AN49

Using the ZXBM1016 single-phase brushless DC motor pre-driver

Laurence Armstrong, Product Designer, Zetex Semiconductors

Device overview

The ZXBM1016 is a high efficiency, low noise, Single-phase DC brushless motor pre-driver. It can be controlled from a number of sources such as a PWM control signal or a thermistor. These signals are first converted into a voltage using conventional integrator or linearization techniques and this voltage is in turn used to control the amount of PWM applied to the motor coil.

The device contains proprietary circuitry to control and limit the current at the end of a commutation cycle, tail-end current control. This tail-end current control enables the use of lower rated H-bridge components to provide a more economic and higher efficiency solution. It is this area that will be discussed in detail here.

Tail-end current control is used to shape the current waveform of a commutation cycle. It ensures that at the end of a commutation cycle the current is gradually reduced down to a minimal or zero value such that at the end of commutation there are no serious voltages and currents generated within the H-bridge part of the circuit.

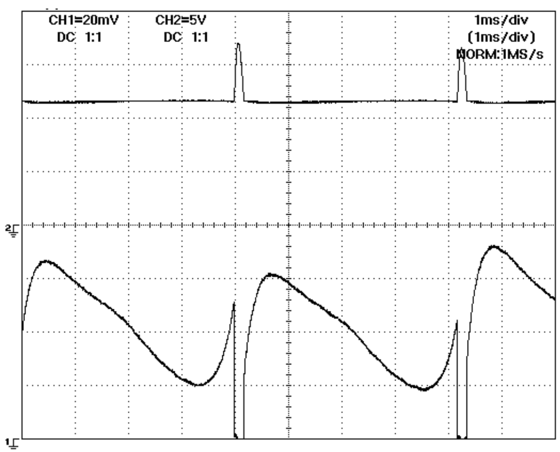


Figure 1 Current waveform and H-bridge supply without tail-end current contro

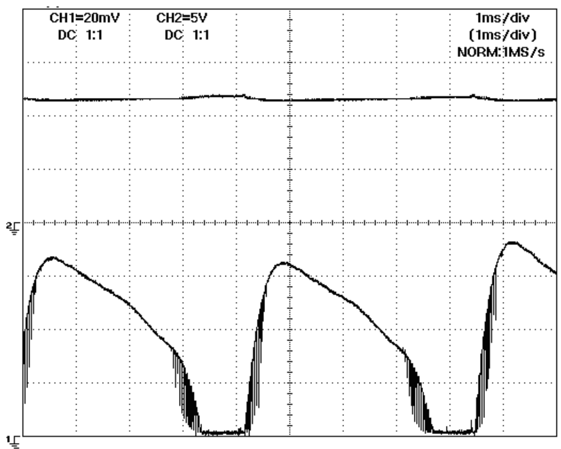


Figure 2 Current waveform and H-bridge supply with tail-end current control

The lower trace in Figure 1 shows a typical motor characteristic where, after reaching a low point, the current starts rising again towards the end of a commutation cycle followed by the abrupt turn-off of that current. The top trace shows the effect that the abrupt change has on the supply to the H-bridge as seen on the source of the high-side P-MOSFETs. These currents have in effect charge-pumped the supply. It is these voltages and currents that result in the over specifying of the H-bridge components.

The similar traces in Figure 2 show how the ZXBM1016 has removed the current at the end of the commutation cycle together with the resultant voltage spike on the H-bridge supply. The only variation left on supply to the H-bridge is as a result of the forward volt drop of the series blocking diode varying with the forward current.

The advantage, therefore, of the tail-end current control is it removes the problem and thus the need to over specify the H-bridge components therefore for a 12V system it becomes possible to use not only 30V rated devices but also devices with a lower current rating.

During the development stage of a new product however, it would be prudent to perform the bulk of the setting-up of the ZXBM1016 with 60V components. This alleviates any possible damage to H-bridge devices should the ZXBM1016 be accidentally be taken out of tail-end current control for whatever reason. Having established correct operation of the tail-end current control, the H-bridge can be converted to the desired 30V devices for the last stages of the testing and evaluation.

If 20V MOSFET devices are being considered special care will be needed as their lower Gate to Source voltage rating can be a restriction.

Typical application circuit

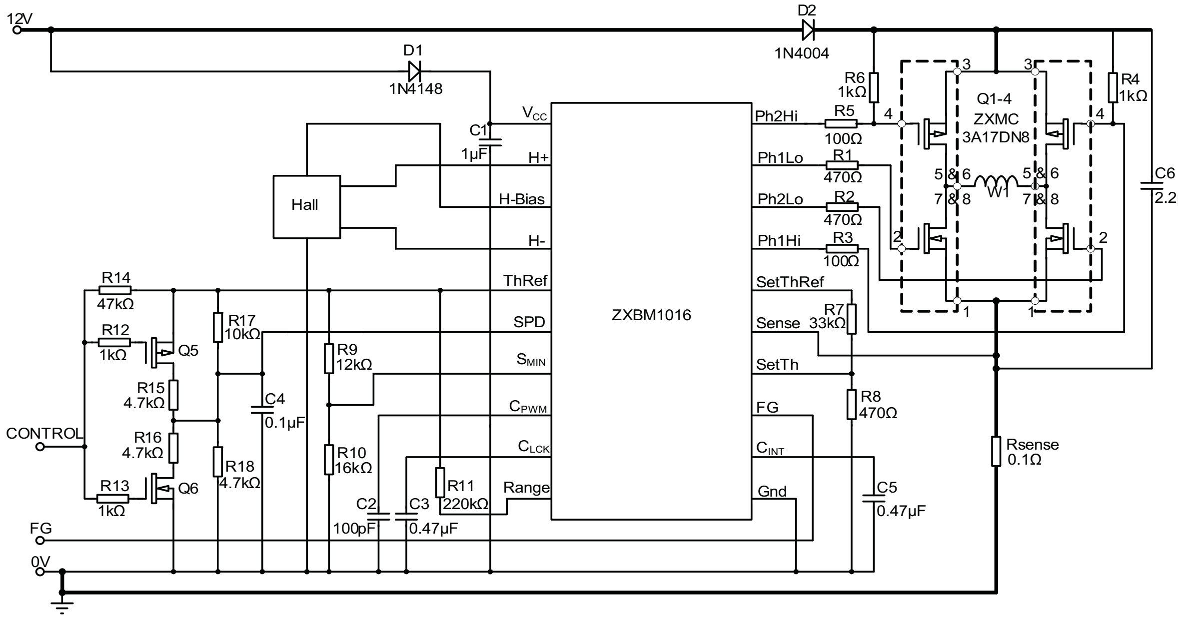


Figure 3 ZXBM1016 Typical applications circuit

The typical applications circuit shown in Figure 3 will be the circuit used as the basis for discussion here. This is the circuit used where speed control is required from an external PWM source. The incoming PWM signal is applied to the Control input.

External component description

- PWM to voltage integrator; R12 to R18, Q5 and Q6, C4
- Set minimum speed; R9 and R10
- Set PWM frequency; C2
- Set current limit; R7, R8, R_{SENSE}
- Start-up and Lock timing; C3
- Set tail-end current operation; C3, C5, R11
- H-bridge drive; R1 to R6, Q1 to Q4

External component set-up

The functions of the components as mentioned above are discussed in detail together with how their variation impacts the overall circuit function.

PWM to voltage integrator; R12 to R18, Q5 and Q6, C4

The PWM Integrator is designed to convert an incoming PWM control signal into a voltage for use by the ZXBM1016. This voltage is acted upon and subsequently altered by the ZXBM1016's current control circuit, its minimum speed circuit and the tail-end current control circuit.

The normal response for the PWM to voltage integrator circuit is for it to give out a straight line or linear characteristic. As the voltage control range for the ZXBM1016 is from 1V for 100% speed, to 3V for 0% speed the PWM integrator should give out 3V for 0% PWMin, 2V out for 50% PWMin and 1V out for 100% PWMin.

The advantage of the 2 transistor integrator shown is that this response can be tuned. When R15 = R16 the response is a straight line characteristic. If R15 was made larger than R16 then it will slew the speed to the faster side of the straight line. If R15 was smaller than R16 the speed will be slewed to the slower side of the straight line. The characteristics of how the integrator output voltage and the resultant speed varies with the incoming PWM signal are shown in Figure 4.

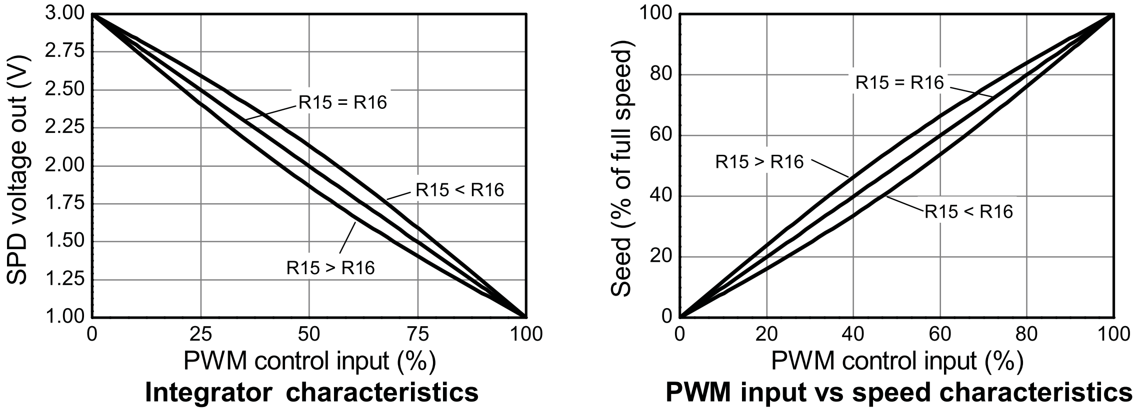


Figure 4 The effect of varying R15 and R16 on the PWM integrator linearity

The voltage extremes for full and zero speed are set by the combination of R15, R16, R17 and R18. R15 in parallel with R17 forms a potential divider with R18 to set the high 3V level for zero speed whilst R16 in parallel with R18 forms a potential divider with R17 to set the low 1V level for full speed.

For the tail-end current control to be effective the combined value of R16/R18 should be >2.2kΩ.

The capacitor C4 is the smoothing capacitor for the PWM to voltage integrator. The ZXBM1016 also uses this capacitor to shape the control signal for tail-end current control. This will be discussed in more detail later.

Set minimum speed; R9 and R10

R9 and R10 form a simple potential divider to set the voltage for the minimum speed at the S_{MIN} pin. This voltage is compared with that from the integrator and restricts the integrator voltage from going above the voltage set on S_{MIN}. For example, if a minimum speed of 25% of full speed is needed then 2.5V would be set on the S_{MIN} pin. So, if the integrator voltage at SPD tries to go above 2.5V the voltage at SPD will be clamped to 2.5V.

The minimum speed needs to be set as low as possible for lowest level of noise during start-up yet just fast enough to ensure the motor will actually start at minimum speed.

Set PWM frequency; C2

This sets the internal PWM generator frequency and will normally be a 100pF capacitor for a 25 kHz nominal frequency.

Set current limit; R7, R8, R_{SENSE}

These components set the maximum value of current taken by the motor at start-up and as the motor is run under heavy load, perhaps as it enters a stalled or lock condition. Once stalled the motor will go into its start-up routine where the coil PWM is reduced to its minimum speed value.

R_{SENSE} would normally be a 100mΩ resistor and will therefore drop 100mV at 1A and 200mV at 2A. If the maximum current to be taken needs to be restricted to 2A the voltage at the SetTh pin needs to be set to 200mV using R7 and R8. R7 would normally be 470Ω with R8 chosen to give the required voltage at the SetTh pin. R7 also sets the effective gain of the current control loop so reducing the value will give a 'tighter' response to the current limit whereas a larger value will allow a softer response where the current may overshoot slightly. The combined values of R7 and R8 should not be less than 25kΩ in total.

Start-up and Lock timing; C3

The device has the conventional method of lock protection. Under stalled conditions the motor will try the restart for a defined period. If it fails to start it will then wait for a short time before attempting to restart again. The cycle is repeated until the motor restarts or the power is removed. This period of try and wait is defined by the capacitor C3. A 0.47µF capacitor will typically give a 1.5s try period followed by a 2s wait.

The wait timing is shorter than would normally be expected as the device will perform its auto restart at its minimum speed level of coil PWM. This will limit the dissipation within the power devices and coil to a lower level than is normally the case. This therefore alleviates the need for a longer wait time.

Set tail-end current operation; C3, C5, R11

The effectiveness of the tail-end current control is dependant upon the values of the C_{LCK} capacitor C3, the C_{INT} capacitor C5 and the Range pin setting resistor R11.

The tail-end current control acts upon the control voltage going into the SPD pin. It does so by applying current into the network that is external to the pin thus the values of these external (integrator) components can influence the response.

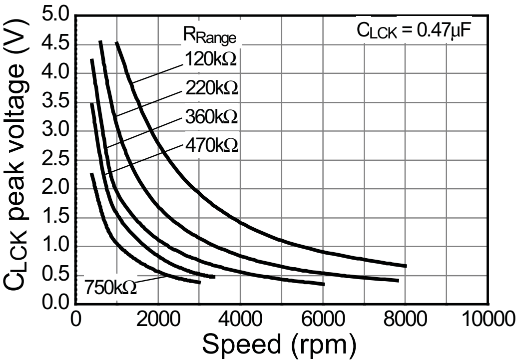
C3 also sets the start-up and lock timing. These functions need considering in conjunction with the tail-end current control. Under normal conditions C5 will be set to the same value as C3, however the effect of varying the ratio will be discussed later. Once C5 is set to the same value as C3 the tail-end current control will start to reduce the current from typically 75% of the way through the commutation cycle. The rate at which the SPD control voltage is backed off at the end of the cycle is then dependant upon the value of C4, the PWM integrator smoothing capacitor, i.e. its rate of charging.

Single-phase DC brushless motors come in a range of sizes and powers and thus have a large range of speed response requirements. A small high power motor, for instance, may have a top speed of 8,000rpm, or perhaps even 10,000rpm, yet a large axial fan or blower may only have a top speed of 2,000rpm to 3,000rpm. The Range pin is provided to set up optimum performance for each type with regards to its required speed range. The Range pin has a resistor, R11, to the ThRef voltage. This sets an internal current that is used to control the dynamic range of the device.

As well as the top speed the minimum speed also needs to be considered where speed control is used. The device will handle speed ranges in excess of 10:1, so for a motor that runs at a full speed of 8,000rpm its minimum speed can be 800rpm or lower.

The technique used to select the correct value for R11 (R_{RANGE}) is to set the motor running at full speed and to monitor the waveform on the C_{LCK} pin. The peak voltage on the C_{LCK} should be set between 400mV to 500mV by adjusting the value of R11.

In order to be able to set the value for R11 as close as possible in the first instance the following Figure 5 can be used. The graph shows the maximum speed that can be expected for some selected resistor values for a C_{LCK} value of 0.47µF. As it is a simple time constant effect, when using a larger value of C_{LCK} it will require selecting a lower value of R11 by a similar proportion.



Speed vs C_{LCK} peak voltage

Figure 5 Selection guide for R11 (RRange)

H-bridge drive; R1 to R6, Q1 to Q4

This is a conventional H-bridge power drive circuit, however, there is a specific consideration here that is of interest. When using lower value MOSFET devices there is an increased possibility of shoot-through currents due to their higher Gate capacitance.

As previously mentioned the advantage of tail-end current control is that lower voltage devices can be used for Q1 to Q4. This gives a more efficient solution as halving the voltage rating from say 60V to 30V will also halve the $R_{DS(on)}$ value of the MOSFET. The disadvantage however, is that reducing the voltage rating also increases the Gate capacitance. The Gate to drain capacitance of the P-MOSFET is of consideration to a designer.

If we consider the circuit in Figure 3 when Ph1Hi is on, Ph1Lo will be driven with a PWM signal. At this time Ph2Hi will be off. Whilst Ph1Lo is driving the PWM waveform it is switching on and off to provide an inverse signal on its Drain. It is this signal that drives the coil. This voltage on the Drain however, is only slightly less than the supply voltage so in this example the same voltage will therefore be present on the Drain of the high-side P-MOSFET device above it. If this voltage is switching too fast (high dv/dt) it is quite possible for the switching to pass through the P-MOSFET's Drain to Gate capacitance. This can create a signal on the Gate of the high-side P-MOSFET during low-side turning on of sufficient magnitude to momentarily turn the high-side device on. This device turning on causes shoot-through currents through the two devices. This, although only for a short period, <1µs, can be excessive and currents in excess of 10A are possible in worst case conditions.

If shoot-through does occur in a design there are three approaches that can be considered and a solution could well be achieved with either one or a combination of the three.

The first is to consider the edge speed of the low-side N-MOSFETs. By slowing down the edge speed there is less energy to be passed through the P-type Drain to Gate capacitance. The edge speed is controlled by using the Gate resistors R1 and R2. Increasing the values will slow the edge speed. The values of R1 and R2 can therefore be slowly increased until the condition is removed or minimized. Too slow an edge speed, however, should be avoided as this will increase the switching losses and could totally negate the efficiency savings made through using lower voltage devices. Also increasing of the Gate resistance tends to increase the turn-off time more than the turn-on time when it is the turn-on edge speed that is of interest. To counter the increased turn-off edge speed due to the increased Gate resistance an anti-parallel diode can be used across the Gate resistor.

A second method is to lower the resistor values of the high-side P-MOSFET drive circuit to make the Gate drive 'stiffer'. This involves reducing the values of R3 and R4 together with R5 and R6. The disadvantage to this approach is that it increases the static drive currents to the H-bridge. The recommended values of 100Ω and 1kΩ give a static current of 12mA. Halving the Gate resistor values will double the current so care has to be taken with this approach.

The third method, and probably the most robust is to add a Gate to Source capacitor to the P-MOSFET. This will act as a sink to the energy passing through the Drain to Gate capacitance. Again avoid too high a capacitance to avoid slowing the switching of the P-type device.

Whether you are likely to get shoot-through can be assessed by looking at the magnitude of the signal spikes on the P-MOSFET Gate during PWM switching of the low side device beneath it.

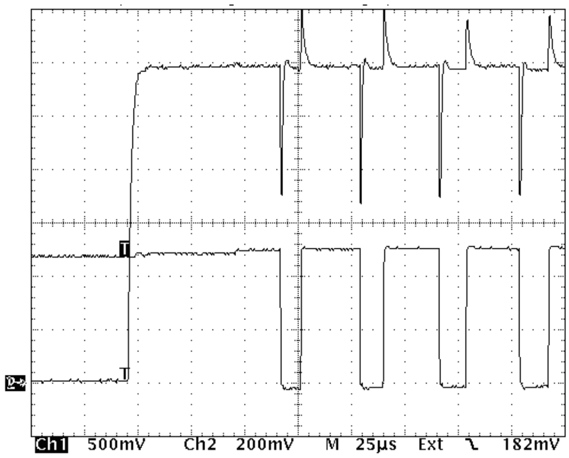


Figure 6 P-MOSFET Gate voltage (top - 2V/div) and coil voltage (lower - 5V/div) with shoot-through present

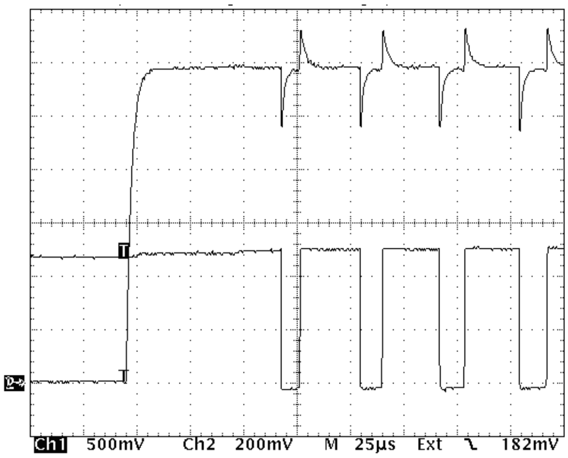


Figure 7 P-MOSFET Gate voltage (top - 2V/div) and coil voltage (lower - 5V/div) with shoot-through removed with 1nF Gate to Source capacitor

The plot in Figure 6 shows the Gate voltage on a high-side P-MOSFET when shoot-through was present. This is due to the Gate voltage being drawn down well below the threshold. A -5V Gate to Source voltage was present in this example. With a 1nF capacitor added across the Gate to Source as in Figure 7 this voltage is brought down to -2V and shoot-through has been removed. This is seemingly still above the specified Gate threshold voltage for the MOSFET of -1.5V, however, the Gate has not entered the enhanced region and so the level of current flowing will be in the range of a few milliamps. The 'On Resistance vs. Drain Current' graph in the datasheet of the MOSFET being used will give an indication of what level the Gate voltage spike needs to be reduced to so as not to present a problem.

Tail-end current control set-up

The effects that the various external components have on the tail-end current control operation of the device has been discussed. The description in the next section is more specific guidance towards getting optimum performance of the tail-end current control together with some possible problem effects and their solutions.

The main purpose when setting up the device is to attain a current profile as shown in Figure 2 when the motor is running at full speed i.e.100% PWM drive. The guidance given in the previous section and in the applications circuit in Figure 3 will attain such a result in most cases, however it is very much motor dependant and so some extra guidance will be given to help setting up and correcting problems in those instances.

When the device is running correctly at full speed the SPD pin should have a SPD and current waveform similar to that shown in Figure 8. In this the SPD voltage can be seen rising at the end of the cycle to back-off the PWM drive.

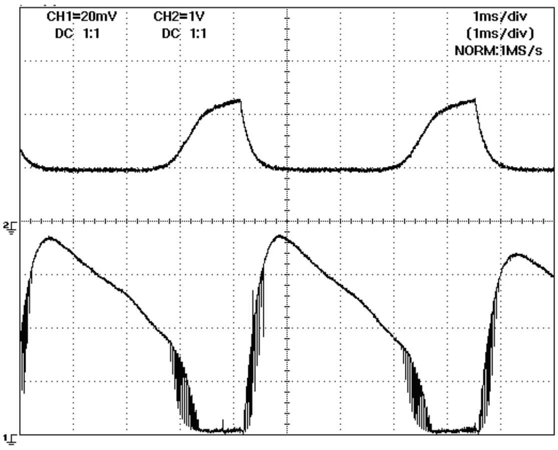


Figure 8 tail-end current control showing SPD control voltage waveform top

There is a large commutation delay following the ramp down of the current profile to the start of the next cycle. It is possible to reduce this, however, consideration needs to be given to when the motor is accelerating as this period will become much shorter.

To illustrate how a motor can influence the response the following scope plot, Figure 9 shows a different motor driven with the same circuit as that in Figure 8. Here the tail current ramp finishes more or less at the point of commutation.

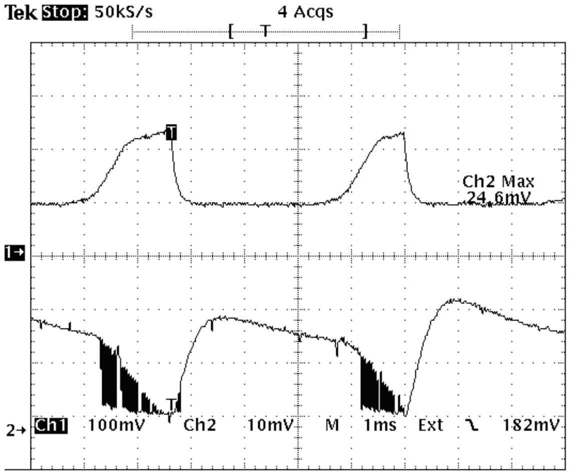
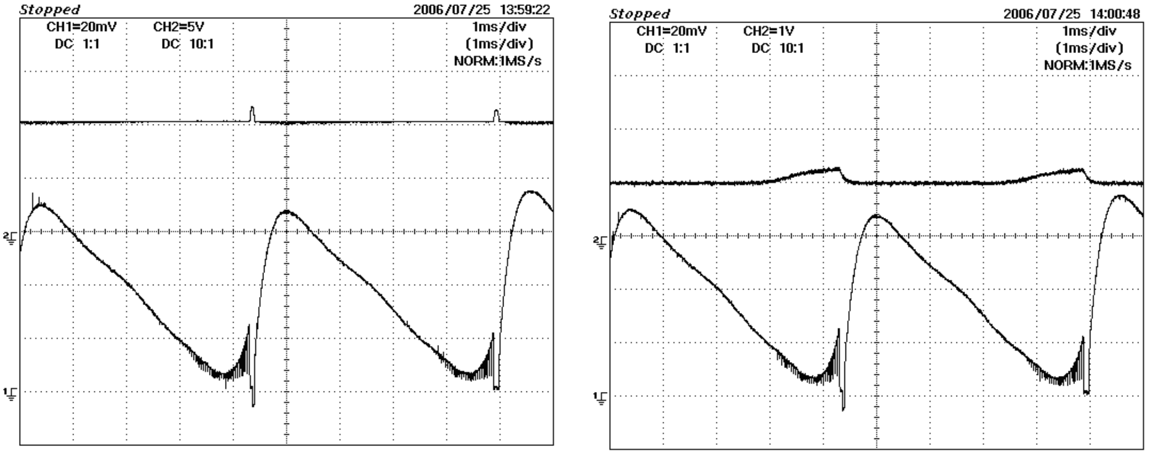


Figure 9 Influence of motor type on circuit performance. Same circuit as in Figure 8.
SPD - top (1V/div)
Motor current - lower (1A/div)

SPD external network impedance

A worse effect to that described in Figure 9 is when there is still some residual current at the end of the commutation cycle as illustrated in Figure 10. A probable cause would be if the Range pin resistor (R11) has not been set correctly and is too high in value for the motor speed. This may result in insufficient correction being applied at the end of the commutation cycle. It would occur in situations when the peak C_{LCK} voltage at full speed is too low and would result in a current profile as in Figure 10. It can be seen here that the control voltage has not been backed off sufficiently at the end of the cycle and results in a residual voltage spike on the H-bridge supply.



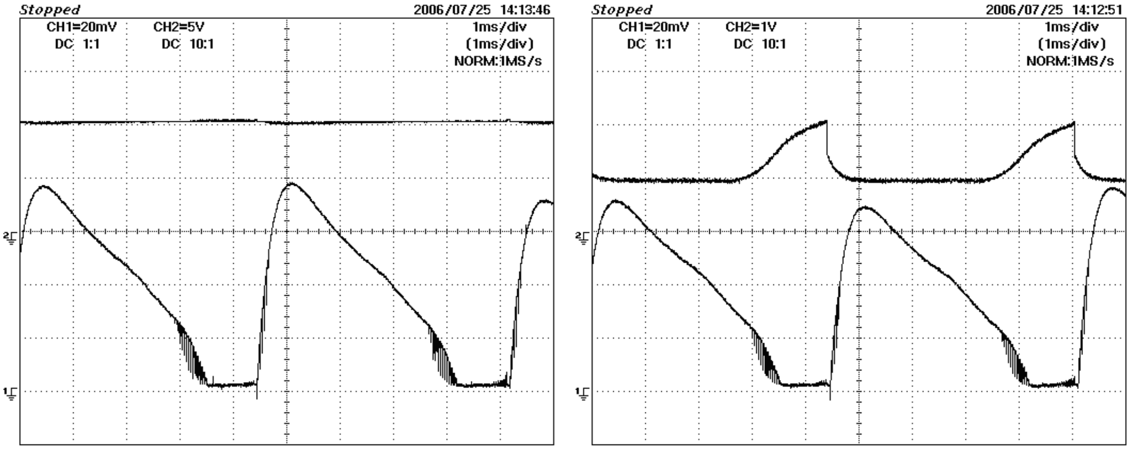
H-bridge supply (top)
and motor current (bottom)

SPD control voltage (top)
and motor current (bottom)

Figure 10 Current waveform with R_{RANGE} set too high.

The solution would be to lower the resistor on the Range pin so that the peak voltage on the C_{LCK} pin is 400mV to 500mV at full speed.

In situations where a large dynamic range of motor speed is required, greater than 10:1, the peak voltage on the C_{LCK} pin will need to be less than 400 mV at maximum speed. In this situation the solution would be to increase the impedance of the network driving the SPD pin. This can be done by increasing the impedance of the network itself or by inserting a resistor between the external network and the SPD pin, between the PWM integrator capacitor (C4) and the SPD pin in Figure 2.



H-bridge supply (top) and motor current (bottom)

SPD control voltage (top) and motor current (bottom)

Figure 11 As Figure 10 but corrected with 2kΩ resistor in series with the SPD pin

The extra resistance has now allowed the SPD voltage to rise higher towards the end of the commutation cycle as can be seen in Figure 11 as compared with that in Figure 10. In most cases a series resistor of 1kΩ to 4.7kΩ will be sufficient.

A second cause of the effect shown in Figure 10 would be that the network components used to derive the SPD control voltage are too low impedance. In the case of the PWM integrator these are R12 to R18 in the circuit shown in Figure 1. The overall values of these can be increased to give more control and thus would also give the same result as shown in Figure 11.

SPD (PWM Integrator) capacitor

Another area worth consideration is that regarding the PWM integrator capacitor.

It is tempting, especially when using a PWM to voltage integrator, to have a large value of capacitor on the output of the integrator to completely remove the ripple. As was explained earlier the tail-end control acts on the SPD input by sourcing current out of the pin. Figure 12 shows the effect of having too large a capacitor as it cannot be charged quickly enough by this current. The result is that the control voltage is also smoothed and becomes ineffective. This therefore leaves some residual motor current flowing at the end of the commutation period. However, more detrimental here is the fact that the PWM integrator impedance is unable to restore the correct running voltage quickly enough as the capacitor voltage at the SPD pin is decaying too slowly. This results in some PWM being present during the initial part of the commutation cycle. This can impact the maximum speed of the motor.

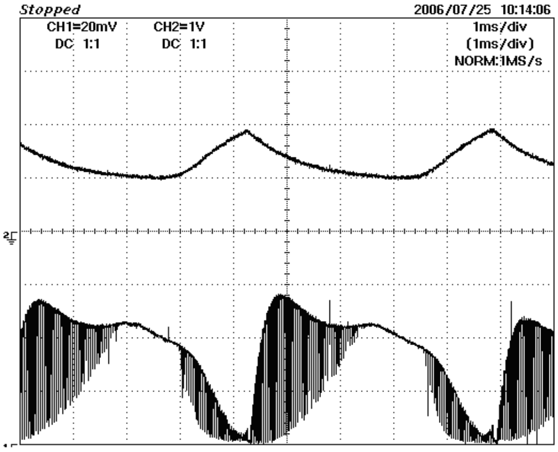


Figure 12 with tail-end current control SPD pin (integrator) capacitor too large

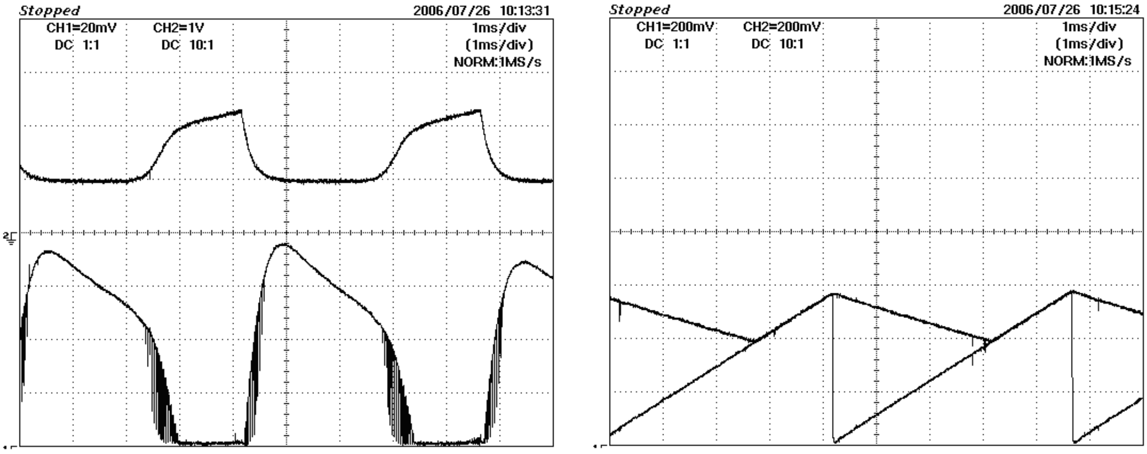
If the effect in Figure 12 is seen the solution is to reduce the value of the integrator capacitor so as to get a current and SPD profile as shown in Figure 8. Having a small amount of ripple on the PWM integrator output is not seen as detrimental to the performance of the PWM drive to the coil. Also note that a motor running at 10,000rpm will require a shorter integrator time constant than one running at say 3,000rpm.

Adjusting the C_{LCK} and C_{INT} capacitors

As mentioned in previous sections, under most conditions the capacitors on C_{LCK} (capacitor C3) and C_{INT} (capacitor C5) would normally be set to the same value. This is not always going to be the case however, as it can be motor dependant, especially regarding coil design and Hall sensor positioning.

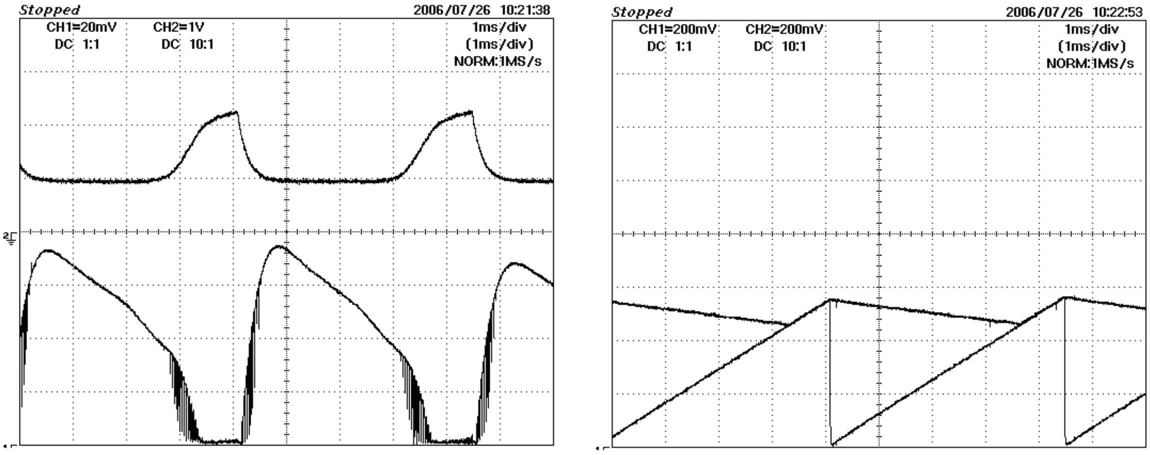
With this in mind Figure 13 has been produced to show the effects of altering the value of C_{INT} against that of C_{LCK}. The middle pair of plots shows the 'normal' set up with the C_{LCK} and C_{INT} capacitor both set to 0.47µF. This is provided for reference and is an identical situation to that shown in Figure 8.

The top pair of plots then demonstrates the effects of widening the off time after the current has been tailed-off, in effect increasing the commutation delay. This has been done by halving the value of C_{INT} in relation to that of C_{LCK}. For the bottom pair the value of C_{INT} has been doubled in relation to that of C_{LCK}. This results in the reduction of the time delay after the current tail-off. Caution should be exercised in this situation as an accelerating motor will cause this delay to reduce further and thus may well leave some residual motor current at the end of the commutation cycle during start-up.



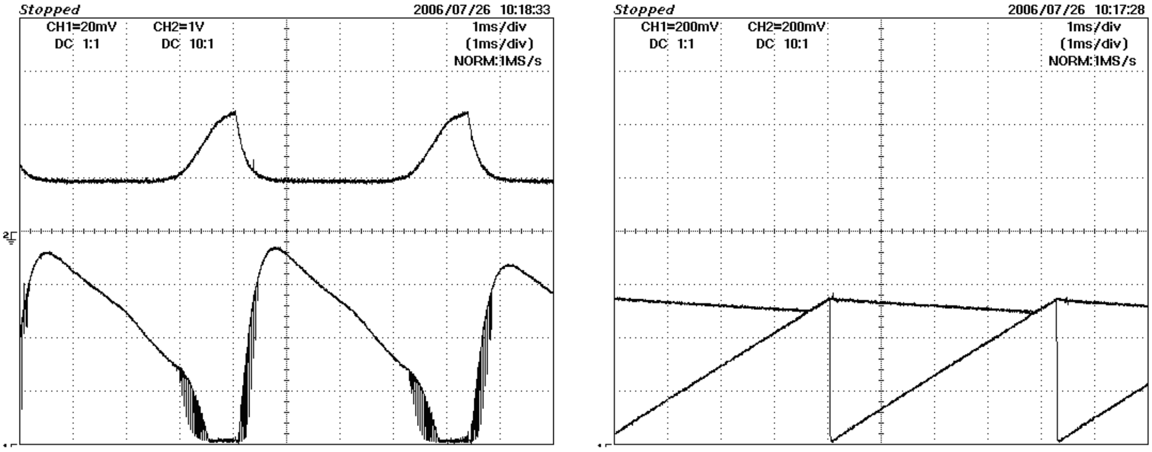
C_{LCK} = 0.47µF; C_{INT} = 0.22µF

C_{LCK} = 0.47µF; C_{INT} = 0.22µF



C_{LCK} = 0.47µF; C_{INT} = 0.47µF

C_{LCK} = 0.47µF; C_{INT} = 0.47µF



C_{LCK} = 0.47µF; C_{INT} = 1µF

C_{LCK} = 0.47µF; C_{INT} = 1µF

Figure 13 Effects of changing the value of the C_{INT} capacitor

Start-up

The motor start-up with the ZXBM1016 is a two stage process. The ZXBM1016 when first powered up or when coming out of a Lock condition first starts the motor from stationary up to its minimum speed. Having decided that the motor is running the ZXBM1016 then enters its run mode and accelerates the motor up to the speed determined by the signal on the SPD pin.

Providing the tail-end current control is now set up correctly the motor will go through its start up routine without causing too large a voltage spike on the supply to the H-bridge. As a motor accelerates from being stationary up to its minimum speed and then accelerates from its start-up mode to tail-end current control mode it is likely the device will produce some spikes on the supply, however, these will be minimal in voltage and will be motor dependant. Voltages of around 5V will not be of any concern. Figure 14 shows one such motor after it has completed its minimum speed start-up and is accelerating in tail-end current control mode. The top trace is the supply to the H-bridge and the lower trace the C_{LCK} waveform. What looks like noise on the H-bridge supply is in effect the forward volt drop of the series blocking diode responding to the PWM current. It also shows some small but acceptable voltage spikes on the supply. This is very much insignificant when compared with the 20V or more voltages normally seen on a motor without tail-end current control.

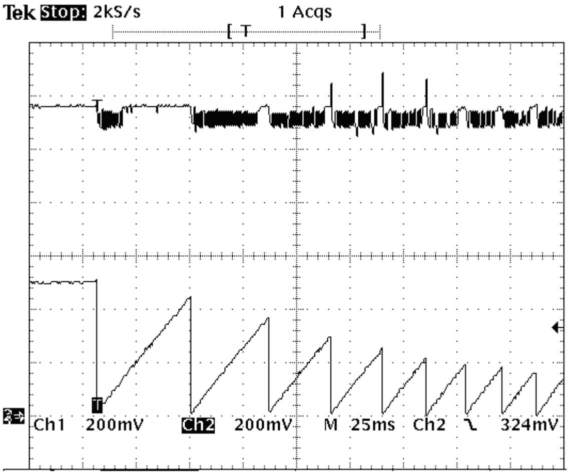


Figure 14 Motor accelerating in tail-end current control mode after minimum speed start-up
H-bridge supply - top (2V/div)
C_{LCK} - lower (200mV/div)

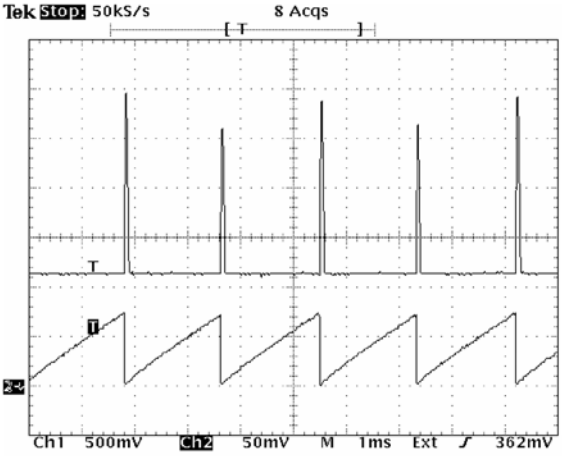


Figure 15 motor running without tail-end current control mode
H-bridge supply - top (5V/div)
C_{LCK} - lower (500mV/div)

Figure 15 shows the same motor as that in Figure 14 to illustrate the severe nature of the spikes that can be generated in a conventional single-phase brushless motor. These are around 20V peaks and required 60V MOSFETs, whereas when running with tail-end current control as in Figure 14, lower current rating 30V MOSFETs were used.

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For the latest information on technology, delivery terms and conditions and prices, please contact your nearest Zetex sales office .

Quality of product

Zetex is an ISO 9001 and TS16949 certified semiconductor manufacturer.

To ensure quality of service and products we strongly advise the purchase of parts directly from Zetex Semiconductors or one of our regionally authorized distributors. For a complete listing of authorized distributors please visit: **www.zetex.com/salesnetwork**

Zetex Semiconductors does not warrant or accept any liability whatsoever in respect of any parts purchased through unauthorized sales channels.

ESD (Electrostatic discharge)

Semiconductor devices are susceptible to damage by ESD. Suitable precautions should be taken when handling and transporting devices. The possible damage to devices depends on the circumstances of the handling and transporting, and the nature of the device. The extent of damage can vary from immediate functional or parametric malfunction to degradation of function or performance in use over time. Devices suspected of being affected should be replaced.

Green compliance

Zetex Semiconductors is committed to environmental excellence in all aspects of its operations which includes meeting or exceeding regulatory requirements with respect to the use of hazardous substances. Numerous successful programs have been implemented to reduce the use of hazardous substances and/or emissions.

All Zetex components are compliant with the RoHS directive, and through this it is supporting its customers in their compliance with WEEE and ELV directives.

Product status key:

"Preview"	Future device intended for production at some point. Samples may be available
"Active"	Product status recommended for new designs
"Last time buy (LTB)"	Device will be discontinued and last time buy period and delivery is in effect
"Not recommended for new designs"	Device is still in production to support existing designs and production
"Obsolete"	Production has been discontinued

Datasheet status key:

"Draft version"	This term denotes a very early datasheet version and contains highly provisional information, which may change in any manner without notice.
"Provisional version"	This term denotes a pre-release datasheet. It provides a clear indication of anticipated performance. However, changes to the test conditions and specifications may occur, at any time and without notice.
"Issue"	This term denotes an issued datasheet containing finalized specifications. However, changes to specifications may occur, at any time and without notice.

Zetex sales offices

Europe	**Americas**	**Asia Pacific**	**Corporate Headquarters**
Zetex GmbH Kustermann-park Balanstraße 59 D-81541 München Germany	Zetex Inc 700 Veterans Memorial Highway Hauppauge, NY 11788 USA	Zetex (Asia Ltd) 3701-04 Metroplaza Tower 1 Hing Fong Road, Kwai Fong Hong Kong	Zetex Semiconductors plc Zetex Technology Park, Chadderton Oldham, OL9 9LL United Kingdom
Telefon: (49) 89 45 49 49 0 Fax: (49) 89 45 49 49 49 europe.sales@zetex.com	Telephone: (1) 631 360 2222 Fax: (1) 631 360 8222 usa.sales@zetex.com	Telephone: (852) 26100 611 Fax: (852) 24250 494 asia.sales@zetex.com	Telephone: (44) 161 622 4444 Fax: (44) 161 622 4446 hq@zetex.com