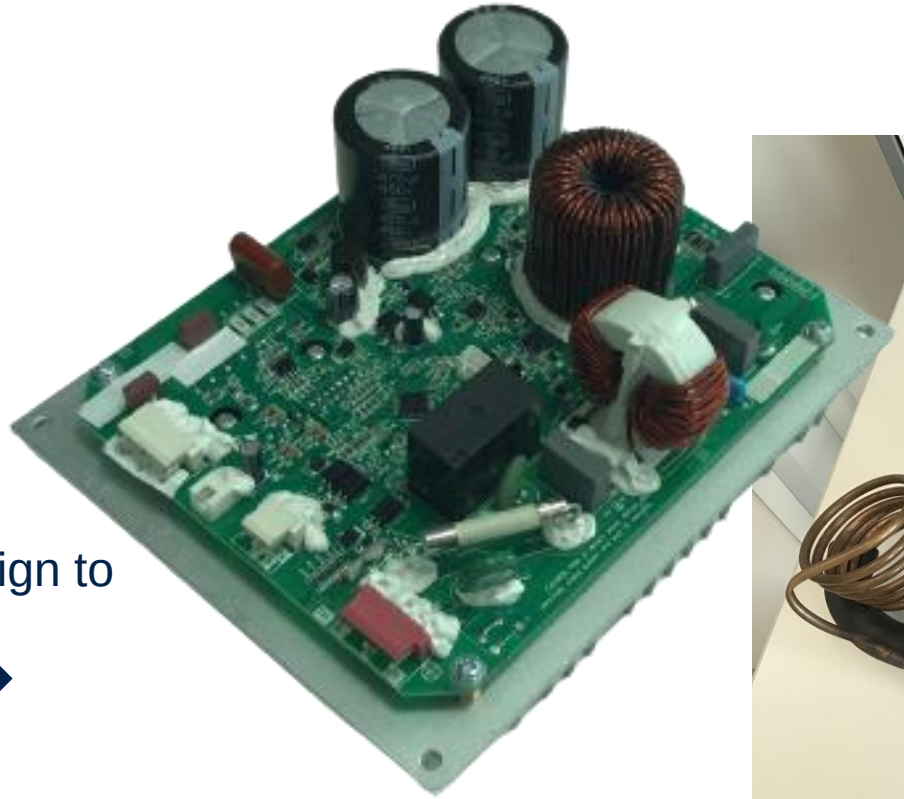
Refrigerator compressor controller

From reference design to customized HW



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STM32 advanced reference design

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Low Power Low Voltage reference design

100[V]/8[A]

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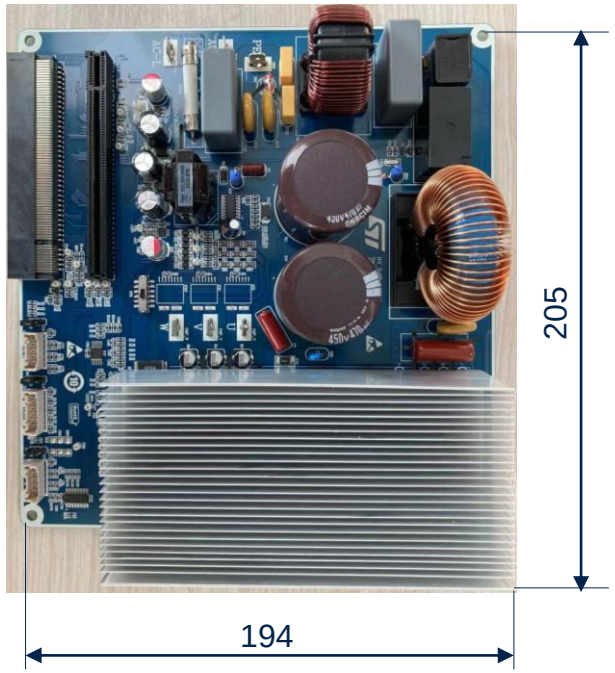
HV board to support one motor control using STM32 ZeST

MCU Board

+

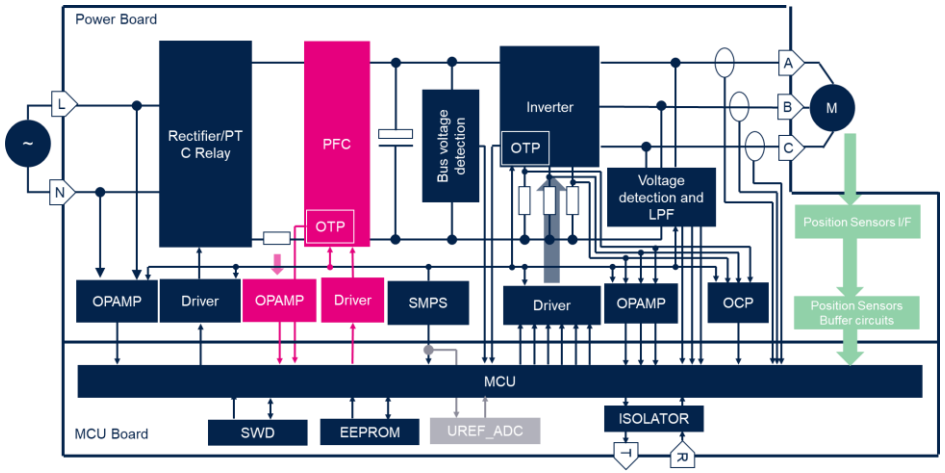


Power Board

=

or

- Input voltage: 110[V]/220[V]
- Input frequency: 50[Hz]/60[Hz]
- Input power: ~2[kW]
- Target motor: single
- PFC(optional)
- Options: Digital Inrush Current Limitation / PTC + Relay
- Motor current detection: DCCT(3)/3-shunt
- HW = Power board(Power) + MCU board(+ SCI->USB TypeC)
- Include position sensors I/F on Power board
- Non isolated power supply
- MCU: STM32G491RC



Tips for using X-CUBE-MCSDK6

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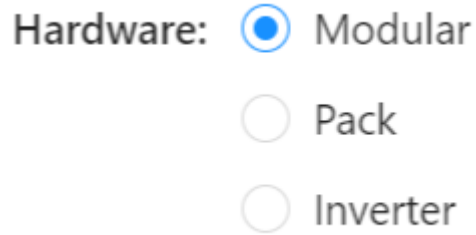
An Example to port MCSDK into an STM32 not in the support list

- Target：
  - Porting MCSDK into an STM32 not in the support list
- Steps：
  - Modify power board json file and add a customized power board into power board list
  - Modify motor parameters json file(it can also be done in WB) and add it into motor list
  - Select customer’s motor
  - Select customized power board
  - Select control board (MCU on the board should be in the same serials as target MCU)

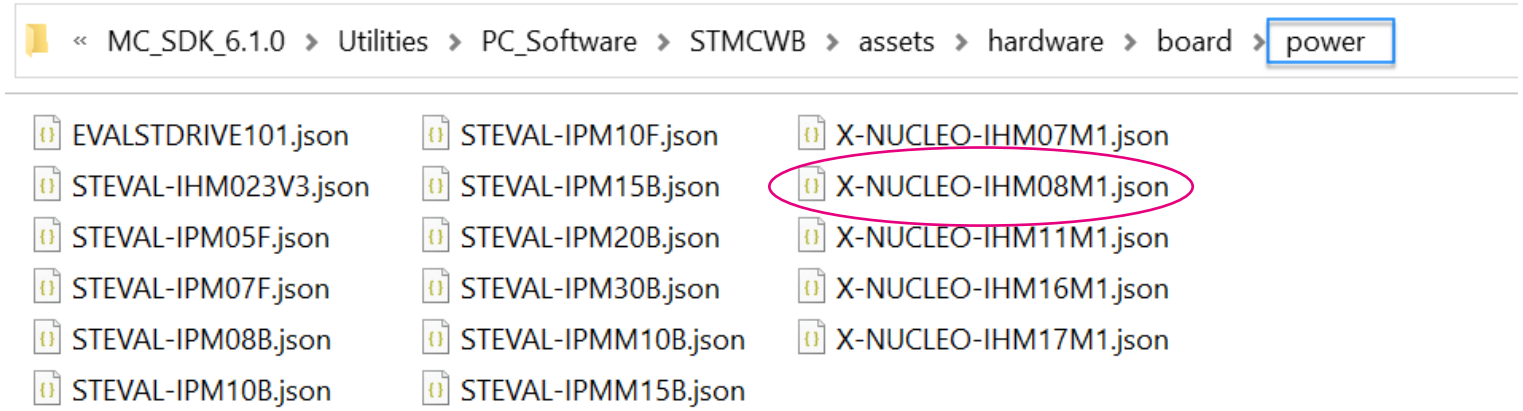
Step1 MCU board selection

- Background：
  - MC Workbench does not support all part numbers of STM32
  - HW options in WB：
    - Modular： the following 3 parts are separated
      - Motor
      - Control
      - Power
    - Pack:
      - P-NUCLEO-IHM…（Including motor, control board and power board）
    - Inverter:
      - Motor
      - Inverter（Including MCU and power electronics components in a PCBA）



Step 1:Modify power board json file and add a customized power board into power board list

- Open …\MC_SDK_6.x.x\Utilities\PC_Software\STMCWB\assets\hardware\board\power\X-NUCLEO-IHM08M1.json，save it as “new_power_board.json”.
- Modify pin allocation and peripheral circuits parameters according customer’s board.
- Modify “name” to “new_power_board”.
- Save the file.



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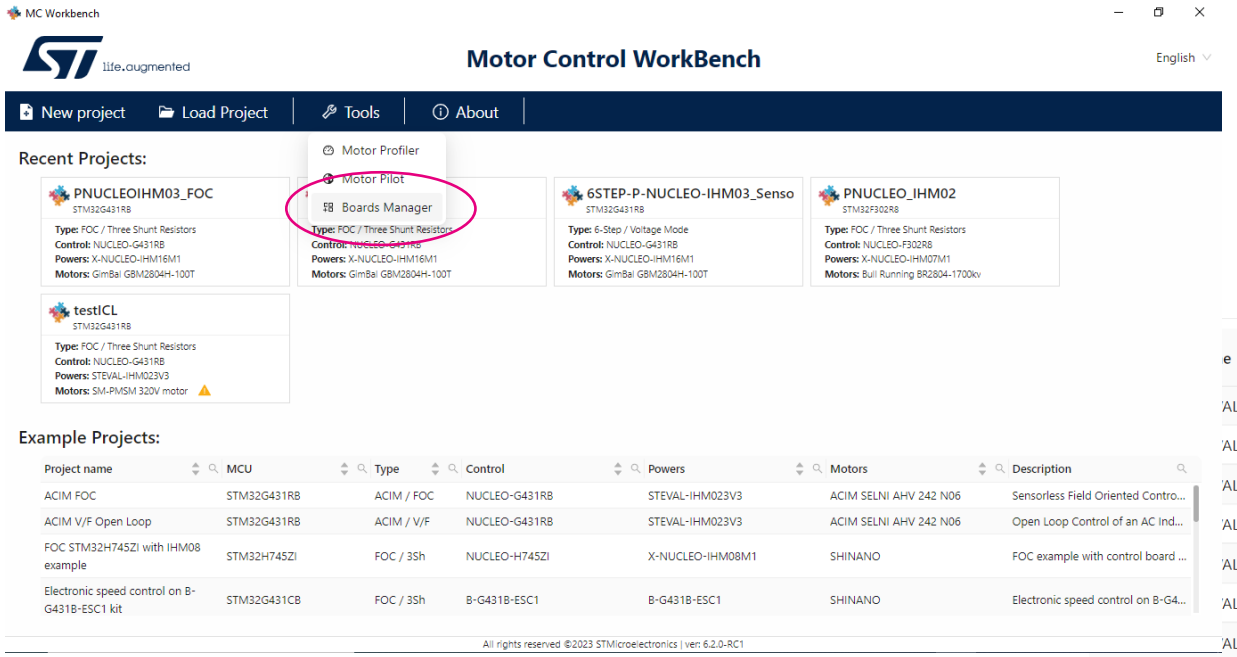
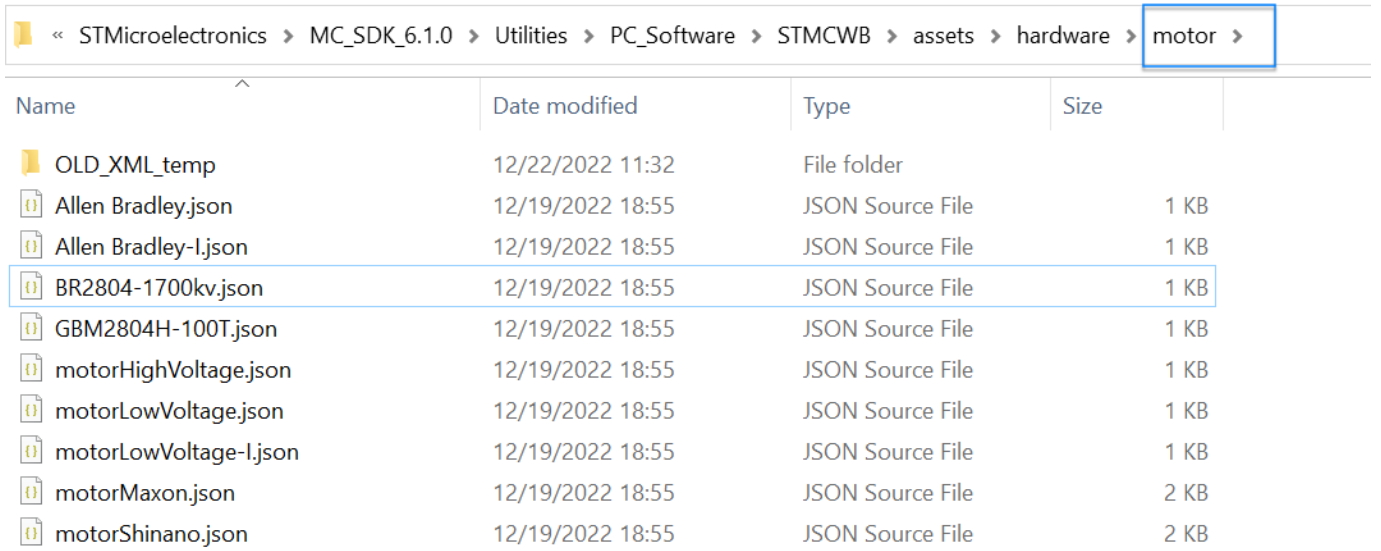
Add new power board json into power board list

- Open WB, select “Board manager” ->import board



Step 2: Setup motor parameters

- Motor parameters files in:
  - ..\STMicroelectronics\MC_SDK_6.x.x\Utilities\PC_Software\STMCWB\assets\hardware\motor\motor.json



- Motor parameters can be modified directly from WB either.

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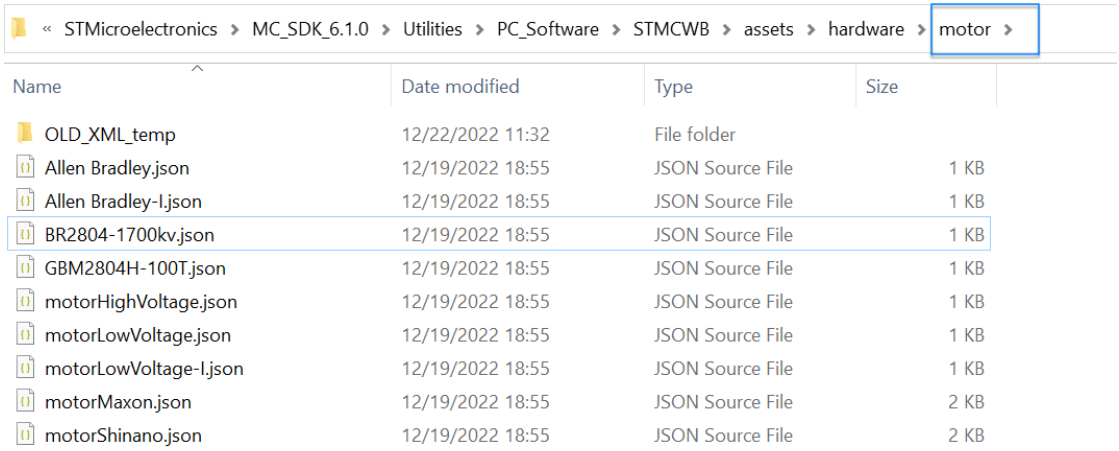
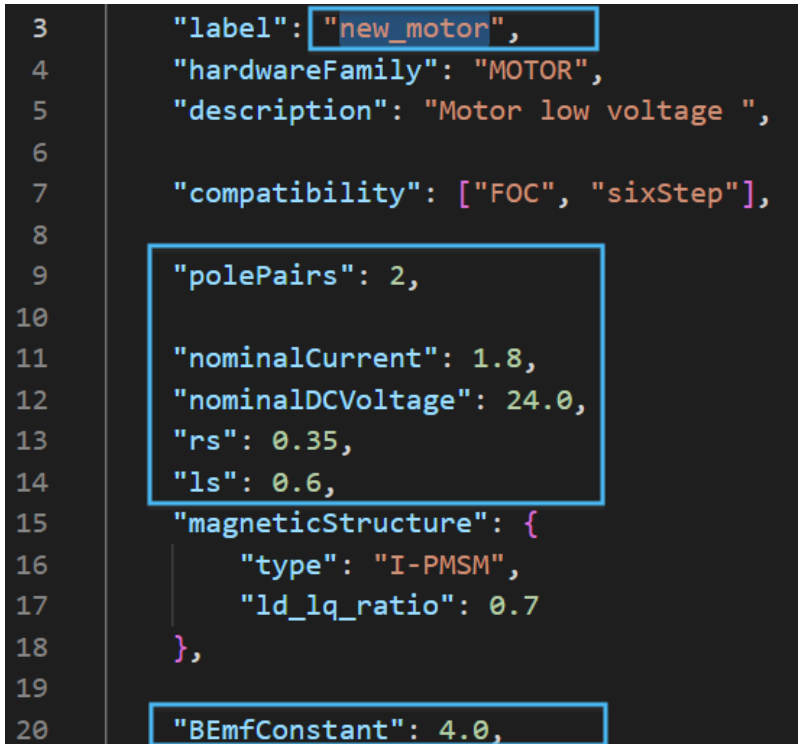
Modify motor parameters in json file

- Open an existed motor parameters json file;
- Modify motor parameters;
- Modify label" to new_motor;
- Save json file to new_motor.json;





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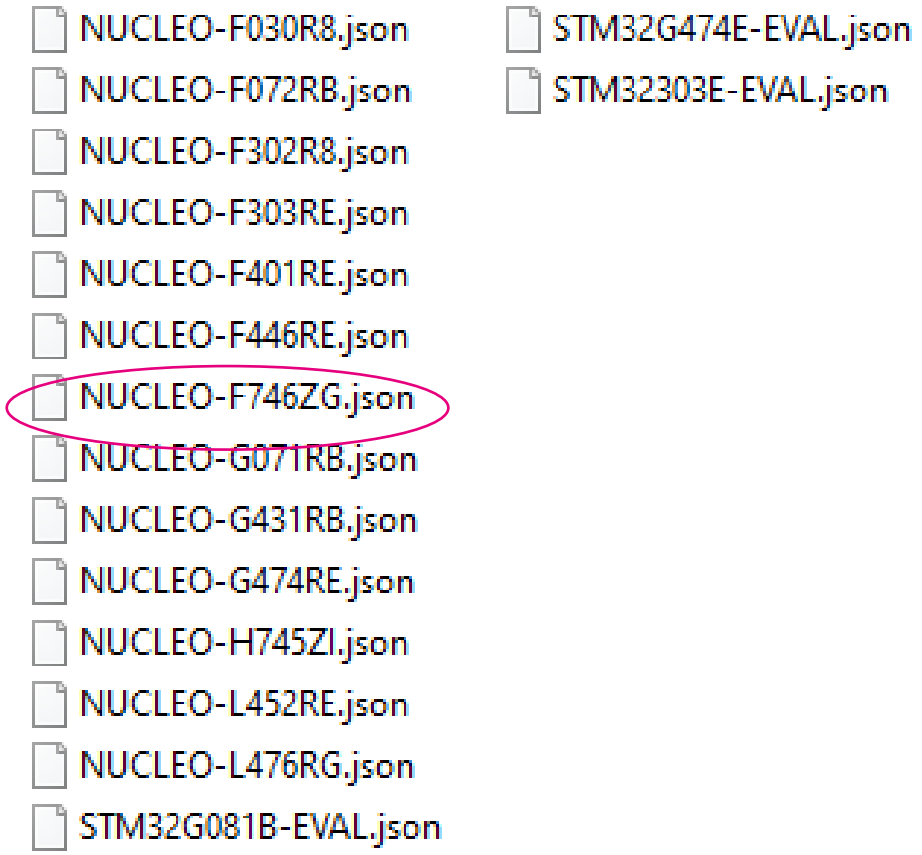
Step 3: Supported MCU by MCSDK6.1.x

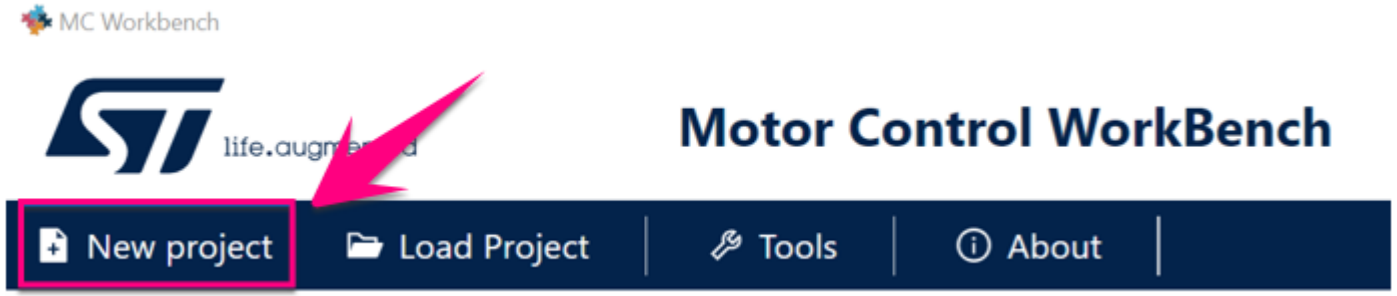
- Target MCU: STM32G030Kx but not in the list
- Select Nucleo-G071RB as control board



life.augmented

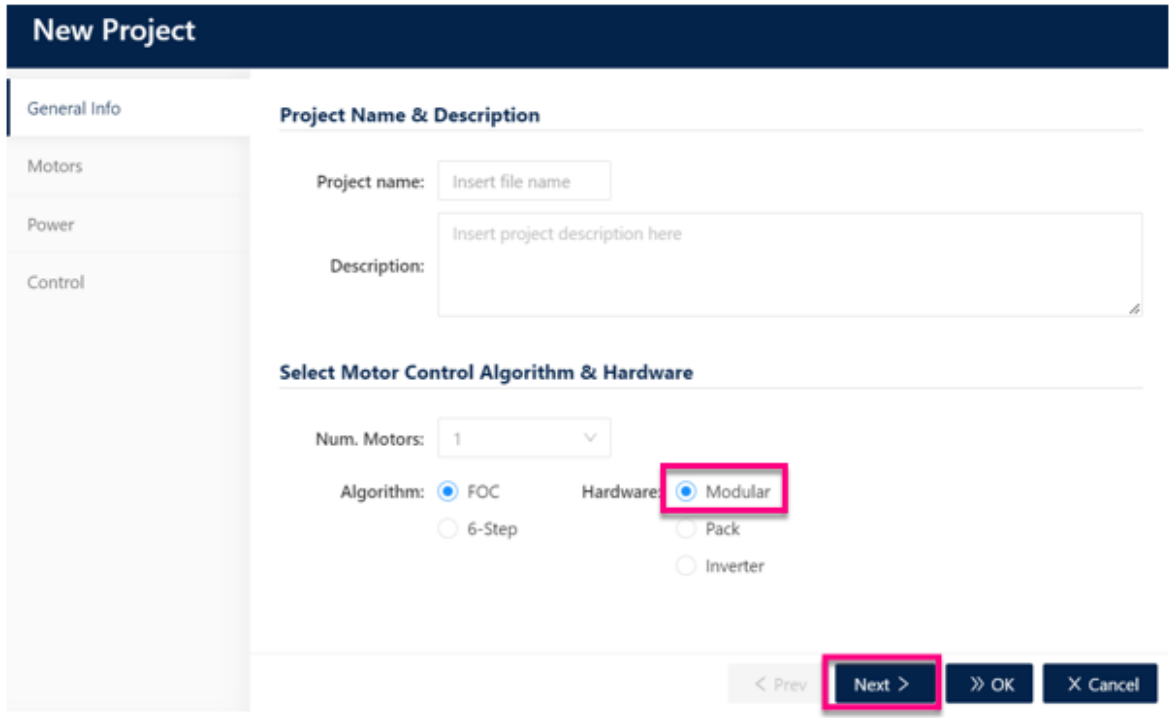
Step 4: Generate FW

- Create a new project from WB



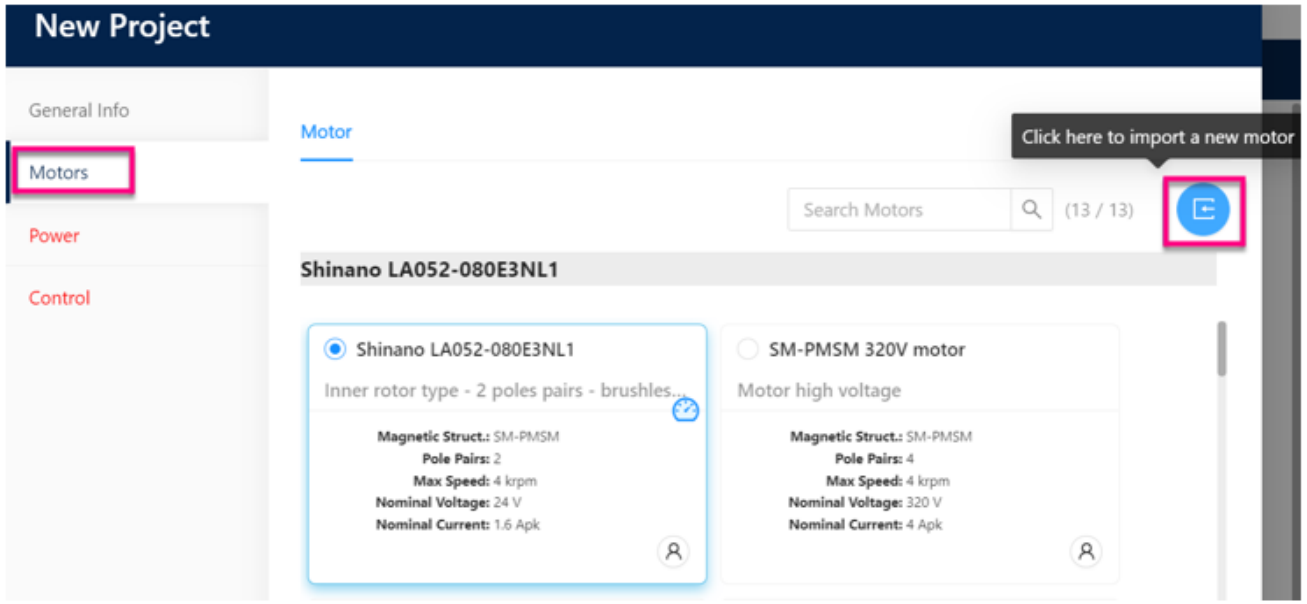
Select Modular

- Select “Modular” -> Next;



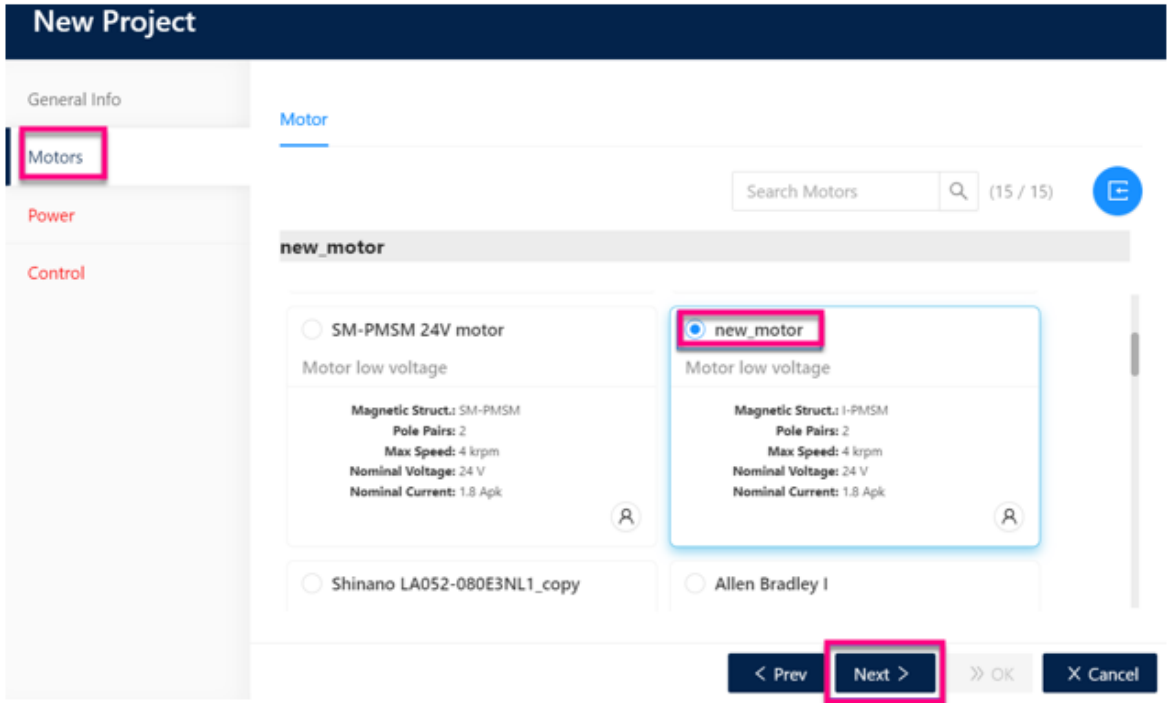
Select modified motor

- 在Motors页面，点击右上角导入图标，导入新修改的用户电机new_motor.json文件，选择new_motor.json文件，点击Next；

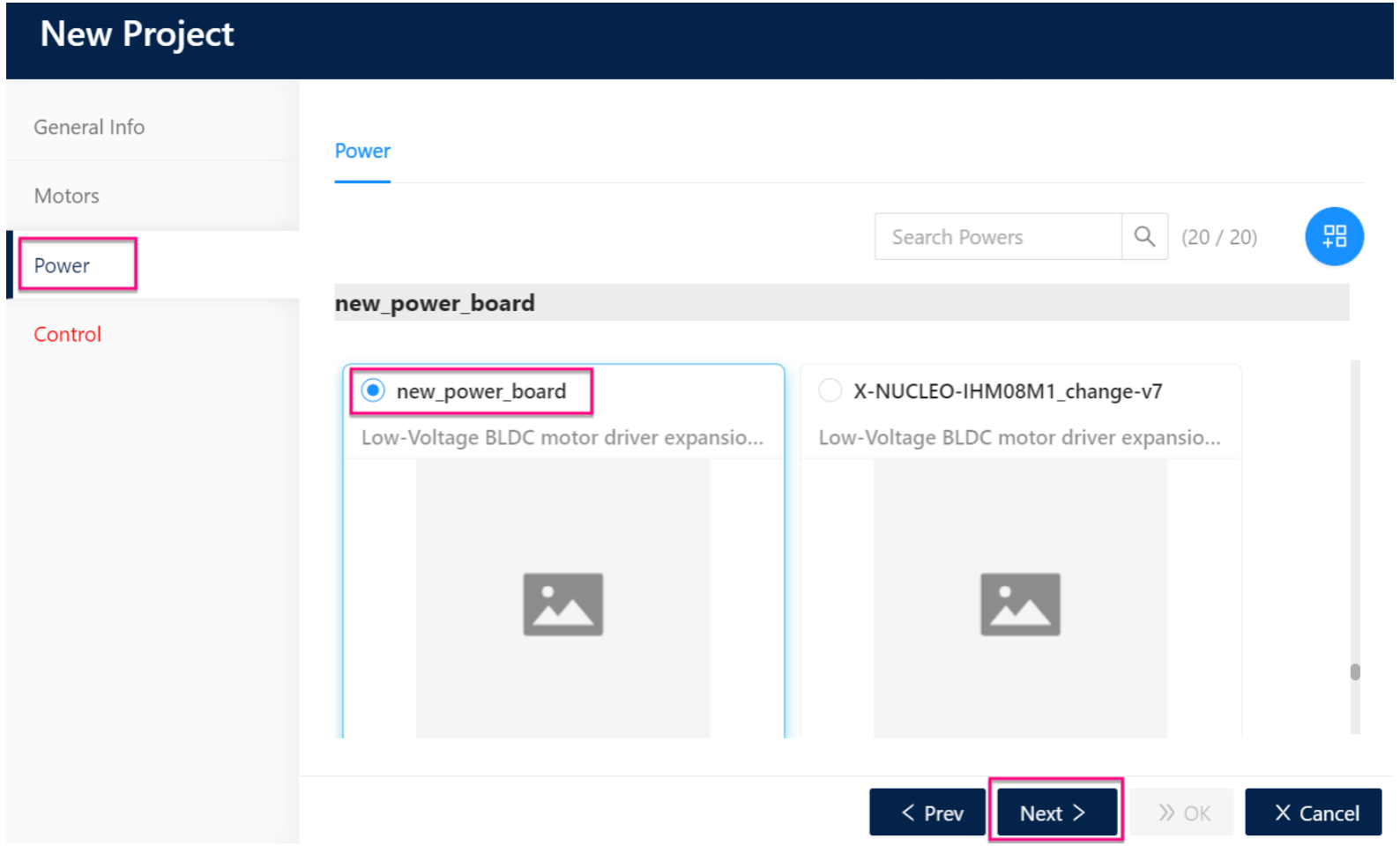


Select modified motor

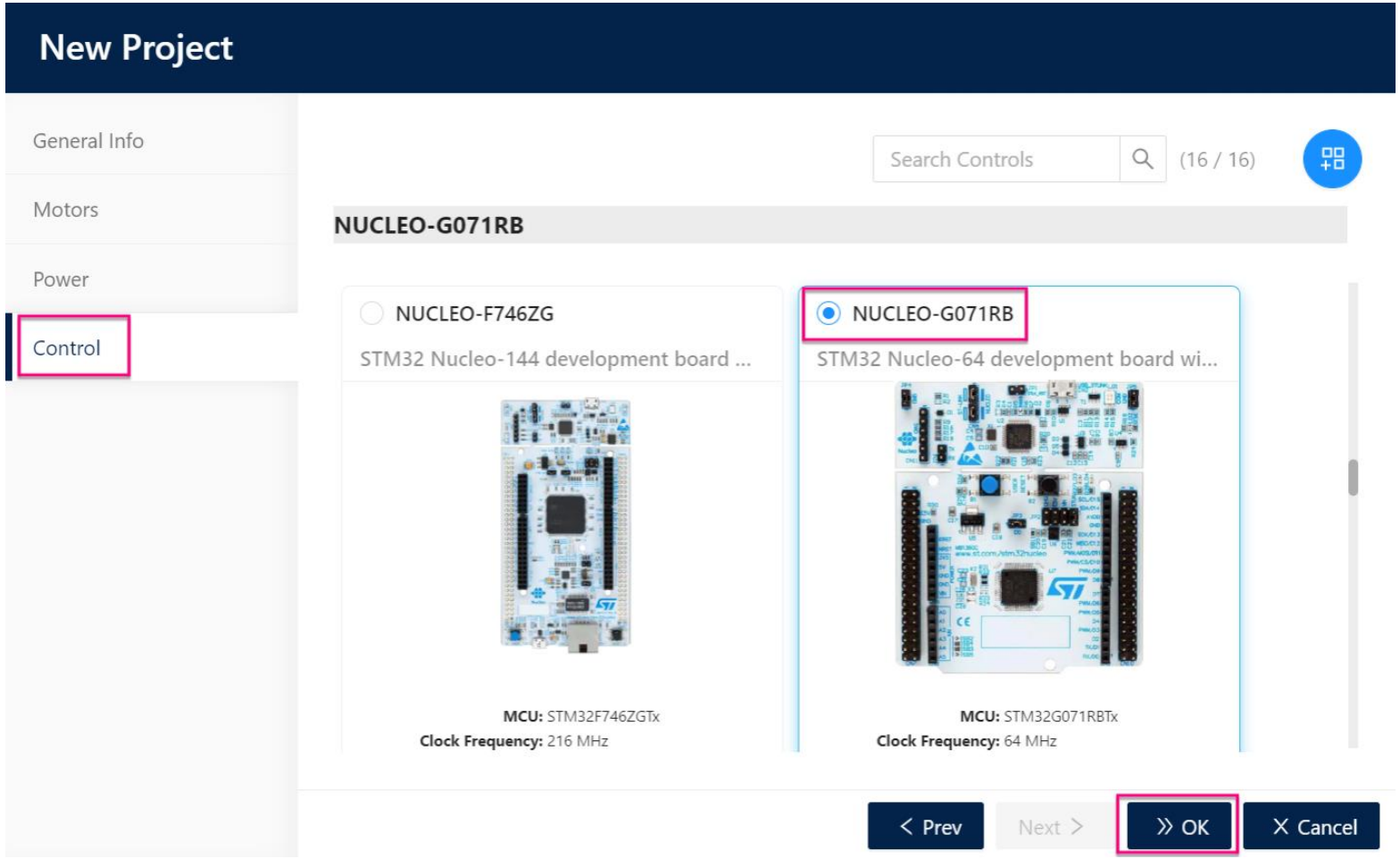
- Select “new_motor” ->Next;



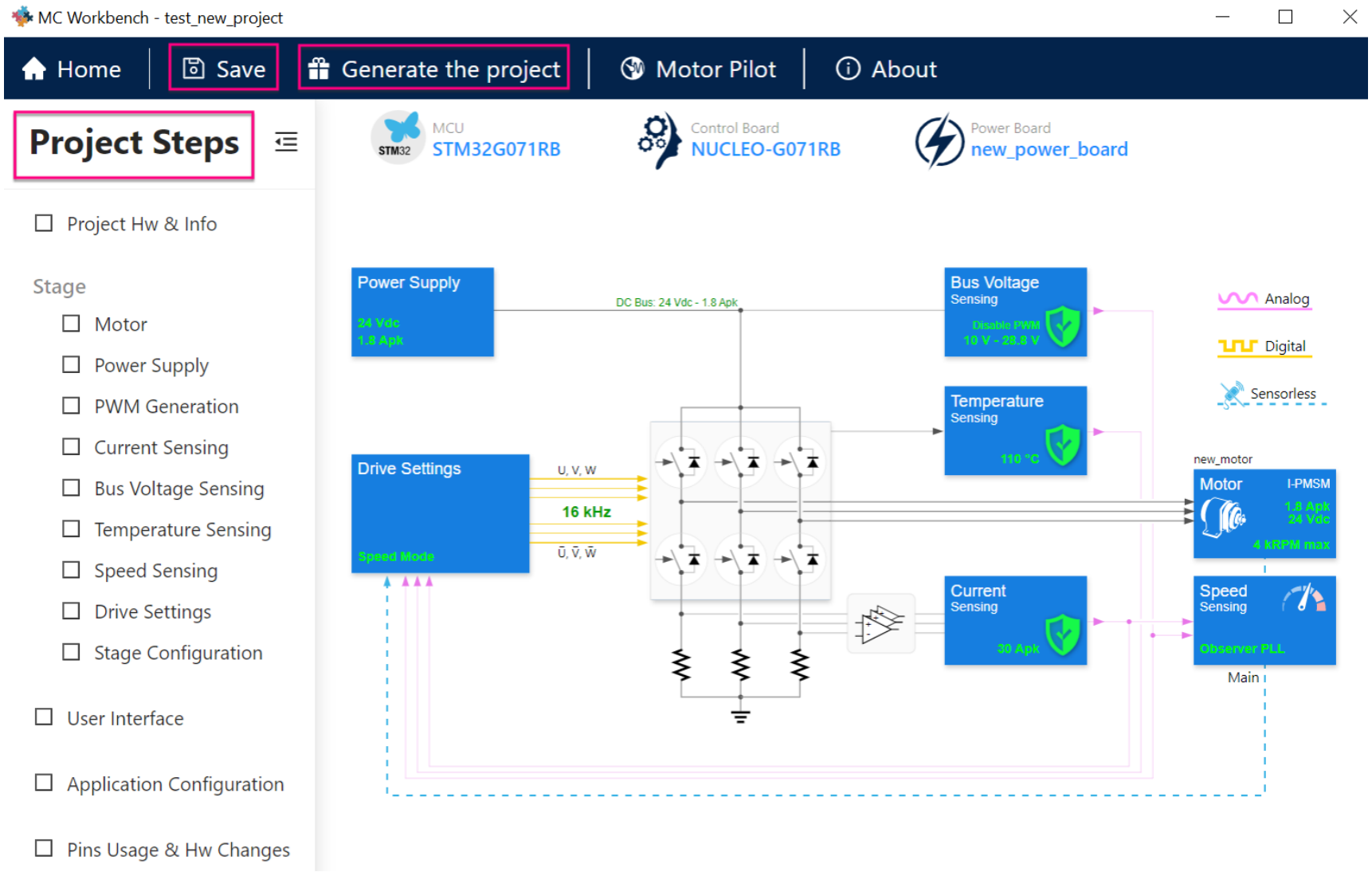
Select new power board



Select control board

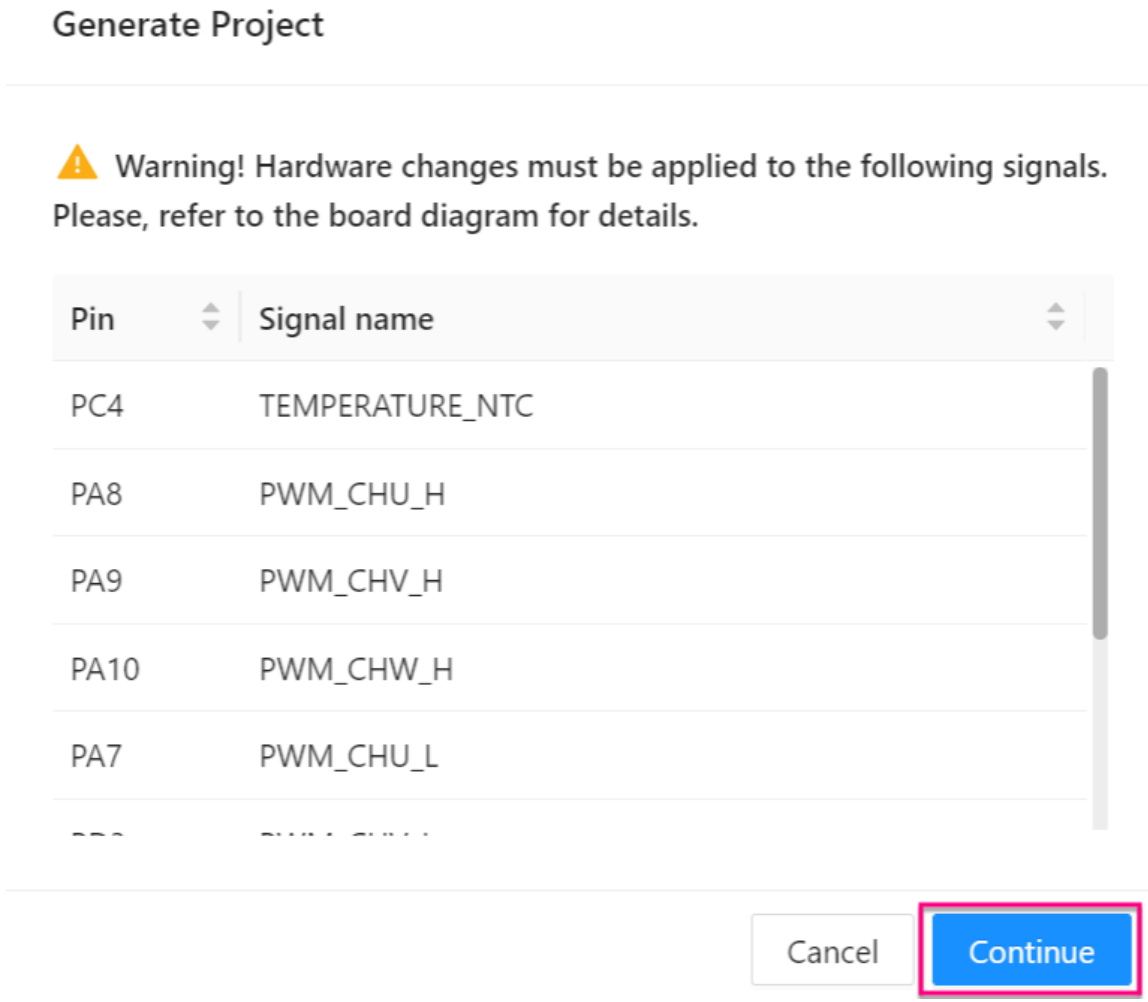


Save and generate the project

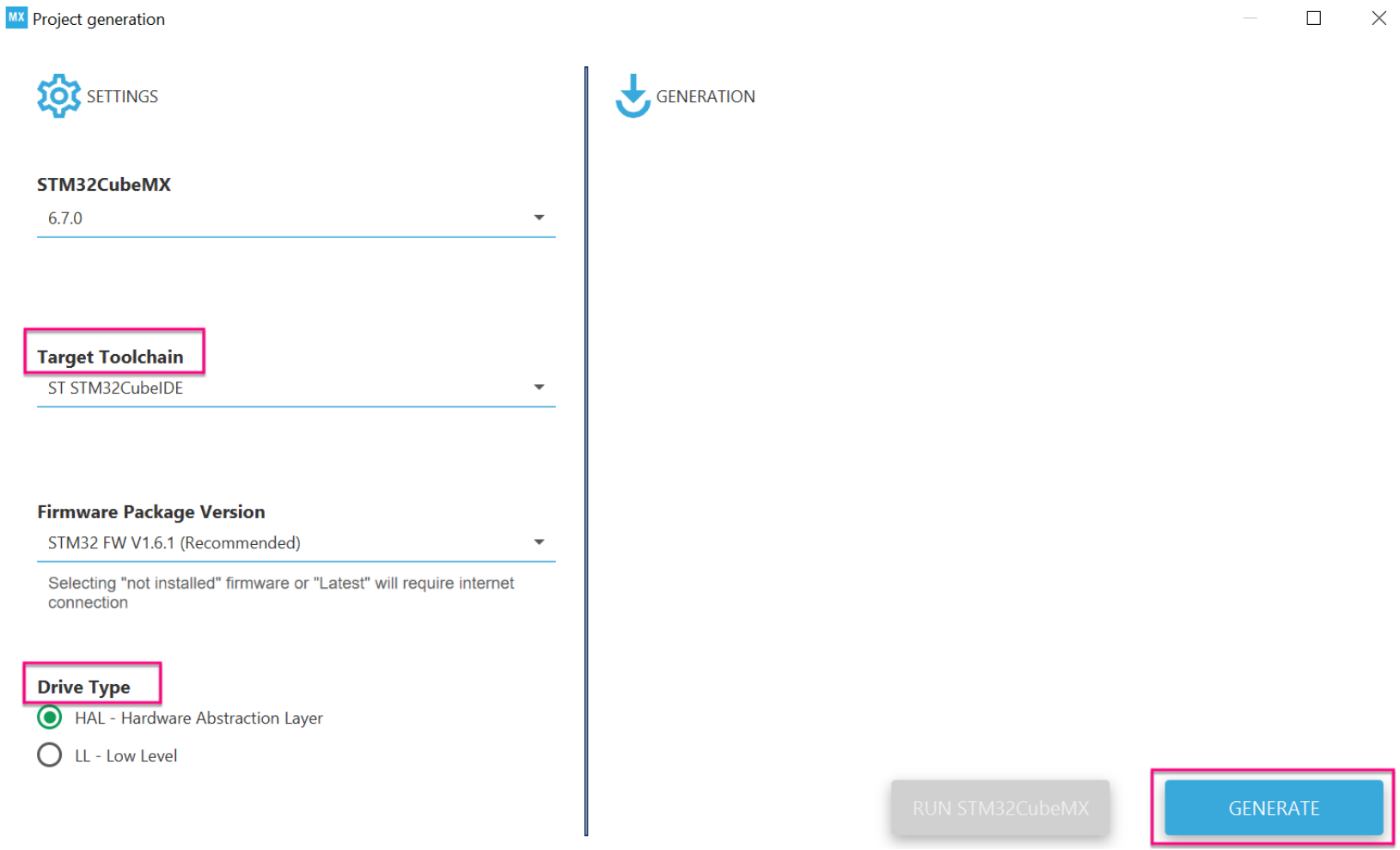


Generate FW project

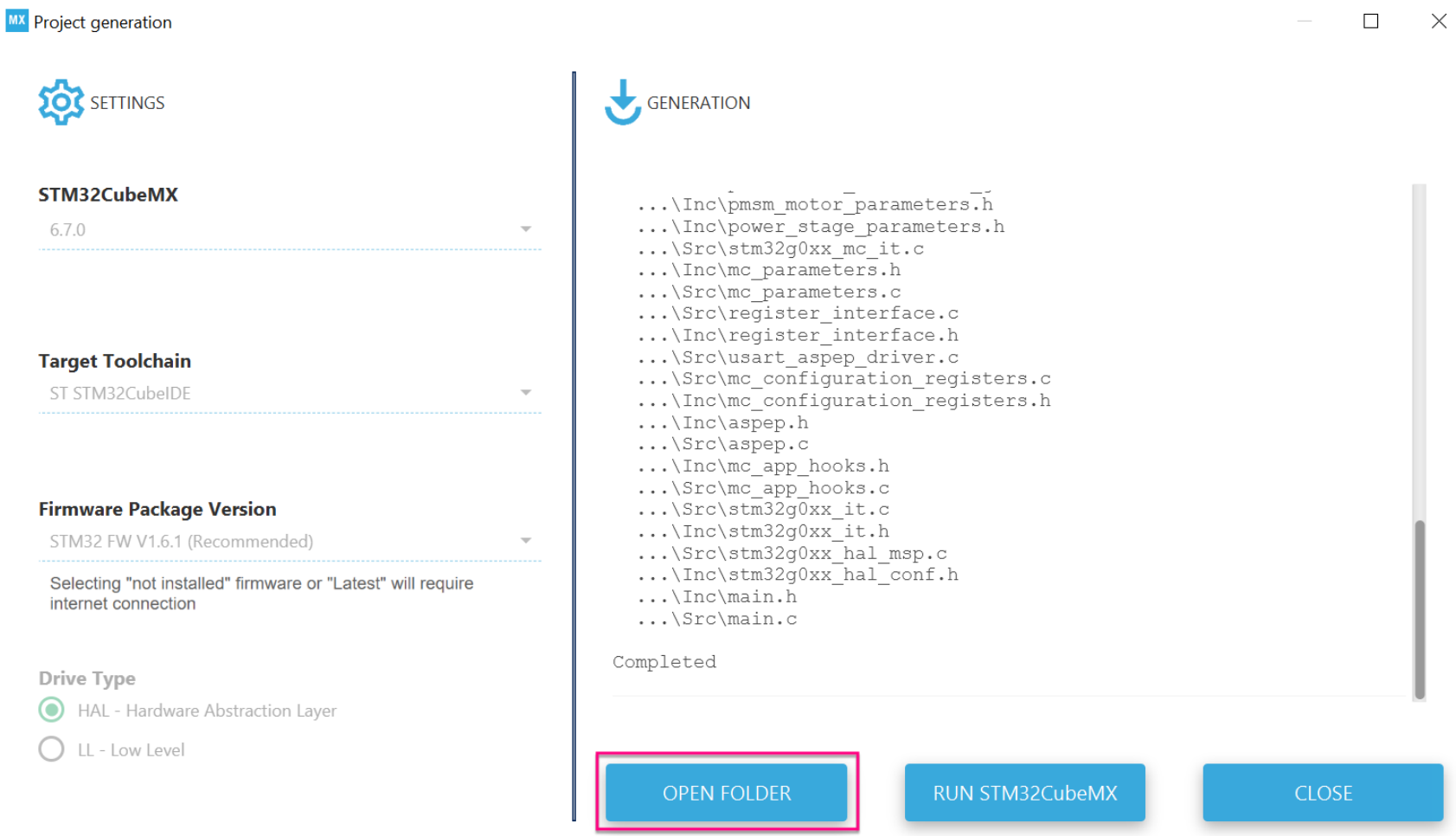
- Click Continue



Generate FW project

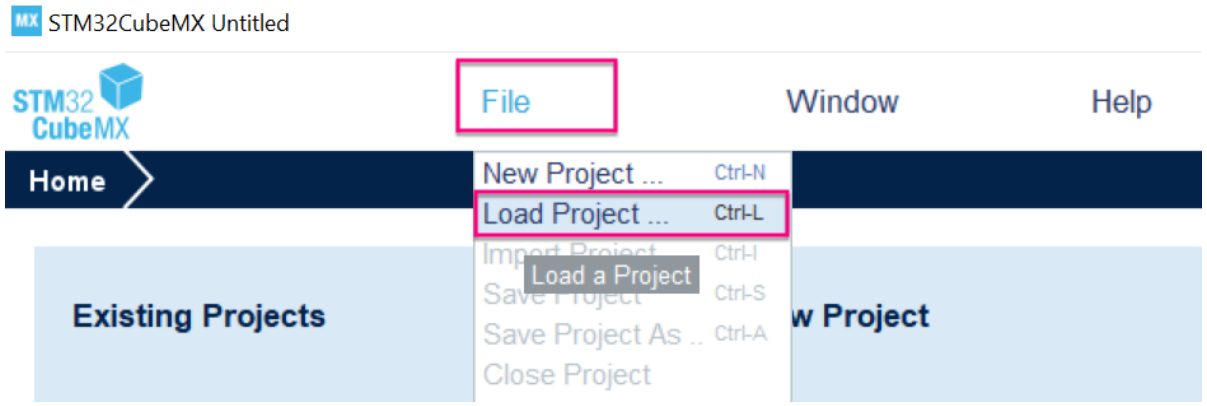


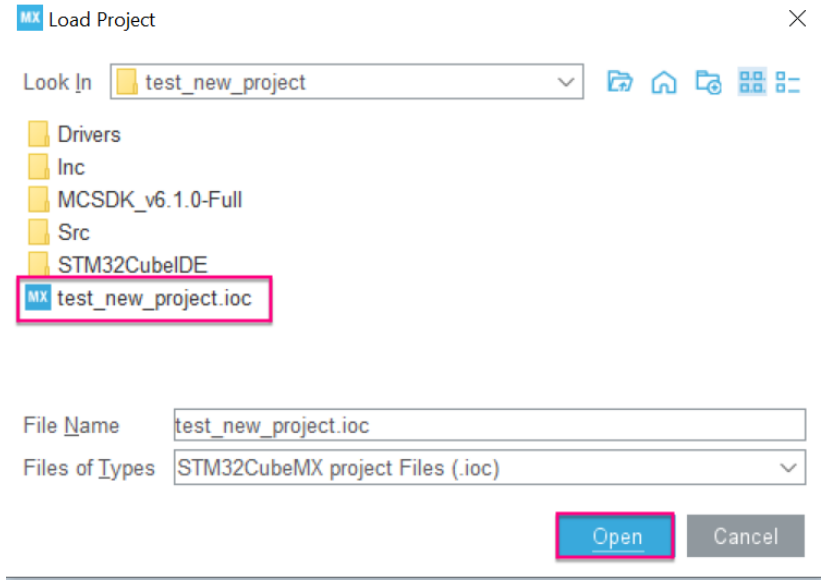
Open the fold of FW project



Select target MCU from CubeMX

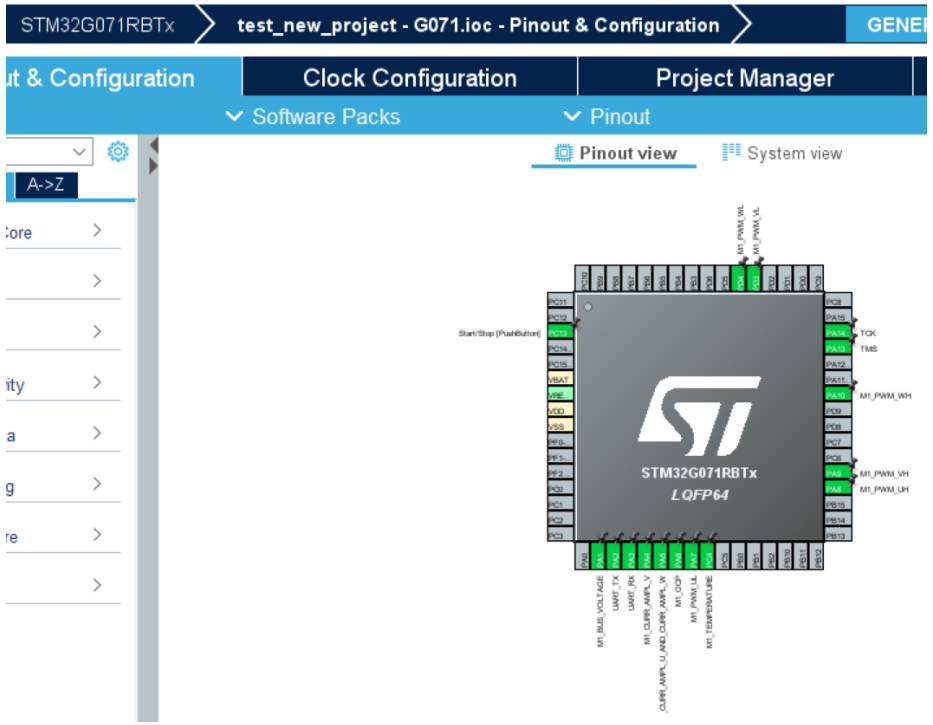
- Load *.ioc file from CubeMX





Modify MCU part number

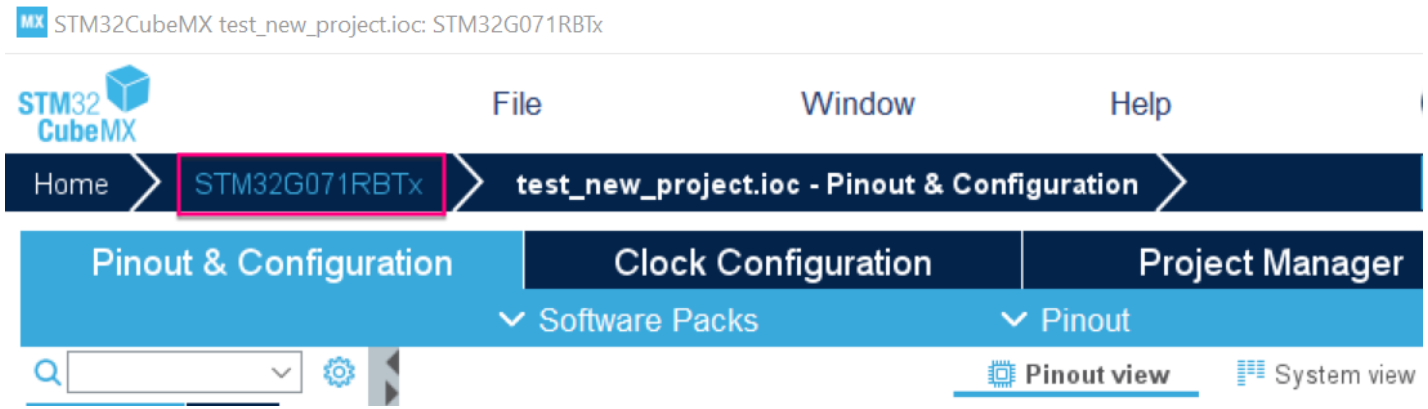
- Now MCU is G071

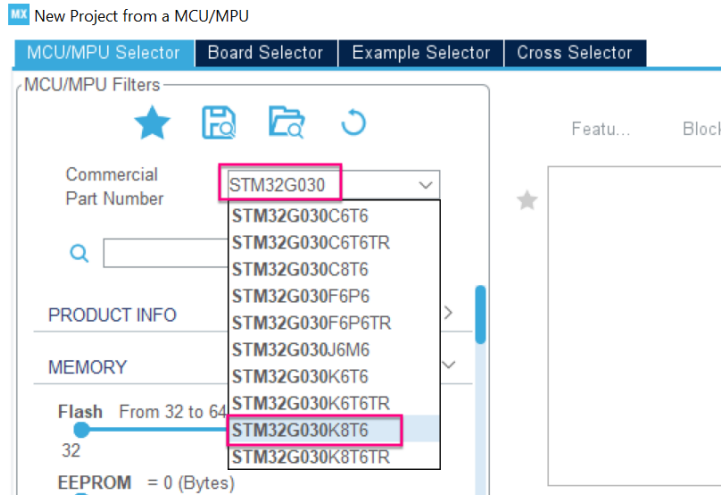


Select MCU

Modify part no. to G030

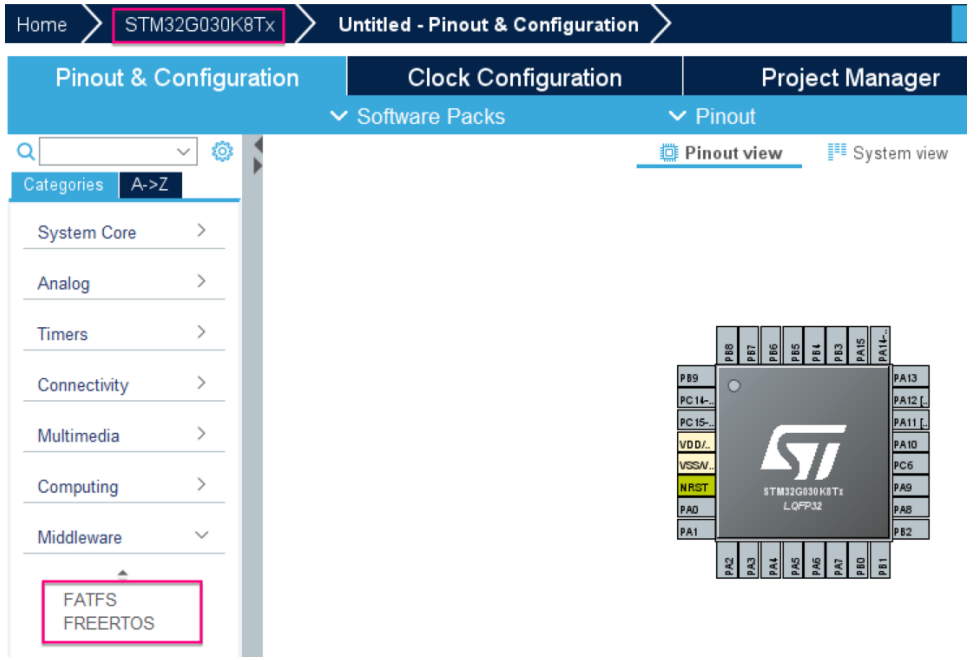
- Modify MCU part number to STM32G030K8T6





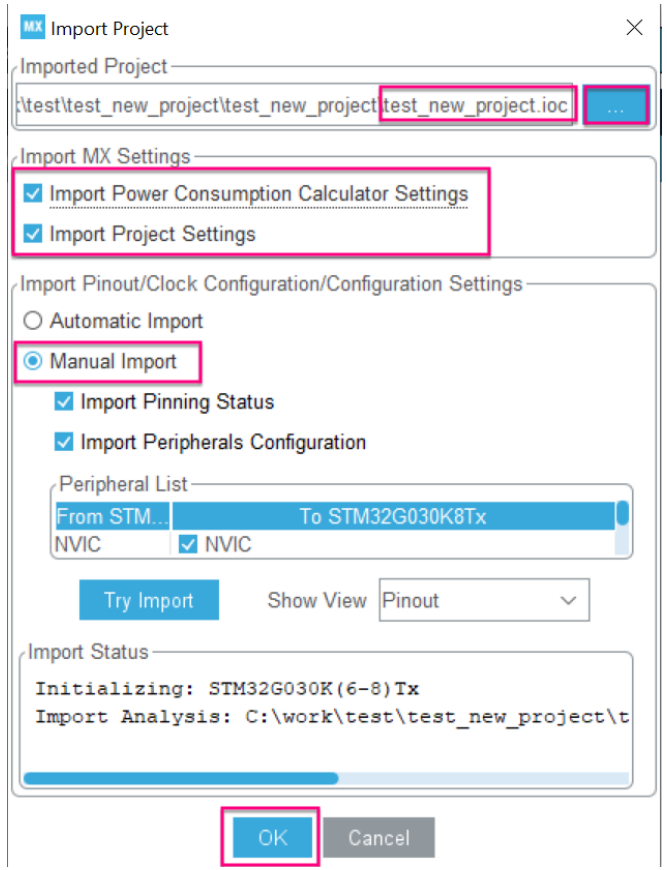
Select MCU

- Then MCU is switched to STM32G030K8T6, but lacking of IO allocation and motor control middleware.



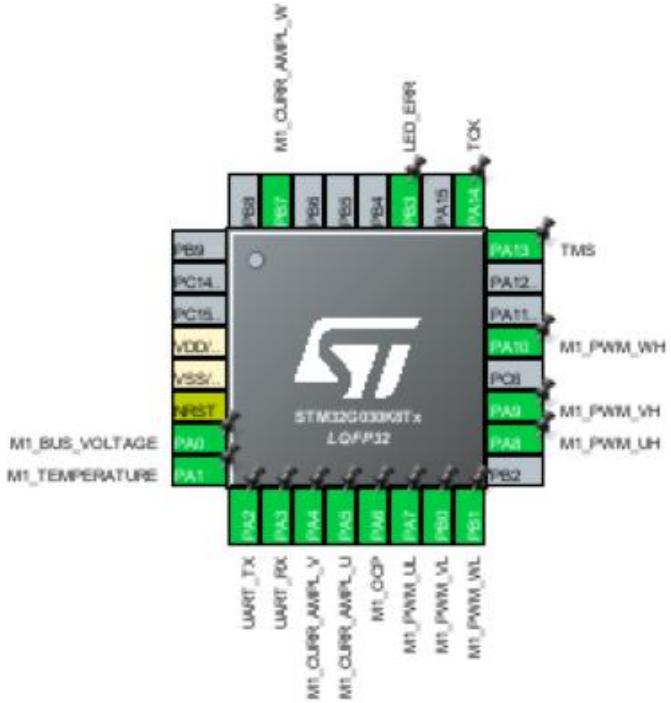
Import an IOC file

- File – Import Project， select test_new_project.ioc



Done to port SDK into a new MCU

- Please check if IO allocation is aligned with schematics



The last step

- Save the ioc (File-Save Project), exit and re-open CubeMX, motor control middleware is loaded. Click GENERATE CODE to generate FW project and codes.

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