

## DRV10974 Tuning Guide

The DRV10974 device is a three-phase sensorless motor driver with integrated power MOSFETs, which provide drive-current capability up to 1 A continuous (rms). The device is specifically designed for low-noise, low external-component count, 12-V motor drive applications. The 180° commutation requires no configuration beyond setting the peak current, the lead angle, and the acceleration profile, each of which is configured by an external resistor.

This tuning guide covers quick tuning and comprehensive tuning. The quick tuning section covers how to get the motor running quickly by inferring usable resistor values for the current, lead angle, and acceleration profile. The comprehensive tuning section covers the methodology for tuning each resistor value experimentally.

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## 1 Bench Set Up

Before connecting a motor, read the *Quick Start Guide* section of the [DRV10974 Evaluation Module User's Guide](#). This will help set up the proper connections for the DRV10974 and DRV10974EVM.

## 2 Quick Tuning

The goal of quick tuning is to get the motor running quickly by inferring usable resistor values for the current (CS pin), lead time (ADV pin), and acceleration profile (RMP pin).

If no information is known about the motor, the recommended the resistors should be as shown. Note that these resistors are the default installed on the DRV10974EVM:

- $R_{CS} = 115 \text{ k}\Omega$ 
  - This sets the current limit to 1.4 A which is the second largest current limit.
- $R_{ADV} = 59 \text{ k}\Omega$ 
  - This sets the lead time to 400  $\mu\text{s}$ , which is a lead time in the middle of the range of possible settings.
- $R_{RMP} = 7.32 \text{ k}\Omega$ 
  - This sets the second-order acceleration coefficient, the first-order acceleration coefficient, the closed-loop acceleration and the closed-loop deceleration to 0.22  $\text{Hz/s}^2$ , 4.6  $\text{Hz/s}$ , 2.7 s, and 44 s, respectively.
  - This is the slowest acceleration ramp rate.

If the motor fails to start up, reduce the CS value by one value, in accordance with the resistor selection in [Table 2](#), and repeat until the motor successfully starts up. The comprehensive resistor selection tables for CS, ADV, and RMP are found in [Table 2](#), [Table 3](#), and [Table 5](#), respectively.

If the user knows the target supply voltage ( $V_{CC}$ ) used in the application and the resistance of the motor, either from the motor data sheet or by measuring the resistance between two phases ( $R_{PH-PH}$ ), obtain a starting CS resistor value from [Equation 2](#).

Using the current gathered from  $I_{CS}$ , an appropriate  $R_{CS}$  can be selected using [Table 2](#).

If motor performance is satisfactory (for example, runs at target maximum and minimum speeds, succeeds on start and stop tests, meets start up time requirements, and starts up reliably) then no further tuning is needed. If the motor will not successfully start up, review [Table 1](#) to make sure the motor is within the application specifications that the DRV10974 can drive. In addition, use the comprehensive tuning section to improve driving performance.

**Table 1. Recommended Application Range for DRV10974**

Parameter	Description	MIN	TYP	MAX	Unit
Motor Voltage	-	4.4	12	18	V
BEMF Constant (Kt)	Phase to center tap. Measured while motor is coasting	5		150	mV/Hz
Motor Phase Resistance	Phase to center Tap. Can be derived from dividing phase-to-phase resistance by two.	1		20	$\Omega$
Motor Winding Current				1	A (RMS)
Absolute Maximum Current	During locked condition			2.5	A (Peak)

## 3 Comprehensive Tuning

The comprehensive tuning section covers the methodology for tuning each resistor value experimentally. As a result, testing is required to find the optimal resistor value for the motor. This includes replacing the resistors on the DRV10974 pins, as necessary. As a result, using a DRV10974EVM is highly recommend for easily replacing resistors on the pins. For more information, see the [DRV10974 Evaluation Module User's Guide](#).

### 3.1 Finding Closed-Loop Current and Coasting Time

To choose the correct resistor values, the Closed-Loop Current ( $I_{PEAK}$ ) and Coasting Time ( $t_{coast}$ ) must be found.

1. Set ADV to 400  $\mu$ s (59 k $\Omega$ ), CS to 1.4 A (115 k $\Omega$ ), RMP to the slowest setting (7.32 k $\Omega$ ) which is mentioned in the previous section. Note these are the default values on the EVM.

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**NOTE:** If the user knows the target supply voltage ( $V_{CC}$ ) used in the application and the resistance of the motor, either from the motor data sheet or by measuring the resistance between two phases ( $R_{PH-PH}$ ), a starting CS resistor value can be obtained from [Table 2](#) and [Equation 2](#).

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2. Apply power to the device to spin the motor to the maximum target speed.
3. If the motor fails to spin up reduce the current limit (CS) by one level. Repeat step 3 until the motor successfully spins up.
4. Record the motor peak phase current during steady-state run ( $I_{PEAK}$ ).
  - This is used to determine the resistor on the CS pin
5. Provide a command of 0 and measure how long the motor takes to coast to a stop ( $t_{coast}$ ).
  - This is used to determine the resistor on the RMP pin

### 3.2 Selecting CS Resistor

The CS resistor controls the current limit during the open loop and align phase. Assuming  $I_{PEAK}$  was captured in the previous section, use the closest value derived from [Equation 1](#) to find an acceptable CS resistor to set  $I_{LIMIT}$ :

$$I_{LIMIT} = 4 \times I_{PEAK} \quad (1)$$


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**NOTE:** Large resistance motors may result in large  $I_{LIMIT}$  values (that is,  $I_{LIMIT}$  values that are larger than in [Table 2](#)). As a result, use [Equation 2](#) instead.

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If the user knows the target supply voltage ( $V_{CC}$ ) used in the application and the resistance of the motor, either from the motor data sheet or by measuring the resistance between two phases ( $R_{PH-PH}$ ), obtain an accurate CS resistor value from [Equation 2](#):

$$I_{CS} = \frac{V_{CC}}{R_{PH-PH}} \quad (2)$$

Using the current gathered from  $I_{CS}$ , select an appropriate  $R_{CS}$  using [Table 2](#).

**Table 2. CS Resistor Table**

$R_{(CS)}$ (k $\Omega$ )	$I_{(LIMIT)}$ (mA)
7.32	200
16.2	400
25.5	600
38.3	800
54.9	1000
80.6	1200
115	1400
182	1600 (1500 during align and startup)

If the target RPM is slow, or the resistor given is larger than the value experimentally found in [Section 3.1](#), then the CS may have to be reduced until the motor can start up successfully.

### 3.3 Selecting ADV Resistor

The ADV pin controls the lead time that the DRV10974 will start driving the motor. The lead time attempts to align the current applied through motor phases and the *Back EMF voltage* (BEMF) induced by the permanent magnets on the rotor passing by the windings on the stator. If the current and the BEMF are perfectly aligned, efficiency and start-up reliability are drastically increased.

However, tuning the lead time is very experimental and methodical. If the motor starts up reliability and reaches the target RPM at 100%, then optimal tuning may not be needed.

To tune the lead time, start with the default lead time (400  $\mu$ s) then:

1. Successfully run the motor at 100% speed
2. Record the current consumed by the power supply ( $I_{CC}$ )
3. Record the frequency on the FG pin ( $f_{FG}$ ) which corresponds to the speed
4. Next, calculate the ratio of frequency (speed) over current ( $f_{FG} / I_{CC}$ )

The highest ratio of frequency over current with the highest speed is the most efficient lead time. As a result, decrease the lead time by one step (that is, lead time = 250  $\mu$ s) by changing the ADV resistor and repeat the process.

- If the ratio gets larger with the same speed after decreasing the lead time
  - Keep decreasing the lead time until the ratio gets smaller
- If the ratio gets smaller with the same speed after decreasing the lead time
  - Increase the lead time instead and see if the ratio gets larger
- If the speed significantly gets smaller after making the lead time larger
  - Check previous values.
- Most applications fall within the 100  $\mu$ s–400  $\mu$ s range but the ratio and speed will show the best lead time
- Once ADV is tuned for a specific motor, it does not need to be tuned again

**Table 3. ADV Resistor Table**

$R_{ADV}$ (k $\Omega$ )	Lead Time ( $\mu$ s)
10.7	10
14.3	25
17.8	50
22.1	100
28	150

**Table 3. ADV Resistor Table (continued)**

$R_{ADV}$ (k $\Omega$ )	Lead Time ( $\mu$ s)
34	200
41.2	250
49.9	300
59	400
71.5	500
86.6	600
105	700
124	800
150	900
182	1000

### 3.4 Selecting RMP Resistor

The RMP resistor controls the acceleration profile used when driving the motor. The acceleration controls how fast the motor accelerates during open loop using the first- and second-order acceleration coefficients (ACCEL2 and ACCEL1, respectively), the closed-loop acceleration, and closed-loop deceleration.

Assuming  $t_{coast}$  was captured in the previous section, a table of recommended RMP resistors are given in [Table 4](#). Using the table, further tests are done to find the final RMP value:

**Table 4. RMP Resistor Values for  $t_{coast}$** 

$t_{coast}$ (s)	$R_{RMP}$ (k $\Omega$ )	ACCEL2 (Hz/s <sup>2</sup> )	ACCEL1 (Hz/s)	Closed-Loop Acceleration Slew Rate (s)	Closed-Loop Deceleration Slew Rate (s)
$t_{coast} < 11$	41.2	27	75	0.2	11
	17.8	3.3	25	1	11
$11 < t_{coast} < 22$	34	14	50	0.2	22
	28	7	35	0.2	22
	14.3	1.65	15	1	22
	10.7	1.65	9.2	2.7	22
$t_{coast} > 22$	22.1	7	25	0.2	44
	7.32	0.22	4.6	2.7	44

To tune RMP:

- Use [Table 4](#) in combination with the measured  $t_{coast}$  to determine the range of RMP resistor values that should be used for this testing.
- Start with the largest value RMP resistor in the range, which indicates the fastest start up in this range, and conduct a few steady-state, stop, start tests.
  - A steady-state, stop, start test refers to running the motor at a 100% for some time, giving a 0% speed command to make the motor coast, and then giving a nonzero speed command before the motor stops coasting. This will be the worst-case start up scenario for the motor
- If the motor successfully and reliability started up after testing, then select the current value as the RMP value.
- If the motor did not successfully and reliability start up after testing, decrease the RMP resistor value in the appropriate range and repeat the steady-state start, stop tests.
  - If every resistor in the current  $t_{coast}$  range does not work, use a lower  $t_{coast}$  range and repeat the process.
  - In addition, reducing the CS value may help increase start up reliability.

**NOTE:** Higher closed-loop acceleration variants are available for each setting in [Table 4](#), consult [Table 5](#) for more information.

**Table 5. RMP Resistor Table**

RMP Selection	R <sub>RMP</sub> (kΩ)	ACCEL2 (Hz/s <sup>2</sup> )	ACCEL1 (Hz/s)	Closed-Loop Acceleration Transition Time (s)	Closed-Loop Deceleration Transition Time (s)
0	7.32	0.22	4.6	2.7	44
1	10.7	1.65	9.2	2.7	22
2	14.3	1.65	15	1	22
3	17.8	3.3	25	1	11
4	22.1	7	25	0.2	44
5	28	7	35	0.2	22
6	34	14	50	0.2	22
7	41.2	27	75	0.2	11
8	49.9	27	75	5.4	11
9	59	14	50	8	22
10	71.5	7	35	11	22
11	86.6	7	25	22	44
12	105	3.3	25	5.4	11
13	124	1.65	15	8	22
14	150	1.65	9.2	11	22
15	182	0.22	4.2	22	44

### 3.5 Example CS, ADV, and RMP Resistor Tuning

This section goes over an example scenario and the steps taken to tune each resistor for the CS, ADV, and RMP settings.

An example motor application has the following parameters:

- $V_{CC} = 12\text{ V}$
- Target RPM = 1500 RPM
- Motor Pole Pairs = 4 pairs

#### 3.5.1 Example Closed-Loop Current and Coasting Time

While the motor was able to start up with the default resistor settings using the DRV10974EVM, some optimization is needed. As a result,  $I_{PEAK}$  and  $t_{coast}$  need to be measured.

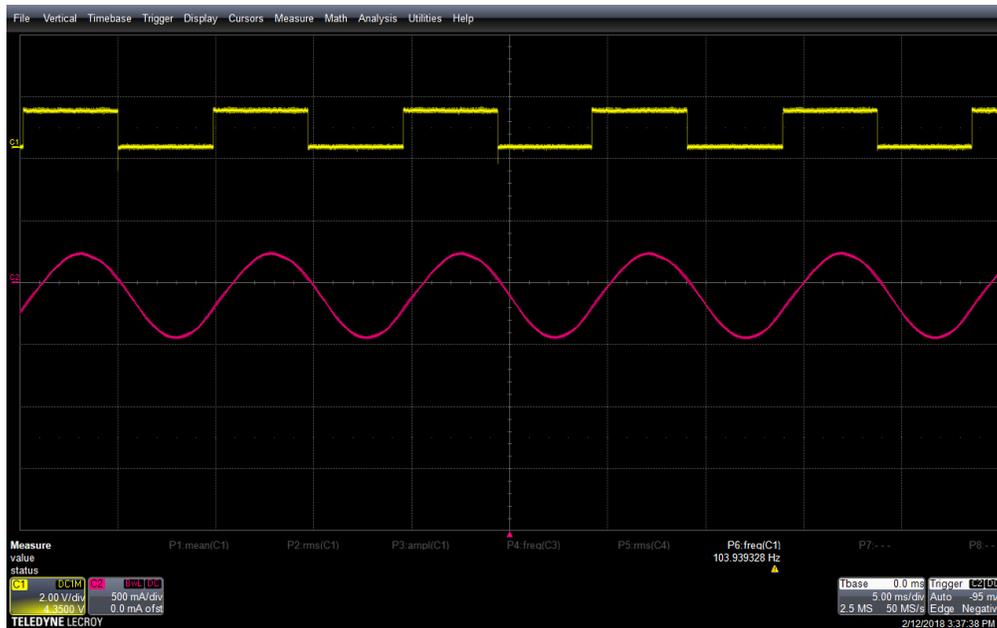


Figure 1. Example Peak Current in Closed Loop

As Figure 1 shows, the peak current can be roughly calculated as 375 mA. This is used when calculating the CS resistor.

$$I_{PEAK} = \frac{I_{PK-PK}}{2}$$

$$I_{PEAK} = \frac{(750 \times 10^{-3})}{2}$$

$$I_{PEAK} = 375 \text{ mA} \tag{3}$$

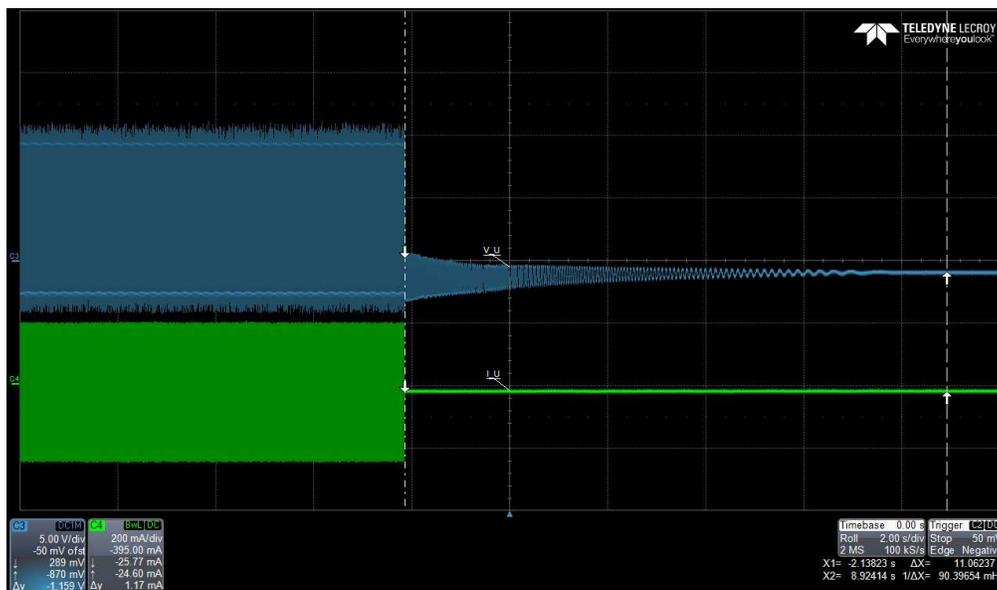


Figure 2. Example Coasting Time

As Figure 2 shows, the DRV10974 stops driving the motor after driving it at 100% speed, and the coasting time,  $t_{coast} = 11 \text{ s}$ .

### 3.5.2 Example CS Resistor Selection

Since  $I_{PEAK} = 325$  mA and the motor will be used in a 12-V application, a CS resistor value is found using Equation 4:

$$\begin{aligned}
 I_{LIMIT} &= 4 \times I_{PEAK} \\
 I_{LIMIT} &= 4(375 \times 10^{-3}) \\
 I_{LIMIT} &= 1.5 \text{ A}
 \end{aligned} \tag{4}$$

Unfortunately, 1.5 A is not a valid current limit value according to CS Resistor Table 2. As a result, the alternative method is used.

Using a DMM, the resistance between any of the 2 phases of a 3-Phase BLDC motor ( $R_{PH-PH}$ ) was determined to be 17  $\Omega$ . Using Equation 2, a general CS resistor value is chosen to be  $R_{CS} = 25.5$  k $\Omega$ , corresponding 600 mA of current limiting according to Table 2.

$$\begin{aligned}
 I_{CS} &= \frac{V_{CC}}{R_{PH-PH}} \\
 I_{CS} &= \frac{(12)}{(17)} \\
 I_{CS} &= 705 \text{ mA} \approx 600 \text{ mA}
 \end{aligned} \tag{5}$$

By populating the resistor, the motor is still able to spin up reliably and enter closed loop.

### 3.5.3 Example ADV Resistor Selection

To find the correct ADV resistor, the highest ratio of speed over supply current ( $f_{FG} / I_{CC}$ ) with the highest speed must be found. By creating Table 6, the ratio and speed can be easily visualized.

**Table 6. Experimental Supply Current, Speed, and Speed/Current Ratio With Different Lead Times**

Lead Time ( $\mu$ s)	$I_{CC}$ (A)	$f_{FG}$ (Hz)	$f_{FG} / I_{CC}$ (Hz/A)
25	0.310	108.7	350.6
50	0.310	108.7	350.6
100	0.300	108.7	362.3
200	0.299	108.2	361.9
300	0.298	107.2	359.7
400	0.293	106.4	363.1
500	0.293	105.5	360.0

As Table 6 shows, the highest ratio with the highest speed corresponds to lead time = 100  $\mu$ s. This corresponds to the resistor value for  $R_{ADV} = 22$  k $\Omega$  in Table 3.

While the 400  $\mu$ s gave the highest ratio of speed over current, the actual speed ( $f_{FG}$ ) dropped 2% (108.7 Hz to 107.2 Hz). This makes 400  $\mu$ s less optimal than 100  $\mu$ s for the lead time.

### 3.5.4 Example RMP Resistor Selection

Since  $t_{coast} = 11$  s,  $t_{coast}$  falls between the 11 s and 22 s range in the RMP selection ( $R_{RMP} = 34, 28, 14.3,$  and 10.7 k $\Omega$ ), the 34-k $\Omega$  resistor is populated and a steady-state, stop, start test is conducted. The 34-k $\Omega$  resistor is used because it is the fastest RMP rate in this range.

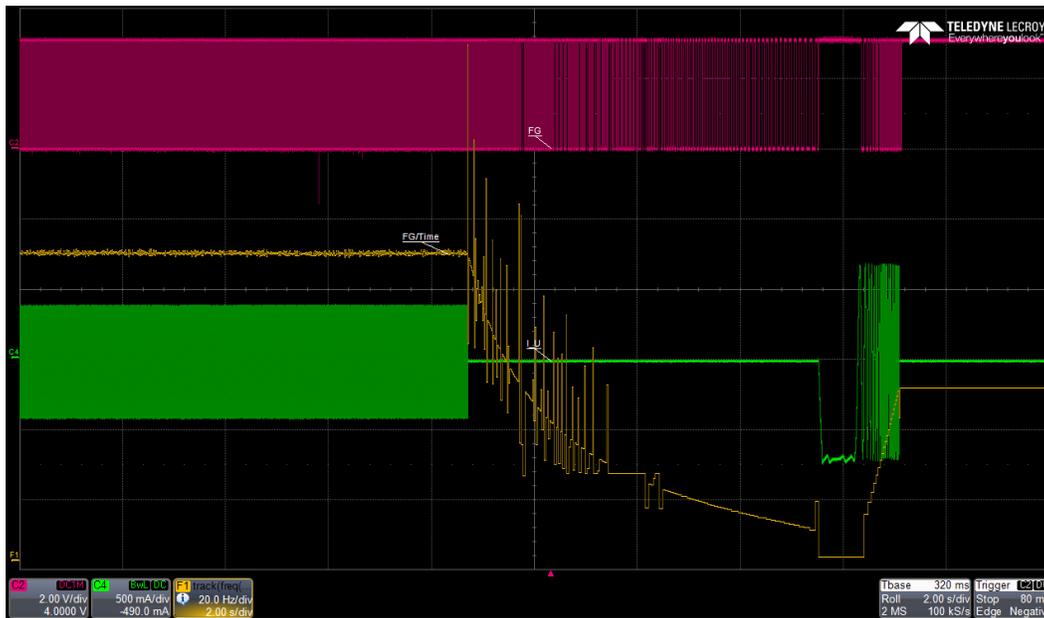


Figure 3. Example Unsuccessful Steady-State, Stop, Start Test

As Figure 3 shows, the hand off from open loop to closed loop was unsuccessful and the DRV10974 stopped driving the motor for protection. Since this test was not successful, the next largest resistor (28 kΩ) was tested.

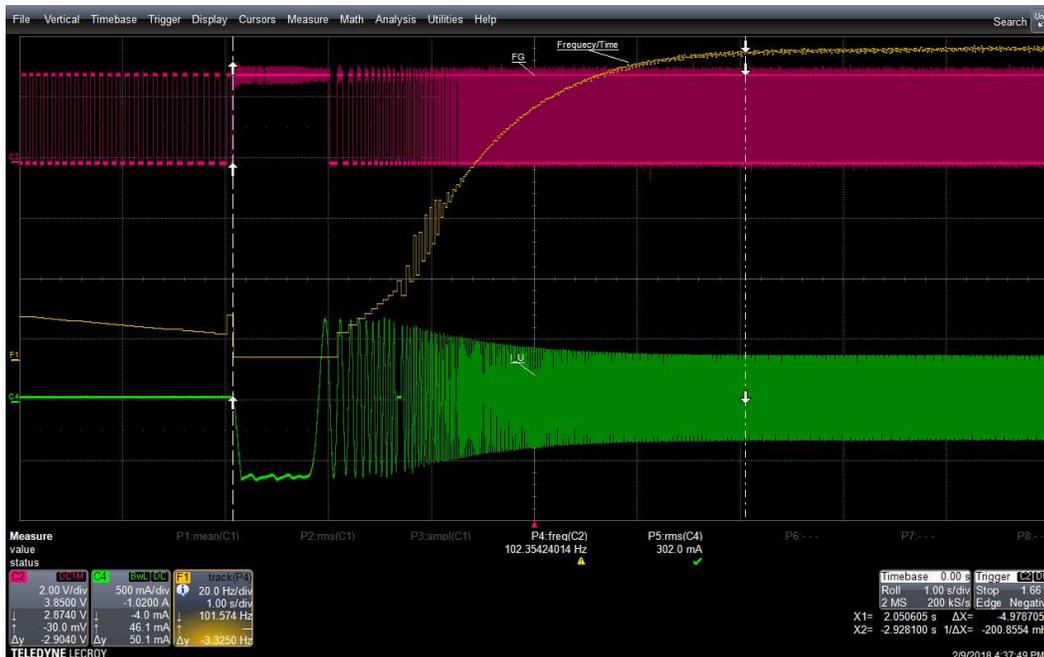


Figure 4. Example Successful Steady-State, Stop, Start Test

As Figure 4 shows, the hand off from open loop to closed loop was successful and the motor is driven to 100% speed. As a result, the resistor value is chosen to be  $R_{RMP} = 28 \text{ k}\Omega$ . The corresponding settings for open-loop acceleration, closed-loop acceleration, and closed-loop deceleration as shown in Table 5.

### 3.5.5 Summary and Results

Using the tuning method, the following resistors were selected:

- $R_{CS} = 25.5 \text{ k}\Omega$  for a current limit of 600 mA
- $R_{ADV} = 22 \text{ k}\Omega$  for a lead time of 100  $\mu\text{s}$
- $R_{RMP} = 28 \text{ k}\Omega$  for a RMP code of 5

The RPM of the motor is calculated by using [Equation 6](#):

$$\begin{aligned} \text{RPM} &= \frac{60 \times f_{FG}}{n_{\text{PolePairs}}} \\ \text{RPM} &= \frac{60(108.7)}{4} \\ \text{RPM} &= 1630.5 \text{ RPM} \end{aligned} \tag{6}$$

Using the number of pole pairs and the speed from the lead time tuning for the ADV resistor, the RPM of the motor is calculated to be above the target RPM of 1500 RPM.

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