

Parameterization of spreadCycle™

Valid for TMC26X, TMC2660, TMC50XX, TMC21XX and TMC51XX, TMC220X, TMC222X and TMC389

This application note is meant to be a practical guideline for parameterization of the TRINAMIC ICs with spreadCycle™ chopper. *In order to understand where to find the parameters mentioned, and how to set them, please refer the specific product documentation.*

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1 Optimizing Chopper Settings

Chopper settings can easily be optimized by watching the motor axis behavior and feeling motor vibration with your finger tips, and by optionally measuring the motor current with an oscilloscope. The following description shall give a guideline to come to good chopper settings for your application with a minimum time-effort.

1.1 Motor Settings

As a first step, you should understand which parameters have a direct or indirect influence on the chopper settings, and thus should be selected before starting optimization.

Parameter	Description	Setting
Motor type	Each motor type has unique characteristics like torque curve, inductivity, back-EMF, microstep quality and coil resistance.	Choose a motor fitting your requirements based on the motor torque curve, cost, current, etc. Generally a higher current winding will bring higher velocity limits.
Driver supply voltage	Motors cannot operate well below or above their specific voltage limits.	As a guideline, satisfy: $R_{COIL} * I_{COIL} \ll VS < 25 * R_{COIL} * I_{COIL}$
Motor coil current	Normally, stepper motors work best at their nominal current, as they provide the highest torque and lowest relative torque ripple. However, factors which might lead to operation at reduced current levels are 1. Reduction of power dissipation 2. Standby operation	As a guideline operate a stepper at 50% to 100% of nominal current. A short time increase using coolStep™ will provide for extra torque, while the nominal current can be reduced. In standby, current can be reduced down to zero, depending on mechanics and application.

Parameter	Description	Setting
Velocity	There are three basic ranges: 1. Low velocity (slow, a few microsteps per second) – here the microstep performance is most important for equidistant steps 2. Medium velocity (motor turning faster) – the optimum sine waveform can be reached, because the back EMF voltage is still below the supply voltage V_s 3. High velocity (motor at several rounds per second) – the sinusoidal target waveform cannot be reached any more. The waveform becomes distorted and motor torque drops with increasing velocity.	The motor behavior can be optimized for all of these velocity ranges. Range 1 (slow) and 2 (medium) can be optimized together. Range 3 (fast) might profit from fullstepping and thus can be optimized separately, in case the optimization for range 1 and 2 does not prove sufficient for the application.
Chopper frequency	The chopper frequency is determined by many parameters. Basically, it usually should be outside the audible range, i.e. above 16 to 20kHz, but not too high, i.e. below 50kHz, in order to limit switching losses in the motor and the power driver.	Try to keep chopper frequency low, but above the audible range. For highest velocity operation, a higher frequency may be beneficial.
Waveform	For most stepper motors a sinusoidal waveform is a good approach. Specific applications requiring most equidistant microsteps may profit from an adapted microstep waveform.	The waveform can be best optimized when using a high resolution encoder or a laser pointer attached to your motor and moving the motor at very low velocity.

Table 1 Parameters which should be considered before optimizing chopper settings

2 Qualitative Approach for a Two Phase Stepper

We will optimize motor settings for the required velocities sequentially; however one or more iterations might be taken in case a single set of settings is desired.

2.1 Preparations

Take your motor into operation at nominal conditions. Attach an oscilloscope with current probe to one of the motor coils, if possible. You might measure the coil voltage to assess the chopper frequency. In case you have access to the sense resistors, measure the voltage over one or both sense resistors. This way, you do not need a current probe.

1. Select proper hardware settings like blank time TBL .
Hint: A too low TBL will lead to distorted sine waves, but the value should not be unnecessarily high. $1-2\mu s$ ($TBL=1$ or 2 at $16MHz$ clock frequency) is a good starting point.

2. Switch on spreadCycle chopper mode ($chm=0$)

3. Choose an off-time setting t_{OFF} in the range of $5\mu s$ to $20\mu s$

$$TOFF = \left\lceil t_{OFF} * \frac{f_{CLK}}{32} - \frac{12}{32} \right\rceil$$

4. Choose a hysteresis end value of 5 to 12, e.g. 10, and write it to $HEND$ ($HSTART=0$, $HEND=13$). Remember, that $HEND$ uses an offset of -3, $HSTART$ uses an offset of +1.

2.2 Low and Medium Velocity Optimization

In the low and medium velocity range, the motor is to work with equidistant steps, lowest possible vibration, and low chopper noise. Use highest possible microstep resolution for your tests.

Operate your motor at a medium velocity. Try feeling motor vibrations at different velocities with your fingertips. Try seeing and feeling microstep equidistance at very low velocities.

Hint: A long pointer attached to the motor axis will help checking microstep performance at lowest velocity.

You might want to check the current waveform using an oscilloscope. The oscilloscope should show a pure sine wave as shown in Figure 1. In case, the sine wave is distorted like shown in Figure 2.2, the motor velocity is too fast, or the supply voltage is not high enough. A distortion as shown in Figure 2.3 is a hint for a too low blank time setting. Increase *TBL* by one. Other distortions are a hint to a layout problem.

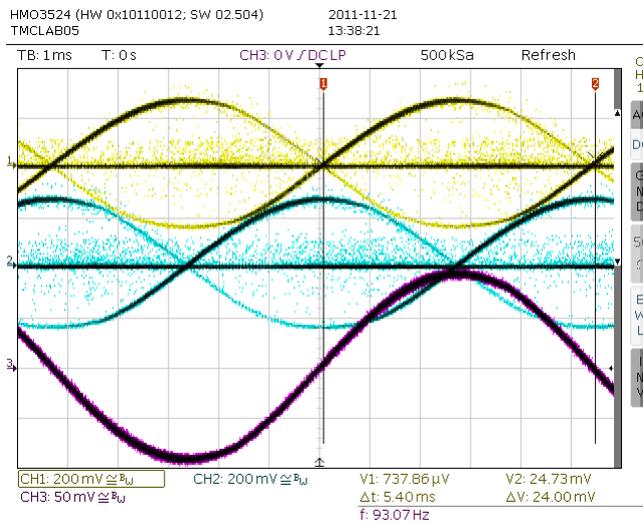


Figure 2.1 Current waves. CH1 & CH2: Sense resistor voltages, CH3: Current probe on coil A

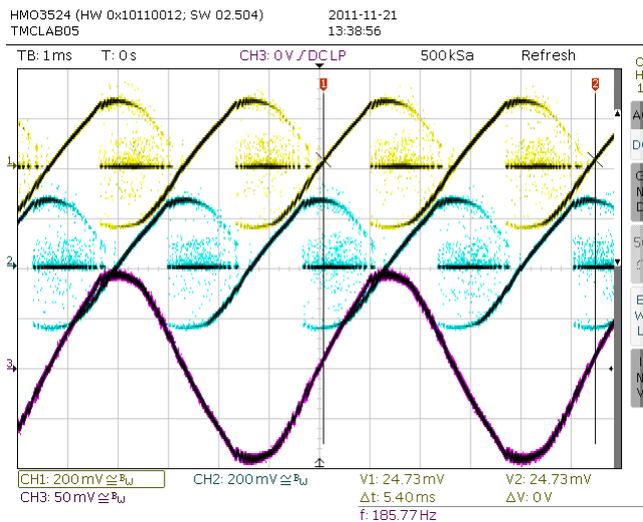


Figure 2.2 Velocity too high – motor current cannot follow

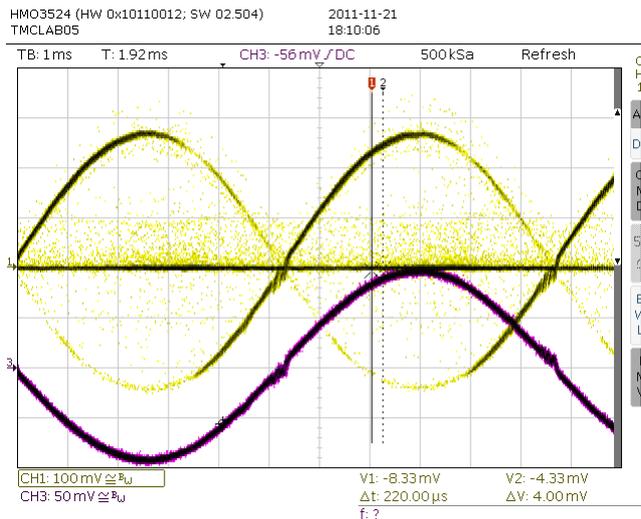


Figure 2.3 Distortion caused by too low blank time setting TBL

2.2.1 Optimize Chopper Settings – Behavioral Approach

1. Now, reduce hysteresis to 0 (e.g. $HSTART=0$; $HEND=2$). You should perceive increased motor noise and less equidistant microsteps. Vary the motor velocity, if you do not perceive any difference in motor vibration between hysteresis 0 and the previous hysteresis value. When observing microstep equidistance at very low velocity, the motor will make a few shorter steps in intervals matching to the microstep resolution – this will look like the motor pausing and continuing rotation once at each halfstep position.

Increase the $HEND$ hysteresis setting, until motor vibration does not reduce further or microstep equidistance does not benefit anymore from a further increase. Do one or two additional increments if in doubt, to compensate for stray of analog parameters, like supply voltage, etc. If you reach the limit of $HEND$ setting ($HEND=15$), you can increment $HSTRT$ up to $HSTRT=3$.

2. In case, you end up with a hysteresis setting higher than 15, or the chopper frequency becomes audible (high pitch chirping), reduce off-time ($TOFF$) and go back to step 1.
3. Try increasing off time ($TOFF$) and find the value where audible chopper noise occurs. Go back by some steps again and go back to step 1 with the new setting. This way, the chopper frequency becomes reduced, in case it was higher than necessary.

2.2.2 Optimize Chopper Settings – Measure with Oscilloscope

1. Stop the motor at a position, where one coil current has a medium value, e.g. at a fullstep position. Attach the oscilloscope probe and measure sense resistor voltage to GND. Take a single shot of one or a few chopper cycles as shown in Figure 2.4 (showing a chopper operating at 40kHz).

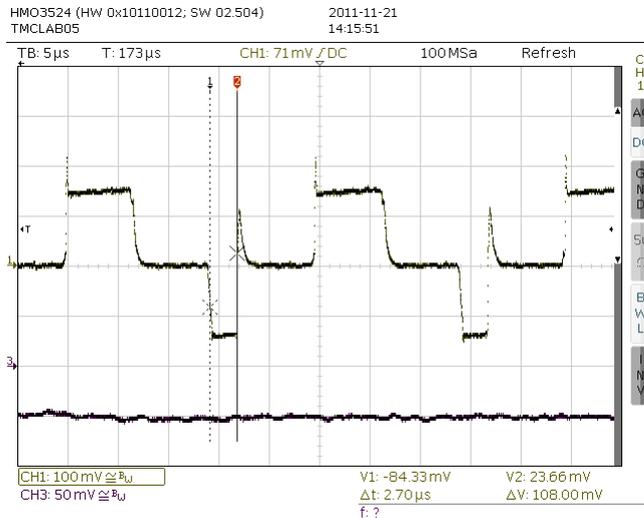


Figure 2.4 Measure the duration of the fast decay state (2.7µs): CH1: sense resistor voltage, CH3: coil current

2. Check the duration of the fast decay cycle as shown – the duration will vary slightly from cycle to cycle. Its (estimated) medium duration should be slightly larger than the blank time t_{BLANK} (see table). In case, the duration is too short, increase the *HEND* hysteresis setting. If you reach the limit of *HEND* setting (*HEND*=15), you can increment *HSTRT* up to *HSTRT*=3. In case the duration is much longer than t_{BLANK} , reduce the hysteresis.

Parameter	Description	Setting	Comment
<i>TBL</i>	Selects the comparator <i>blank time</i> t_{BLANK} .	0	16 t_{CLK}
		1	24 t_{CLK}
		2	36 t_{CLK}
		3	54 t_{CLK}

Table 2 Blank time setting

3. Measure the chopper frequency. A frequency between 20kHz and 50kHz is a reasonable value. Decrease *TOFF* in case the frequency is too low, increment *TOFF* in case the frequency is too high. Go back to step 1, after changing *TOFF*.

2.3 Using Hysteresis Decrement

The hysteresis decremter will stabilize the chopper frequency in low voltage situations and when the motor back EMF comes near to the supply voltage at increased motor velocity. Therefore, two additional steps are required:

1. Now distribute the hysteresis value you determined to *HSTART* and *HEND* value. As a thumb rule, we will put 20%-30% of the hysteresis value to hysteresis start setting.

Example: In case you determined a hysteresis value of 10, set $HSTART=2$; $HEND=10$. Taking into account the offsets of +1 for $HSTRT$ and -3 for $HEND$, this results in hysteresis start = 3+7 and hysteresis end = 7.

2. Choose hysteresis decrement speed if your driver allows it. In case you target high chopper frequencies ($\geq 40\text{kHz}$), use 16 clocks ($HDEC=0$) setting. In case you target lower chopper frequencies (25 - 40kHz), you can increase to 32 clocks ($HDEC=1$), or for lower frequencies a higher setting. If hysteresis decrement shall not be used, put most of the value to $HEND$ or use highest $HDEC$ setting.

2.4 Stand Still Optimization

In standstill, chopper noise and position maintenance are the main targets of optimization. In case the current can be reduced to zero (driver off), chopper noise is zero, but the motor position must be maintained by mechanical friction. In order to keep the microstep target position, or in case increased holding torque is required, the motor current cannot be reduced to zero, but typically to 25% to 75% of operating current.

Put the motor to very slow motion but use the stand still current settings. One or a few microsteps per second will fit, in order to assess stand still chopper noise at different positions, as it will randomly occur at some microstep positions.

In case, stand still chopper noise is not an issue or is already good, you can skip this step.

Hint: Stand still chopper noise often can only be assessed in a quiet environment, as it should be barely audible

1. Try increasing the chopper frequency by reducing $TOFF$ setting to reduce audible noise at noisy positions. You might also try reducing the chopper frequency, as mechanics transmits different frequencies with different quality.
Hint: After modifying $TOFF$, you might need to optimize low and medium velocity chopper settings again.
2. Try switching on random off time ($rndtf$). This will spread the spectrum of noise.
3. In case your driver supports chopSync™, switch on chopSync™ alternatively to $rndtf$. Use a frequency f_{SYNC} near your target chopper frequency. Reduce $TOFF$ by a few decrements to ensure that the native chopper frequency is lower than the chopSync™ frequency.

$$SYNC = \left\lfloor \frac{f_{CLK}}{64 * f_{SYNC}} \right\rfloor$$

In case switching on chopSync™ leads to half the desired chopper frequency becoming audible, reduce $TOFF$ or increase SYNC.

Additionally, select a velocity threshold $VHIGH$ at low or medium operating velocity, above which chopSync™ becomes switched off, as it will lead to worse motor noise at increased velocity.

Hint: After switching on chopSync™, you might need to optimize low and medium velocity chopper settings again.

4. Try reducing motor current further, if feasible.
5. Use a set of *good microstep positions* in standstill by always positioning to these positions. A good microstep position will reoccur at a distance of one fullstep. Read out the microstep pointer to make sure that you stop at the same position.

Attention: Excessive standstill chopper noise often is a hint to a bad PCB layout.

2.5 High Velocity Optimization

At high velocity, the motor resonance must be kept low, in order to maintain torque as high as possible. Microstep waveforms play a reduced role, as the waveform cannot be maintained in this velocity range anymore (see Figure 2.2), getting worse with each increase in velocity. Fullstepping sometimes brings a few percent increased motor torque. For high velocity behavior, it is more important to operate the motor with its application specific load or in its application environment, but you can do first tests by braking the motor with your fingers, in order to assess its torque before it stalls.

You can test high velocity behavior by slowly accelerating the motor to the target velocity. In case, your motor has high resonances or even stalls, before it reaches the target velocity, retry with a faster acceleration, and try to make sure that you skip the critical velocity in your later application. At extremely high velocities, the impact of mechanical motor load and mounting conditions is larger, as the driver cannot control the current waveform anymore (compare Figure 2.7)

1. You might decide to increase chopper frequency for high velocity operation by reducing *TOFF* setting. A setting in the range of two to four often gives the optimum performance for highest velocity. A higher chopper frequency reduces the response time of the chopper.

Hint: After modifying *TOFF*, you might need to optimize low and medium velocity chopper settings again.

2. Try switching the motor to fullstepping, if your driver supports it. Make sure, that the driver coils see a fixed current. Therefore it is important to switch to fullstep at or near the fullstep positions (TMC26x based drivers) – compare Figure 2.5. Set *vhighfs* (for TMC5XXX drivers).
3. As fullstepping does not require high precision chopper operation, you can try to switch to slow decay only chopper – compare Figure 2.6, e.g. by setting *vhighcm* (for TMC5XXX drivers).
4. Figure out a velocity threshold *VHIGH* for switching to fullstepping. The threshold can be determined using an oscilloscope and finding the velocity, above which the microstep sine wave cannot be maintained, as shown in Figure 2.2, or, by assessing motor noise and vibration.

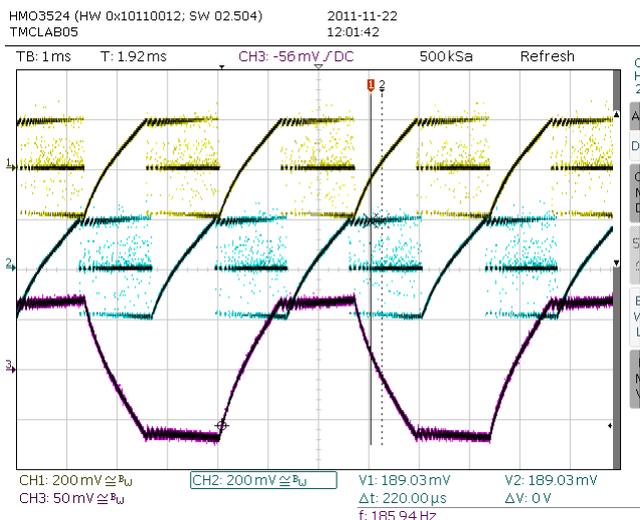


Figure 2.5 Motor in fullstep operation (CHM=0); CH1 & CH2: Sense resistor voltages, CH3: Current probe coil A

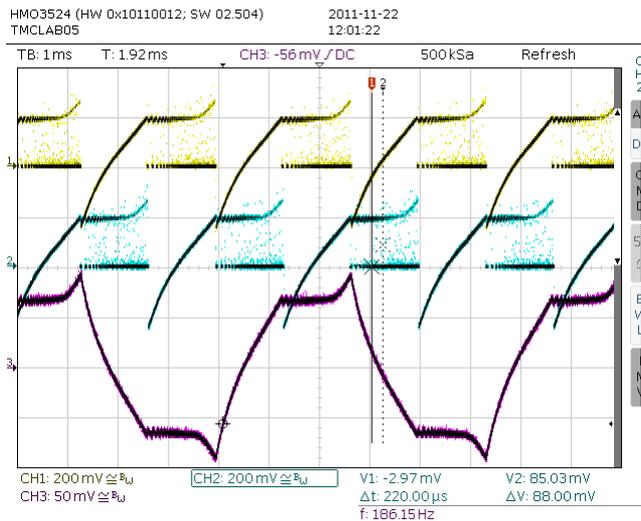


Figure 2.6 Motor operation in fullstep with slow decay only (CHM=1)

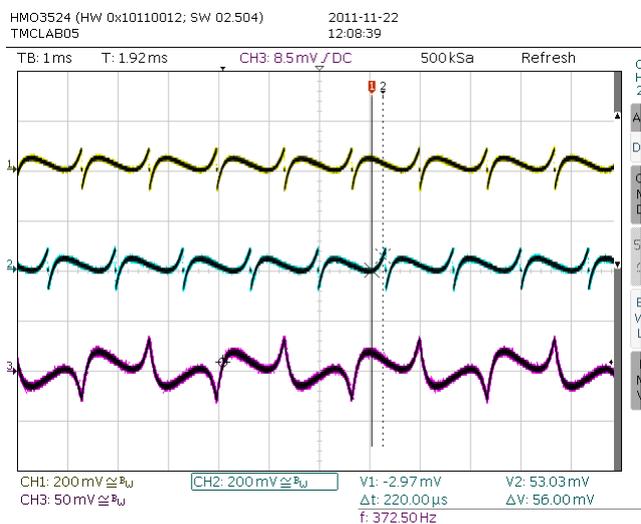


Figure 2.7 Motor operation at very high velocity

2.6 Low Inductivity Motor Optimization Example

Low inductivity motors allow high velocity operation. On the other hand, chopper ripple may become excessively high, because the coil current raises and falls quickly due to the low inductivity. This example guides through the optimization with an example motor using a TMC5130-EVAL. The result may be used also for all spreadCycle drivers, like TMC2130.

Motor: QSH4218-47-28-040 (0.50hm, 0.6mH)

Checking performance using Eval board default settings

Standard settings: Velocity=200 000 for all measurements (about 4 RPS).

Rsense=0R15, IRUN=23

TOFF=5, HSTRT=5, HEND=3, TBL=2 (f=27kHz)

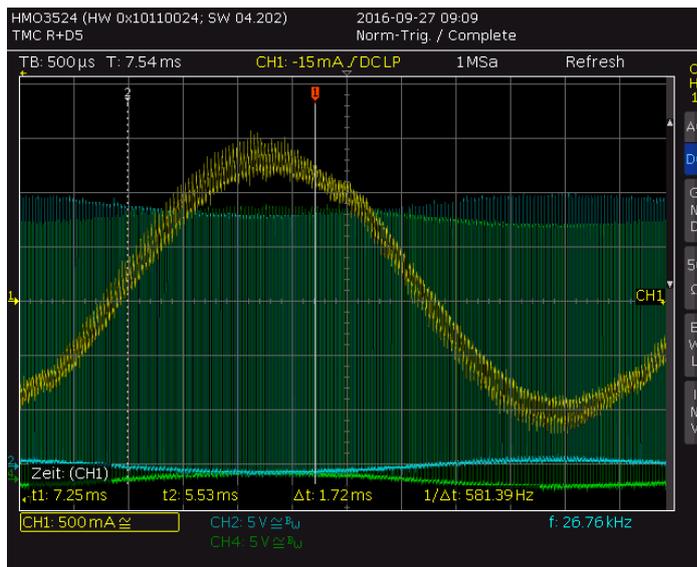


Figure 2.8 Scope shot with original settings: Wave is distorted (Yellow: Current, Blue and Green: voltage at driver outputs)

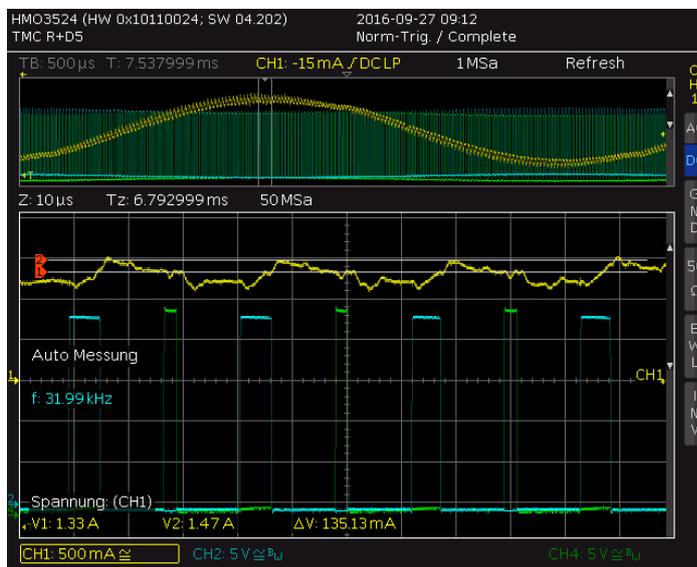


Figure 2.9 Scope shot with original settings (zoom) showing current ripple

Zoom: The motor loses about 135mA in each slow decay period. Part of this loss results from break-before-make time, which act like a fast decay. Over all current ripple is 300mA. This is much more, than the hysteresis chopper can do at maximum setting. Therefore the negative on (fast decay) cycle is at its minimum. The minimum duration is limited by TBL, as the chopper cycle cannot terminate before end of the blank time.

Improving Settings

From the measurement we can see, that the chopper frequency should be increased, and TBL should be reduced, if possible:

1. TOFF=2 → reduces peak current ripple from 300mA to 240mA
2. TBL=1 → reduces peak current ripple from 240mA to 200mA

Now the current wave looks better. Its shape is thinner, because of reduction of the current ripple from 300mA (Figure 2.8) to 200mA (Figure 2.10). Chopper frequency went up from 26kHz to 60kHz.

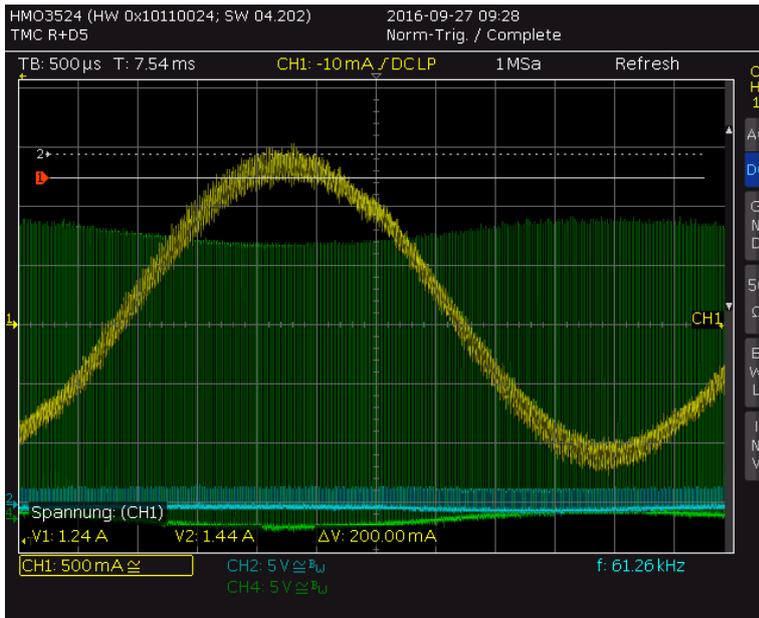


Figure 2.10 Reduced TBL=1 and TOFF=2

Still, the wave shows distortion, and the motor is noisier than it should be. To eliminate distortion, the chopper hysteresis has to cover the 200mA current ripple:

Increasing HSTRT=12 and HEND=8 improves the wave to a sine wave (*attention* – with this high setting of HSTRT and HEND IRUN must be 30 or lower (Figure 2.11)).

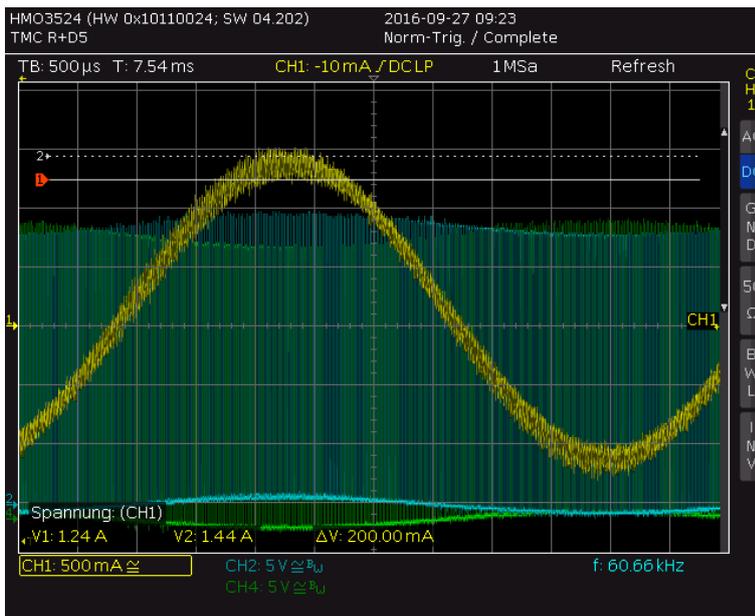


Figure 2.11 Increased Hysteresis HSTRT=8, HEND=12

3 Optimizing Chopper Settings for Classic Chopper Operation

The classic chopper mode can be used instead of spread cycle chopper, in case you want to try operation in this mode. For most motors it will be inferior to spreadCycle™. Similar to the descriptions on spreadCycle™, *TBL*, *TOFF*, *TFD* and wave offset (*OFFSET*) can be determined for *chm=1* based on motor resonance and microstep quality. The following scope shots are meant to give some hints on good and bad settings. The scope shots show: CH1 & CH2: Sense resistor voltages, CH3: Current probe on coil A.

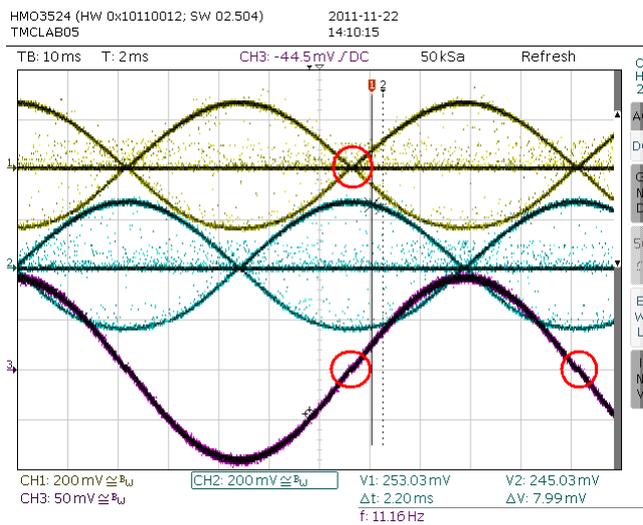


Figure 3.1 Offset too low (plateau in current zero crossing) – increase OFFSET

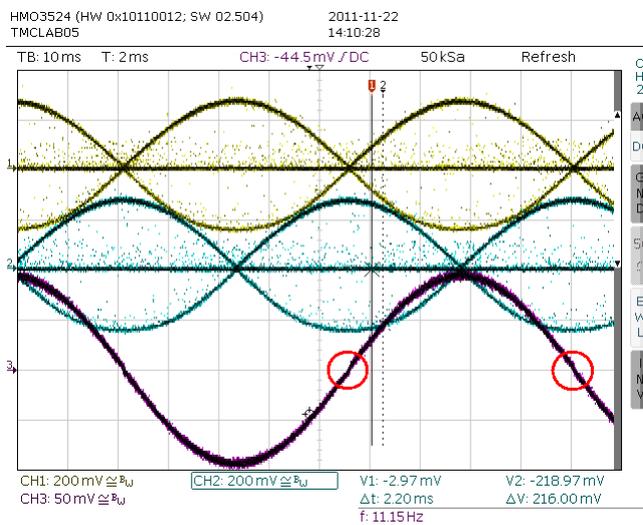


Figure 3.2 Offset too high (step in current zero crossing) – decrease OFFSET

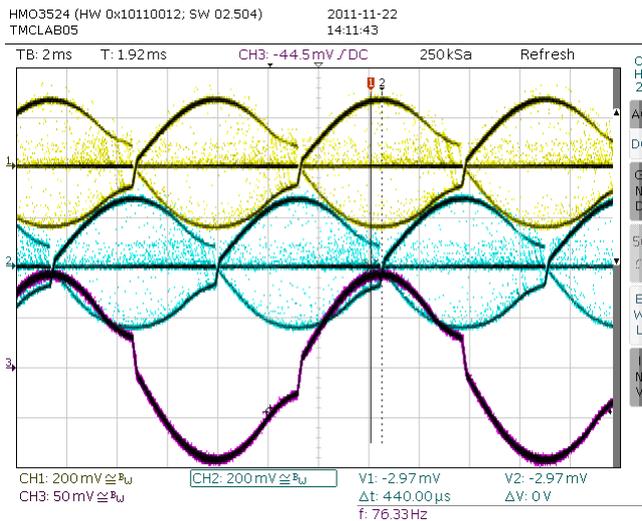


Figure 3.3 Fast decay portion insufficient at increased velocity (increase TFD or reduce TOFF)

3.1 High Speed Fullstepping with Slow Decay

Classic chopper especially is good for high speed fullstepping operation. This configuration also is used for dcStep™ operation. The TMC5130 and TMC2130 support a special high speed mode, switching the driver to fullstepping and slow-decay only mode. Figure 3.4 shows the waveform at both sense resistors at high speed. The wave shows, that the target current still is reached. When further increasing velocity, the target current cannot be reached any more. Torque sinks, and the wave looks similar to operation with spreadCycle at high speed (Figure 2.7).

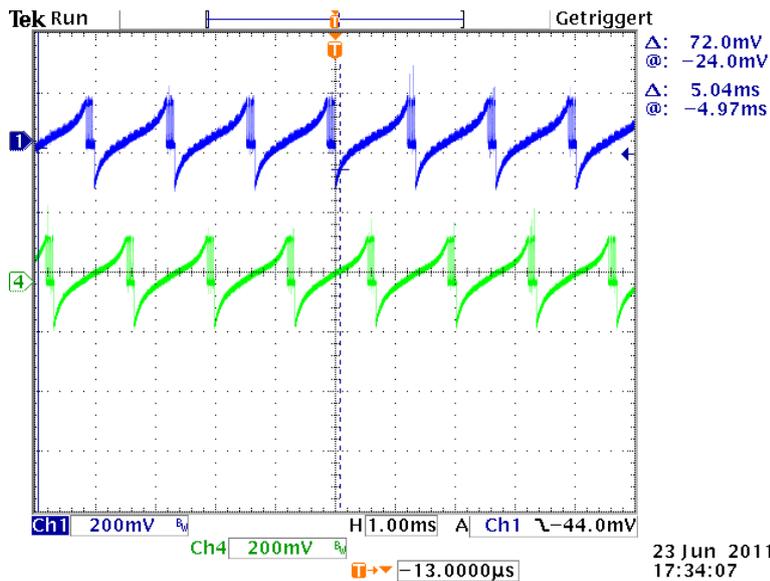


Figure 3.4 High Speed Fullstepping with Slow Decay only

4 Qualitative Approach to Optimize Chopper Settings for a Three Phase Stepper

A three phase motor differs from the two phase motor in one main aspect: Its coils have an internal interconnection. Thus, the chopper scheme differs. However, having taken into operation a two phase motor with spreadCycle™ chopper will allow you to get a three phase motor parameterized quickly.

We will optimize motor settings for the required velocities sequentially; however one or more iterations might be taken in case a single set of settings is desired.

4.1 Preparations

Take you motor into operation at nominal conditions. Attach an oscilloscope with current probe to one of the motor coils, if possible. You might measure the coil voltage to assess the chopper frequency. In case you have access to the sense resistor, measure the voltage over the single sense resistor, too. This way, you do not even need a current probe.

1. Select proper hardware settings like blank time *TBL* and motor current scale.
Hint: A too low *TBL* will lead to distorted sine waves, but the value should not be unnecessarily high. 1.5-2.5 μ s (*TBL*= 2 or 3 at 16MHz clock frequency) is a good starting point.
2. Choose an off-time setting t_{OFF} of two: *TOFF* = 2. Set the flag *nosd* in order to skip off time. Most motors will not need an additional off time in each chopper cycle.
3. As we will work with Step/Dir input, choose chopper direction UVW (*cdir*=1). This will always chop the coils in the same order as the motor runs, which is optimum. Let the chopper synchronization switched off (*csync*=0), as it is not needed unless you want to turn the motor quickly.
4. Choose a hysteresis end value of 5 to 12, e.g. 10, and write it to *HYST*.

4.2 Low and Medium Velocity Optimization

In the low and medium velocity range, the motor is to work with equidistant steps, lowest possible vibration, and low chopper noise. Use highest possible microstep resolution for your tests.

Operate your motor at a low to medium velocity. Try feeling motor vibrations at different velocities with your fingertips. Try seeing and feeling microstep equidistance at very low velocities.

Hint: A long pointer attached to the motor axis will help checking microstep performance at lowest velocity.

You might want to check the current waveform using an oscilloscope. The oscilloscope should show a pure sine wave as shown in Figure 4.1. In case, the sine wave is distorted like shown in Figure 4.2 or Figure 4.3, the motor velocity is too fast, or the supply voltage is not high enough. A completely distorted waveform at a low velocity is a hint for a too low blank time setting. Increase *TBL* by one..

For a three phase stepper motor operated with spreadCycle chopper, tuning of the hysteresis setting is most important – it trades chopper noise against accuracy. At the optimum setting, the motor runs smoothly. When increasing the hysteresis, chopper noise increases, but the motor does not benefit.

Tuning *HYST* setting:

1. Increase *HYST* coming from a low setting like 5. Stop as soon as the motor is not turning more smoothly with an additional increment. If checked with an oscilloscope, you will see the sine wave becoming more smoothly, but it is very hard to see distortion in the wave.
2. In case chopper noise becomes audible, increase supply voltage if possible, or decrease motor current. If there is no good setting, you will need to use a lower inductivity motor.

4.3 High Velocity Optimization

In the high velocity range (see Figure 4.2 or Figure 4.3), the motor is to work with low resonance. Best setting is typically with a synchronized chopper. Switching on *csync* will also not harm at low velocities, but you will see a little disturbance in current zero crossing when checking with an oscilloscope.

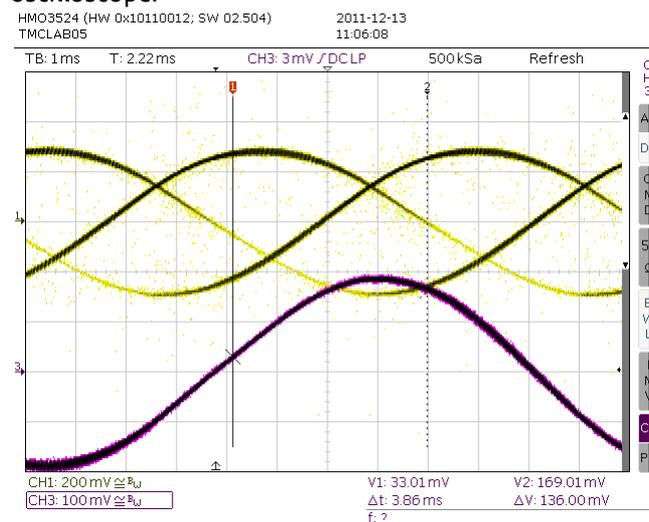


Figure 4.1 Three phase motor operating optimally - ch1: sense resistor, ch3: current probe

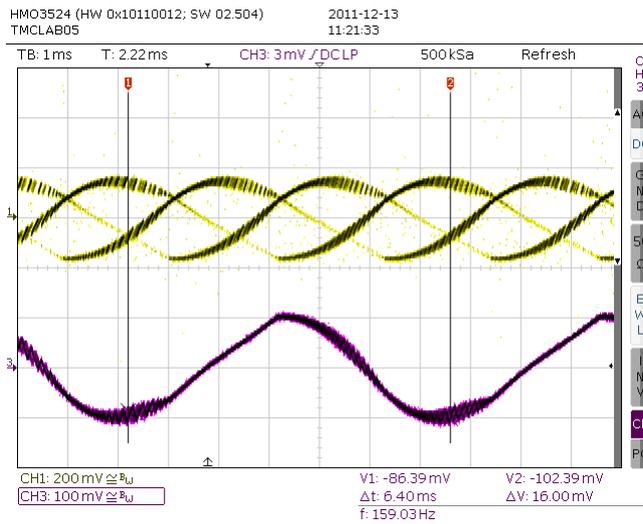


Figure 4.2 Three phase motor operating slightly above back EMF voltage limit velocity

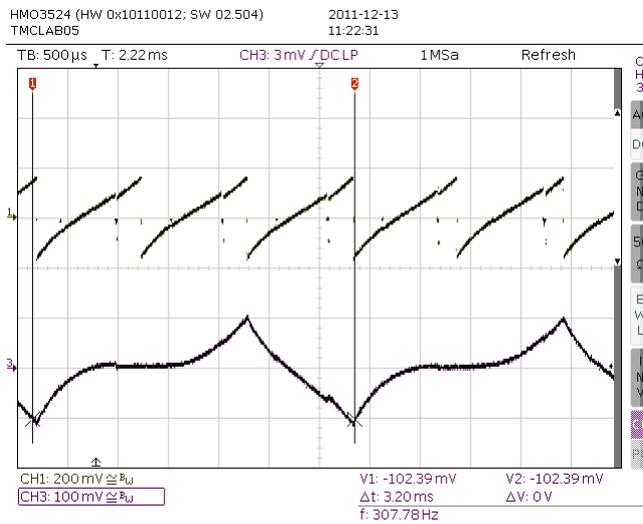


Figure 4.3 Three phase motor operating at high velocity with synchronized chopper (csync=1)

5 Chopper Noise Trouble Shooting Guide

Hissing or chirping chopper noise can be annoying. Especially in motor standstill, many applications are required to be silent. While the latest TRINAMIC drivers support stealthChop for absolutely silent motor operation, spreadCycle also provides a good performance when compared to traditional chopper schemes.

In case the optimization process described does not yield the desired result, additional measures can bring success.

Checklist:

1. PCB layout. The PCB layout is critical for optimum motor performance and for low chopper noise. As the chopper for both coils of a two phase motor run independently, any coupling between them will lead to interdependent modulation. This modulation results in current variation, which can cause vibration of the motor as well as audible noise caused by magnetostriction within the motor. The most critical point is the tight and symmetrical connection between sense resistor ground and driver chip ground, because the sense resistor voltage measurement determines the motor current and is related to the common ground. Please refer to [AN011 - Good Ground Connections](#).
2. Choice of driver clock frequency. As a higher chopper frequency will generally reduce audible noise due to both, reduction of current ripple as well as shifting the frequency out of the audible range, as a first measure chopper off time and hysteresis can be reduced. An increase in driver clock frequency can additionally support this measure, especially when the original frequency was low, e.g. 10 MHz or less.
3. Choice of motor and supply voltage. A low and audible chopper frequency can result from low headroom between nominal motor voltage (Coil resistance multiplied by motor current) and supply voltage. Increasing the supply voltage to at least the double nominal motor voltage, or choosing a motor with higher current winding will often eliminate chopper noise.
4. Choice of motor type. Some motor types are very prone to audible amplification of chopper noise, due to certain materials or mounting processes used. Try a different manufacturer.

6 Revision History

6.1 Document Revision

Version	Date	Author BD - Bernhard Dwersteg SD - Sonja Dwersteg	Description
0.10	2011-NOV-24	BD	First preliminary version
1.00	2012-FEB-06	SD	First complete version
1.01	2012-AUG-30	SD	Chapter 2.4: information about good standstill position added
1.02	2015-FEB-18	BD	Added chopper noise trouble shooting guide
1.03	2016-NOV-21	BD	Added example for low inductivity motor and scope shots for fullstepping

Table 3 Document revisions