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ST电机控制解决方案及应用

2020年3月27日

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Motor Control Competence Center
Asia Pacific Region



- 1 ST亚太电机控制创新技术中心
- 2 ST电机控制生态系统
- 3 STM32 MC SDK v5.4.3 新特点
- 4 ST电机控制应用及IPs
- 5 ST电机控制硬件工具



Motor Control Competence Center Functions

- 设计
 - 硬件参考设计, 应用开发板
 - 用于ST电机库的软件应用模块设计
 - 系统级解决方案
- 客户支持
 - 评估和培训 (使用ST工具)
 - ST套件及产品的选择(in cooperation with TM)
 - 原理图
 - Layout 检查
 - 调试 (in cooperation with FAE)
 - 性能提升
- 咨询
 - 全面的电机控制系统专业知识
 - 伙伴关系和新算法;
 - 客户Ips移植到ST平台

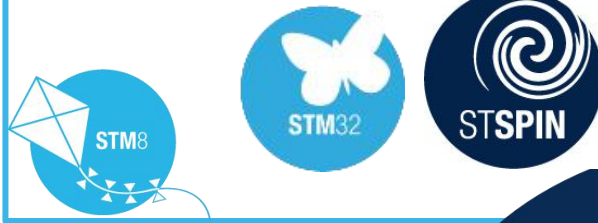


ST电机控制生态系统

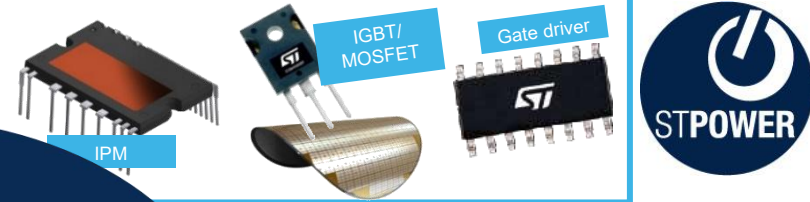
三相电机 PMSM FOC SDK

技术支持(全球层面)

MCUs for
Motor Control (8-32 bit)



IPM, Power transistors, AC
switches, Motor Driver ICs



ST MC Workbench
STM32 Cube Mx



PC SW GUI
Full customization
and real time
communication

电机
控制
生态系统

HW Boards

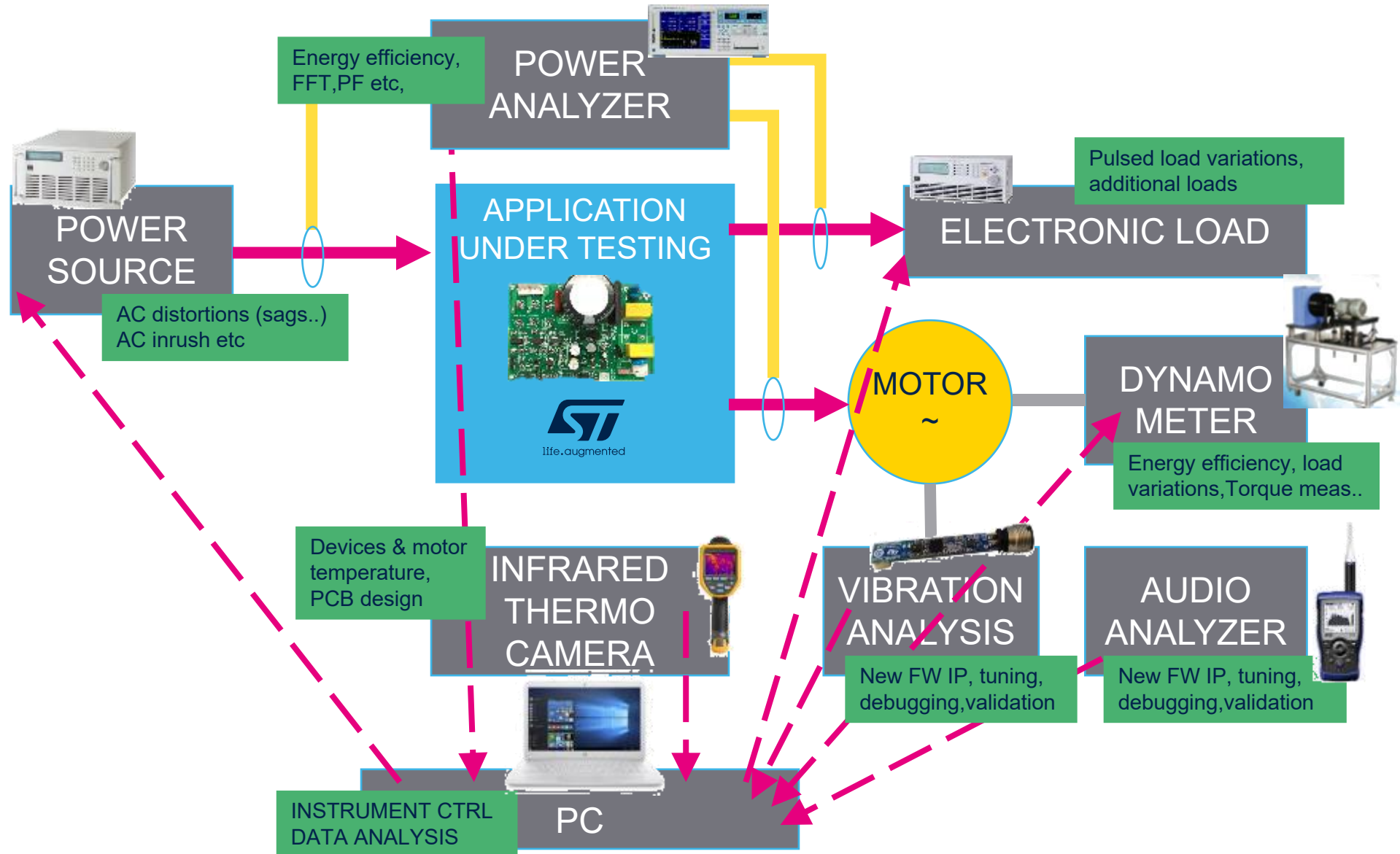


FW library

wide range of features &
algorithms (FOC – 6step)



Software
Development
Kit (SDK)





Home and Professional Appliances



Power Tools



Factory Automation



MOTOR CONTROL



Industrial Drives

Motor

- 3phase BLDC or ACIM
- Stepper
- DC

Design

- Architecture
- Power

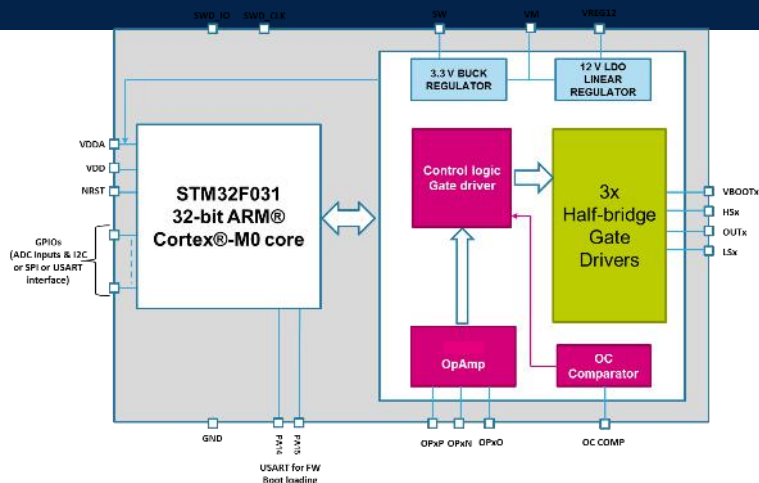
Behavior

- Energy Efficiency
- Dynamics
- Safety - Reliability



STSPIN32F0 / A / B概述

Advanced 3-phase BLDC driver + STM32 – from 2 Li-Po Cells to 45V



KEY BENEFITS & FEATURES

STM32 Cortex M0 + 3-phase Gate Driver

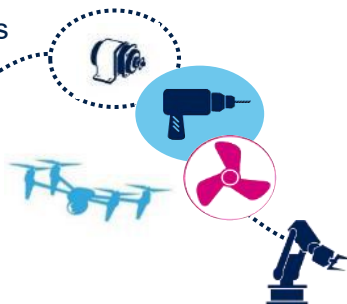
Fully compatible with STM32 ecosystem

12V LDO & 3.3V DCDC regulators integrated

6 step & FOC sensorless / sensed algorithms

KEY APPLICATIONS:

- Battery powered Home Appliances
- Power tools
- Fans
- Industrial automation
- Robotics
- Drones and aeromodelling



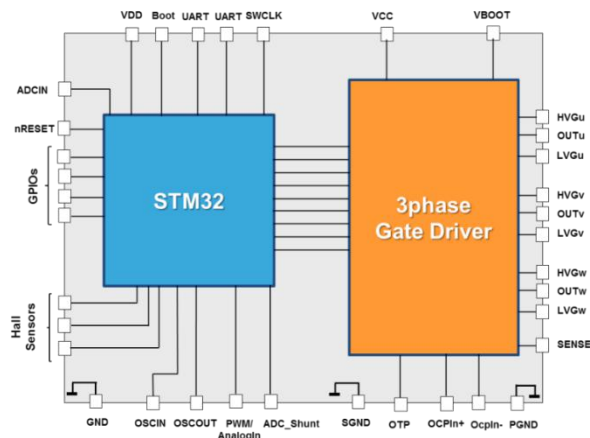
- VS = 6.6V–45V (A version), I_{gate} = 600mA sink / source current
- 48 MHz, 32k Flash & 4k SRAM
- 12 bit ADC , I2C / UART / SPI
- **FW boot loader support** (A version)
- Fully protected (UVLO, Short-circuit, OCP, OTP)
- 3 Op-Amps & 1 Comparator (A version) ,
- **Compact design** with 7x7 mm QFN
- Extended temp range: -40 to 125°C



NEW

STSPIN32F060x/25x 概述

Advanced 250V & 600V 3-phase BLDC Drivers with embedded STM32 MCU



Key Features

- STM32 Cortex M0 + 3-phase Driver
- Fully compatible with STM32 ecosystem
- 6step & FOC sensorless / sensed algorithms
- 0.35A & 1A I capability
- All devices P2P among them

KEY APPLICATIONS

- 36V – 120V Power and garden tools
- Air conditioning compressors & FANs
- Home and Industrial refrigerators compressors
- Industrial Pumps
- High power tools
- Industrial automation



Value & Benefit

- **Extremely compact & flexible solution**
- **Exhaustive ecosystem for fast design**
- **High below-ground robustness**
- **High immunity / Low EMI Noise**



STM32 G4

G4 = next generation of F3 series



F3 series



- **Gain in robustness, Safety, Security**
 - EMC (EMI, EMS) → continuous improvement
 - **Dual Bank** Flash w/ ECC (Live FW Upgrade)
 - HW encryption AES
 - **Securable Memory Area**
- **Gain in Performance**
 - **170MHz** even from internal oscill. (**213DMIPS**)
 - ART accelerator (~dynamic cache)
 - CCM-SRAM Routine Booster (~static cache)
 - **Mathematical accelerator** (Trigo, Filtering)
 - Better dynamic power conso (160µA/Mhz) = ~2.7 times lower than F3 series
- **Gain in Peripheral set and Architecture**
 - **1%** RC accuracy [-5°..90°C], 2% full range
 - ADC with HW oversampling = 16-bit resolution
 - Renewed Op-Amp, DAC, Comparator
 - New HR timer features (digital part)
 - MC timer improvements (encoder mode...)
 - USB type-C with Power Delivery incl. PHY
 - 85° up to **125°C** (limited condition)
- **STM32 F3 portfolio extension**
 - D-Power portfolio (STM32F334) extension
 - **NEW 128pin** and **80pin** packages (LQFP)



G4 series



STM32 G4

升级版模拟外设

New design

Op-Amp	F3	G4	Comment
Power supply (V)	2.4 .. 3.6V	2.0 .. 3.6V @ functional 2.2 .. 3.6V @ full perf.	Only PGA gain error is improved from 2.2V
GBW (MHz)	8.2 MHz	13 MHz	Typ. value
Slew rate (V/μs)	4.7 us	45 V/μs (high speed mode) 6.5 V/μs (normal mode)	Typ. value
Offset (full temp range) (mV)	3 mV	3mV (full temperature range)	1.5mV @ 25°C
	Rail to rail input/output	Rail to rail input/output	
PGA Gain	x2, x4, x8, x16	2, 4, 8, 16, 32, 64,	1% accuracy

New design

Comparator	F3	G4	Comment
Power supply (V)	1.8 .. 3.6V	1.62 .. 3.6V @ full perf.	
Propagation delay	25ns	16.7ns	Typ. value
Offset (mV)	+/-4mV	-6 .. +2 mV (typ.)	Max. -9 .. +3 mV
Hysteresis	No (except 256, 128KB version)	8 steps: 0,9,18,27,36,45,54,63 mV	Programmable with step 9mV

New concept

DAC	F3	G4	Comment
Power supply (V)	2.4 .. 3.6V	1.8 .. 3.6V @ functional 2.7 .. 3.6V @ full perf.	
Sampling rate	1MSps	15MSps (internal use only → DAC connected to COMP input)	Settling time: 16ns (10%-90%) 64ns (1LSB)

G4 includes 3xDAC 1Msps (same as in F3) and 4xDAC 15Msps (internal only)

Target applications

Motor control



Washing Machine



Air Conditioning



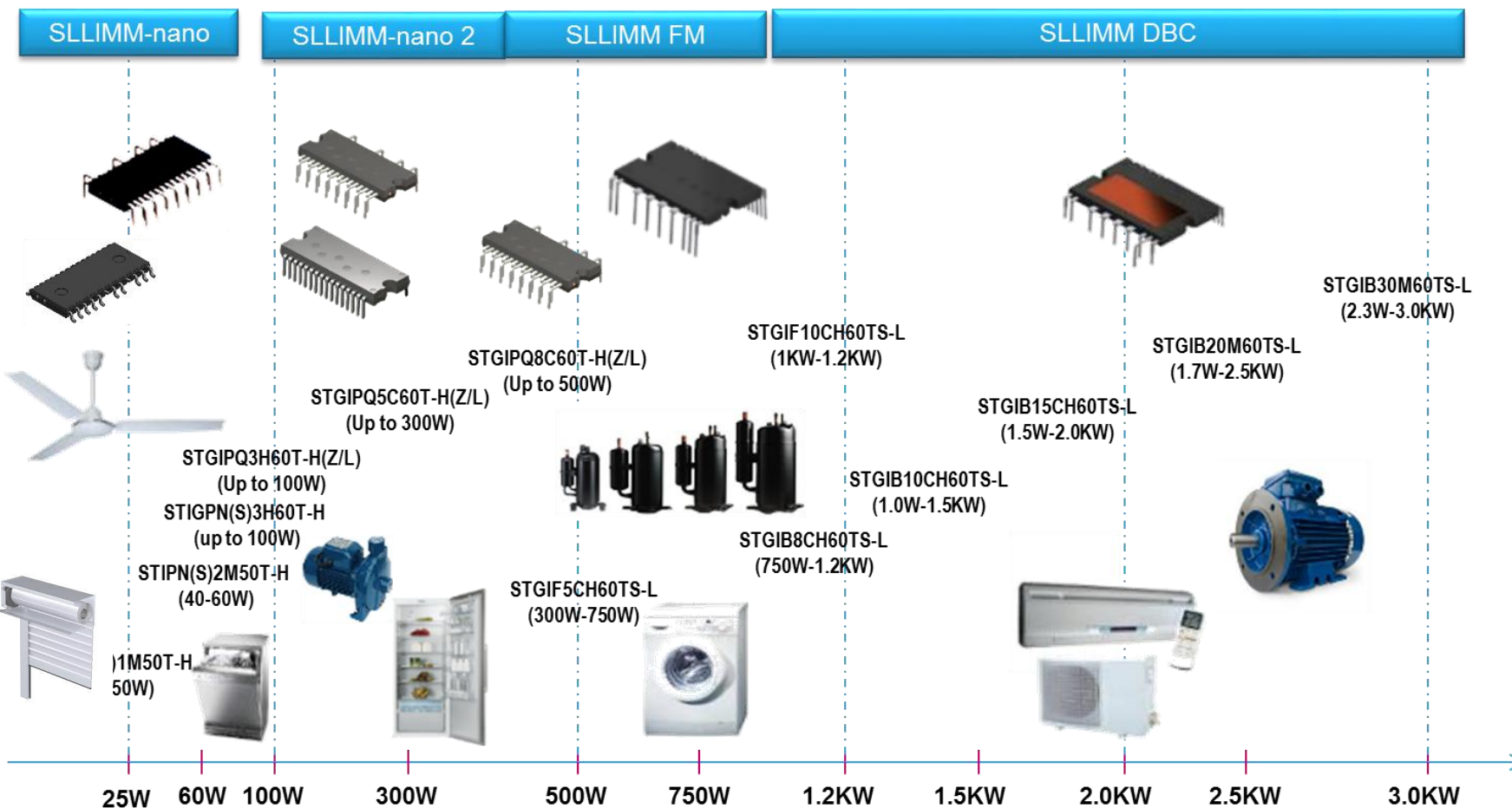
Pumps



Compressor

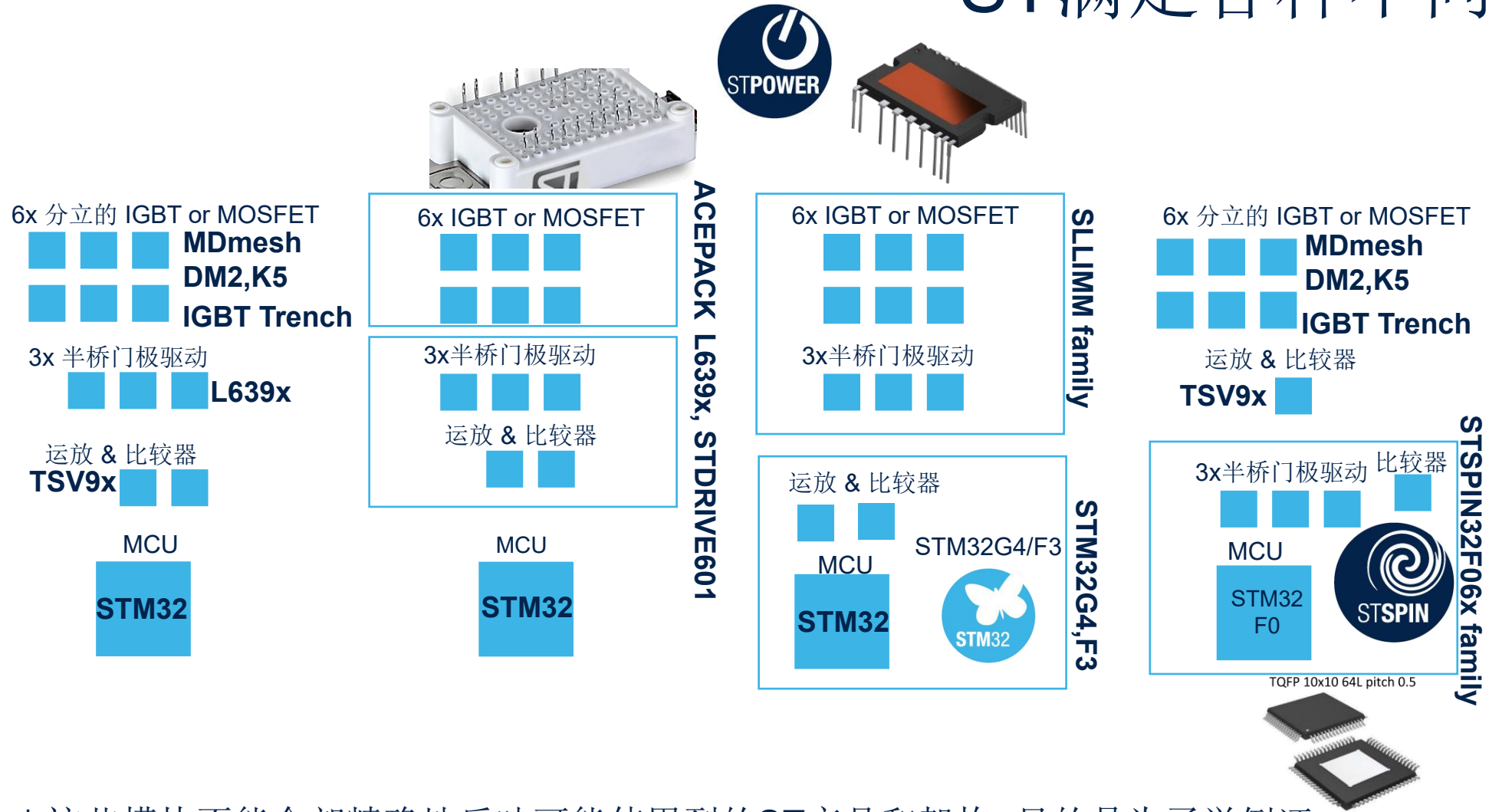


Industrial drives



高压电机控制方案架构

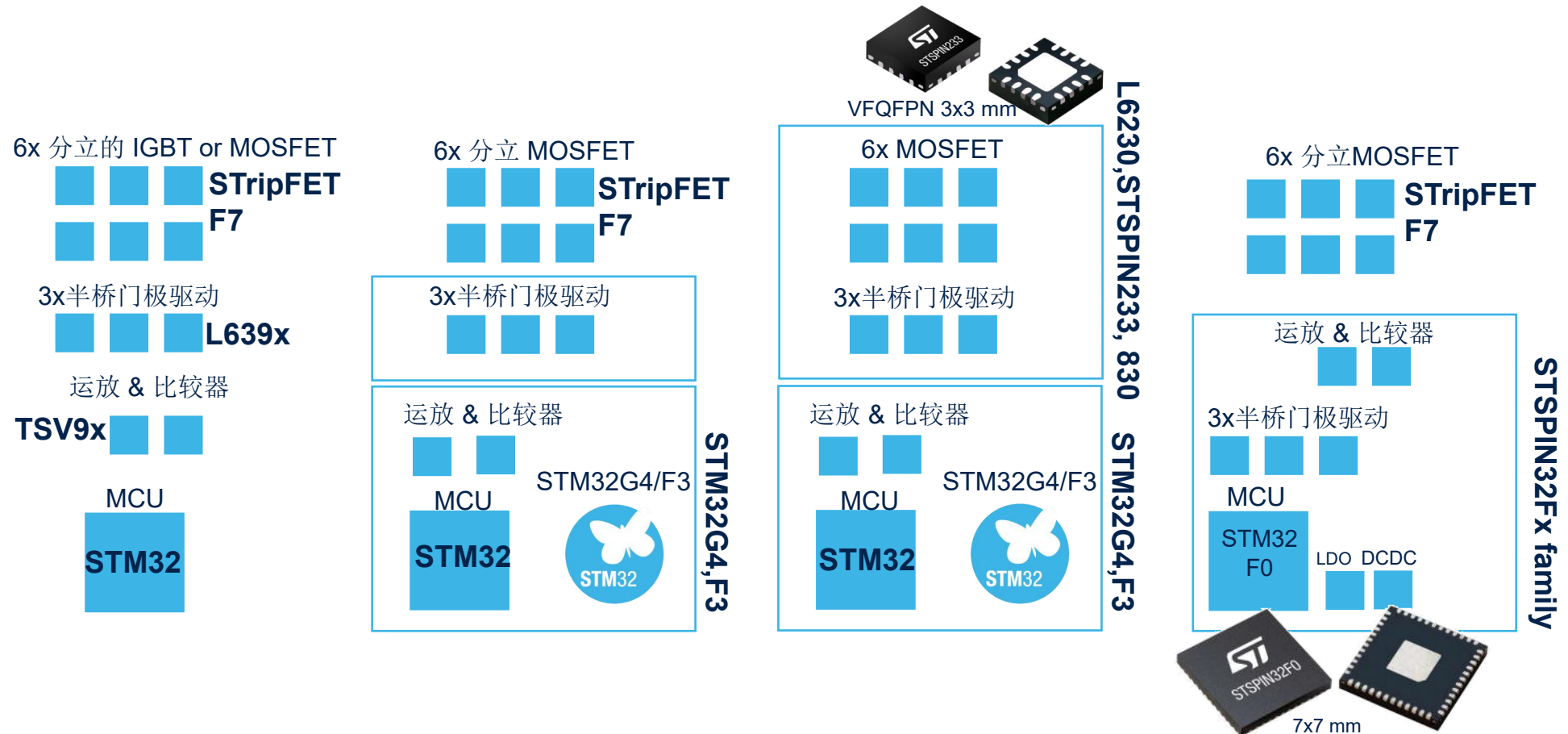
ST满足各种不同需求*



* 这些模块不能全部精确地反映可能使用到的ST产品和架构. 目的是为了举例证明ST产品可以涵盖不同架构和应用。

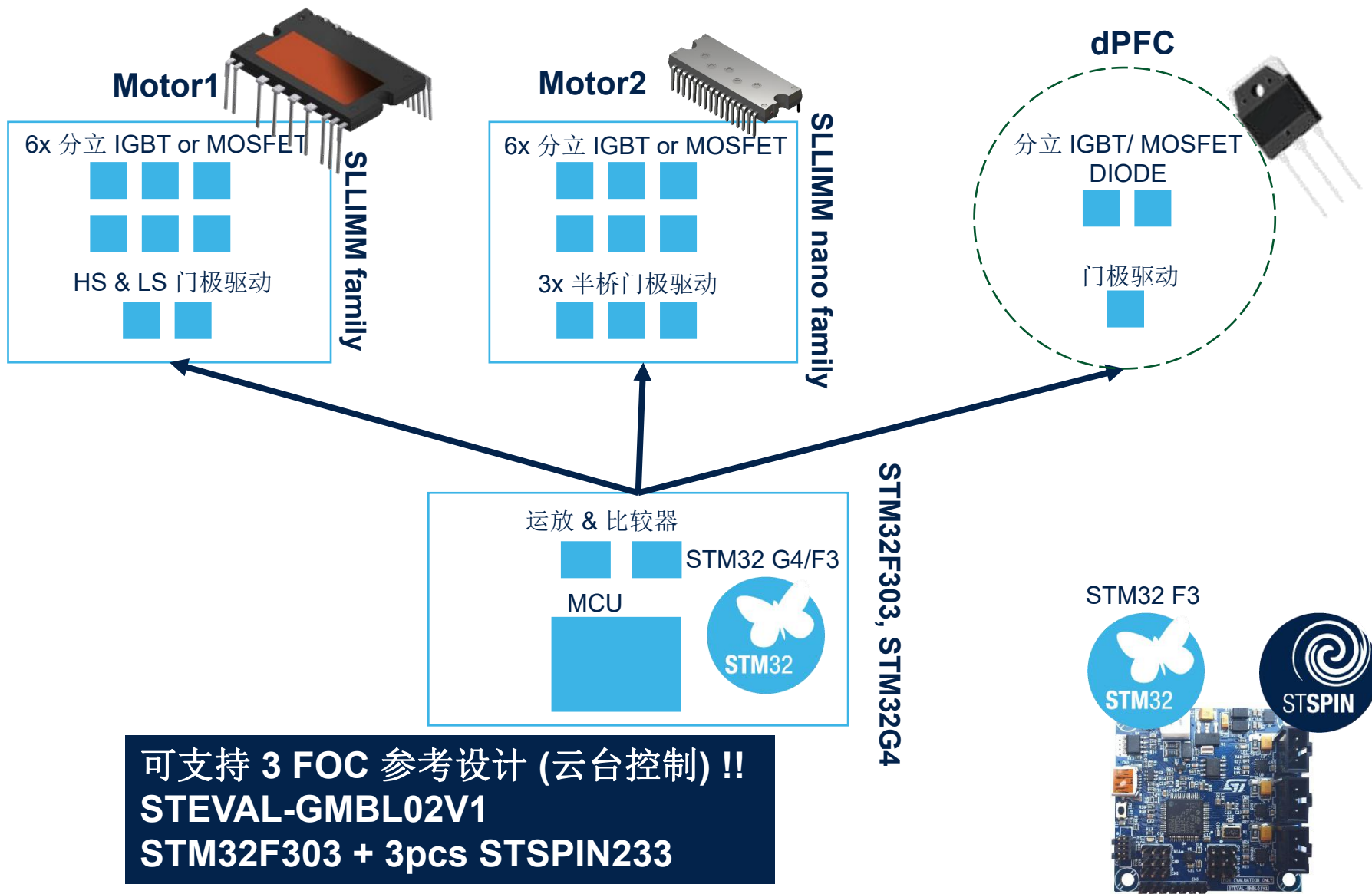
低压电机控制方案架构

ST满足各种不同需求*:



* 这些模块不能全部精确地反映可能使用到的ST产品和架构. 目的是为了举例证明ST产品可以涵盖不同架构和应用

双电机控制&数字PFC方案架构

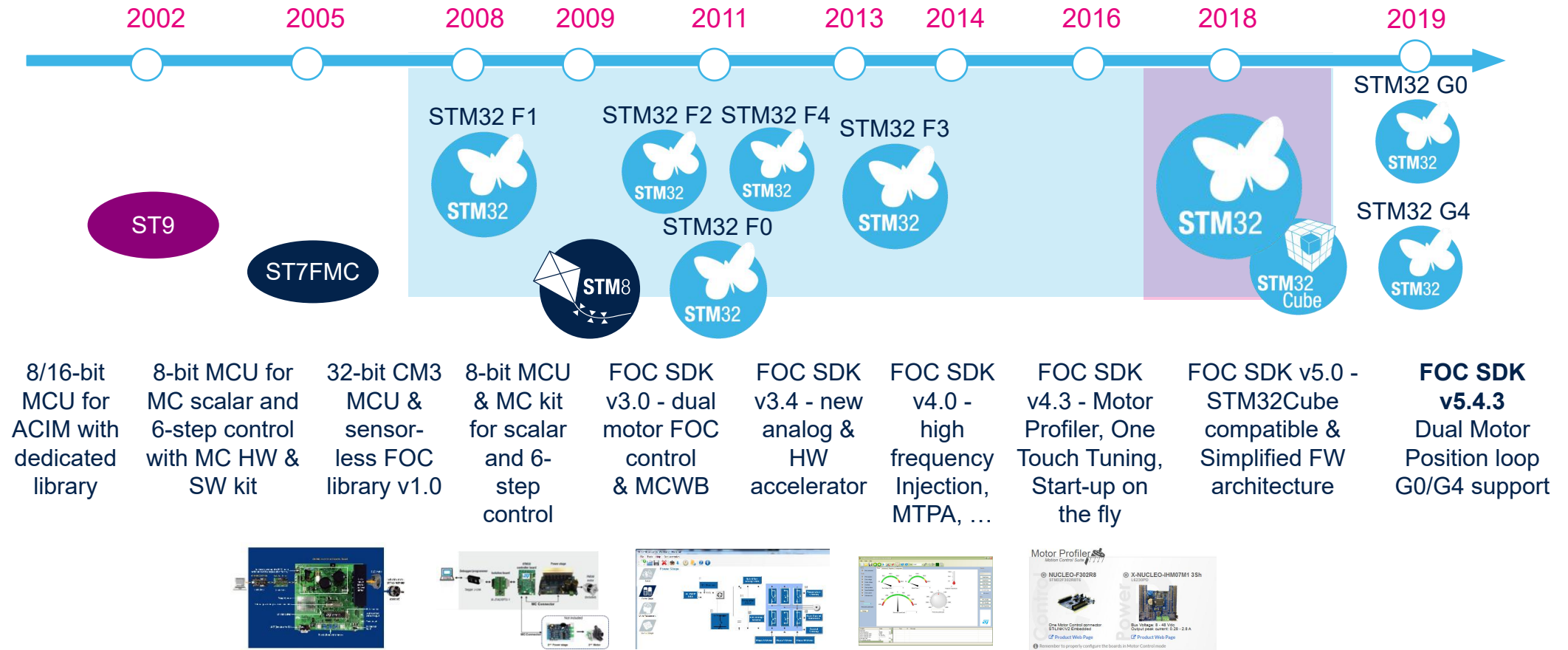




STM32 电机控制SDK

电机控制软件开发套件

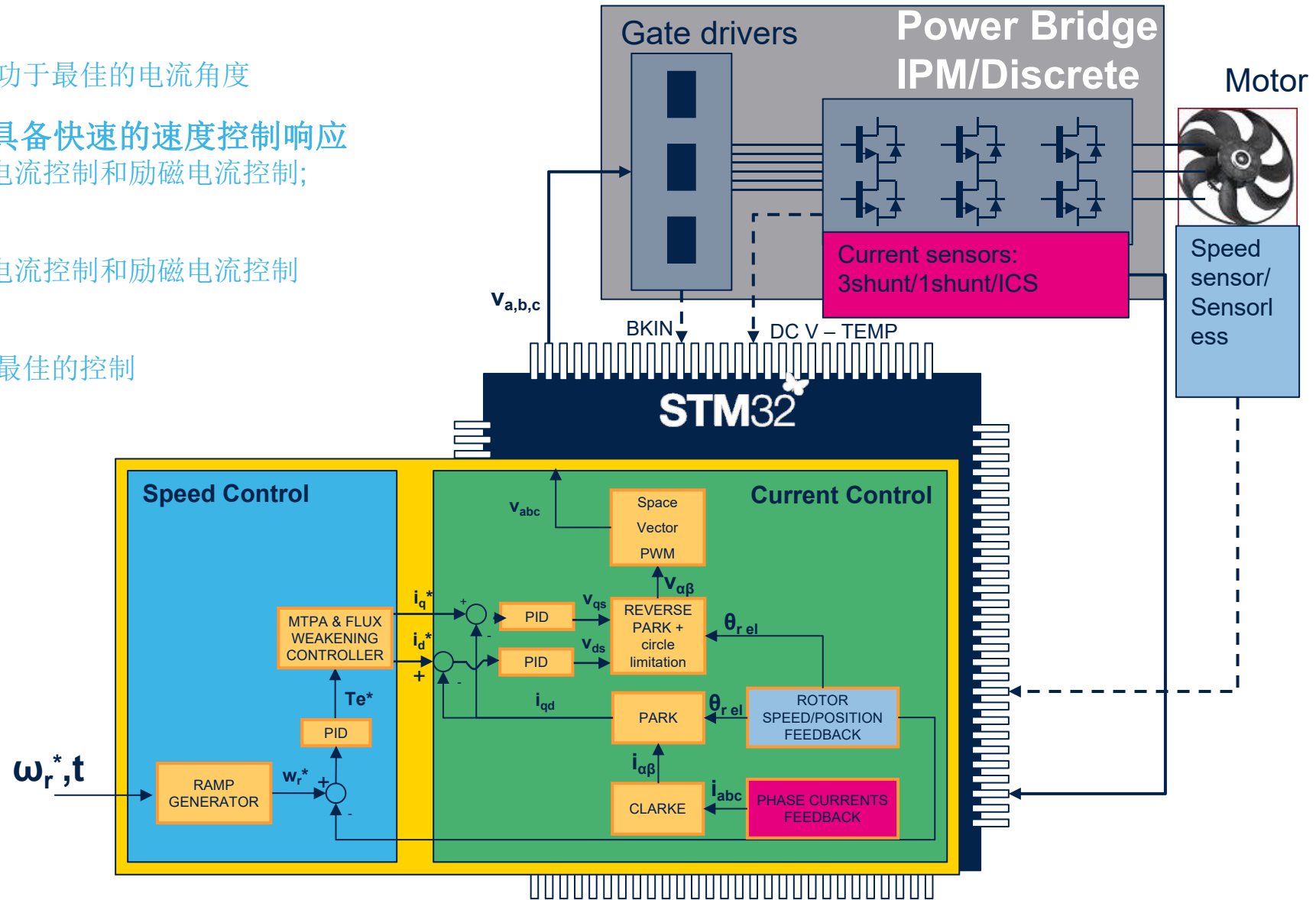
十八年三相电机控制 FOC MCSDK



PMSM FOC – 框图

FOC的优势:

- 最好的能效
甚至是过渡工况,归功于最佳的电流角度
- 对于负载的变化具备快速的速度控制响应
归功于直接的转矩电流控制和励磁电流控制;
- 精准的位置控制
归功于直接的转矩电流控制和励磁电流控制
- 噪音的减少
归功于正弦波驱动/最佳的控制



电流采样 架构&软件模块

• 单电阻采样

- ST 专利算法
- 只需要一个采样电阻和运放成本最低
- 电流采样算法可能导致扭矩控制精确度不高

• 2 + 1 电阻采样

- 电流采样准确性: 高
- 最优的折中: 成本/性能

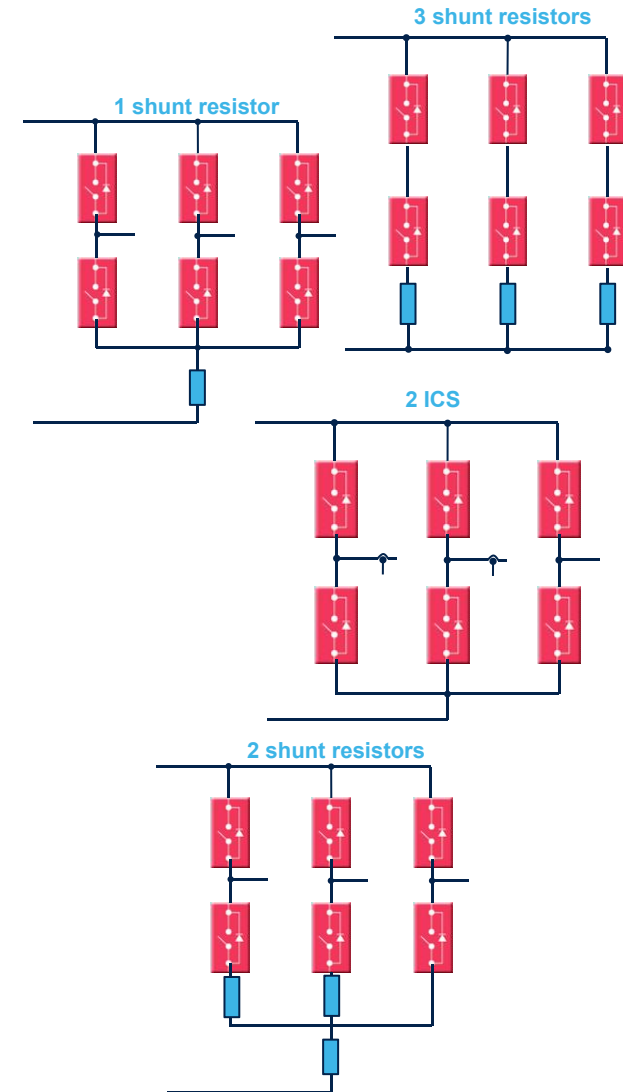
• 3 电阻采样

- 电流采样比较精确
- 最佳的成本 / 性能组合

• 2隔离电流传感器(ICS)

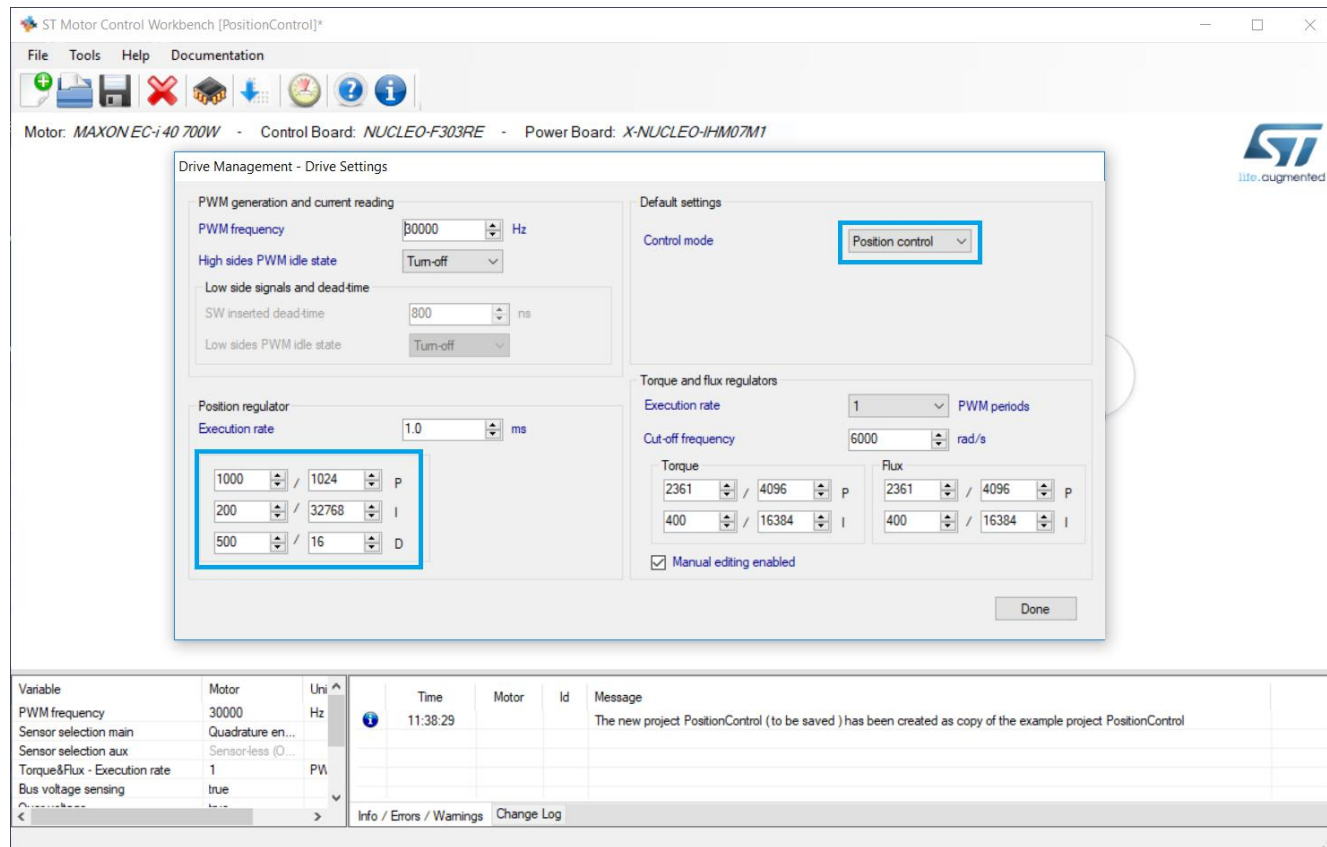
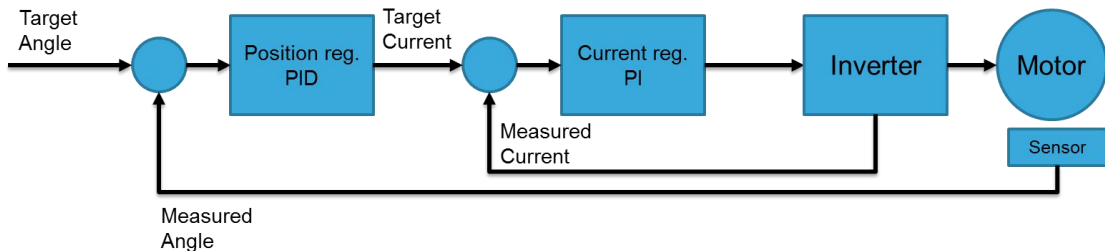
- 不需要损耗电流的采样方式 当电流比较大时（几十安培）采用的方式
- 昂贵

电机库支持任意的电流采样组合(2 种电机x 4种电流采样x 3种速度采样类型)

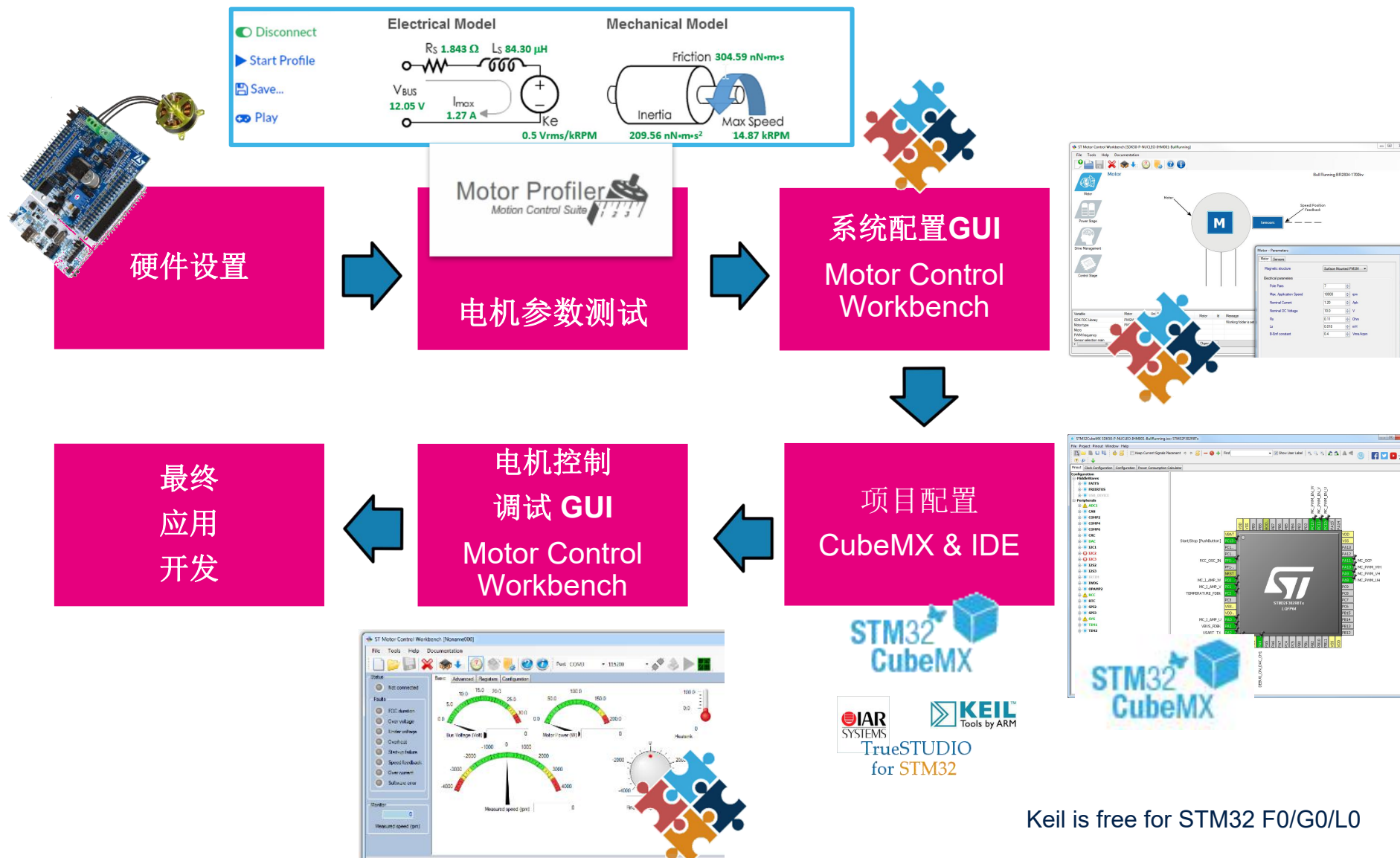


位置控制 (云台/摄像头/机器人/传送带 或其他)

- 执行方法是“两个调节器”的过程
- 位置调节器采用**PID**控制 (比例, 积分 和微分作用) **1kHz**的执行频率
- 电流调节器采用**PI**控制 (比例和积分作用) **20kHz**的执行频率
- 当传感器提供精确的位置信息, 控制器可进行很好的位置控制
- 不需要其他的精确速度测量



MCSDK工作流程



支持的 MCU 系列 until X-CUBE-MCSDK 5.4.3

STM32 系列	F0	F1	F3	F4	F7	L4	G0	G4
• 1 电阻采样	✓	✓	✓	✓	✓/✗	✓	✓	✓
• 3 电阻采样	✓	✓	✓	✓	✓	✓	✓	✓
• 霍尔传感器	✓	✓	✓	✓	✓	✓	✓	✓
• 隔离电流传感器	✗	✓	✓	✓	✓	✓	✗	✓
• 弱磁	✓	✓	✓	✓	✓	✓	✓	✓
• 最大转矩每安培	✓	✓	✓	✓	✓	✓	✓	✓
• 无传感器 (PLL / CORDIC)	✓	✓	✓	✓	✓	✓	✓	✓
• 前馈	✓	✓	✓	✓	✓	✓	✓	✓
• 单 FOC	✓	✓	✓	✓	✓	✓	✓	✓
• 双 FOC	✗	✓/✗	✓	✓	✓/✗	✗	✗	✓
• 位置控制	✓	✓	✓	✓	✓	✓	✓	✓

NEW

✓/✗: MCU supports but SDK does not support so far.



具体应用



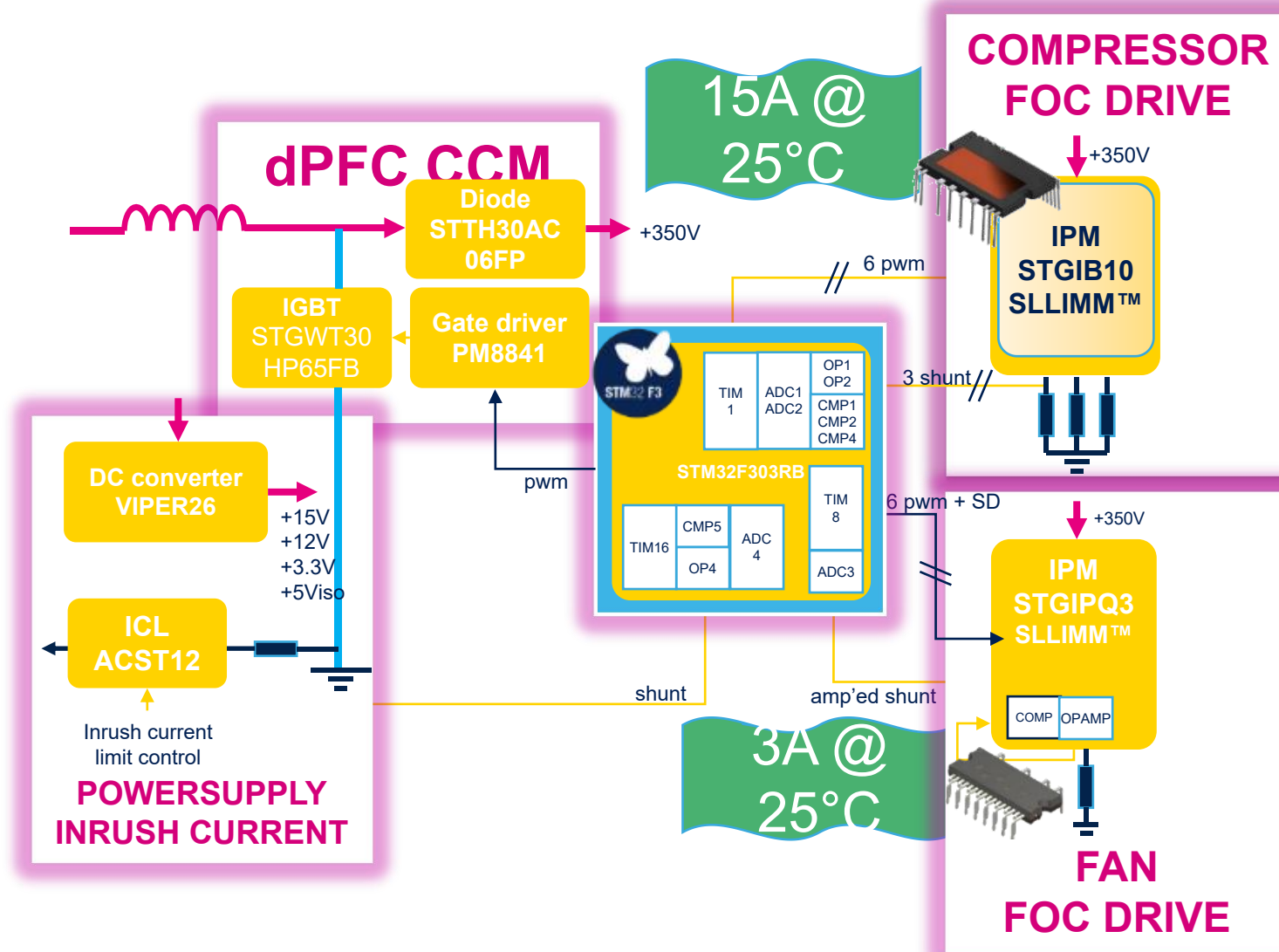


ST空调室外机Gen2

架构：双电机 FOC + DPFC

ST Products (1.5HP example)

- STM32F303RBT6
- STGIB10CH60TS-L
- STGIPQ3H60T-HZ
- STGWT30HP65FB
- STTH30AC06FP
- VIPER26LD
- PM8841D
- T1235T-8FP
- ST3232BDR



Compressor Protections:
OC, OT, UVLO

Fan Protections:
OC, OT, UVLO

PFC Protections:
OC, UVLO, OV

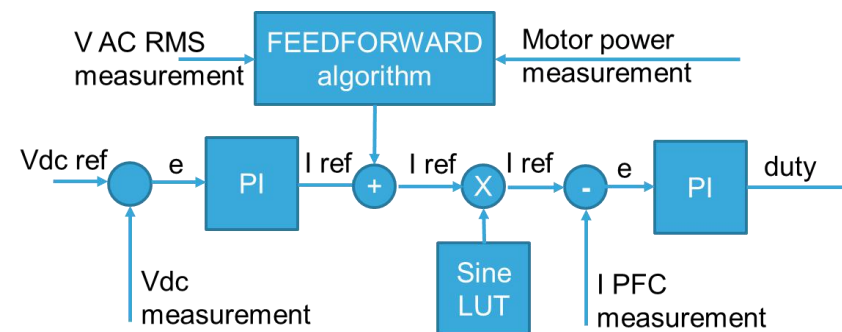
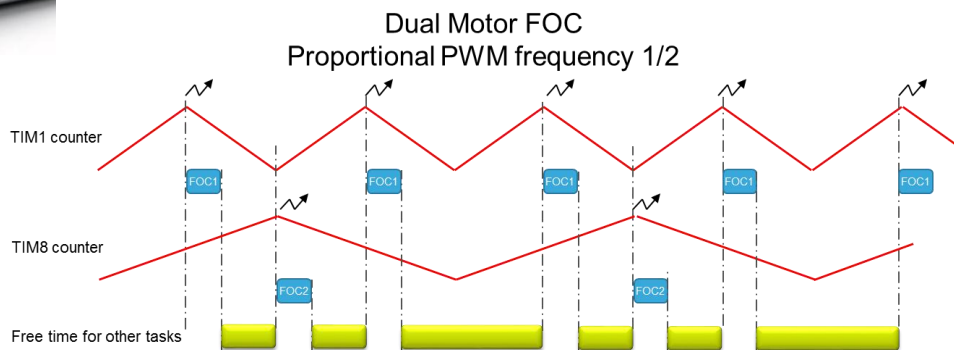
Power scalability
1 HP – 3HP

Small BOM
High Integration



ST空调室外机Gen2

STM32F3 CPU负载 (<56% !)



工作	PWM频率	控制频率	任务时间	CPU负荷
压缩机FOC (无传感器, 1个分流电阻)	6 kHz	6 kHz	22 us	13.2 %
风扇FOC (无传感器, 1个分流电阻)	18 kHz	9 kHz	22 us	19.8 %
PFC电流调节	40 kHz	40 kHz	4.39 us	17.56 %
PFC电压调节		2 kHz	4.095 us	0.82 %
压缩机, 速度循环和其它任务		0.5 kHz	42 us	2.1 %
风扇, 速度循环和其它任务		0.5 kHz	42 us	2.1 %
总计				55.6 %



ST空调室外机Gen2 SLLIMM® IPM最佳能效

能效



壳温



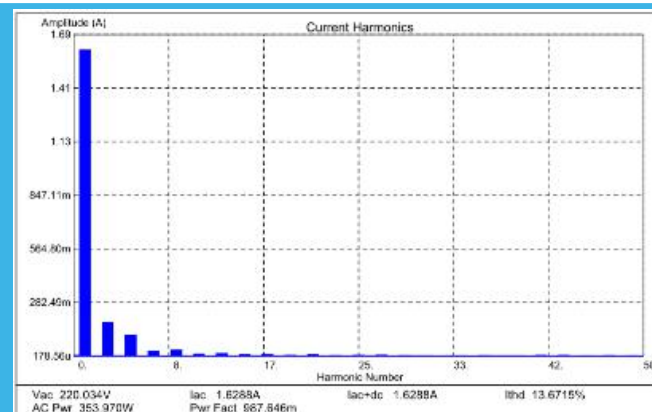
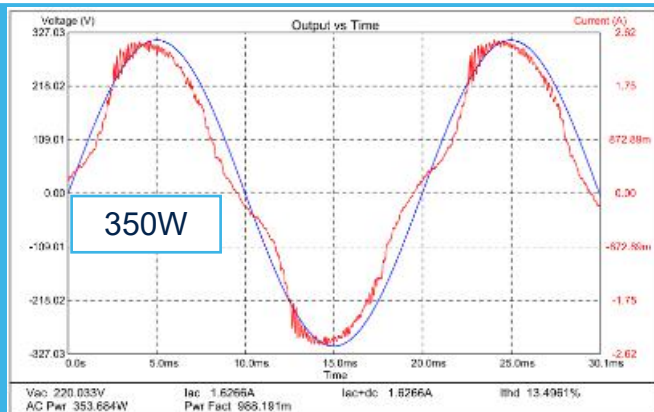
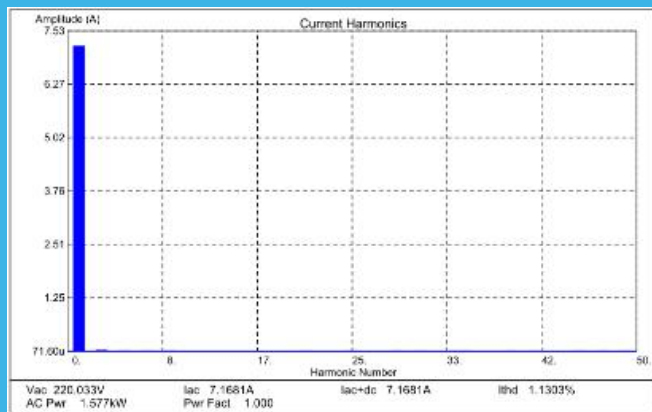
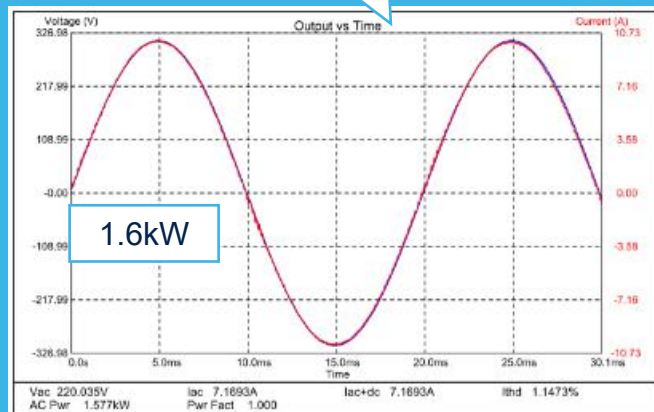
在IPM的IN/OUT上测量效率，使用ST MC SDK v4.3 的FOC驱动BLDC电机，
在空调上实际应用上测试所得。

ST的IPM的效率比竞争对手高0.15%~0.38%

** 有功功率 $P = \text{AVG}[u(n) \cdot i(n)]$

dPFC被
STM32F3
ST MC SDK v4.3驱动;
接电子负载

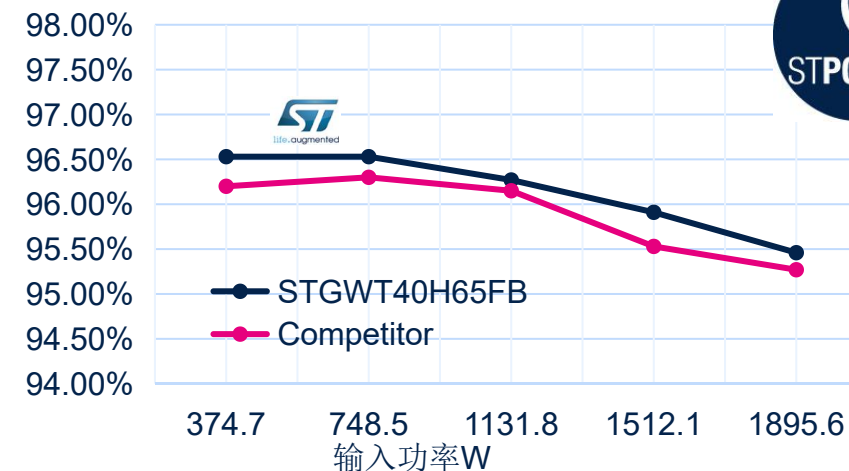
杰出的 PF, THD, @ 40kHz
Ton/Toff 延迟补偿
350uH/10A 电感



ST空调室外机Gen2 DPFC THD & PF

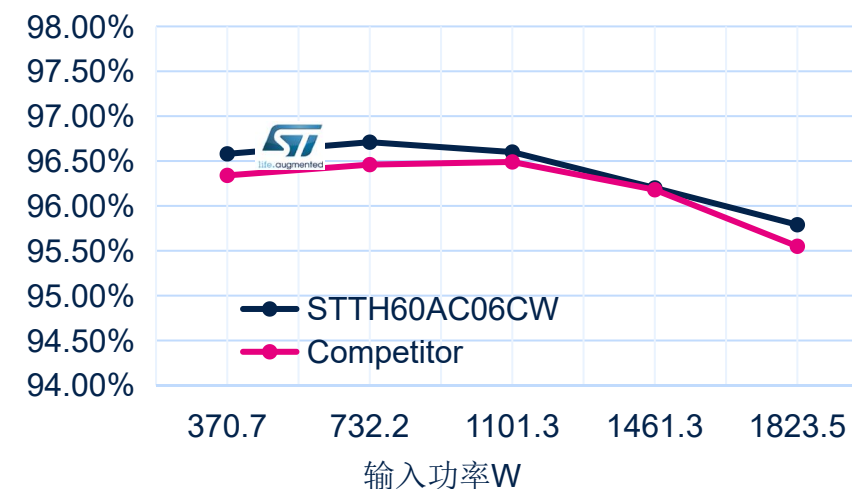
能效

转换效率



能效

转换效率





ST冰箱解决方案

250w / 300w（650L）

与传统单相感应电机相比，具有逆变器解决方案的三相BLDC电机压缩机已成为新的市场趋势。

得益于高性能和高价值的产品，**ST**解决方案脱颖而出

电机驱动电子部分可以与板子分开或合并使用。

对于不同的**MC**部分没有区别，**ST**解决方案都能正常工作

解决方案1：替代



解决方案2：替代 冰箱温度优化



解决方案3：一体化





ST refrigerator solutions

- 5款不同250W冰箱整体解决方案
- 所有器件基于ST全新技术

	1	2	3	4	5
SELLING POINT	IPM, highest integration	Discretes, high integration	Discretes	Discretes, high integration, full protection, higher performance (2shunt version), low code size	SIP Highest integration, full protection, higher performance (2shunt version) 125C
BOM IDEA	STM32F030K6T6 STGIPQ5C60T-HL VIPER16LD LD1117S33TR 1Shunt	STM32F030K6T6 L6390D L6388E x 2 STGD5H60DF x 6 VIPER16LD LD1117S33TR 1 Shunt	STM32F030K6T6 L6388E x 3 TSV912ID STGD5H60DF x 6 VIPER16LD LD1117S33TR 1Shunt	STM32F030F4P6 L6392D x 2 L6391D STGD5H60DF x 6 VIPER16LD LD1117S33TR 1Shunt (or 2+1 shunt)	STSPIN32F0601 TSV912ID STGD5H60DF x 6 VIPER16LD LD1117S33TR 1Shunt (or 2+1 shunt)
REF DES BOARD available from SZ MC Team					

NEW

MCU: F0或G0系列

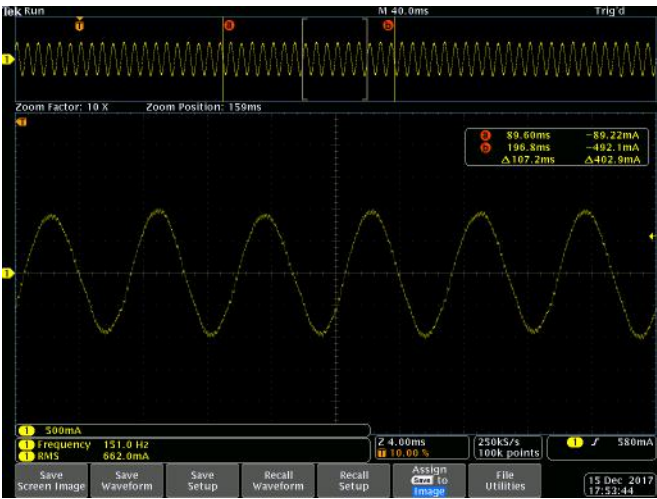
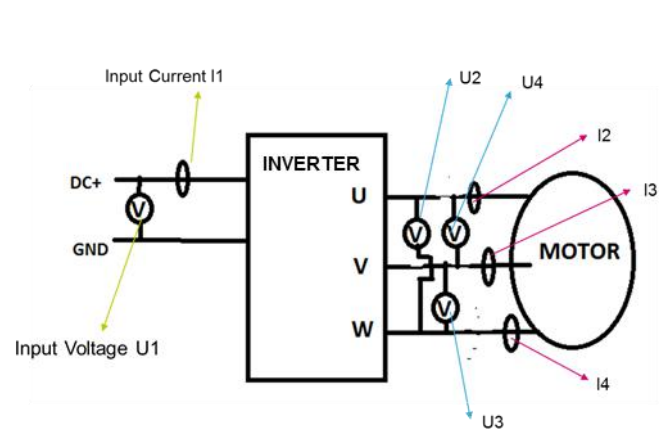
IGBT: STGD5H60DF 或
MOSFET: STD8N60DM2
或IPM: STGIPQ5C60T-HL

ST冰箱解决方案

能源效率

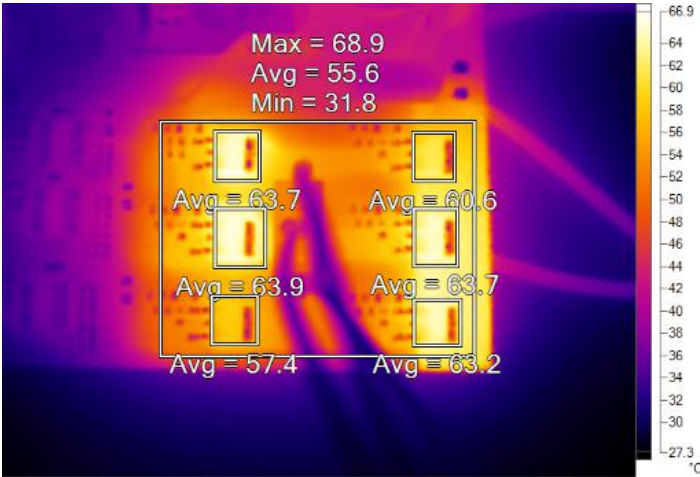
IGBT: STGD5H60DF

No.	Input Voltage	Phase current	Input Power	Output power	Efficiency(%)
3	320 V	0.68 A	197.76 W	194.24 W	98.22



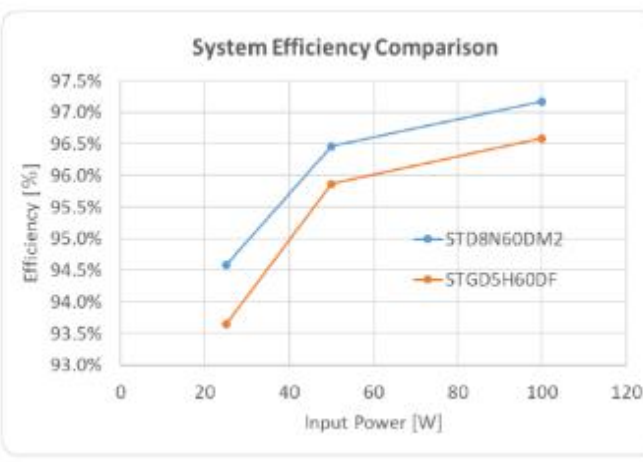
Temperature measurement at 200W steady state

Highest temperature: 68.9C
Average highest: 63.9C



STGD5H60DF & STD8N60DM2
Comparison at low power

Device	Input Power		
	25[W]	50 [W]	100 [W]
STD8N60DM2 [A]	94.58%	96.46%	97.17%
STGD5H60DFS [B]	93.65%	95.87%	96.59%
Difference [A]-[B]	0.94%	0.59%	0.58%





ST洗衣机硬件架构

500/700W IPM - ST的IGBT Trench Gate技术 – STM32G030K6/8

保护: OC, UVLO

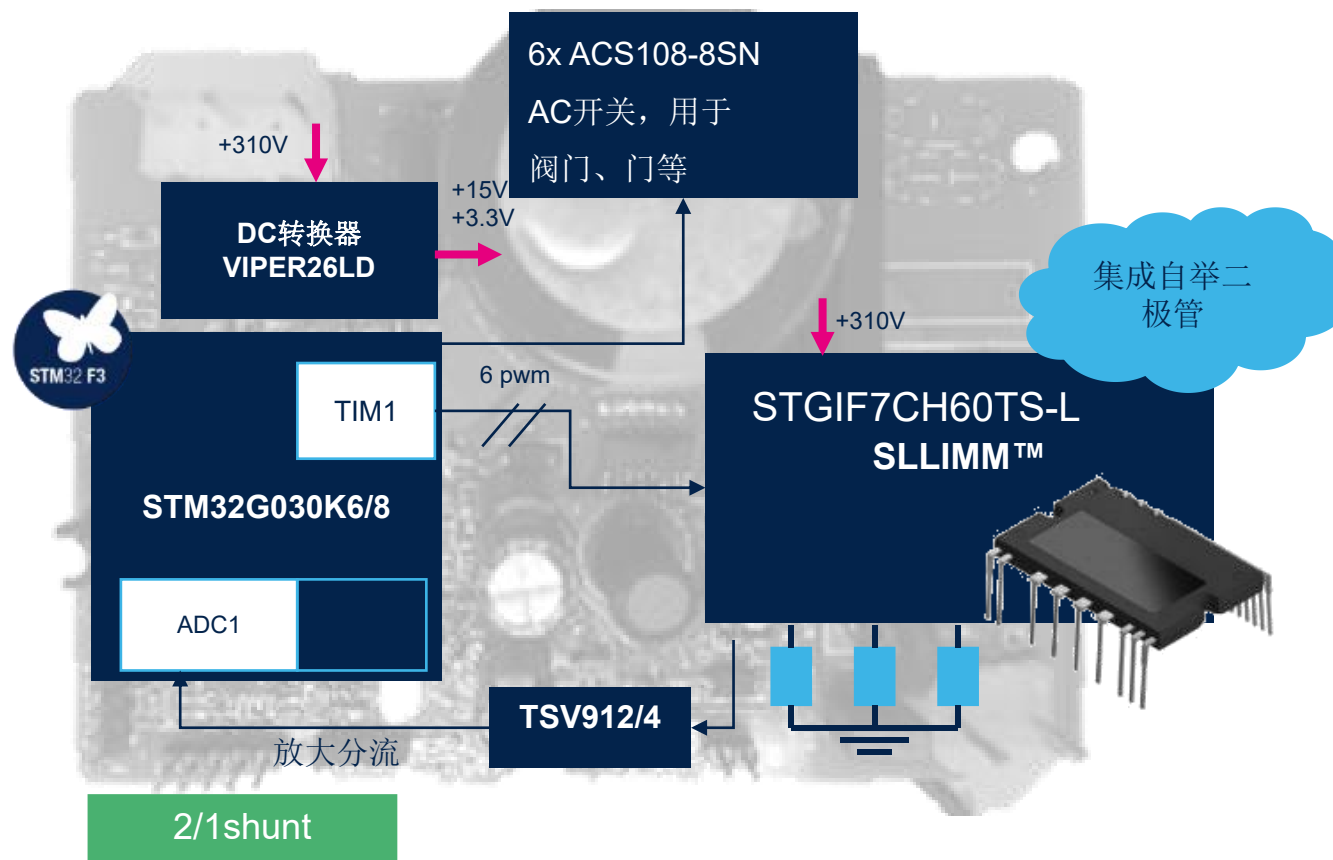
极大地减小了尺寸

开发时间短

高性能

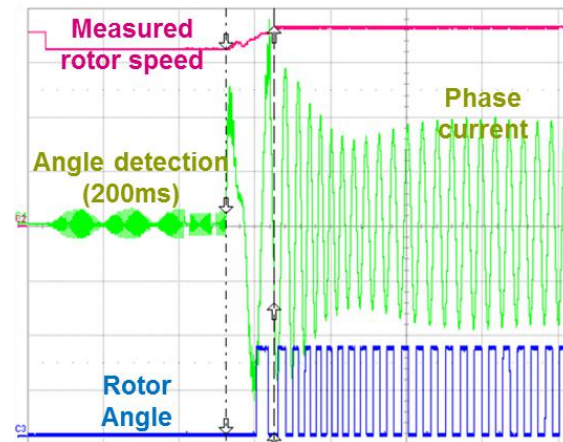
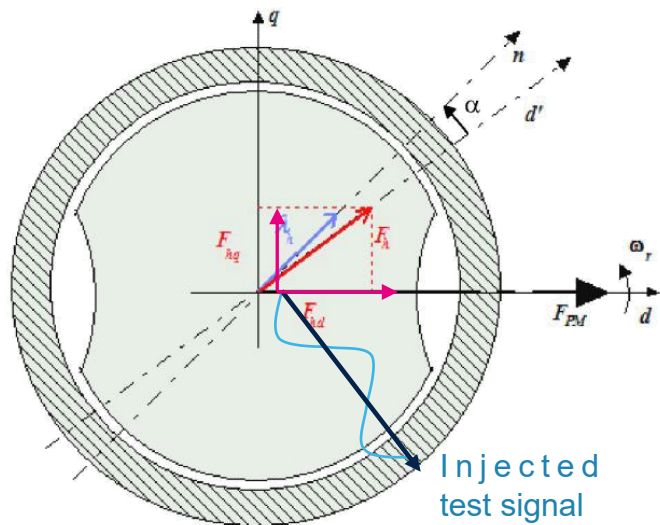
ST产品:

- STM32G030K6/8
- STGIF5CH60TS-L
- STGIF7CH60TS-L
- TSV912/4
- VIPER26LD
- ACS108-8SN



伺服驱动 高频注入无传感器算法

- ST 专利算法 “HFI”, 可以通过连续扫描I-PMSM电机的磁场的凸极特性, 在低速和零速时发挥出全部力矩.
- 在d-q坐标系一个假定的位置, 沿着假定的d'轴注入一个高频 (200Hz-1kHz) 正弦测试信号 (电压或电流)



- 产生力 F_h ; 由于转子的凸极特性, d轴方向上的磁阻 $\mathcal{R}_d$ 大于q轴方向上的磁阻 $\mathcal{R}_q$, 可以得到 F_{hd} (在实际d轴上的分量) 大于 F_{hq} (在实际q轴上的分量)
- 产生的结果是, 所产生的磁场 λ_h 方向和 F_h 的方向之间出现一个相位移角 α , 和一个小的分量 (λ_h 在q'轴上)
→ 磁偏差

(12) **United States Patent**
Costanzo et al.

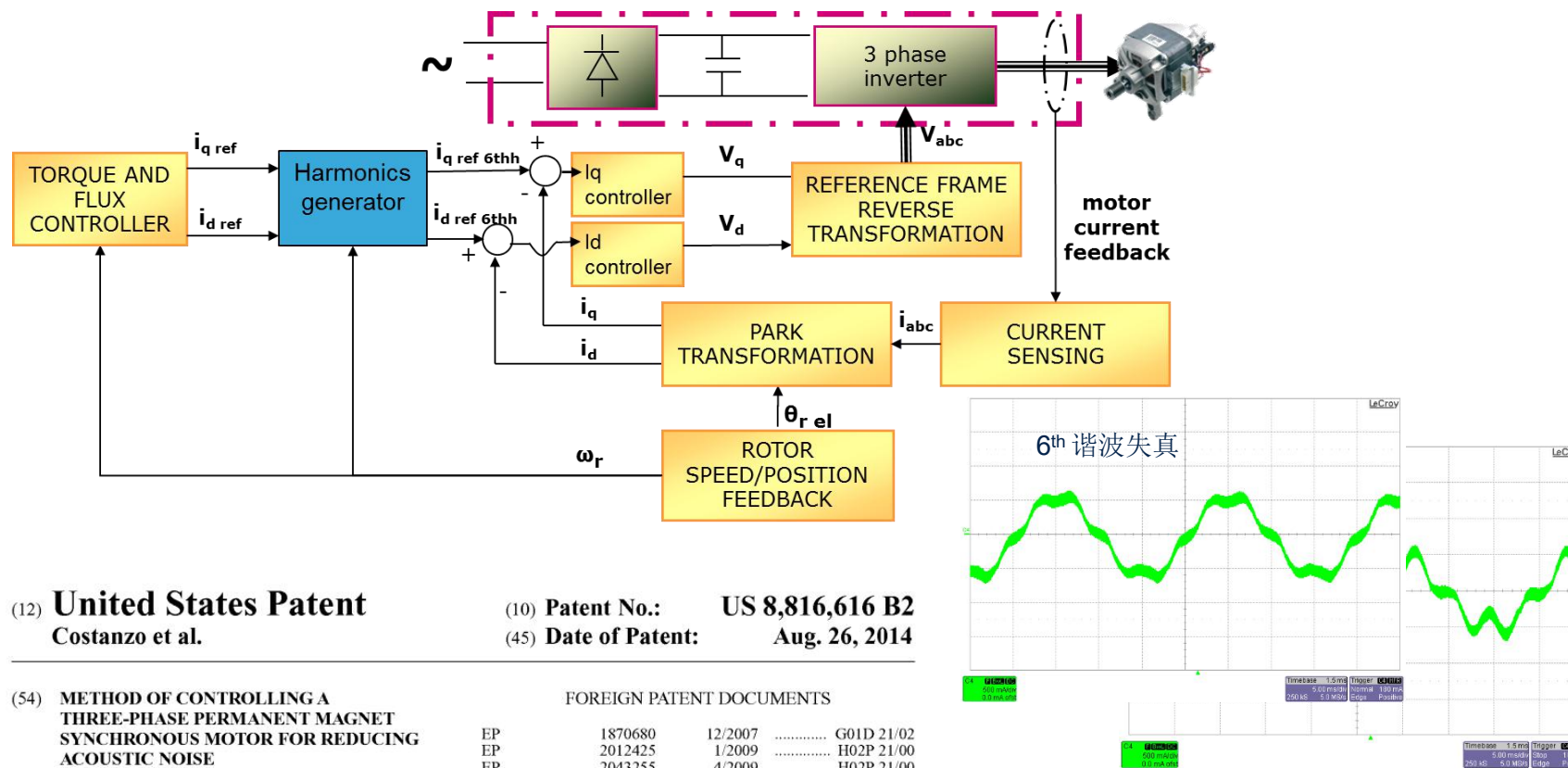
(10) **Patent No.:** US 9,325,263 B1
(45) **Date of Patent:** Apr. 26, 2016

(54) **SENSORLESS ROTOR ANGLE DETECTION**

SPEEDAM 2008, International Symposium on Power Electronics,

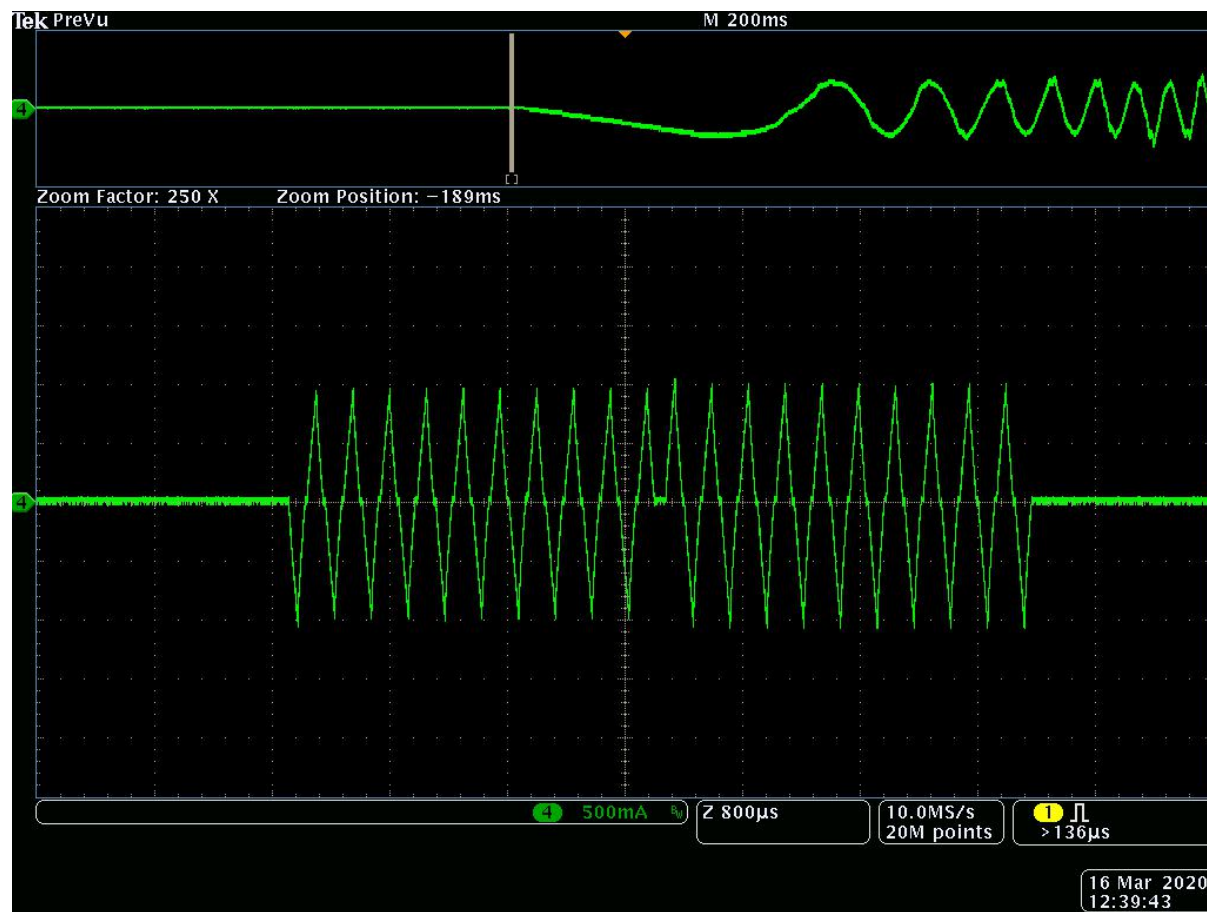
噪声减少 (风机 / 泵 / 压缩机 等)

- 为了减少噪声，可以注入五次和七次谐波参考量到电机相电流中来抵消六次谐波转矩波动
- 根据如下框图（ST 专利），在PARK变换参考系中，足以产生一个基于电机电气频率的六次谐波



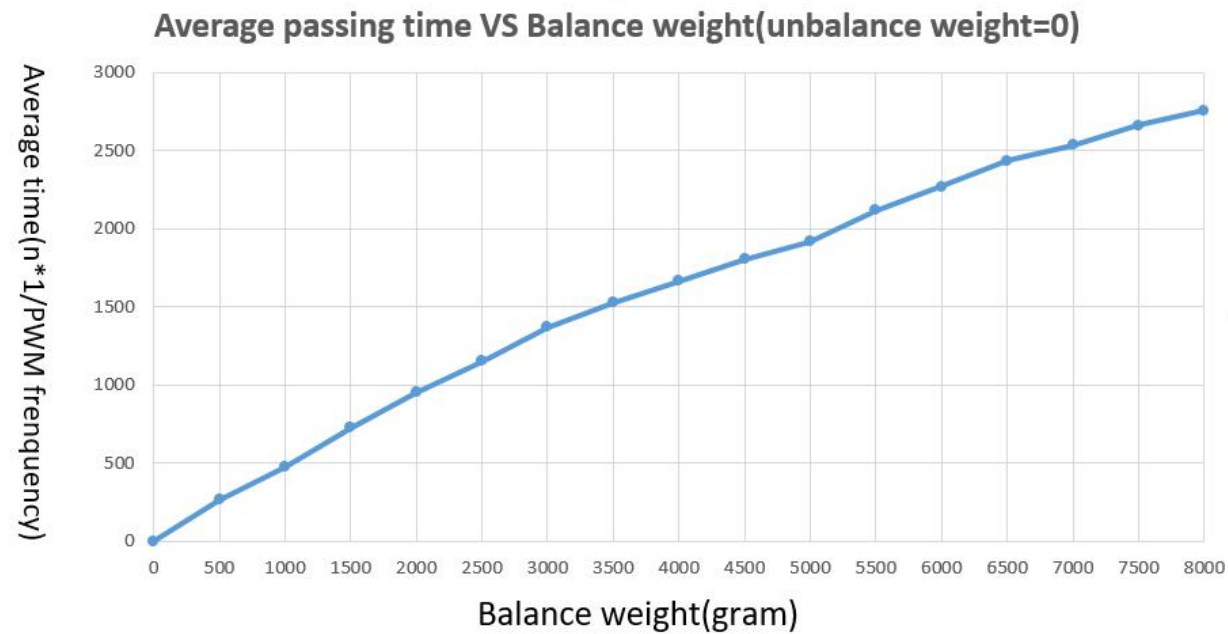
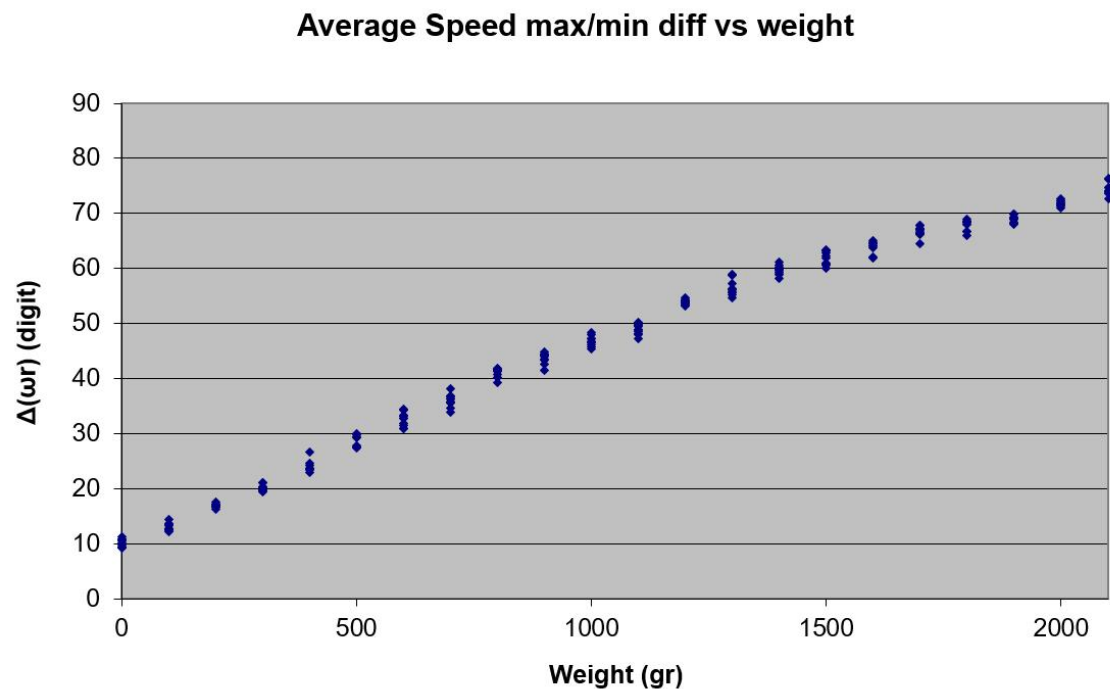
初始位置检测IAD (initial angle detection)

- 在静止和极低的速度下，几十毫秒可以得到转子的初始位置（角度），电机启动时不需要定位，不会出现逆转
- 应用场合（无感）：
 1. 启动时不允逆转、定位：吊扇、风扇、ATM等
 2. 快速启动：风扇类、制冷类（压缩机)等



滚筒洗衣机称重算法

- 不平衡负载检测精度达到200g
- 整体负载精度达到500g(不平衡负载 < 500g)



矢量和标量控制软件感应电机 软件概述

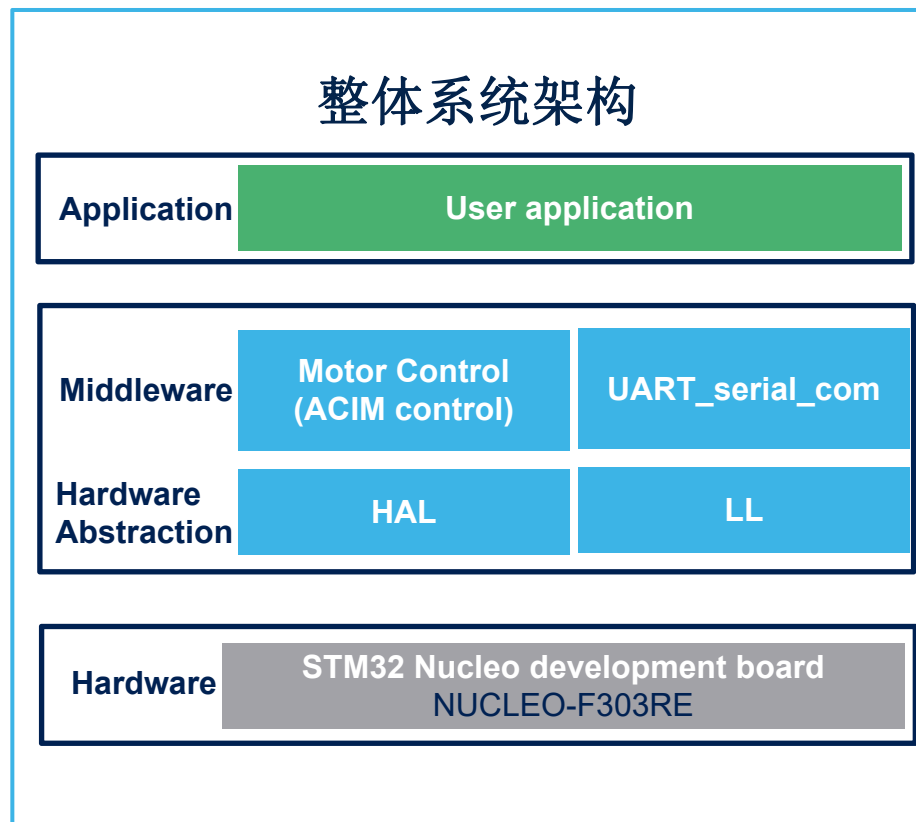
ACIM SDK 描述

- **ACIM SDK** 是一个基于交流感应电机开发应用的软件库. 这个库包含了一个驱动高压感应电机的应用实例, 基于**NUCLEO-F303RE** 和 **STEVAL-IPM10B** 的硬件评估平台(连接部分使用 **X-NUCLEO-IHM09M1**扩展板)
- 基于**X-CUBE-MCSDK**但不是其中的一部分

主要特征

- 基于**STM32 F3**的感应电机方案
- 高性能的矢量控制驱动方式
 - 带速度传感器的FOC控制 (I-FOC)
 - 自检测的FOC控制 (LSO-FOC)
- 高性价比的标量控制驱动方式
 - 开环 **V/f** 控制
 - 闭环 **V/f** 控制
- 使用**ST** 电机控制 **Workbench** 工具生成由应用调配的**API**函数来与电机驱动底层进行交互
- 提供图形化的软件配置器来配置感应电机的专用参数(**ACIM GUI**)

整体系统架构





电机控制硬件板

Control + Power

Eval/Nucleo + Power/Expansion

Control stages



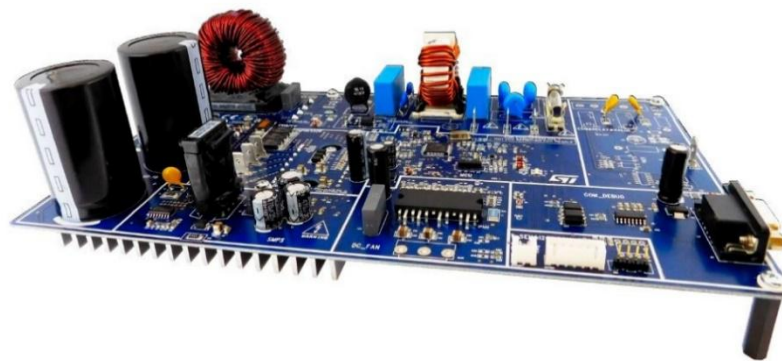
MC Connector



Power stages

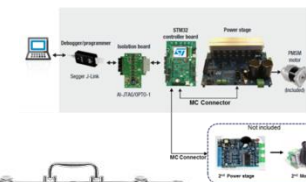


Inverter (Complete Drive)



STEVAL-CTM010V1

MC Kits



MC Connector

Test included

21 Power stage

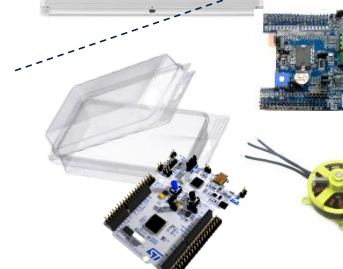
21 Motor

MC Connector

Test included

21 Power stage

21 Motor



P-NUCLEO-IHM001
IHM002 or IHM03

P-NUCLEO-IHM001 , IHM002或IHM03

Support: FOC & 6-step

- 低成本MC套件
 - 可以评估BLDC电机控制应用（高达36V, 1.4 A rms）的STM32
- 内容：
 - NUCLEO-F302R8
 - 基于STM32F302的微控制器板
 - X-NUCLEO-IHM07M1
 - 基于L6230的驱动器板
- BLDC电机



- 低成本MC套件
 - 可以评估BLDC电机控制应用（7~45V, 1.5 A rms）的STM32
- 内容：
 - NUCLEO-G431RB
 - 基于STM32G431的微控制器板
 - X-NUCLEO-IHM16M1
 - 基于STSPIN830的驱动器板
- BLDC电机





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