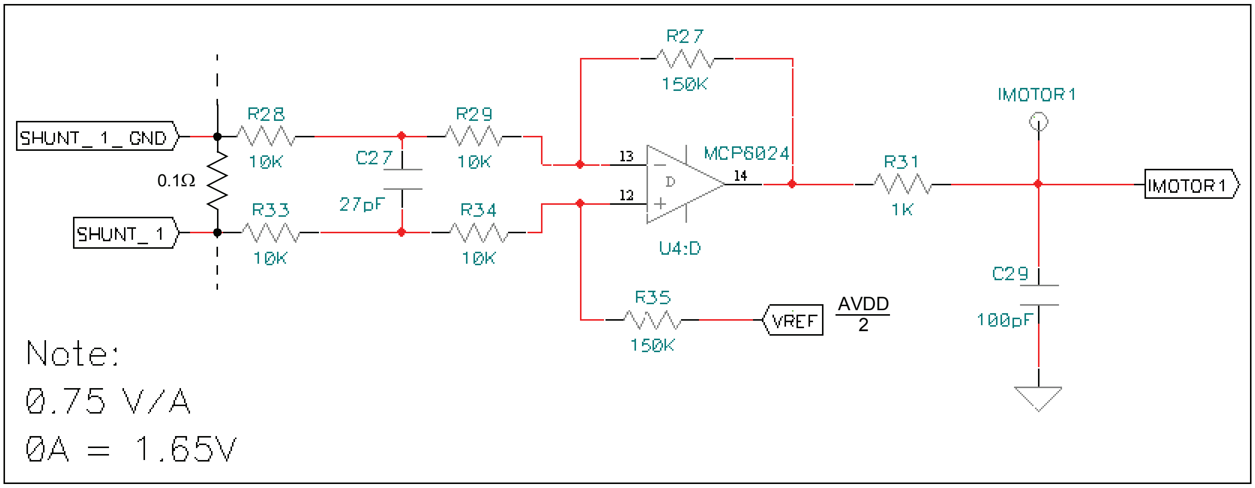
AN1307 Tuning Guide

1.1 SETTING HARDWARE PARAMETERS

Each of the two motor winding currents is read with the aid of a shunt resistor located at the bottom of a H-bridge. The default shunt value is $R_{66} = 0.1\Omega$.

The shunt voltage signals are passed through filters and an amplifier scales it into the ADC range of 0V to 3.3V. The default gain is 0.75V/A. This means a current of ±2.2A can be measured by the ADC in this configuration.

FIGURE 1-1: ADC CURRENT MEASUREMENT



The formula shown in Equation 1-1 is a simplified version of the complete formula and is only valid when $R_{28} = R_{29} = R_{33} = R_{34}$ and $R_{27} = R_{35}$. If changes to the amplifier gain are needed, use the formula in Equation 1-1 to calculate R_{27} corresponding to the desired gain, then replace both R_{27} and R_{35} with the calculated resistor value. Make the same changes for R_{39} and R_{45} (for winding 2).

EQUATION 1-1: CURRENT MEASUREMENT

$$Gain_{ADC} = R_{shunt} \cdot \frac{R_{27}}{R_{28} + R_{29}}$$

For example, if a gain of 0.5V/A is desired, in Equation 1-1 we find $R_{27} = R_{35} = 100\ K\Omega$. The maximum ADC current would be 3.3/(2 * Gain) = 3.3A as indicated by Equation 1-2.

EQUATION 1-2: MAXIMUM ADC CURRENT

$$CurrentMax_{ADC} = \frac{3.3}{2 \cdot Gain_{ADC}}$$

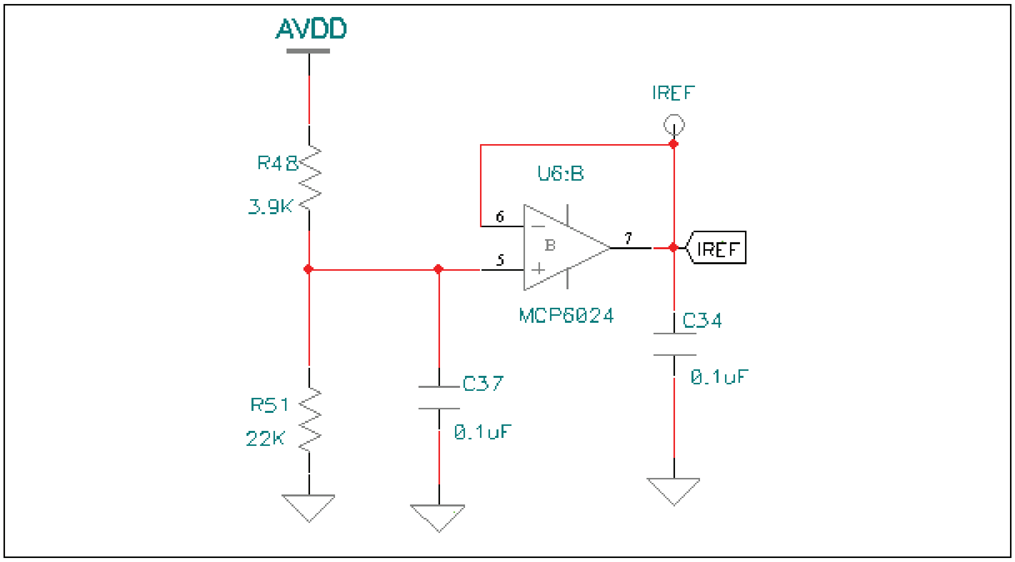
The MCSM features a hardware fault current detection. The limit is set by default at 1.5A . The formula used to calculate the limit is shown in Equation 1-3:

EQUATION 1-3: FAULT CURRENT

$$I_{Fault} = \frac{3.3}{Gain_{ADC}} \cdot \left(\frac{R_{51}}{R_{48} + R_{51}} - \frac{1}{2} \right)$$

The 1/2 is due to the reference of the amplifier, which is AVDD/2.

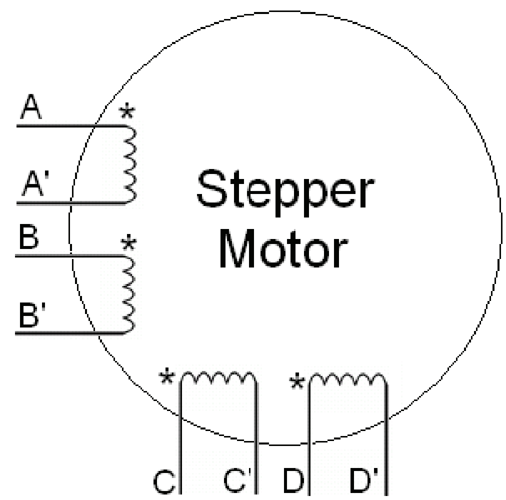
FIGURE 1-2: FAULT CURRENT SCHEMATIC



If a different Fault current is desired, change R_{48} and R_{51} based on Equation 1-3.

1.2 MOTOR CONNECTIONS

FIGURE 1-3: TWO-PHASE EIGHT-WIRE STEPPER MOTOR



Considering an eight-wire two-phase stepper motor, as shown in Figure 1-3, all possible motor connections to the MCSM board are listed in Table 1-1:

TABLE 1-1: MOTOR CONNECTIONS

J8 Pin Number	J8 Pin Name	Bipolar series	Bipolar parallel	Bipolar half winding	Unipolar
1	NC	A'+B	—	B	—
2	M1	A	A+B	A	A
3	DC+	—	—	B'	A'+B
4	M2	B'	A'+B'	A'	B'
5	M3	C	C+D	C	C
6	DC+	—	—	D	C'+D
7	M4	D'	C'+D'	C'	D'
8	NC	C'+D	—	D'	—

1.3 MOTOR PARAMETERS IN SOFTWARE

Motor parameters are usually available as they are provided by the manufacturer. Considering the unipolar parameters as a starting point, Table 1-2 shows how the parameters change for all possible motor configurations.

TABLE 1-2: MOTOR PARAMETERS BASED ON CONNECTION

Connection	Current	Resistance	Inductance
Unipolar	i	R	L
Bipolar series	0.7 * i	2 * R	4 * L
Bipolar parallel	1.4 * i	R / 2	L
Bipolar half winding	i	R	L

The unipolar ratings for the 42HS03 Motor are: i = 1A, R = 4.6Ω, L = 0.004H. The motor is connected in a bipolar parallel configuration, as it is the most commonly used configuration. Example 1-1 shows the correct software setting for this configuration.

EXAMPLE 1-1: BIPOLAR PARALLEL MOTOR CONFIGURATION IN `UserParams.h`

```
/******************** Motor parameters *************************/

#define UNIPOLAR                 0         //set to 0 for Bipolar motor configuration
                                           //set to 1 for Unipolar motor configuration
#define MOTOR_R                  2.3       //(Ohm) motor resistance
#define MOTOR_L                  0.004     //(H)   motor  inductance
#define DC_BUS                   24.0      //(V)   board power supply

#define RATED_MOTOR_CURRENT      1.4       //(A)   maximum desired motor current
```

1.4 PI CONTROLLER PARAMETERS

PI controller parameters are calculated from the motor parameters, more exactly from the winding resistance and inductance. The only adjustable parameter is the PI controller gain, which is set by the define value `PI_GAIN`. It is calculated based on the desired rise time of the winding current.

EQUATION 1-4: PI CONTROLLER GAIN

$$PI\_GAIN = \frac{12}{DC\_BUS \cdot Rise_{time}}$$

The default value is calculated at a bus voltage of 24V and a rise time of 70 microseconds. The rise time was chosen as low as possible in order to have a fast reaction time, but large enough to avoid oscillations. Since the output voltage becomes saturated often, a high gain is also needed to allow large voltage jumps in short times. When returning from saturation, the PI voltage output should reach the steady state value as fast as possible, with minimal or no overshoot. If large overshoot is present, reduce the gain. A gain value of 70 µs is approximately three times larger than the PI controller rate (25 µs) and approximately the same as one half step at 2000 RPM motor speed.

EQUATION 1-5: DEFAULT PI CONTROLLER GAIN

$$PI\_GAIN = G_0 = \frac{12}{24 \cdot 70\mu s} = 7143$$

In this tuning procedure, a PI controller with anti-windup is implemented. At low speeds, a low anti-windup gain is used. At high speeds, phase advance is needed so a high anti-windup gain is set. The variables in Example 1-2 control the behavior of the anti-windup controller:

EXAMPLE 1-2: PI CONTROLLER DEFINES

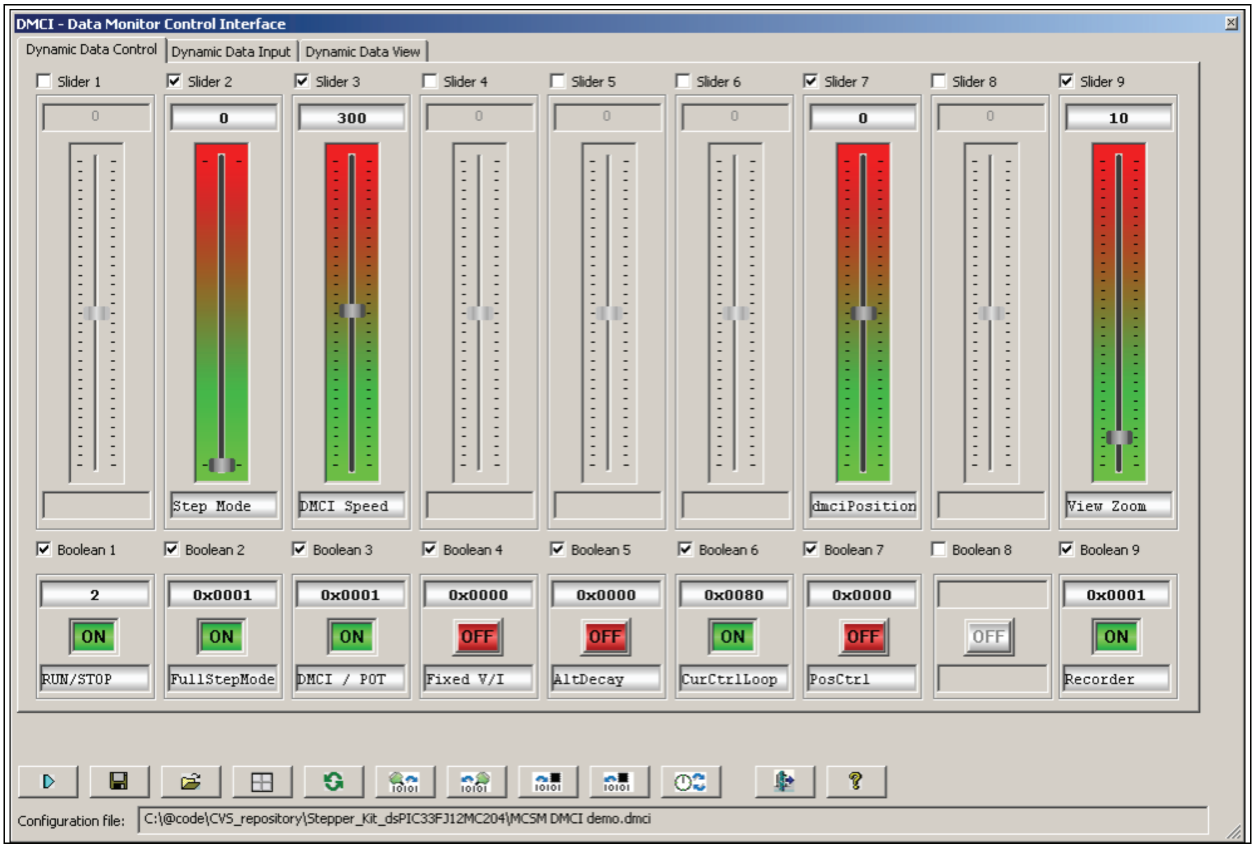
```
//PI controller defines
#define PI_GAIN                 7143   //PI gain value
#define PI_ANTI_WINDUP_GAIN1    500    //Anti-Windup gain value at low speeds
#define PI_ANTI_WINDUP_GAIN2    17000  //Anti-Windup gain at high speeds
#define PI_ANTI_WINDUP_SPEED    2800   //speed at which the anti-windup gain is changed
```

For values of the variable `speedOut` below the `PI_ANTI_WINDUP_SPEED`, the variable `PI_ANTI_WINDUP_GAIN1` is used. For speeds above that value, the variable `PI_ANTI_WINDUP_GAIN2` is used. Note that a value of 2800 for `PI_ANTI_WINDUP_SPEED` corresponds to 336 RPM (or 1120 steps per second). Refer to application note AN1307 for additional information.

To determine `PI_ANTI_WINDUP_GAIN1`, perform the following steps in Closed Loop Control mode:

1. Set the motor to run in closed loop current control, Full Step mode, two-phase on, and set the DMCI_Speed slider to 300 as shown in Figure 1-4.

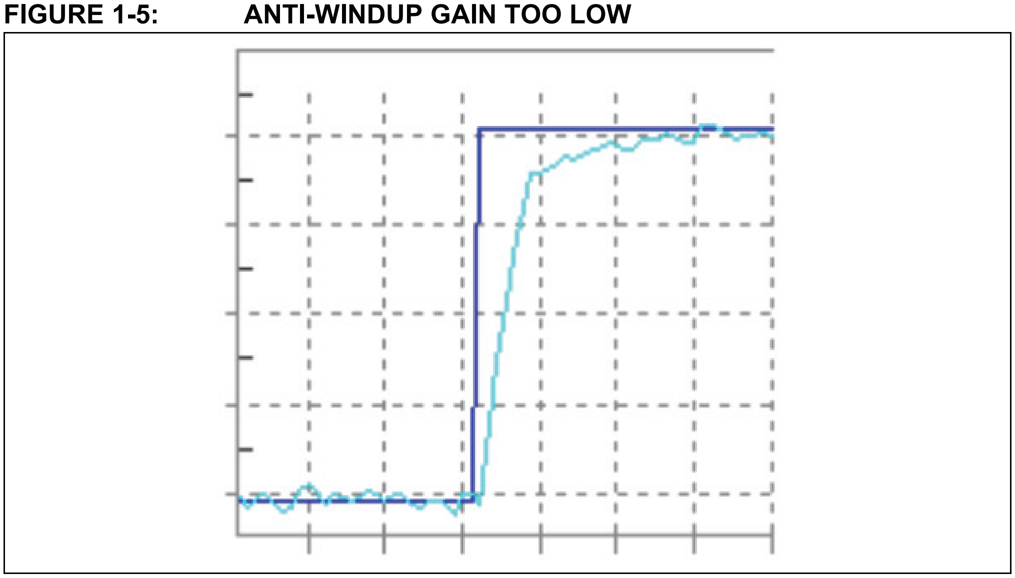
FIGURE 1-4: DMCI CONTROL INTERFACE



2. From the **Dynamic Data View** tab, press the Automated Event Control Button ().

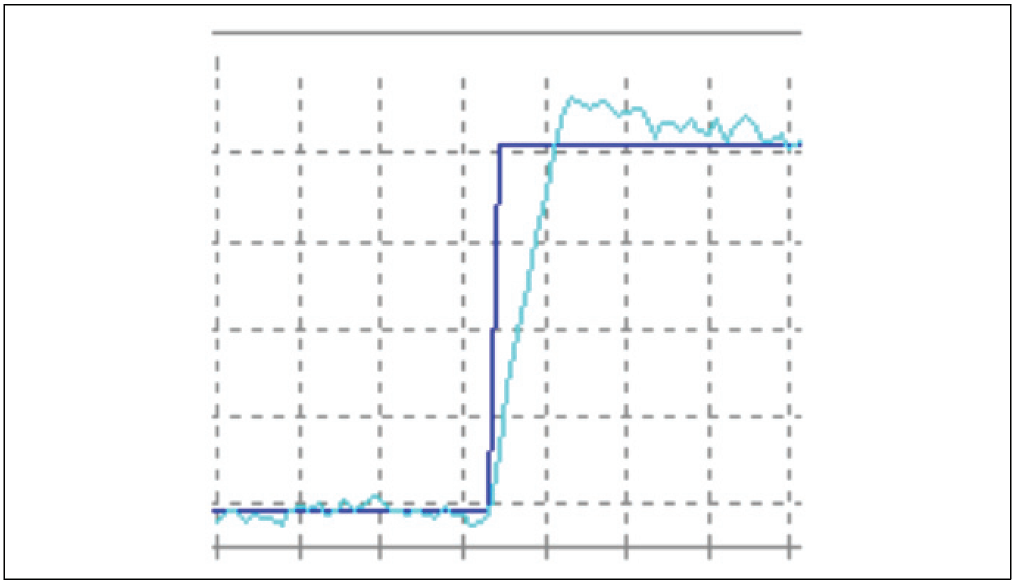
   a) If the current (cyan signal) shown in the Dynamic Data View looks like Figure 1-5, the `PI_ANTI_WINDUP_GAIN1` is too low.

FIGURE 1-5: ANTI-WINDUP GAIN TOO LOW



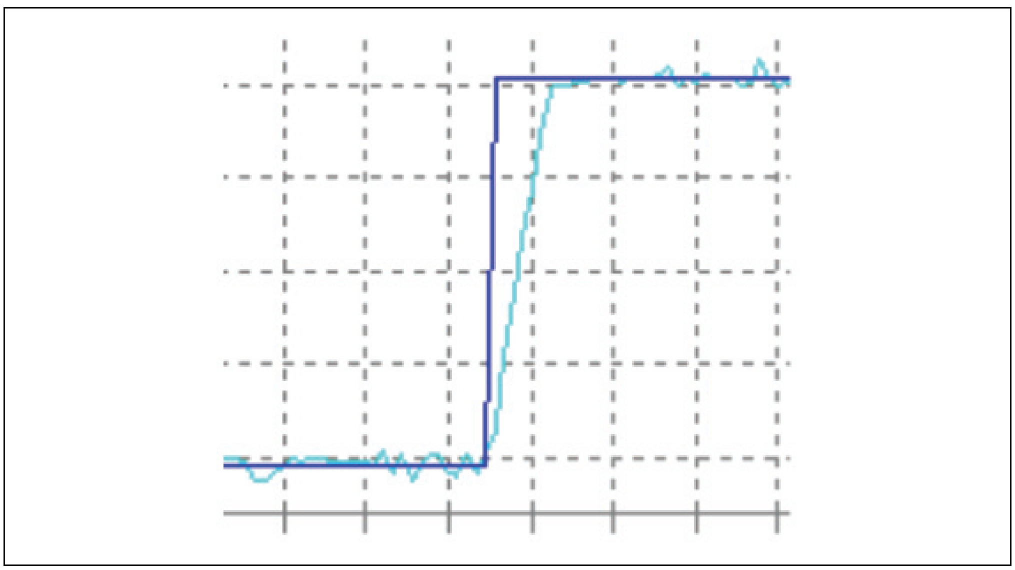
b) If the current in looks like Figure 1-6, the PI_ANTI_WINDUP_GAIN1 is too high.

FIGURE 1-6: ANTI-WINDUP GAIN TOO HIGH



c) The current should look like Figure 1-7, which shows a well-tuned PI_ANTI_WINDUP_GAIN1.

FIGURE 1-7: ANTI-WINDUP GAIN OKAY



d) ANTI_WINDUP_GAIN2 controls the phase shift between winding voltage and winding current. A higher gain will increase the phase shift allowing the motor to reach higher speeds, but with the cost of lower torque. A lower gain gives better torque, but the maximum speed drops. The maximum speed that can be achieved with ANTI_WINDUP_GAIN1 is about 1100 RPM (using half step).

e) PI_ANTI_WINDUP_SPEED controls the moment at which the PI controller changes from ANTI_WINDUP_GAIN1 to ANTI_WINDUP_GAIN2. The default value of 2800 corresponds to 336 RPM (1120 steps per second). Lowering this threshold allows faster and more robust transitions from low to high speeds using high acceleration rates. Increasing PI_ANTI_WINDUP_SPEED results in better torque at low speeds since ANTI_WINDUP_GAIN1 is used. The drawback is that the rotor may stall under high acceleration from low to high speeds. Set the threshold at the maximum speed from which the torque is not critical. For example, if at 330 RPM all the motor torque is needed, and at speeds above this point just a minimal torque is required, set this point as the threshold.

1.5 MOTOR START-UP MODE

The InitControlMode() function in the init.h header file controls the start-up configuration of the stepper motor. Table 1-3 Shows all possible values for the start-up configuration variables.

TABLE 1-3: MOTOR START-UP CONFIGURATION

Control Variable	Default Value	Possible Values	Description
currentControlLoop	OFF	ON OFF	Closed loop PI current control ON Open loop current control ON
controlMode	FIXED_VOLTAGE	FIXED_VOLTAGE FIXED_CURRENT	Open loop fixed voltage control ON Open loop fixed current control ON
decayMode	FIXED_DECAY	FIXED_DECAY ALTERNATE_DECAY	Open loop uses only baseDecay Open loop uses baseDecay and alternateDecay
stepSize	ST_HALFSTEP	ST_FULLSTEP ST_HALFSTEP ST_1_4STEP ST_1_8STEP ST_1_16STEP ST_1_32STEP ST_1_64STEP	Full step 1/2 step 1/4 step 1/8 step 1/16 step 1/32 step 1/64 step
positionControl	SPEED_CONTROL	SPEED_CONTROL POSITION_CONTROL	Speed control ON Position and Speed control ON
speedSource	POT_REF_SPEED	POT_REF_SPEED DMCI_REF_SPEED	Potentiometer sets motor speed DMCI slider sets motor speed
baseDecay	D_SLOW_L_MOSFET	D_FAST D_SLOW_L_DIODE D_SLOW_H_DIODE D_SLOW_L_MOSFET D_SLOW_H_MOSFET D_REVERSE	Fast decay Slow decay - low diode recirculation Slow decay - high diode recirculation Slow decay - low MOSFET recirculation Slow decay - high MOSFET recirculation Fast decay MOSFET recirculation (Reverse)
alternateDecay	D_FAST	D_FAST D_SLOW_L_DIODE D_SLOW_H_DIODE D_SLOW_L_MOSFET D_SLOW_H_MOSFET D_REVERSE	Fast decay Slow decay - low diode recirculation Slow decay - high diode recirculation Slow decay - low MOSFET recirculation Slow decay - high MOSFET recirculation Fast decay MOSFET recirculation (Reverse)
fullStepMode	FULLSTEP_WAVE_DRIVE	FULLSTEP_WAVE_DRIVE FULLSTEP_TWO_PHASE_ON	Full step wave drive is active Fulls step with Two-Phase_ON is active

With the exception of baseDecay and alternateDecay, all of these parameters can be selected in real-time while running the DMCI/RTDM software.

Changes can also be made in the `init.c` file to modify stepper motor operation.

EXAMPLE 1-3: MOTOR START-UP CONFIGURATION FROM init.c

```
void InitControlMode(void)
{
    //SET UP THE STARTUP CONTROL MODE

    //set initial current control mode to open loop
    uGF.currentControlLoop = OFF;

    //set initial control mode to fixed voltage (fixed current mode disabled)
    uGF.controlMode = FIXED_VOLTAGE;

    //set initial decay mode to fixed (alternate decay disabled
    uGF.decayMode = FIXED_DECAY;

    //set initial step size
    stepSize = ST_HALFSTEP;

    //set initial control mode to speed control (disable postion control)
    uGF.positionControl = SPEED_CONTROL;

    //set initial speed source to pot
    uGF.speedSource = POT_REF_SPEED;

    //set decay modes for base and alternate decay
    baseDecay = D_SLOW_L_MOSFET;
    alternateDecay = D_FAST;

    //Set initial full step Mode to Two-phase-on
    fullStepMode = FULLSTEP_WAVE_DRIVE;
}
```

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