Application Note
Operating Time of MSPM0 Powered by a Capacitor

![Texas Instruments logo]

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ABSTRACT

MSPM0 is typically powered from a 3.3V DC supply with decoupling capacitors. A common situation here is that when the DC power supply is unstable, it is easy to cause the MCU to stop working. To overcome this problem, an external capacitors can be chosen to maintain the power supply. Therefore, it is important to select the appropriate capacitor to in the event of a power failure. In this application note, the operating time of different operating currents and capacitor values is tested, and a simple model relationship between the three is obtained, which, under the known normal operating current, can help to choose the appropriate supply capacitor.

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1 Relationship Between I, C and t

Under certain conditions, capacitors can be used to power the MCU. But how long the capacitor can last, and what factors are related to the maintenance time. Here, the relationship between hold-up time and supply capacitance is given in Equation 1.

$$t = \frac{C \times \left(V_{\text{work}}^2 - V_{\text{cutoff}}^2 \right)}{I \times \left(V_{\text{work}} + V_{\text{cutoff}} \right)}$$ (1)

where,

t is the device operating maintenance time,

C represents the capacitance value, which is chosen by the user,

V_{work} is the normal operating voltage of the MCU, that is, the starting voltage of the capacitor power supply,

V_{cutoff} is the cut-off voltage at which the MCU stops working. As the power supply is below Brown-out reset voltage level 0 (BOR0-), the device will discharge slowly because only Power-on Reset (POR), Bandgap (BG) and BOR are active, which means the MCU can not work normally. According to device-specific data sheet, the maximum of $V_{\text{BOR0-}}$ is 1.61V, *I* is the constant operating current of MCU, which depends on the operating mode of the MCU and the operation of the peripherals. In addition to direct measurement, here we provide two ways. One is to consult the device-specific data sheet, which includes the operating current of different peripherals under different operating conditions. The other is to directly use the EnergyTrace™ provided by TI to calculate the operating current of the device.

According to Equation 1, the correspondence between *t* and *C* can be obtained with the known operating current. This provides a reference to select the appropriate capacitor.

2 Application Scenarios
*   With unstable power supply, the capacitor can be used as a backup power supply to support the MCU to operate for a certain period of time until the power supply is restored, or to provide a certain amount of time to save the MCU's data.
*   In the printer cartridge, the three-wire system cannot meet the MCU communication needs, as UART need two wires, VCC one and Ground one. Here we can multiplex the VCC end with the TXD of the UART. While TXD is high, it can charge capacitor as well as supply power for MCU. And as TXD goes to LOW, a diode can separate the VCC terminal of TXD from the MCU, and rely on the capacitor to power the MCU.

3 Derivation of Formulas

First of all, the premise of the formula is that the operating current of the MCU is consistent at different operating voltages. So the operating current at different voltages was tested. The starting voltage was 3.3V, and the supply voltage was gradually reduced, during which the change in operating current was measured by the ammeter connected in series between the power supply and the MCU. Here comes the result. Figure 3-1 shows that the current remains the same while MCU is working normally (VCC is greater than 1.6V). Besides, the device operates in run0, sleep0, and stop0 modes with currents of 1.55mA, 0.93mA, and 0.32mA, respectively, which conform to the device-specific data sheet specifications.
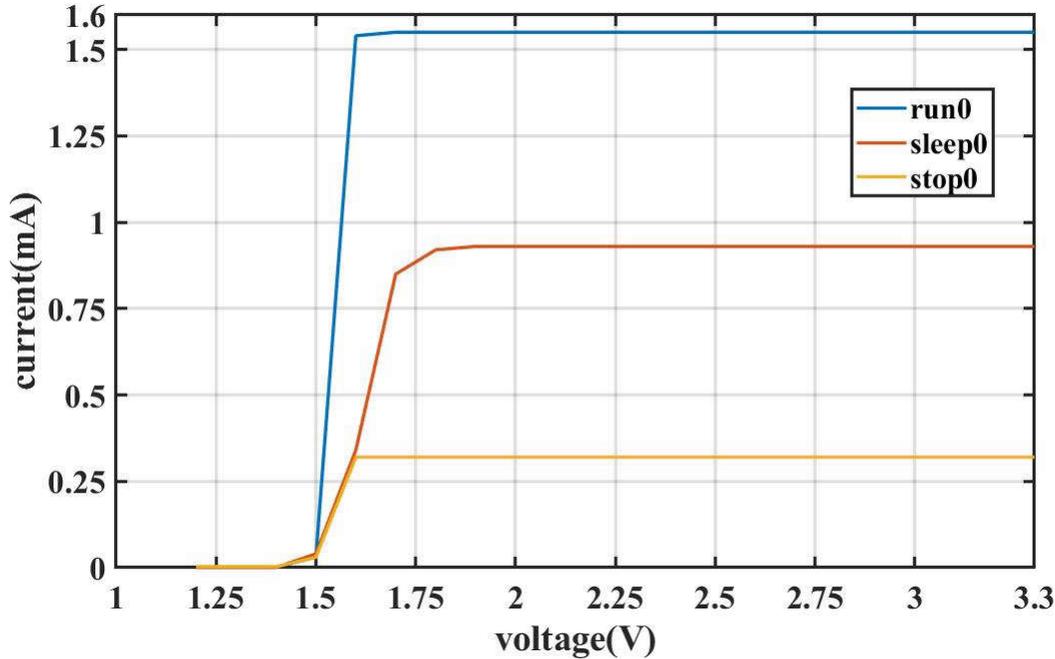
Figure 3-1. Diagram of the Operating Current of the MCU vs. Supply Voltage

Based on constant current, the MCU maintains the required energy for:

$$E = 0.5 \times It \times (V_{\text{work}} + V_{\text{cutoff}})$$ (2)

And from a capacitance point of view, the reduced energy can be expressed as:

$$E = 0.5 \times C \times \left(V_{\text{work}}^2 - V_{\text{cutoff}}^2\right)$$ (3)

The energy of the capacitor is used to supply the normal operation of the MCU, so Equation 2 and Equation 3 can be connected to further obtain the equipment operating maintenance time *t* which is expressed as Equation 1.

4 Experimental Verification
4.1 Test Environment Setup

To verify the feasibility of Equation 1, it is necessary to first test the normal operation time of the MCU with a 3.3V capacitor supply. Thus, the following method is adopted. As shown in Figure 4-1, by changing the state of MCU1's PA25 pin, the power-down condition of MCU2 is simulated. Specifically, when the PA25 output is high, MCU2 supplies power normally, while charging the capacitor to reach 3.3V. When PA25 is in a high-impedance state, it can be considered that the power supply is disconnected at this time. Thus, MCU2 relies on capacitor for power.

High output
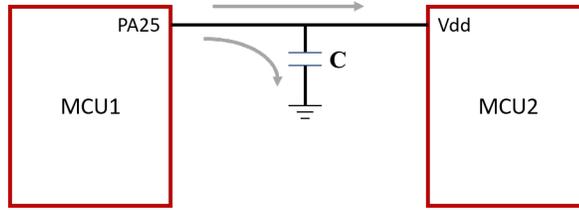
Hi-Z output
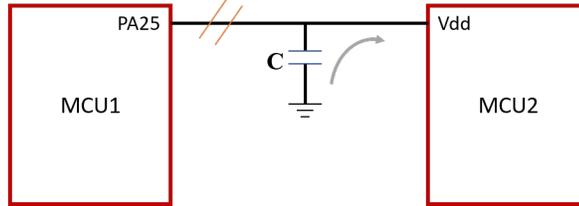
Figure 4-1. Hardware Connection Diagram

For MSPM0L1306 Launchpad connection:

- Connect the USB cable from micro-USB connector on the MCU1 to the PC. As for
- Connect the MCU1 PA25 and MCU2 3.3V Power pins.
- Co-ground connection.
- Unplug the jumper cap in MCU2.

According to PCB of Launchpad, the C4 and C5(shown in the green box in the Figure 4-2) ,as decoupling capacitors, is connected the ground and VCC. In this way, C4 and C5 meet the connection requirements of the power supply capacitor shown in Figure 4-1. In the following tests, simply change the capacitance sizes of C4 and C5 to simulate different capacitor supply situations.
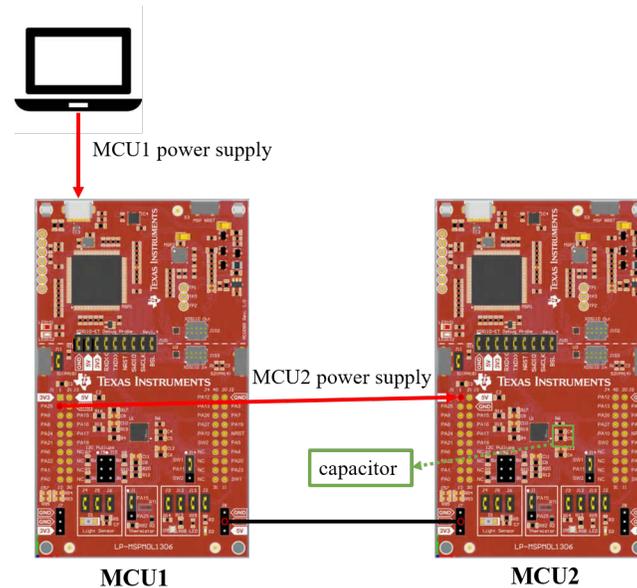
Figure 4-2. LP- MSPM0L1306 Hardware Board Connection

For software set up, MCU2 is running *while(1)* code in different operation mode.

MCU1 is set up every 2s period to change itsstate through Timer. Besides, another GPIO is toggled at the same time to provide the capacitor charge and discharge start signal.

4.2 The Result of Experiment

The Figure 4-3 is the experimental result of operating current of MCU run in run0 mode. Both EnergyTrace and direct measurement are all show the run0 current is around 1.5mA.

EnergyTrace result：
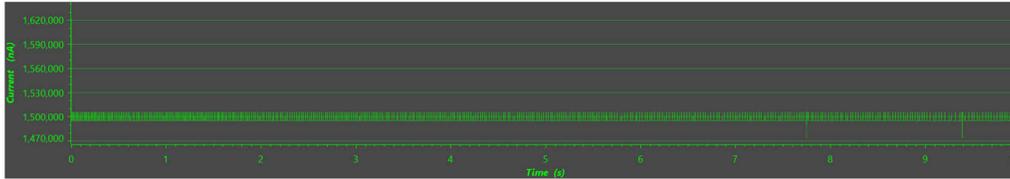
Actual current value：

Figure 4-3. Operating Current of MCU in run0 Mode

The power supply of MCU2 was monitored using a logic analyzer and the results are shown in the figure. Channel 1 identifies the GPIO port, and when set to low, MCU1's GPIO is in a high-impedance condition, and MCU2 is powered only by capacitors. Channel 2 is the voltage on both sides of the capacitor, which is the supply voltage of the MCU. As can be seen from the figure, when the voltage drops from 3.3 V to 1.61 V, the duration is about 2.66ms, which is close to the theoretical calculation of 2.56 ms.
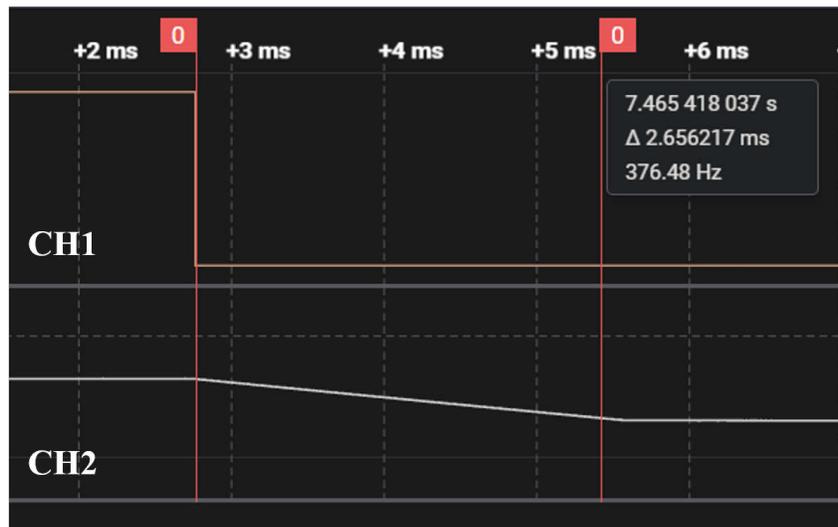
Figure 4-4. The Operating Time of MCU in run0 Mode

Table 4-1 shows a table summary of the working time of different capacitors in each operating mode.

Table 4-1. Summary of Test Result in Different Operating Mode

Capacitors		STOP0 I=0.32mA		RUN0 I=1.5mA	
Type	Capacitance	Measurement Time	Calculation Time	Measurement Time	Calculation Time
Tantalum capacitors TAJA225K010RNJ	2.2µF	12.01ms	11.55ms	2.66ms	2.56ms
Tantalum capacitors TAJA475K010RNJ	4.7µF	23.29ms	24.68ms	5.10ms	5.48ms
Tantalum capacitors TAJA106K010RNJ	10µF	56.72ms	56.00ms	12.33ms	11.67ms
Electrolytic capacitors ASLI-D37	10µF	53.79ms	56.00ms	11.35ms	11.67ms
Electrolytic capacitors ASLI-E13	40µF	278.95ms	263.2ms	57.59ms	54.33ms
Ceramic capacitors GRM21BR61A	2µF	12.15ms	11.2ms	12.15ms	11.20ms
Ceramic capacitors GRM21BR61A	4.3µF	22.76ms	22.58ms	4.88ms	5.02ms
Ceramic capacitors GRM21BR61A	6.3µF	34.08ms	33.08ms	7.30ms	7.35ms

As can be seen from the table, the theoretical calculated value is basically consistent with the actual measurement. The reasons for some errors can be: capacitance error value; There is a leakage condition in the meter pen; Cable resistance, energy dissipation, etc. But, the error is within a reasonable range.

5 Notes

The selection of capacitors requires attention to the following points.

1. Pay attention to the error of the capacitor's own capacitance.

   Capacitor material. Here is the example of GRM188R60J106ME47(muRata, MLCC, X5R)'s DC Bias characteristics. When DC increases, the capacitance of the ceramic capacitor has a large error. In this example, when the dc bias voltage is 3.3 V, the capacitance error can reach 50%.
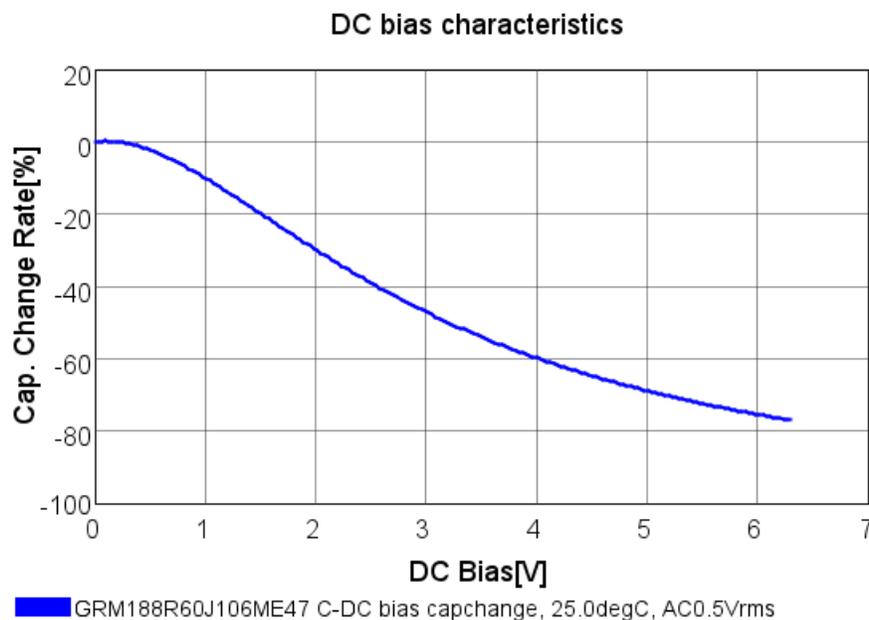
Figure 5-1. GRM188R60J106ME47's DC Bias Characteristics.

For further validation, the capacitor was used to test the power supply of the MCU. The result is shown in Figure 5-2. The operating current is 1.5 mA, and the supply capacitance is 41.1 µF. But the operating time is 29.95 ms, which is far lower than the theoretical calculation of 45.76 ms.

As a result, when using capacitors, it's necessary to pay attention to the characteristics of the capacitor itself.
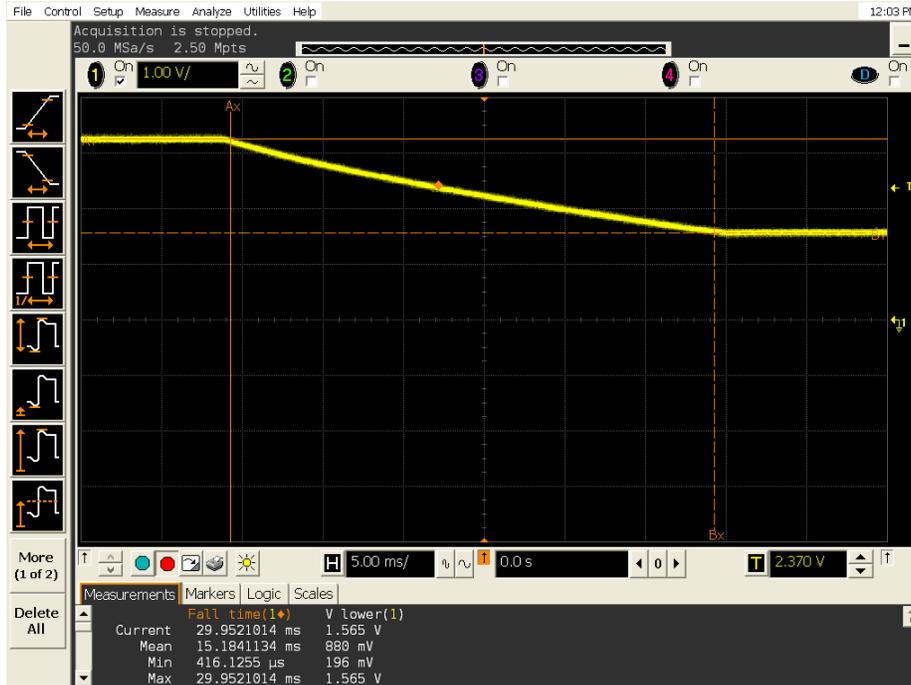
Figure 5-2. The Operating Time of MCU Powered by GRM188R60J106ME47

Size of capacitor. The size of the package affects the thickness of the dielectric, and in the case of applying the same voltage, especially for ceramic capacitors with ferroelectric materials as dielectric materials, the smaller the thickness of the dielectric, the greater the internal electric field stress, which can lead to the large error of capacity. As a result, capacitors with stable capacitance values are preferred in this model. Therefore, please test the capacitance value with a tool such as a multimeter between uses

2. Pay attention to the effect of leakage.

Capacitor material. Compared to capacitors of other materials, electrolytic capacitors have a larger leakage current. When the MCU is in standby0 mode, that is, the operating current is close to 1.5µA, the effect of leakage current becomes obvious. Therefore, when the operating current is small, the leakage current needs to be considered.

PCB layout. It should be noted that there will be equivalent resistance in the trace between the power supply capacitor and the MCU power pin, which will lose the energy of part of the capacitor, so this factor needs to be taken into account when the capacitor selection capacity is small.

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