

Servo Drive Current Loop Tuning Procedure (intended for Analog input PWM output servo drives)

The standard tuning values used in *ADVANCED* Motion Controls drives are conservative and work well in over 90% of applications. However some applications and some motors require more complete current loop tuning to achieve the desired performance.

Since most *ADVANCED* Motion Controls drives close the current loop internally, poor current loop tuning cannot be corrected with tuning from an external controller. The current loop must be tuned by changing the current loop components on the drive. Only after the current loop tuning is complete can optimal performance be achieved with the velocity and position loops.

This guide is intended to show the proper procedure for tuning the current loop of *ADVANCED* Motion Controls servo drives.

Disclaimer: The following procedure is intended for advanced users of high performance applications only. Contact the factory to discuss application requirements and proper drive tuning prior to making any adjustments.

CAUTIONARY NOTES:

IMPROPER CURRENT LOOP TUNING MAY RESULT IN PERMANENT DRIVE AND MOTOR DAMAGE REGARDLESS OF DRIVE CURRENT LIMITS!

ALWAYS REMOVE THE POWER SUPPLY VOLTAGE BEFORE MAKING ANY RESISTOR OR CAPACITOR MODIFICATIONS!

THE FOLLOWING ADJUSTMENTS MUST BE MADE WITH THE MOTOR UNCOUPLED FROM THE LOAD! ALSO SECURE THE MOTOR AS SUDDEN MOTOR MOVEMENT MAY OCCUR!

General Procedure

The following steps outline the current loop tuning procedure.

1. Determine if additional current loop tuning is necessary.
2. If available, try tuning the drive using the Current Loop DIP switches.
3. If the current loop cannot be tuned with DIP switches, then the current loop components must be changed.
 - a. Tune the Proportional gain.
 - b. Tune the Integral gain.

The appendices at the end of this document go into further detail about the following:

Appendix A: Describes how to view the current loop response on an oscilloscope.

Appendix B: Describes how to find the current loop tuning components on the block diagram and on the drive PCB.

Appendix C: Hints to make the tuning process easier.

Appendix D: Examples of real drive and motor systems.

1) Determine if Additional Current Loop Tuning is Necessary

The following are indications that the current loop may need to be further tuned:

- Motor rapidly overheats even at low current
- Drive rapidly overheats even at low current
- Vibration sound comes from the drive or motor
- The motor has a high inductance (>10mH)
- The motor has a low inductance (near minimum rating of the drive)
- Slow system response times
- Excessive torque ripple
- Difficulty tuning position or velocity loops
- Electrical noise problems
- High power supply voltage (power supply voltage is significantly higher than

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- the motor voltage rating or near the drive high voltage rating)
- Low power supply voltage (power supply voltage is near the low voltage rating of the drive)

The above indicators are subjective and suggest that the current loop may need to be tuned. These can also be signs of other problems not related to current loop tuning. If several of the indicators are true, then the current loop response should be looked at on an oscilloscope (see Appendix A).

2) Tuning the Drive with DIP Switches

Some servo drives have DIP switches that control current loop tuning. If these are available they should be tried first before changing the components on the drive PCB (see Appendix B).

The two current loop tuning switches are “Current Loop Gain” and “Current Loop Integrator”. Some drives don’t have these switches, some have one, and some have both.

While viewing the current loop response on an oscilloscope (see Appendix A) try the different switch settings. If acceptable performance cannot be achieved with the switches, then the current loop tuning components will need to be changed.

3) Tuning the Drive by Changing the Current Loop Tuning Components on the Drive PCB

The resistors and capacitors shown under the current control block on the functional block diagram for the drive control the response of the current loop. It is important to tune the current loop appropriately for the motor inductance and resistance, as well as the power supply voltage to obtain optimum performance.

Note: Always remove the power supply voltage before making any resistor or capacitor modifications!

Tune the Proportional Gain

1. Short out the current loop integrator capacitor(s) using the appropriate DIP switch or a jumper (see functional block diagram and data sheets).

2. Apply power to the drive. Approximate application power supply voltage should be used or the current loop compensation will not be correct.
3. View the current loop response on an oscilloscope. Small step tuning is different than large step tuning, so adjust the function generator square wave amplitude so the drive outputs a current step similar to what will be expected when the drive is in operation.
4. Increase the value of the gain resistor to the point of overshoot in the current response. If there is a large amount of overshoot or there are oscillations, decrease the gain resistor value until there is little or no overshoot.

Tune the Integral Gain

1. After the gain resistor has been adjusted, re-enable the integrator capacitor(s).
2. Using a function generator, adjust the square wave amplitude as in the proportional gain adjustment procedure above.
3. Apply power and observe the current loop response with the default current loop capacitor. If necessary, adjust the value of the capacitor so the drive outputs a critically damped square wave. Be sure to use non-polarized capacitors. The square wave can have a small amount of overshoot, but it should settle to a flat top. Use smaller value capacitors to sharpen the corners of the square wave. Use larger value capacitors to reduce oscillations or overshoot. Approximate application power supply voltage should be used or the current loop compensation will not be correct.

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Appendix A – View Current Loop Response

Concept

The drive output should follow the input command. To see if your drive does this, simply use an oscilloscope to display the input command on channel 1, and the drive output on channel 2. By comparing the two waveforms you can determine if the current loop needs tuning.

Procedure

1. Use the DIP switches to set the drive in current mode. The switch settings are listed on the drive datasheet. Even if the drive is intended to run in velocity mode, it will need to be in current mode while tuning the current loop.
2. Use a function generator to produce the input command. Hook it up to the input reference of the drive and set it to output a 50-100 Hz square wave. Set the square wave amplitude so the drive outputs a current step similar to what will be expected when the drive is in operation. Use channel 1 of the oscilloscope to view the square wave. Also use this channel to trigger the oscilloscope.
3. Use a current probe to view the drive output to the motor. Clamp the current probe to motor phase A.

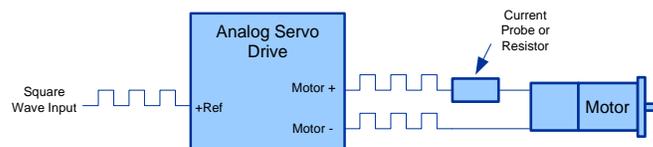
Note: If a current probe is not available, use the drive current monitor pin. The signal from this pin is unfiltered and may be difficult to view. Also depending on the drive, this pin may not be isolated from the drive power ground. If this is the case, the oscilloscope must have isolated channels to avoid large ground currents.

An alternate method of viewing the current is to use a resistor in series with the motor. The current through the resistor will be proportional to the voltage across the resistor ($I = V/R$). Make sure the resistance is less than 1/10 of the motor resistance, and make sure the power rating of the resistor is sufficient to handle the current. Be very careful with oscilloscope grounding if using this method.

4. Different drives need to be set up differently to view the current loop response properly. Use the following diagrams and explanations to help set up your system properly.

Single Phase (Brush Type) Drives

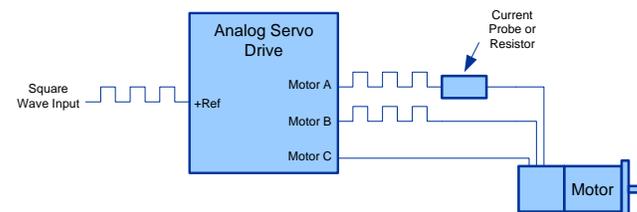
Brush type drives have two motor outputs, Motor+ and Motor-. Since the two motor wires are in series, the current through the wires is the same. The current probe can be attached to either wire with the same results.



Note: To keep the motor from turning during the tuning process, the motor shaft must be locked.

Three Phase (Brushless) Drives

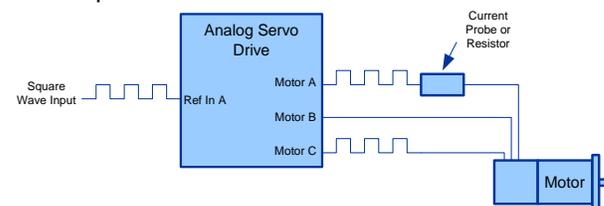
Brushless drives have three motor outputs, Motor A, Motor B, and Motor C. The current through the motor outputs changes depending on the signal from the Hall Sensors. The current out of the drive can be forced to go through Motor A and Motor B by disconnecting the Hall Sensors from the drive and setting the 60/120 degree phasing switch to the OFF position. With this configuration, attach the current probe to either Motor A or Motor B.



Note: The motor shaft does not need to be locked since the drive will not commutate without the Hall Sensors.

S-Series (Sinusoidal Command) Drives

S-Series drives have three motor outputs, Motor A, Motor B, and Motor C. The current through the motor outputs changes depending on the relationship between the "Ref In A" signal and "Ref In B" signal. The current out of the drive can be forced to go through Motor A and Motor C by applying the square wave command signal to "Ref In A" only. With this setup, attach the current probe to either Motor A or Motor C.



Note: The motor shaft does not need to be locked since the drive is not commutating.

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Appendix B – How to Find the Current Loop in the Block Diagram

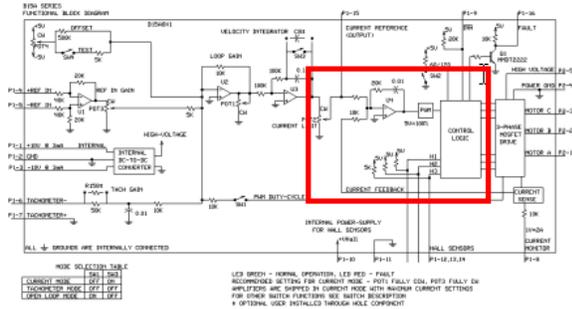
Brush type and brushless DC (or trapezoidal) drives have a single current loop. S-Series (sinusoidal) drives have three current loops. In the case of S-Series drives, all three loops must be tuned the same or the drive will not operate properly. The loop gain and the integrator capacitance of the current loop must both be adjusted for the tuning to be complete.

The functional block diagram of the drive conceptually shows where the current loop is.

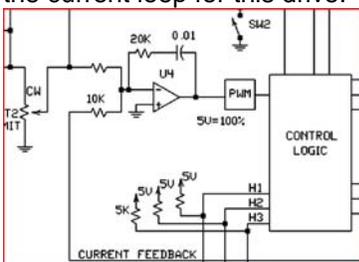
Contact **ADVANCED Motion Controls** to get the actual locations of the current loop components. Ask for a copy of the PCB silk screen for the drive model you are tuning.

Example Block Diagrams

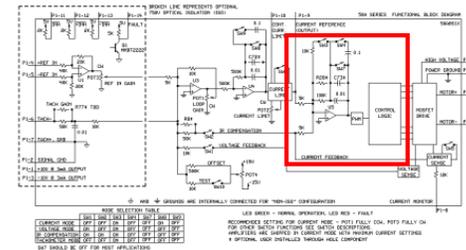
B15A8



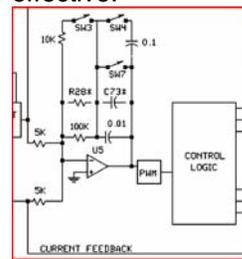
The current loop on the B15A8 can be located by following the line labeled “Current Feedback” to the gain stage U4. The 20k resistor in the current loop adjusts the current loop proportional gain. The 0.01uF capacitor adjusts the current loop integrator. There are no DIP switches that control the current loop for this drive.



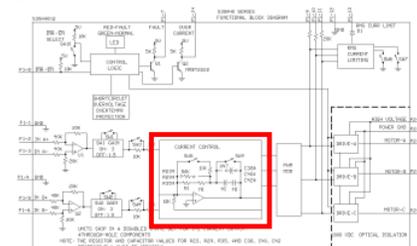
50A8



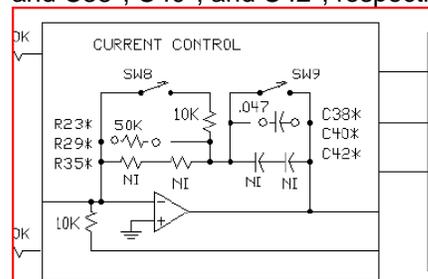
The current loop can be located by following the line labeled “Current Feedback” to the gain stage U5. SW3 increases the current loop gain resistance. SW4 increases the current loop capacitance. SW7 shorts the current loop capacitor. In addition, through-hole locations R28 and C73 can be used to adjust the current loop response if adjusting the switches is not effective.



S30A40



The current loop is found at the gain stage marked “Current Control”. SW8 increases the proportional gain resistance. SW9 activates or deactivates current loop integration. If neither switch position gives sufficient current loop performance, then the resistance and capacitance can be changed further by the through-hole components at R23*, R29*, R35*, and C38*, C40*, and C42*, respectively.



Appendix C – Helpful Hints

The following are some helpful hints to make the current loop tuning process easier.

Use pin receptacles to reduce the need for soldering.

Some drives have pin receptacles that make it easy to change the tuning resistors and capacitors without the need for soldering. Other drives do not have these receptacles so soldering is required. To avoid the need to solder every time a tuning value needs to be changed a pin receptacle can be soldered into the through-hole location of the tuning component. Mill Max P/N 8427 works well for this purpose.

Use a potentiometer to find the correct current loop gain value more quickly.

A potentiometer can be used to continuously adjust the gain resistance value during the tuning process. Install a potentiometer in place of the gain resistor. Adjust the potentiometer while viewing the current loop response on an oscilloscope. When the optimal response is achieved turn off the drive, remove the potentiometer, and measure the resistance. Use the closest resistor value available.

Note: This method will not work if the optimal tuning value is beyond the range of the potentiometer. This method also does not work for sine drives since it is difficult to keep the tuning values in the three current loops the same.

Progressively double the resistance value when tuning the current loop gain for faster results.

If the gain resistor needs to be increased during the tuning process, the fastest results are achieved by doubling the resistance from the last value tried. Use this method until overshoot is observed, and then fine tune from there.

Be aware of any components that are in parallel with the values you are trying to tune.

On some drives, there may be one or more gain resistors in parallel with a through-hole resistor location. The equivalent resistance value of the SMT resistors on the board and the additional through-hole resistor will be limited by the smallest resistance value of the group of resistors in parallel. Consult the block diagram on the drive datasheet to determine the specific resistor values. The same situation can occur when trying to decrease the integrator capacitor value, since capacitors in parallel will be added together.

Safety

Always remove power when changing components on the drive.

Float the oscilloscope and function generator grounds to avoid large ground currents.

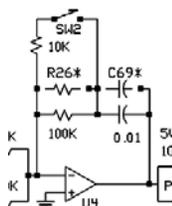
Decouple the motor from the load to avoid being injured by sudden motor movements.

Appendix D – Examples

Example 1: System with Oscillating Current Loop Response

In this example, the machine doesn't have the expected bandwidth. The motion seems sluggish and tuning the PID parameters in the controller doesn't seem to help. It is suspected that the current loop is not tuned and is causing the system to have slow response.

The first step is to take a look at the current loop response, and to use the drive functional block diagram to find the current loop and current loop components and switches (Appendix A and Appendix B).



The drive in use has a current loop proportional gain DIP switch, SW2, which is ON by default. The current loop proportional gain resistance is therefore 9.1k (10k and 100k in parallel). The drive also includes the option of adding through-hole components to the current loop if desired.

The following scope images show the commanded signal on channel 1 and the actual output current on channel 2. The command signal scaling is 0.5V per division. The current output scaling is 2A per division. The amplitude of the current step should be adjusted to match the expected current step when the system is in operation. In this case, the command signal amplitude was adjusted so the current output was a 2A step.

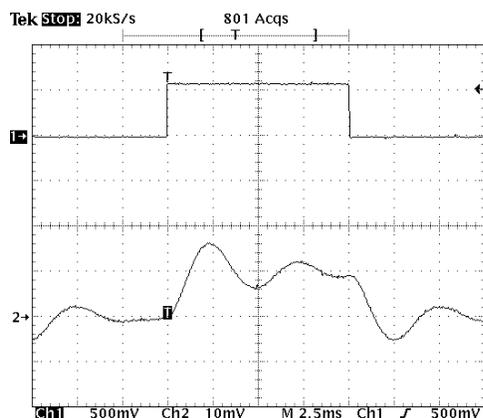


Figure 1: Current loop response with SW2 ON

The scope image clearly shows that the drive is not tuned to the motor. The rise time is slow, there is excessive overshoot, and there are heavy oscillations. Since the leading edge of the square wave is not very steep, this indicates the gain probably needs to be increased.

The next step is to try switching the current loop proportional gain DIP switch to OFF (short the 10k resistor) to increase the proportional gain resistance to 100k.

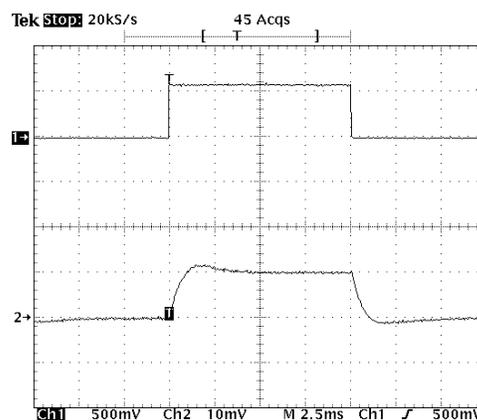


Figure 2: Current loop response with SW2 OFF

The response improved greatly with the increased current loop gain. The current response now resembles a square wave. There is still some overshoot and the corners of the square are rounded, but this response will be sufficient for the application.

If desired, the current loop can be further improved by removing the 100k current loop resistor and 0.01uF integrator capacitor and replacing them with different values at the through-hole locations R26* and C69*. This will be demonstrated in the next example.

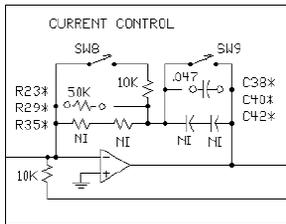
Note: Convention says that overshoot is an indication that the gain is too high. However, from experience second order responses have also been observed when the gain is too low. To determine if the gain is too high or too low you should look at the step response with the integrator capacitor shorted. If the overshoot persists with no integrator then the gain is too high. If the overshoot goes away, then the gain is too low.

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Example 2: System With Over Damped Current Loop Response

This system uses a high inductance linear motor with a sinusoidal (S-Series) drive. The system bandwidth is much lower than expected.

As in the previous example, the first step is to look at the current loop step response and try to tune the drive using DIP switches.



DIP switch SW8 is on by default, so the proportional gain resistance is 8.3k (50k and 10k in parallel). The 50k resistors and 0.047uF capacitors in the three current loops

are through-hole components in pin receptacles on S-Series drives for easy component changes if neither SW8 position gives sufficient current loop performance.

The following scope images show the commanded signal on channel 1 and the current output on channel 2. The command signal scaling is 0.5V per division. The current output scaling is 2A per division. The amplitude of the current step should be adjusted to match the expected current step when the system is in operation. In this case the command signal amplitude was adjusted so the current output was a 3A step.

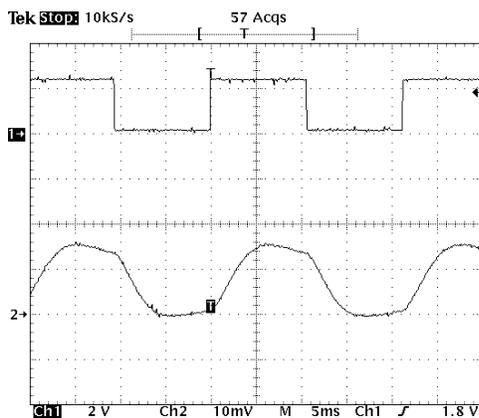


Figure 1: Current loop response with SW8 ON.

The figure above shows the current response with SW8 ON. The current loop response is very poor with this setting. The output looks more like

a sine wave than a square wave. The rise time is very slow and the corners are totally rounded.

The next step is to try turning SW8 OFF to increase the gain resistance from 8.3k to 50k.

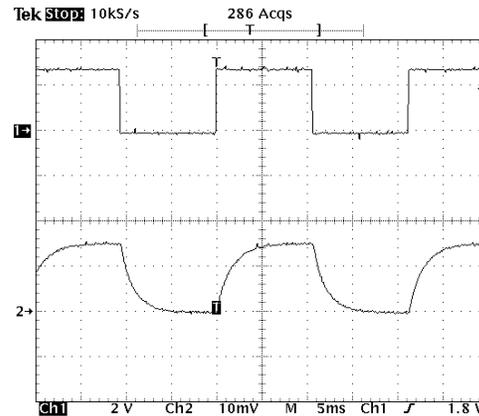


Figure 2: Current loop response with SW8 OFF

The performance is slightly increased with this setting but the rise time is still slow, and the leading corner of the square wave is overly rounded. Increasing the gain should square up the leading corner of the square wave. Since it is not possible to increase the current loop gain any further by using the DIP switches, it will be necessary to use the through-hole locations on the PCB.

S-Series drives have three current loops. To keep the three phases balanced it is necessary to always keep the current loop resistors at identical values. This also applies to the current loop capacitors.

Please contact ADVANCED Motion Controls for the PCB location of the loop gain resistors and capacitors.

The following steps describe the process of tuning by changing the loop gain resistors and capacitors.

1. Locate the loop gain resistors and capacitors on the PCB.
2. Short the capacitors either by DIP switch (if available) or use jumpers.
3. If there is a Current Loop Gain switch, check the drive block diagram and set the switch so there are no other resistors in parallel with the through-hole resistors you are changing.

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4. Increase the gain resistors incrementally until the response is critically damped with little or no overshoot.
5. Un-short the capacitors.
6. Change the capacitor values until the response is critically damped with little or no overshoot.

For this system, make sure SW8 is in the OFF position to short out the 10k resistor, and make sure SW9 is in the ON position to short out the 0.047uF integrator capacitor. After removing the 50k resistors from the pin receptacles, the first through-hole resistor values tried will be 100k.

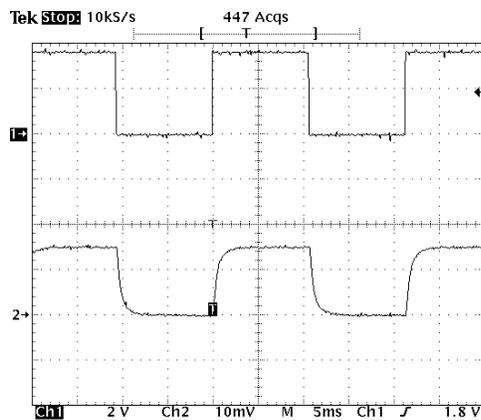


Figure 3: 100k resistors, SW8 OFF, SW9 ON

The response is getting better, so a higher resistor value will be tried next.

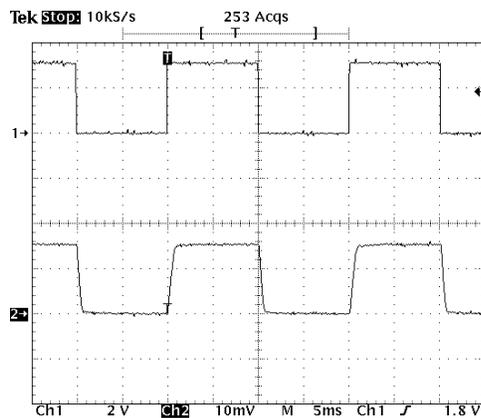


Figure 4: 270k resistors, SW8 OFF, SW9 ON

The response has greatly improved with 270k resistors. This value may be sufficient, but a higher value should be tried to see if performance improves.

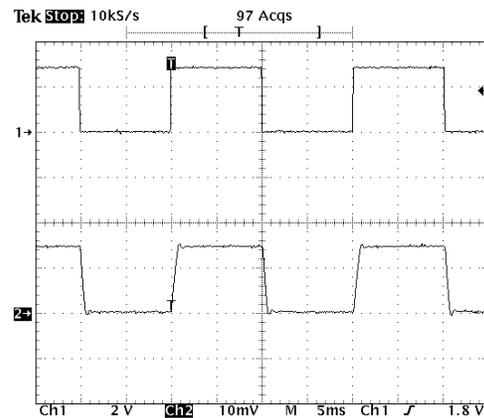


Figure 5: 510k resistors, SW8 OFF, SW9 ON

With 510k resistors, there is some overshoot starting to appear. The rise time is slightly improved, and the corners are as sharp as they are going to get. The rise time is now limited more by the power supply voltage and motor inductance, and can no longer be significantly improved with loop tuning.

Note: It is up to the system designer to decide how much overshoot is acceptable. As a rule it should be less than 10%.

The next step is to add the capacitors back into the loop (SW9 OFF). The capacitors eliminate the steady state error in the current loop. The steady state error is proportional to $1/K_p$ (K_p = proportional gain). With the gain resistors as 50 times the nominal value, it is unlikely there is very much steady state error. The capacitors will add little to the performance of the system, and may actually cause the response to be a little slower and more unstable. The next figure shows the response with the standard capacitor values added in.

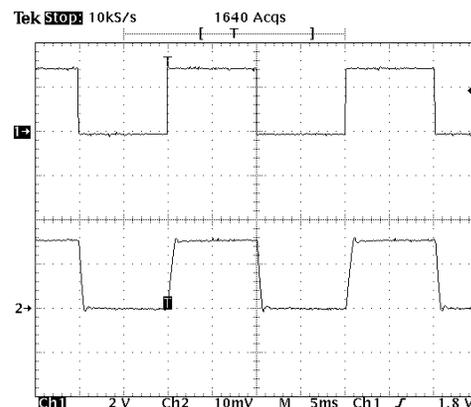


Figure 6: 510k resistors, SW8 OFF, SW9 OFF

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The 0.047 μ F capacitors didn't affect the response significantly. The overshoot is slightly more pronounced, and the performance didn't appear to improve. A faster (lower value) capacitor can be tried at the through-hole locations (remove 0.047 μ F capacitors) to see if this will increase performance.

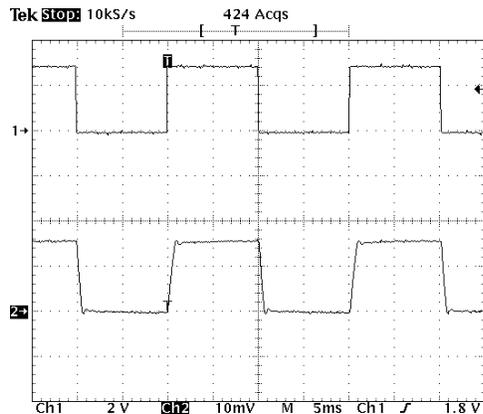


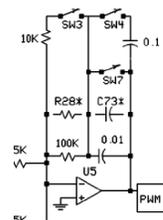
Figure 7: 510k resistors, 0.01 μ F capacitors, SW8,9 OFF

There is no noticeable improvement in performance. Notice that the flat portion of the square wave has a slight upward slope. This may indicate there was some steady state error that was not being closed off when the capacitor was shorted. A faster capacitor may eliminate this, but at the expense of stability. With the gain so high, the contribution of the capacitor to the loop tuning is very small. It is up to the system designer to decide whether to stay with the 0.01 μ F capacitor or to continue trying capacitors of smaller values, or to leave the capacitors shorted as in Figure 5.

Example 3: Brushed Motor

This system uses a low inductance brushed motor with a high winding resistance. Tuning the drive to this motor requires increasing the gain resistor to a relatively high value and decreasing the capacitor value substantially.

As in the previous examples, the first step is to look at the current loop step response and try to tune the drive using DIP switches.



This drive has several options to tune the current loop via switches. SW3 toggles the current loop gain resistance between 9.1k and 100k. SW4 toggles the current loop capacitance between 0.01 μ F and 0.11 μ F. SW7 shorts the current loop capacitance.

Through-hole locations R28* and C73* allow further tuning if necessary.

The following scope images show the commanded signal on channel 1 and the current output on channel 2. The command signal scaling is 0.5V per division. The current output scaling is 1A per division. The amplitude of the current step should be adjusted to match the expected current step when the system is in operation. In this case, the command signal amplitude was adjusted so the current output was a 2A step.

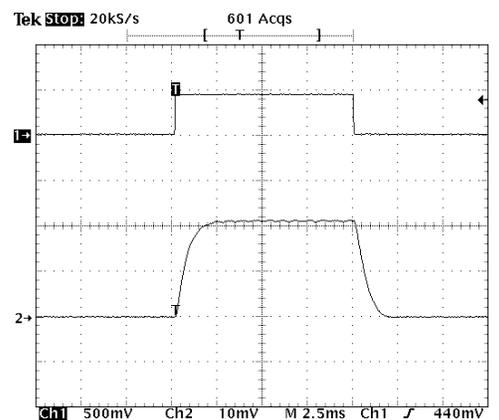


Figure 1: Current loop response, SW3 ON, SW4,7 OFF

The switch settings were set to the default current mode settings (found on the drive datasheet). With SW3 ON, the gain resistance is 9.1k, and with SW4 and SW7 OFF the capacitance is 0.01 μ F. Figure 1 shows that with

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these settings the step response is slow and the leading corner is rounded. In most applications this response would be good, but to increase performance for high bandwidth applications, the drive should be further tuned.

The first step is to try increasing the proportional gain resistance by setting SW3 OFF.

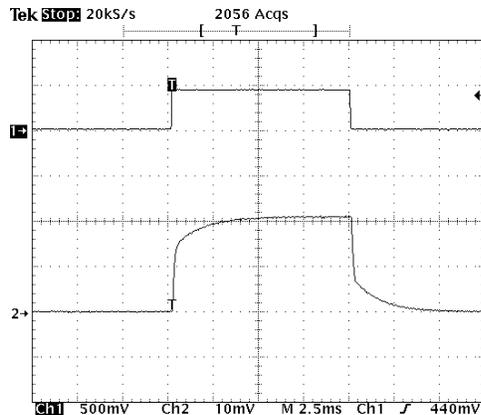


Figure 2: Current loop response, SW3,4,7 OFF

With SW3 OFF, the proportional gain resistor was increased from 9.1k to 100k. This resulted in a faster initial rise, but the leading corner is still very rounded.

To further increase performance, the standard tuning procedure should be followed. The capacitor should be shorted while the proportional gain resistor value is increased. The resistor value should be increased until a small amount of overshoot starts to appear. Once the resistor value is set, the capacitor should be adjusted until the step response has square corners with little or no overshoot.

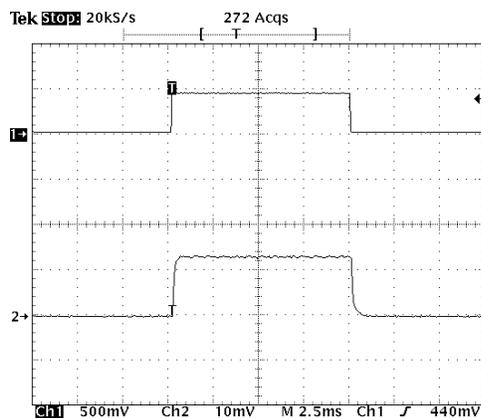


Figure 3: 100k resistor, SW3,4 OFF, SW7 ON

With the shorted capacitor (SW7 ON) and the 100k proportional gain resistor, the response looks very good. The leading corner is slightly rounded, so a higher resistor value should be tried to see if the response can be improved (remove 100k SMT resistor, add through-hole resistor to R28*).

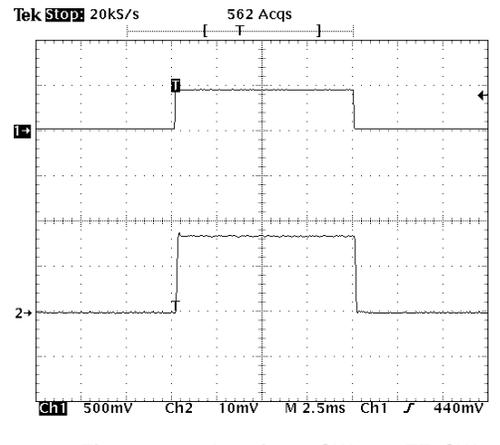


Figure 4: 240k resistor, SW3,4 OFF, SW7 ON

With a 240k resistor, the corners are very crisp and well defined. However, there is some overshoot starting to appear. It is up to the system designer to decide whether to go with this value, or with the more conservative 100k resistor (or try and intermediate value). A higher resistor value will be demonstrated next to show the effects of over-tuning the drive.

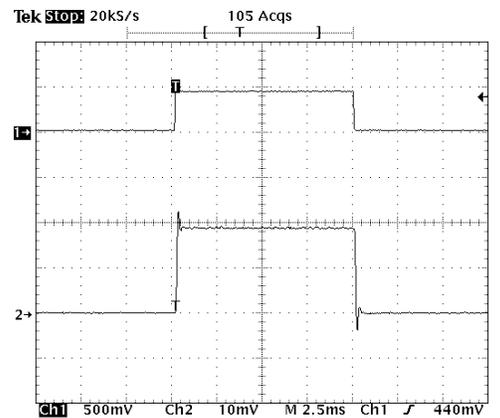


Figure 5: 510k resistor, SW3,4 OFF, SW7 ON

A 510k resistor value is much too high, and is causing the sharp overshoot on the square wave. Don't tune your system this aggressively.

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The next step is to add the capacitor back into the current loop. The onboard 0.01uF capacitor will be tried first by switching SW7 OFF.

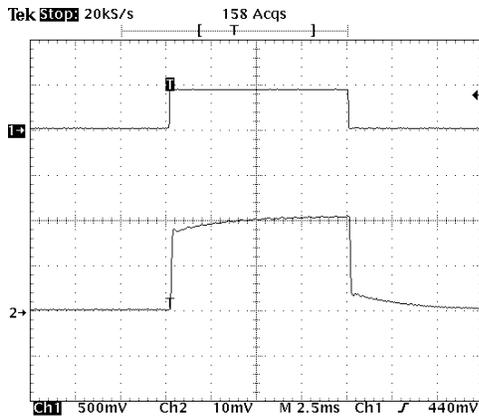


Figure 6: 240k resistor, SW3,4,7 OFF

With the 0.01uF capacitor added in, you can see there was a steady state error that the resistor wasn't able to close off by itself. The current rises quickly to the same value as in Figure 4, but the capacitor is slow to close off the error. A faster capacitor will be required to square up the corners on the square wave (remove 0.01uF SMT capacitor, add through-hole capacitor to C73*).

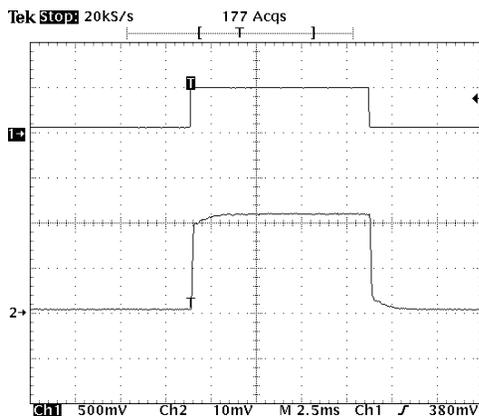


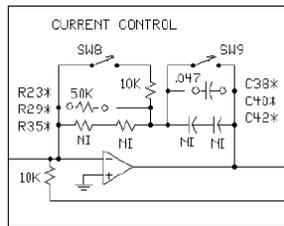
Figure 7: 240k resistor, 0.0025uF capacitor, SW3,4,7 OFF

The 0.0025uF does a better job of closing off the steady state error, but the leading corners are still rounded. This tuning is sufficient for this application; however if better response is required, continue to decrease the capacitor value until the desired response is achieved.

Example 4: Low Torque Ripple Application

This system uses a sinusoidal (S-Series) drive to reduce the torque ripple in the application. During operation, there is much more torque ripple than was expected.

The first step is to look at the current loop response and try to tune the drive using the DIP switches.



DIP switch SW8 is on by default, so the proportional gain resistance is 8.3k (50k and 10k in parallel). The 50k resistors and 0.047uF capacitors in

the three current loops are through-hole components in pin receptacles on S-Series drives for easy component changes if neither SW8 position gives sufficient current loop performance.

The following scope images show the commanded signal on channel 1, and the current output on channel 2. The command signal scaling is 100mV per division. The current output scaling is 200mA per division. The amplitude of the current step should be adjusted to match the expected current step when the system is in operation. In this case the command signal amplitude was adjusted so the current output was a 400mA step.

During operation, the S-Series drives generate a sinusoidal current in each phase as the motor turns. To verify that the commutation will be smooth, the sine wave response should be looked at, as well as the square wave step response.

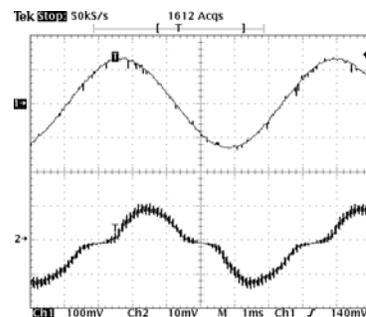


Figure 1: Sine wave response with SW8 ON, SW9 OFF

Current Loop Tuning Procedure

With SW8 ON, the gain resistance is 8.3k. The standard capacitor value is 0.047uF. It is easy to see where the torque ripple is coming from. Since torque is proportional to the current in the motor, the dead band in the sine wave shows up as torque ripple.

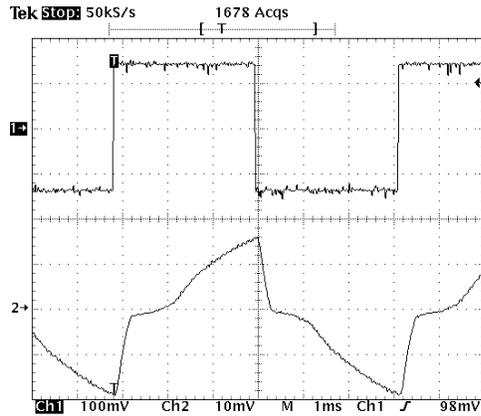


Figure 2: Step response, SW8 ON, SW9 OFF

From the square wave step response, it is easy to see that the drive is very mistuned. The next step is to look at the step response with the capacitors shorted.

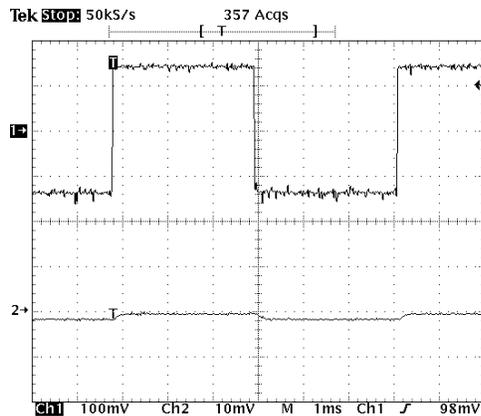


Figure 3: Step response, SW8 ON, SW9 ON

It is clear now that the proportional gain is set much too low. Almost all of the current response was driven by the integrator capacitor. Without the capacitor, there is almost no response.

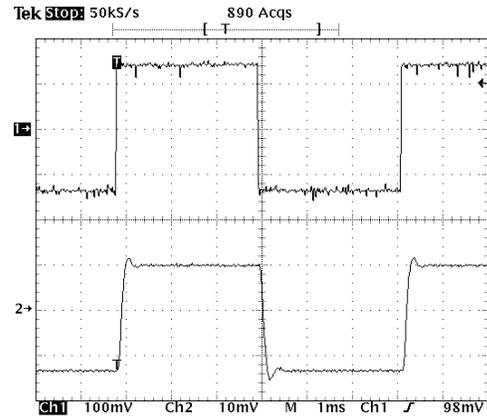


Figure 4: Step response, SW8 OFF, SW9 ON

With SW8 off, the gain resistance is 50k. This gives a very good response with some overshoot. The overshoot can be addressed by trying smaller gain resistor values, however in this case we will stay with these values.

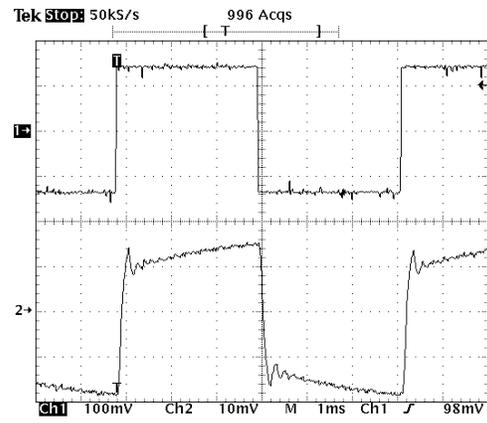


Figure 5: Step response, SW8 OFF, SW9 OFF

With the standard capacitor values added back in, the steady state error is being closed off, but not very quickly. A faster capacitor should be tried. Also, the proportional gain value may need to be looked at again, since the overshoot is now more pronounced.

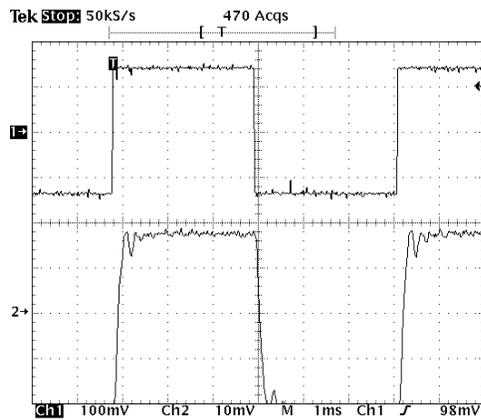


Figure 6: Step response, SW8 OFF, 0.0056uF capacitors

The 0.0056uF capacitor does a much better job of closing off the steady state error. Everything looks good about this square wave except the initial oscillation at the leading edge of the square wave.

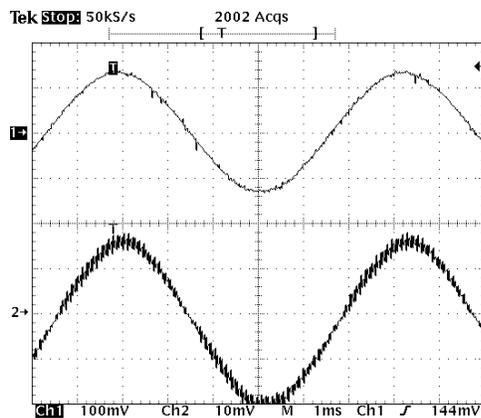


Figure 7: Sine response, SW8 OFF, 0.0056uF capacitors

The sine wave response has been greatly improved. There is no longer any dead band, so there should be little or no torque ripple caused by the drive. The oscillations at the peaks of the sine wave are probably related to the overshoot that was seen in the step response in Figure 6. It would probably be best at this point to run the drive in the system to see if performance is acceptable. If not, the tuning can be refined.