Application Note

How to Use the MCF831x to Solve Thermal and Quick Startup Challenges

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ABSTRACT

The MCF831x is an integrated code-free sensorless FOC device, which can be widely used in appliance systems, such as residential fans, ceiling fans, air purifiers, washer pumps, and suction motor in vacuum robot. The high level of integration and reduced development time due to being code-free of MCF831x brings great convenience to customers, but also brings some challenges to customers. This application note analyzes thermal and quick startup design challenges and proposed how to solve the challenges.

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1 Introduction

MCF831x is a code-free and sensorless field-oriented control (FOC) motor driver. MCF831x has a highly integrated architecture, incorporating three 1/2-H bridges with 40-V absolute maximum capability and a very low $Rds_{(ON)}$ of 95-mΩ (high-side + low-side) to enable high power drive capability. Current is sensed using an integrated current sensing circuit which eliminates the need for external sense resistors. An adjustable buck regulator and LDO generate the necessary voltage rails for the device and can be used to power external circuits. Due to their high level of integration, MCF831x devices can satisfy customers by driving their motors with only one chip. The EEPROM inside allows for stand-alone operation through power cycles.

Many customers feel that the flexibility of a code-free system is not sufficient, and that they cannot be programmed to achieve various desired functions like a microcontroller unit (MCU) can. However, MCF831x devices have many configuration registers which can be tuned to meet the needs of most customers. As mentioned at the beginning, for example, customers think that a high level of integration could lead to concerns about thermal performance, or they want to implement some specific functions, such as quick startup, fast braking, control speed precisely to achieve system-level requirements. These challenges can be controlled through the SCH, PCB layout, or EEPROM configuration.

The next step is with the thermals and the quick startup challenges, and discuss how to solve and optimize these challenges.

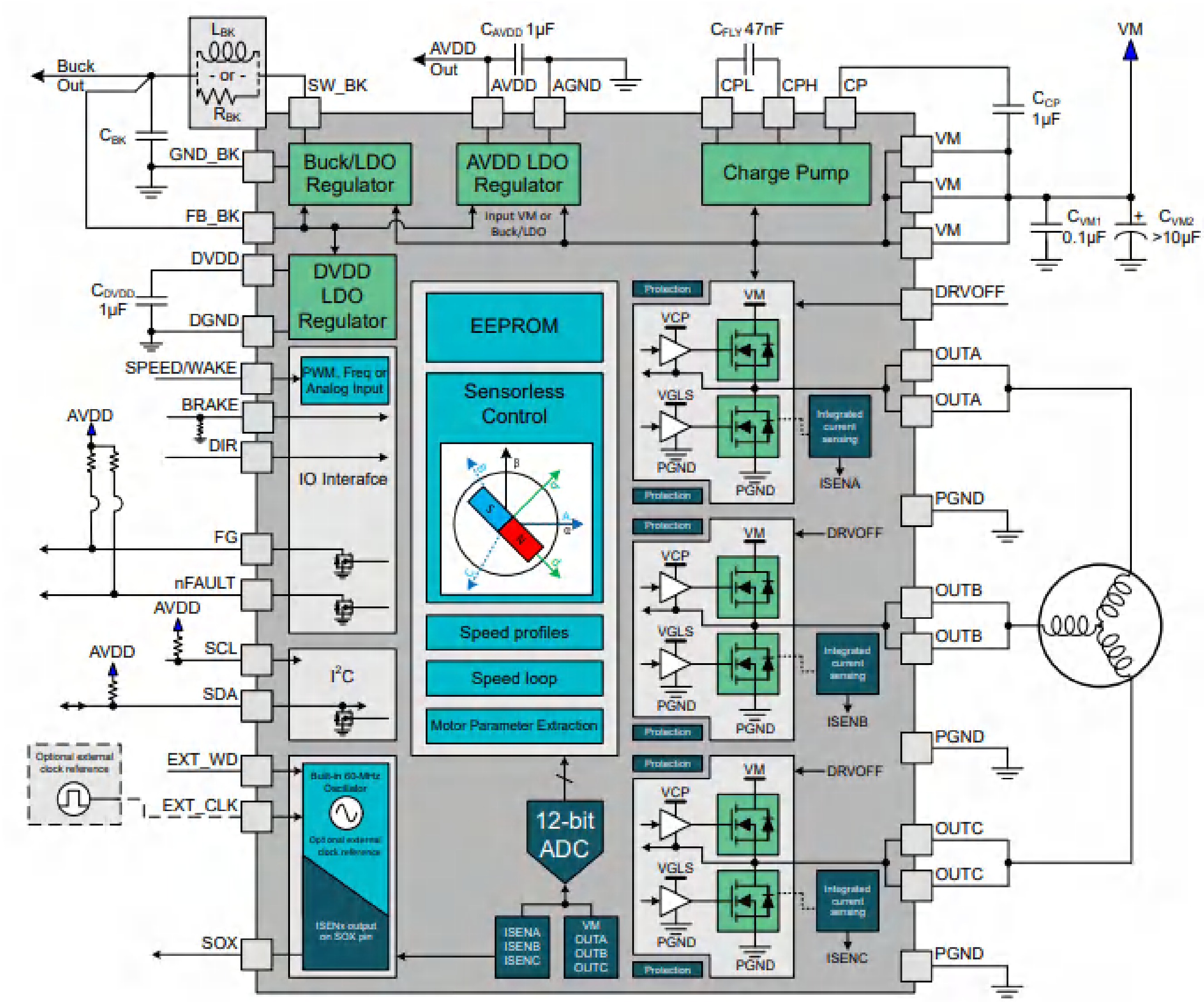

Figure 1-1. MCF831X Block Diagram

2 Design Challenge 1: Thermal Challenges

For single-chip integration designs, especially designs with integrated FETs, customers will worry about the thermal performance of the device. If the customer's application is relatively closed-off and there is no good heat dissipation, they will pay more attention to the thermal performance of the device. For example, for the application of ceiling fans and water pumps, the PCB is placed in the motor and is in a closed-off environment. So thermal design is a challenge for MCF831x, the following is the analysis for this challenge.

2.1 Causes of Thermal Issues

The first step is to analyze which factors can cause thermal challenges for MCF831x, starting with hardware, layout, and algorithm, respectively:

1. Hardware
   From the hardware point of view, the heat sources of MCF831x are mainly divided into the following points.
   - The conduction and switching loss of the internal MOSFET
   - The loss on the sampling resistor
   - The loss generated by the internal LDO/BUCK.
2. Algorithms
   Due to the FOC control method used by MCF831x, the efficiency is relatively high, but the PWM frequency, accuracy of current sampling, and accuracy of the observer's observation angle also affect the efficiency. Correct configuration is conducive to better thermal performance.
3. PCB Layout
   This is an easily overlooked factor in PCB design. In fact, the temperature difference between a good layout and a poor layout can be as high as 10°C during the test!

2.2 How to Solve Thermal Issues

2.2.1 Solve the Thermal Problem From Hardware

Since MCF831x devices are an integrated FET device, the conduction loss and turn-off loss of the Mosfet can inevitably affect the thermal performance. For most logarithm integrated FET motor control device, the $Rds_{(ON)}$ of HS+LS is 200moh approximately 300moh, but for MCF831x, $Rds_{(ON)}$ (HS+LS) is 95mohm, which can greatly reduce the conduction loss. And for MCF831x, the $Rds_{(ON)}$ of MOSFET lower bridge is used as the sampling resistor to further reduce the loss caused by the sampling resistor in the conventional drive.

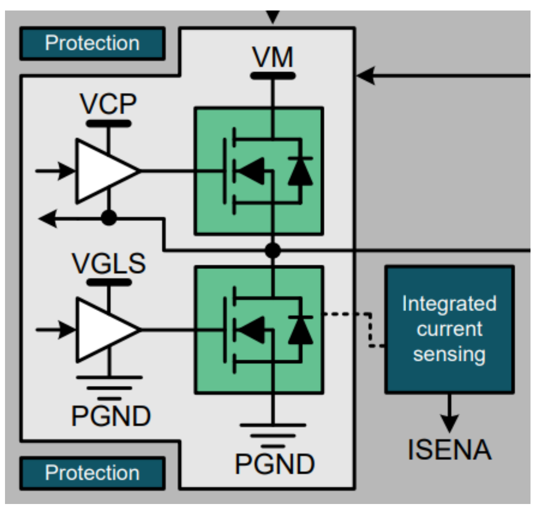

Figure 2-1. MCF831X Current Sensing Circuit

For the loss caused by the internal LDO and buck, view the power rail path inside the MCF831x from Figure 2-2.

From the perspective of efficiency, the best practice is to enable the internal buck or LDO, and set the Buck output to 3.3 V so that the loss caused by the LDO can reach the minimum value.

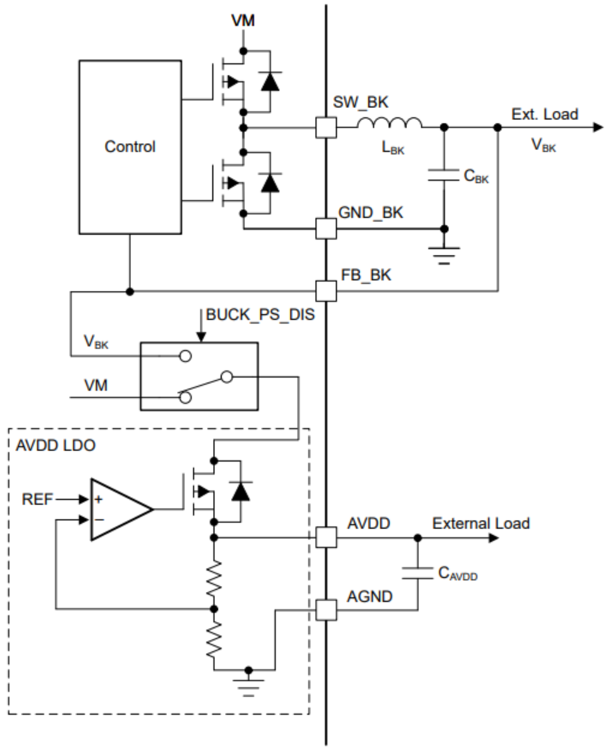

Figure 2-2. MCF831X Power Sequence

2.2.2 Solve the Thermal Problem from Algorithm

Although FOC is an efficient motor drive method, using these settings can further optimize the thermal performance:

1. Reduce the PWM frequency
2. Increase CSA gain
3. Turn on dead time compensation
4. Configuring the PWM modulation scheme to '*Discontinuous space vector PWM modulation*'.

Through the previous configuration, the Thermal performance can be improved from the perspective of the algorithm.

In general, Power losses in MCF831xA can be minimized by enabling buck regulator power sequencing, increasing the slew rate of the MOSFET switching, decreasing the PWM output frequency and configuring the PWM modulation scheme to *Discontinuous space vector PWM modulation*.

The following is test data to show the different algorithm techniques to improve thermals:

2.2.2.1 MCF8315 Test 1

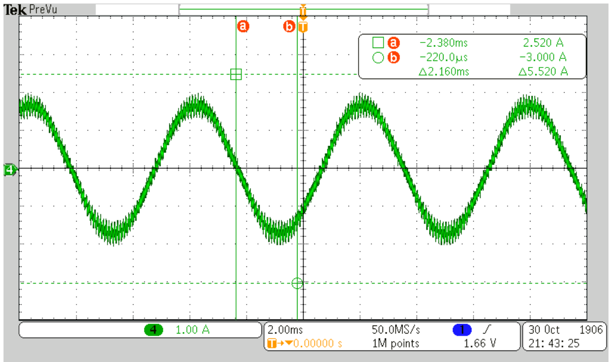

Figure 2-3. MCF8315 Current Waveform in Test 1 Configuration

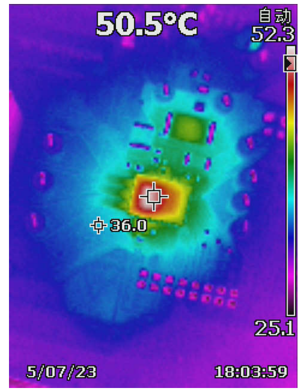

Figure 2-4. MCF8315 Thermal Image in Test 1 Configuration

- Slew Rate[SLEW_RATE]=200V/us
- PWM output frequency[PWM_FREQ_OUT]=15KHz
- PWM modulation scheme[PWM MODE]=Discontinuous Space Vector Modulation
- Dynamic Voltage adjust[DYNAMIC_VOLTAGE_GAIN_EN]=Enabled
- Dynamic CSA Gainb adjust[DYNAMIC_CSA_GAIN_EN] = Enabled
- Deadtime compensation[DEADTIME_COMP_EN] = Enabled

2.2.2.2 MCF8315 Test 2

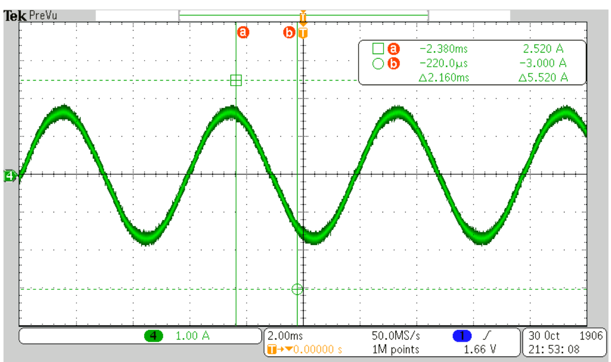

Figure 2-5. MCF8315 Current Waveform in Test 2 Configuration

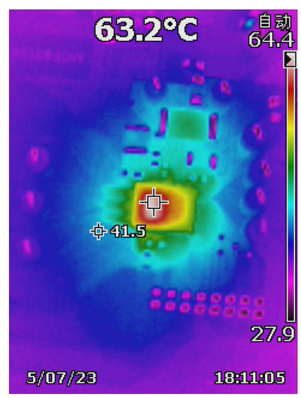

Figure 2-6. MCF8315 Thermal Image in Test 2 Configuration

- Slew Rate[SLEW_RATE]=25V/us
- PWM output frequency[PWM_FREQ_OUT]=30KHz
- PWM modulation scheme[PWM MODE]=Continuous Space Vector Modulation
- Dynamic Voltage adjust[DYNAMIC_VOLTAGE_GAIN_EN]=Disabled
- Dynamic CSA Gainb adjust[DYNAMIC_CSA_GAIN_EN] = Disabled
- Deadtime compensation[DEADTIME_COMP_EN] = Disabled

2.2.2.3 MCF8316 Test 1

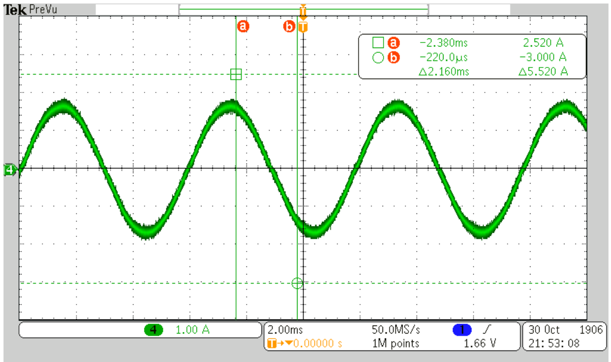

Figure 2-7. MCF8316 Current Waveform in Test 1 Configuration

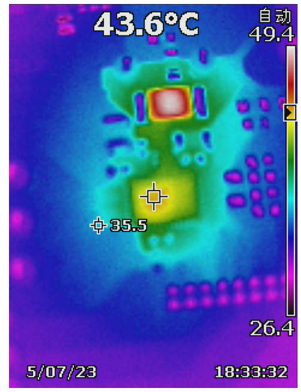

Figure 2-8. MCF8316 Thermal Imagein in test 1 configuration

- Slew Rate[SLEW_RATE]=200V/us
- PWM output frequency[PWM_FREQ_OUT]=15KHz
- PWM modulation scheme[PWM MODE]=Discontinuous Space Vector Modulation
- Dynamic Voltage adjust[DYNAMIC_VOLTAGE_GAIN_EN]=Enabled
- Dynamic CSA Gainb adjust[DYNAMIC_CSA_GAIN_EN] = Enabled
- Deadtime compensation[DEADTIME_COMP_EN] = Enabled

2.2.2.4 MCF8316 Test 2

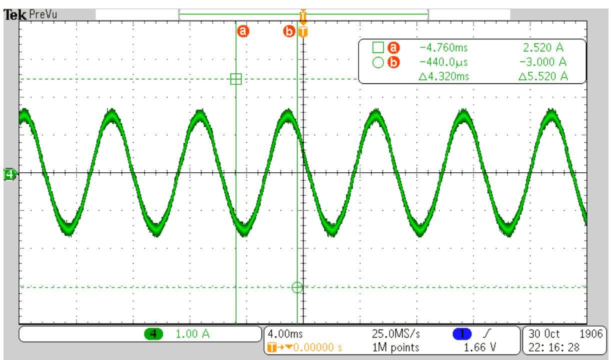

Figure 2-9. MCF8316 Current Waveform in Test 2 Configuration

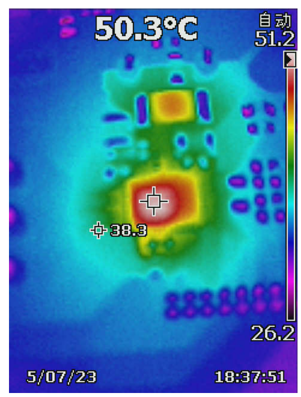

Figure 2-10. MCF8316 Thermal Image in Test 2 Configuration

- Slew Rate[SLEW_RATE]=25V/us
- PWM output frequency[PWM_FREQ_OUT]=30KHz
- PWM modulation scheme[PWM MODE]=Continuous Space Vector Modulation
- Dynamic Voltage adjust[DYNAMIC_VOLTAGE_GAIN_EN]=Disabled
- Dynamic CSA Gainb adjust[DYNAMIC_CSA_GAIN_EN] = Disabled
- Deadtime compensation[DEADTIME_COMP_EN] = Disabled

2.2.3 Solve the Thermal Challenges From PCB Layout

PCB layout also has a large impact on thermal performance. The following example shows that the temperature difference between a good layout and a poor layout can reach 15°C.

1. For systems without heat sinks, the heat dissipation on the chip can be improved with larger copper pours. Choose 2 oz. or more of copper thickness as much as possible, which greatly help heat dissipation. However, larger copper pours also mean more cost, so system requirements need to be accounted for when choosing copper thickness.
2. MCF831x has Thermal Pad, we need to use MCF831x as much as possible to dissipate the heat through the common. Note it is important to transfer heat to other PCB layers through as many vias as possible. (As shown in Figure 2-11, the PCB on the right is better).and open solder mask in the vias, which help transfer the heat of the MCF831x through the thermal pad to the copper on the PCB. And use multi-layer boards as much as possible to provide more heat dissipation area.

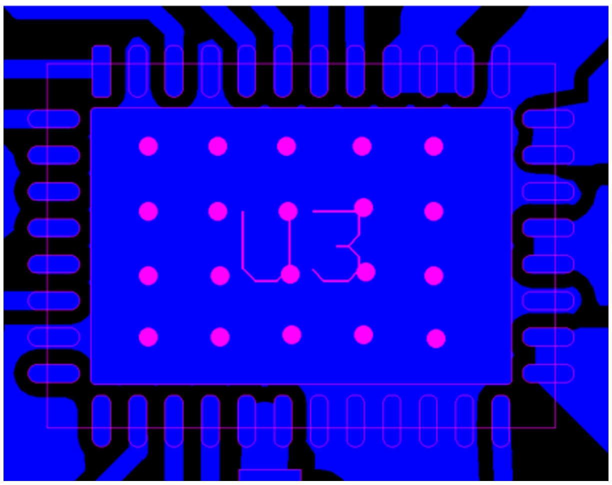

Figure 2-11. MCF831X PCB With Few Vias

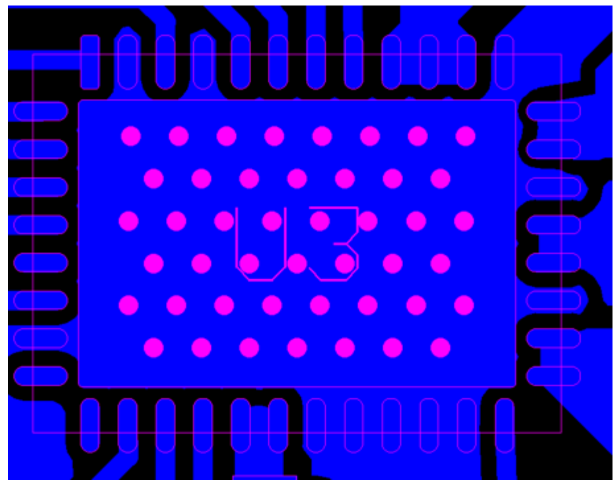

Figure 2-12. MCF831X PCB With More Vias

In the Top layer, connect the pins with the Thermal pad as much as possible to transfer the heat out through them.

Thermal pad connection to a solid copper plane is an important requirement to create a heat dissipation path. For heat to flow away from the device, the copper plane must be continuous. Connect thermal pads to other areas on the board. The best practice is to include wide exit paths in the copper fill. Create a wide, high-surface-area plane below the driver. If these planes are interrupted, the heat dissipation path is shrunk, thereby increasing the thermal resistance. An increase in thermal resistance produces a greater temperature difference between the thermal pad and a wider surface area on the same plane.

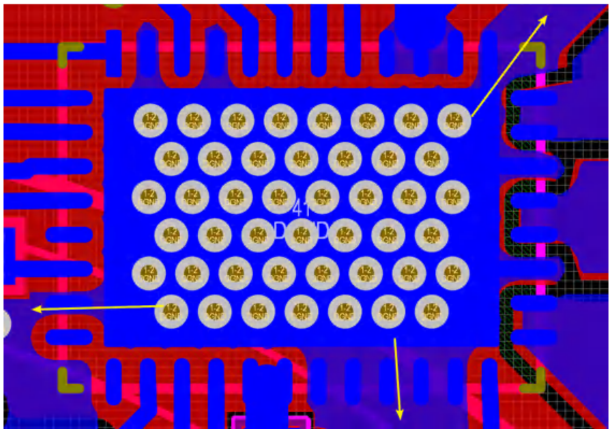

Figure 2-13. MCF831X Heat Dissipation Path (Bottom Layer)

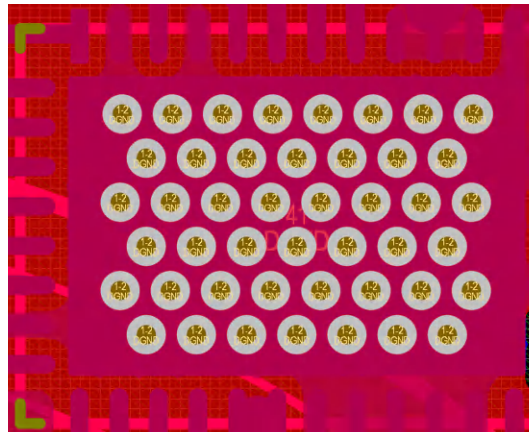

Figure 2-14. MCF831X Heat Dissipation Path (Top Layer)

Figure 2-15 shows a thermal simulation; optimizing the PCB layout reduces the overall temperature rise by 15°C.

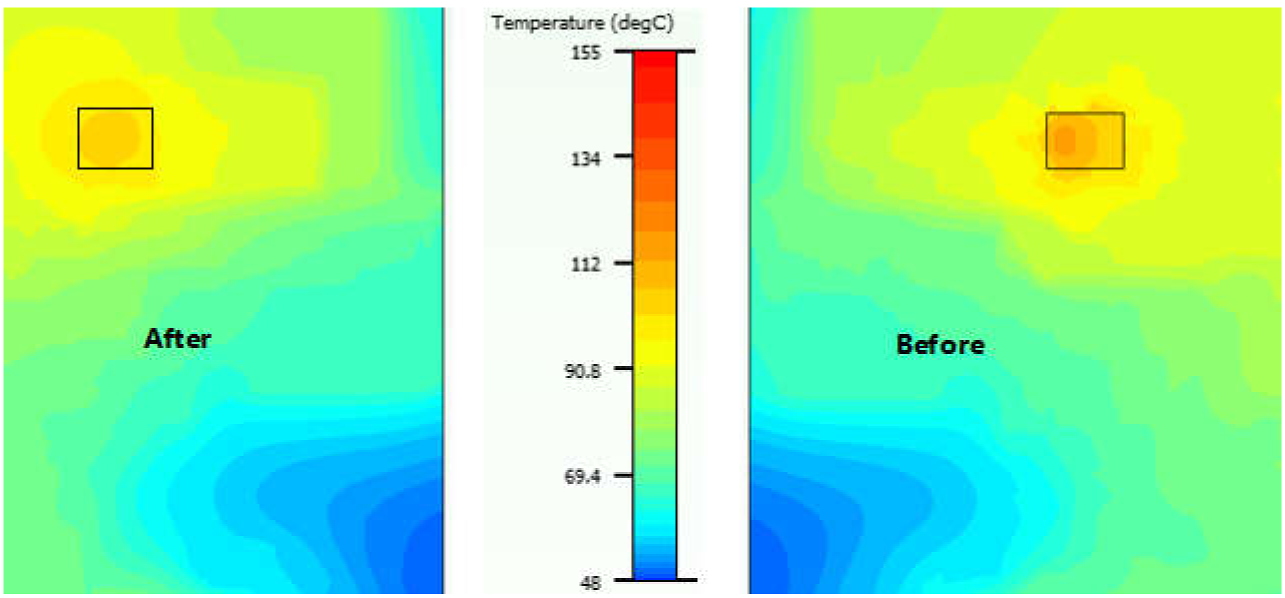

Figure 2-15. Thermal Simulation for MCX831X Layout

3 Design Challenge 2: Quick Startup

For single-chip integration solutions, especially code-free designs, customers can worry whether they can meet system-specific requirements, such as a quick startup. In some applications such as fans, customers need to reach 2000RPM within 1s to bring customers a better experience. With water pumps, customers need to be able to quickly start out of water. For this challenge, the customer's requirements are fulfilled through the many registers available to configure in MCF831x devices.

3.1 Causes of Quick Startup Issues

For sensorless FOC, since MCF831x has no sensors to provide position information, the startup is divided into the following steps: motor start-up , open loop, and hand off, close loop. Dividing the startup is because there is a complicated start-up process, but to make sure that each start-up link is executed correctly, so the start-up speed is not as fast as that of a brushed motor. However, we can take the time to optimize each step at the algorithm level and minimize the start-up time to be as short as possible.

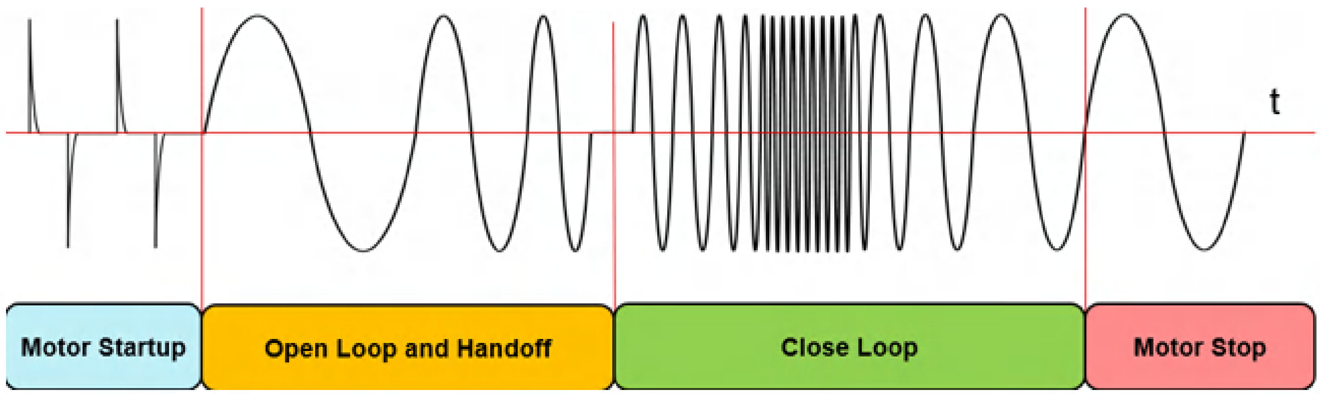

Figure 3-1. MCF831X Startup Process

3.2 How to Solve Quick Startup Issues

We need to adjust the speed in each step to the designed for value separately to obtain the fastest startup speed which is still successful.

1. Motor startup

   The fastest choice for Motor startup is IPD, but IPD also introduces other potential problems, such as audible noise. We need to carefully adjust Increase IPD current threshold [IPD_CURR_THR] to rated current of the motor. For more introduction to starting, please refer to: *MCF8316A -Design Challenges and Solution* application note.
2. Open Loop and Hand off

   The parameters that affect startup at this stage are the open loop acceleration coefficient A1 [OL_ACC_A1] and open loop acceleration coefficient A2 [OL_ACC_A2]. We can increase the acceleration as much as possible, knowing that some protections are triggered, such as Lock – Limit.

   For the Handoff stage, we can use automatic conversion, select Minimum BEMF for hand off [AUTO_HANDOFF_MIN_BEMF] to 0 mV, and turn on automatic switching,or switch manually, and choose a location that can make sure switching to the closed loop and quickly switch to the closed loop.
3. Closed Loop

   The key parameters are closed Loop acceleration when the estimator is not yet fully aligned and closed loop acceleration rate [CL_ACC]. We need to increase them as much as possible without losing sync and triggering overcurrent.

   For the previous part, we need to make adjustments carefully to make sure that the motor does not lose synchronization/trigger protection. Remember, a quick startup is only meaningful if the startup is successful.

The following is an example configuration and the result :

Example 1:

Motor Parameter:

Motor phase resistance [Motor_RES]:1.15Ω

Motor phase inductance [Motor_IND]:0.96Ω

Motor BMEF Constant [Motor_BEMF_CONST] : 23 mv/Hz

Motor Start up option[MTR_STARTUP]:Align

Align or Slow first cycle current limit[ALIGN_OR_SLOW_CUR RENT_ILIMIT]: 0.15625A

Align or Slow first cycle ramp rate[ALIGN_SLOW_RAMP_RATE] : 1 A/s

Align time[ALIGN_TIME]:50ms

Open Loop current limit[OL_ILIMIT_CONFIG] : 0.3125A

Open Loop acceleration coefficient A1[OL_ACC_A1]:2.5Hz/s

Open Loop acceleration coefficient A2[OL_ACC_A2] :2.5Hz/s2

Open to close loop threshold[OPN_CL_HANDOFF_THR]: 8%

Close Loop acceleration when estimator is not yet fully aligned[CL_SLOW_ACC]: 10 Hz/s

Closed Loop acceleration rate[CL_ACC]:40Hz/s

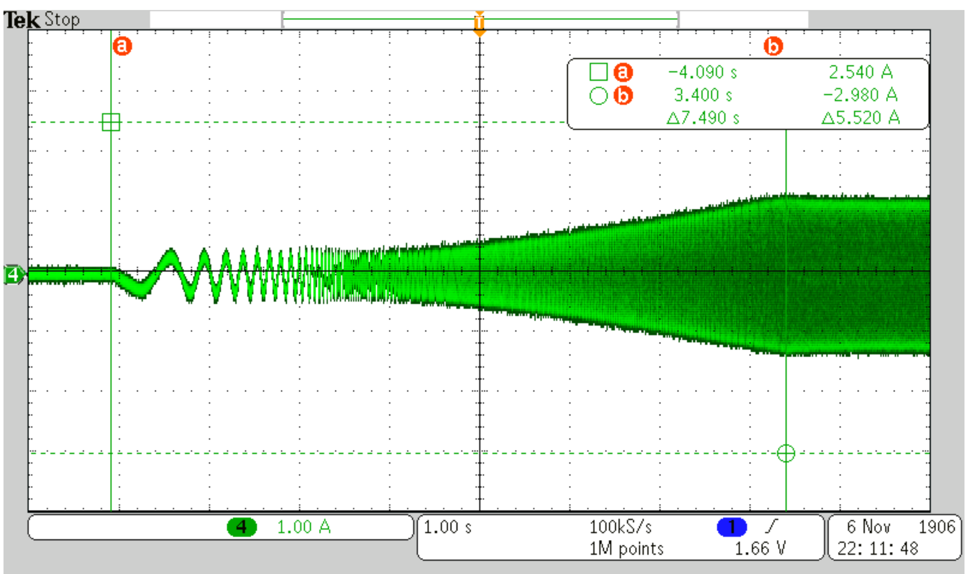

Figure 3-2. Example 1 Current Waveform

Example 2:

Motor Start up option[MTR_STARTUP]:IPD

IPD current limit[IPD_CURR_THR] : 0.3125A

IPD Clock value[IPD_CLK_FREQ]: 1000 Hz

IPD Repeating time[IPD_REPEAT]:1 times

IPD High Resolution Enable[IPD_HIGH_RESOLUTION _EN]: Enable

Open Loop current limit[OL_ILIMIT_CONFIG] : 0.3125A

Open Loop acceleration coefficient A1[OL_ACC_A1]:10Hz/s

Open Loop acceleration coefficient A2[OL_ACC_A2]:80Hz/s2

Auto Handoff from open to close loop[AUTO_HANDOFF_EN]: Enabled

Close Loop acceleration when estimator is not yet fully aligned[CL_SLOW_ACC] : 100 Hz/s

Closed Loop acceleration rate[CL_ACC]: 300 Hz/s

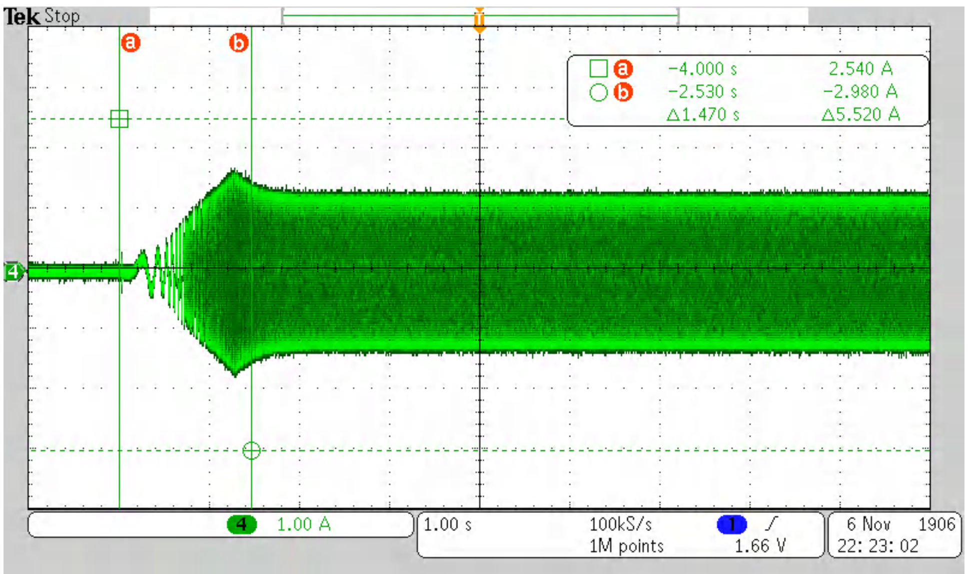

Figure 3-3. Example 2 Current Waveform

Figure 3-3 shows that after parameter optimization, we can run the motor at 3000RPM within 1.5S.

4 Summary

This application note provides a detailed analysis of Thermal challenge and Quick Startup in MCF831X applications, and provides designs to Thermal challenge and Quick startup.

This application note provides an analysis of the hardware, algorithm, and layout for the Thermal challenge, proposes specific optimization designs, and provides analysis of thermal simulation results. For Quick Startup, the startup steps are analyzed in detail, and an optimized design is proposed and test results are provided.

4.1 Acknowledgment

Acknowledging Jayden Li for contributing some data for this application note.

5 References

- Texas Instruments, *Reed Switch Replacement with TI's Hall-Effect and Linear 3D Hall-Effect Sensors*, application note.
- Texas Instruments, *MCF8316A Sensorless Field Oriented Control (FOC) Integrated FET BLDC Driver*, data sheet.
- Texas Instruments, *MCF8316A Tuning Guide*, user's guide.
- Texas Instruments, *How to Design a Thermally-Efficient Integrated BLDC Motor Drive PCB*, application note.
- Texas Instruments, *MCF8316A -Design Challenges and Solution*, application note.

6 Revision History

Changes from Revision * (September 2023) to Revision A (October 2023)	Page
• Updated the numbering format for tables, figures, and cross-references throughout the document	1
• Added *residential fans, ceiling fans, air purifiers, washer pumps, and suction motor in vacuum robot*	1