

ZXBM200x SERIES OF VARIABLE SPEED 2-PHASE FAN MOTOR CONTROLLER

PURPOSE

This Applications document is intended to aid users in their development of the controller electronics for fan and blower motors using the ZXBM200x series of variable speed, 2-phase, DC brushless motor controllers.

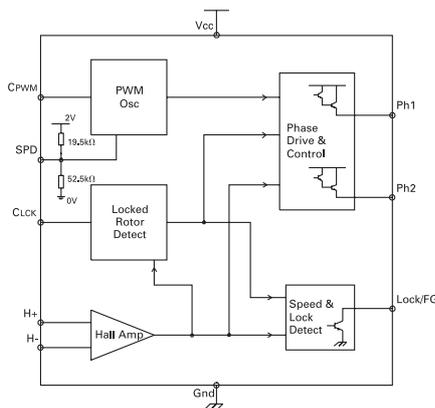
The document will not discuss mechanical details of motor design including such aspects as the position of commutation in relationship to windings etc, for which it is assumed the user already has prior knowledge.

ZXBM200x DESCRIPTION

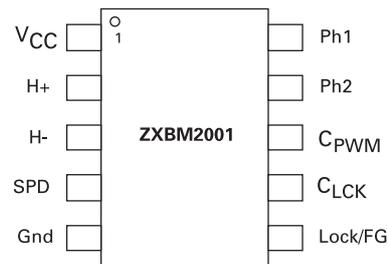
The ZXBM200x is a series of 2-phase, DC brushless motor pre-drivers with variable speed control suitable for fan and blower motors. A full description is to be found in the device Datasheet available by logging on to www.zetex.com/zxbm.

There are three variants available for the controller and all are identical in every aspect except the Lock and FG output functions on Pin 6. The output on the ZXBM2003 is rotational frequency FG, on the ZXBM2002 the pin indicates when the controller in the Lock state whilst in the ZXBM2001 the output is a combination of both the Lock and FG signals.

Block Diagram



Pinout Diagram



The Pinning is shown for the ZXBM2001 as this is the variant discussed and illustrated in this document. Applications for the ZXBM2002 and ZXBM2003 will be identical with the only difference being the function of Pin 6 as discussed above.

APPLICATION REQUIREMENTS

Introduction

A typical electronics application circuit for a 2-phase, DC brushless motor will consist of, but not be restricted to, three main building blocks. First will be the controller itself containing the functions as described in the datasheet. Attached to this will be a Hall device as a means of monitoring and controlling the commutation of the motor and finally there will be the power driver devices used to switch the two Phase windings.

On top of these three building blocks will be other items such as the Speed Control stimulus circuit, e.g. a thermistor. Further functions may be required dependant upon application, perhaps as a means of 'value adding' to the overall final product. Some ideas of this nature will also be discussed in a later section.

The first part of the Applications Note, however, discusses the various interface aspects of the external component requirements to the ZXBM200x series. To aid clarity in this first section any circuits given will show only the areas of interest to that section of discussion. This is followed by a section of practical examples that will include circuits in their entirety.

The Hall Sensor

Two types of Hall sensor can be used in conjunction with the ZXBM200x controllers, those having an unbuffered output stage, sometimes known as a 'naked' Hall, and those with a buffered output. Figures 1 and 2 show the two respective types and their connection to the ZXBM2001.

The unbuffered type have a differential low level signal output with the shape of this signal being a direct representation of the magnetic field from the permanent magnet Rotor. These sensors are connected to the ZXBM using the differential inputs H+ and H- on Pins 2 and 3 respectively. See Figure 1 for connection details. R1 in Figure 1 should be chosen to suit the Hall sensor type and is provided to bias to the Hall device.

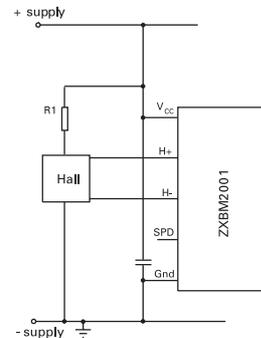


Figure 1
Connection of unbuffered (naked) Hall

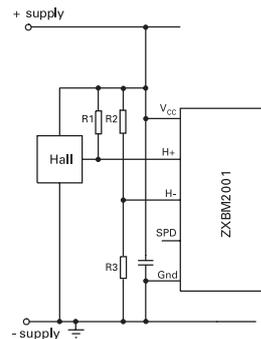


Figure 2
Connection of buffered Hall

The buffered type of Hall sensor should be of the latching or bipolar type. These have an internal amplifier and thus provide a large amplitude square wave output. This signal is single ended and is applied into Pin 3, H+, as shown in Figure 2. On some buffered Hall sensors the output is of the Open Collector type and will therefore require a pull-up resistor (R1 in Figure 2) to attain the full signal amplitude. The H- pin will require to be held at a voltage approximately half the Hall output swing. The potential divider R2 and R3 in Figure 2 is provided for this.

Speed Control

Applied power, motor efficiency and mechanical loading determine maximum motor speed, the controller allows full speed adjustment by modifying the applied power only.

Speed control is attained through an integral Pulse Width Modulation (PWM) circuit within the ZXBM200x series. The PWM signal controls the speed by switching the respective active Phase output at a much higher frequency, typically 25kHz, compared with the commutation¹ frequency. The PWM is used to control the percentage of time the output driver is turned on for. This PWM circuit is controlled through two pins, Pin 6, the C_{PWM} pin, and Pin 4, the SPD input. The C_{PWM} pin has a capacitor attached of 150pF to produce a 1V p-p 25kHz triangular waveform. The circuit has also been used quite successfully with 100pF to produce a PWM frequency of 34kHz. The motor speed is determined by the voltage at the SPD pin.

There are two methods for controlling the ZXBM200x using the SPD pin. The first is the direct control of the SPD pin by a voltage from an external voltage source or system controller. The second method is to use a thermistor as a temperature sensor so as the ZXBM200x is in a feedback loop to control the fan speed against the temperature conditions. A third method of control is available by applying a PWM signal from an external source. All these will be discussed in more detail in the following sections.

Voltage control of the SPD pin

Voltage control is achieved by applying a voltage of between 1 volt and 2 volts to the SPD pin. A voltage of 1 volt on this pin will ensure the drivers are switched on for 100% of the PWM duty cycle i.e. the motor will run at full speed.

Progressively increasing the SPD voltage to 2 volts will reduce the percentage of PWM duty cycle drive to the Phase windings to reduce the motor speed. With a SPD voltage of 2 volts the outputs will be switched off all the time i.e. no drive will be present.

In reality a 2-phase DC brushless motor will have a minimum practical rotational speed below which the motor will not run. This is very much dependant upon the power, size and mechanics of the motor concerned but could well mean that anything less than 40% PWM drive, represented by a SPD voltage of 1.6V, is impractical.

The ability of starting the motor under such low speed conditions also has to be considered as in most cases a motor will rotate at a far lower power input than is needed to start it. Further discussion will be given on this subject later.

Note:

¹ Commutation is the process of alternate (phase) switching at the speed of rotation.

NTC Thermistor

The ZXBM200x series are designed to be used in conjunction with an NTC type thermistor with a value of 100kΩ at 25°C. The thermistor is connected directly between the SPD pin and Ground. The thermistor can either be local i.e. part of the Fan or Blower itself and positioned where it can easily detect the air temperature, or it can be remote to the device, perhaps positioned on a motherboard or in an air duct.

An NTC thermistor has a non-linear characteristic whereby there is a larger change in resistance between 25°C and 30°C than there is between 55°C and 60°C. See Figure 3. However from Ohms Law when two resistors are in parallel and one changes in a linear fashion it will produce a resultant non-linear resistance characteristic but with the opposite curve to that of the thermistor. See Figure 4. Now when these two effects are put together the resultant characteristic seen in Figure 3 is achieved.

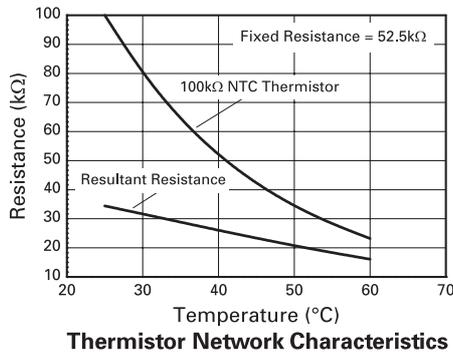


Figure 3

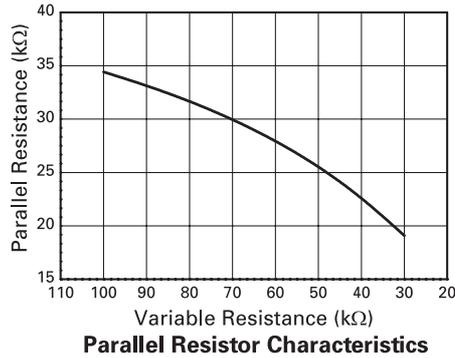


Figure 4

The SPD pin on the ZXBM200x series contains an internal resistor network of 19.5kΩ to an internal 2V rail and 52.5kΩ to Ground. The purpose of this is to set the speed range for a 100kΩ NTC thermistor and to help cancel out the thermistor's non-linearity against temperature.

The manner in which the non-linearity is removed can be seen in Figure 14 where the SPD voltage is linear with any slight non-linearity in the speed response more likely due to other motor characteristics.

It is also possible to use the ZXBM200x series in conjunction with other lower values of NTC thermistor, for example one with a value of 10kΩ at 25°C. In this case an external resistive divider as shown in Figure 5 below is used to set the control speed range. The ratio of R1 and R2 in this figure should be chosen to give the desired speed range against temperature. With careful selection of the R1 and R2, it is possible for a linear response within ±1% to be achievable.

If needed R1 and R2 can also be added when using a 100kΩ thermistor in order to adjust the speed range to match the particular thermistor's characteristics.

Applications Note AN36 Issue1 - JULY 2002

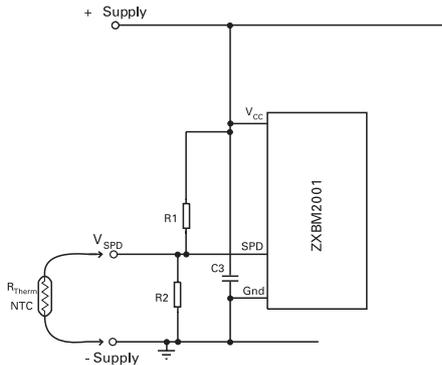


Figure 5
showing resistive divider used with <100kΩ thermistors

One problem with using an external potential divider (R1 & R2 in Figure 5) is that the motor becomes susceptible to supply voltage changes. Say the supply voltage falls, normally the speed would drop due to less voltage across the windings, however as the potential divider is across the supply, as the voltage falls so the voltage at the SPD pin will fall. As a lower SPD voltage represents a higher speed so a lowering of the supply therefore causes the fan to speed up. To overcome this it is probably best to use a Zener regulated supply to the ZXBM200x.

The following Table 1 gives an indication of the values required for R1 and R2 against different thermistor values. It should be noted that these are only for guidance as the final value will depend upon the thermistor and motor characteristics and so will need fine adjustment by experimentation. If the ZXBM200x device is to be run from a Zener regulated supply to control the speed verses supply voltage variation so R1 and R2 will need allowances made for the voltage value of Zener chosen.

As the Bipolar drivers have a slower turn-off characteristics when driven from the ZXCB200x series slightly different values of R2 are required over those for MOSFETs.

When driving the SPD pin from a signal or thermistor remote from the fan or controller there may be a need to provide noise protection at the SPD pin. In order to maintain a smooth speed control characteristic this will take the form of a capacitor of between 100nF and 1μF connected between the SPD and Gnd pins somewhere close to the device. This should suffice for most purposes and can be determined for each particular application.

A capacitor on this pin also has an effect on the start-up characteristic of the motor as the charging of the capacitor will lag behind the rise of the supply voltage. As a low voltage on the SPD pin represents a higher speed the effect at start-up, if the SPD value is not set for full speed, will be for the motor speed to increase past its allotted point before settling back to that required. Whilst for the capacitor values stated above this effect may not be noticeable, for values greater than 1μF it can be used to advantage. In situations where the motor will be regularly started at a speed lower than its practical start value it can help to get motors started, in effect giving the motor a 'kick' to start it.

Table 1

Thermistor Value	Supply Voltage	MOSFET		Bipolar	
		R1	R2	R1	R2
4.7kΩ	5V	3.3kΩ	2.2kΩ	3.3kΩ	1.5kΩ
	12V	6.8kΩ	1.2kΩ	6.8kΩ	1.0kΩ
	24V	15kΩ	1.3kΩ	15kΩ	1.0kΩ
10kΩ	5V	5.6kΩ	3.3kΩ	5.6kΩ	2.4kΩ
	12V	13kΩ	2.2kΩ	13kΩ	1.8kΩ
	24V	36kΩ	3.3kΩ	33kΩ	2.2kΩ
47kΩ	5V	24kΩ	12kΩ	22kΩ	8.6kΩ
	12V	56kΩ	9.1kΩ	56kΩ	7.5kΩ
	24V	130kΩ	10kΩ	130kΩ	8.6kΩ
100kΩ	5V	*	*	*	*
	12V	*	*	*	*
	24V	*	*	*	*

* Note: Not normally required - dependent upon thermistor and speed range needed.

External PWM

The ZXBM200x series are also capable of being driven from an externally derived PWM signal. This is particularly useful where the device is to be used with existing system controllers that provide such an output.

The PWM control waveform can be in the form of a digital signal. The main criteria being that it should have a low level of less than 1V and a high level greater than 2V (but not exceeding 5V). A conventional 3.3V or 5V based TTL or CMOS signal is ideal. The signal is applied to Pin 8, the C_{PWM} pin, with Pin 4, the SPD pin, being left open circuit. A low level on the C_{PWM} pin represents the winding drive Off period and a high level the On period.

Figure 6 illustrates an external input waveform on the C_{PWM} pin together with the resulting drive at one of the phase windings. There is some delay through the ZXBM200x device that ensures the drive reaches 100% PWM slightly before the input reaches 100% duty cycle.

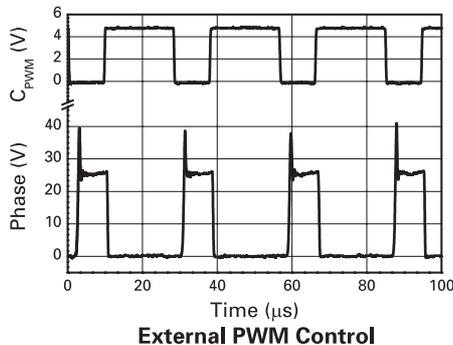


Figure 6

Fixed speed applications

For applications where the speed control function is not required the device can be set to run at full speed by simply holding the SPD pin at a voltage below 1V. The best way to do this is by attaching a 10kΩ resistor to Ground. A direct link to Ground can cause the SPD pin and its associated circuit not to function as required.

Winding Drive

The driving of the two phases of the motor is achieved using a pair of external power transistors driven from Pin 10 and Pin 9, Ph1 and Ph2 respectively, of the ZXBM200x controller. These transistors can be either of the Bipolar or MOSFET type. Both methodologies are similar and incorporate clamping to restrict the level of winding avalanche to be within the capabilities of the transistors chosen. Each Transistor type will be discussed in detail together with their respective merits and limitations.

Bipolar Power Transistors

Bipolar devices at one time were the universal power driving method, however, with MOSFETs becoming more readily available bipolar use has diminished. In the case of the ZXBM200x series it has been found that bipolar devices are very suited to the lower power, lower current end of the applications range.

Figures 7 and 8 illustrate a bipolar driver output stage with two methods of clamping.

In both Figures 7 and 8, R1 and R2 provide the base drive to the Output transistors Q1 and Q2. The value of these resistors should be chosen to provide sufficient current to maintain a good saturation voltage of the driver transistors but not to exceed the Ph1 and Ph2 drive capabilities of the ZXBM200x under worst case conditions.

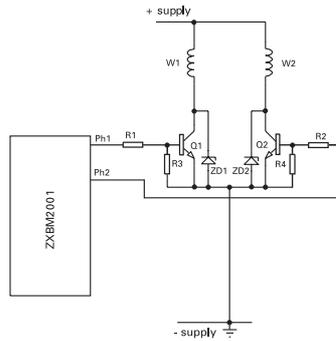


Figure 7
Bipolar Output Drive Stage

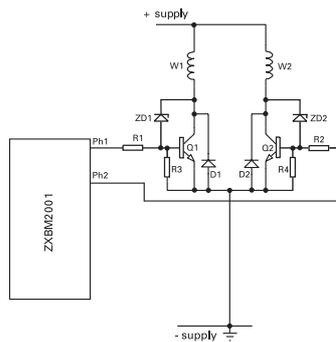


Figure 8
Bipolar Output Drive Stage Using Active Clamping

The ZXBM200x series have a Darlington emitter follower output stage and therefore rely upon an external method of turning the drivers off. R3 and R4 provide that function. It should be borne in mind that R3 and R4 will detract from the base current drive provided by R1 and R2 so the final choice of values will be a balance of the two requirements, turn-off and base drive.

Another consideration of the output stage is that of protecting the bipolar drivers from the effects of the back emf when switching the windings. This takes the form of a voltage 'fly-back' of several times the supply voltage and so some form of clamping is required to prevent this voltage from over-stressing the driver devices.

Two forms of clamping can be recommended, that in Figure 7 shows a straightforward Zener diode placed across the collector to emitter of Q1 and Q2. This will absorb any voltage spikes appearing at the collector. This arrangement also has the effect of protecting Q1 and Q2 against any negative going voltages appearing as a result of the switching. The disadvantage is that the size of the Zener needs to be sufficient to absorb all the energy from the voltage spike.

Figure 8 provides an alternative method of clamping whereby the Zener diodes are connected between the collector and base of Q1 and Q2 to form an active clamping arrangement. Any voltages seen at the collector will provide base current to the drivers to turn them back on. This has the effect of limiting the voltage excursion at the collector and the power is thus absorbed in the larger output devices.

The disadvantage of this active clamping scheme is the need to protect for negative voltage excursions of the power transistor collector. The need for this is twofold, the first being to limit the negative voltage induced noise and the second to avoid exceeding the emitter-base breakdown voltage of the power transistors. To prevent this the diodes D1 and D2 are included as protection to restrict the negative excursion of the Q1 and Q2 collectors.

MOSFET Power Transistors

Power MOSFET devices are becoming increasingly popular and as regard the ZXBM200x provide a very good method of driving the motor phase windings. Figures 9 and 10 illustrate the methodology of the driver circuit.

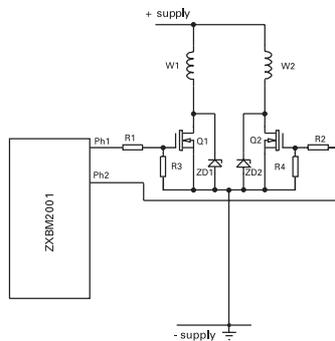


Figure 9
MOSFET Output Drive Stage

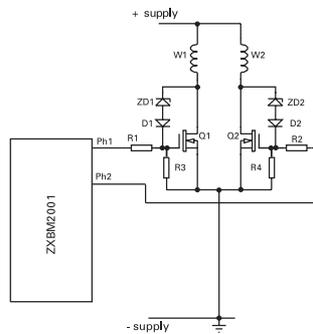


Figure 10
MOSFET Output Drive Stage Using Active Clamping.

The components in Figures 9 & 10 have a very similar topography to that of the Bipolar drive with again two variants, one with the direct Zener clamping and the second having active clamping.

The main difference arising in the active clamping circuit in Figure 10 is the need for a diode in series with the active clamp Zener diode. This prevents the Zener being forward biased and thus detracting from the gate drive when the MOSFET is turned on. In the active clamp circuit there is also no need for any drain to source negative voltage protection as this will be achieved by the inherent body diode of the MOSFET.

When using MOSFET devices it is a compromise between the Voltage rating and the RDS(on) of the MOSFET with a higher voltage rating producing a higher RDS(on). The aim therefore should always be to use the lowest voltage rating to suit the application as this will give the lowest full-speed RDS(on) related dissipation. The disadvantage is that there will be a slightly higher dissipation when using active clamping as this will be working harder to maintain a lower voltage when the fan is running at near to full speed.

The latest generation of N channel trench MOSFETS from Zetex provide suitable solutions with the ZXMN6A11G and the ZXMN10A11G, 60V and 100V devices respectively, having been used in the applications described.

Reverse Supply protection

An increasingly common requirement for modern systems is for components and modules to have a degree of reverse supply protection. This is particularly so for Automotive applications. To achieve this a supply blocking diode is required in the Fan electronics.

For the best performance from the ZXBM200x device it is best to provide separate diodes for the device and the winding supplies. This is illustrated in the full applications circuit in Figure 17. The main reason for this is that having blocked the reverse path to the power supply for the switching currents, high voltages can be experienced at the winding high end. This energy manifests itself as excessive voltages and these are required to be kept away from the device supply.

Another hazard with the excessive voltages from the blocking diodes is that it can cause this energy to be dissipated within the Zener clamping arrangement. As this energy would normally have been returned to the supply for reuse it seems appropriate to attempt to save the energy for reuse within the fan itself. This is achieved with the Capacitor C5 in Figure 17.

Care needs to be taken with the selection of the capacitor type and value for each application. For multilayer chip capacitors it will be a cost verses value issue and for electrolytic capacitors a size verses value issue. In both cases the voltage tolerance of the chosen part needs careful consideration as the capacitor needs to reliably withstand the peak voltages.

When used, the capacitor gives considerable efficiency improvements with noted reductions in supply current and driver device temperature. Figure 11 shows the winding supply at the winding common point and shows the voltage being clamped by the driver active clamping. Figure 12 shows the effects of adding a 4.7 μ F multilayer ceramic capacitor (C5 in Figure 17).

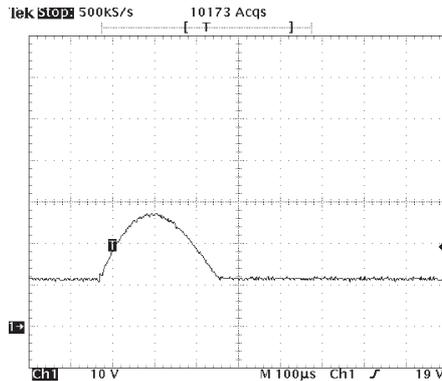


Figure 12
Winding Supply with 4.7 μ F Capacitor

APPLICATION CIRCUIT EXAMPLES

In this section are shown complete circuit examples developed using the ZXBM2001 together with the type of fan it was developed for. Examples are given for a variety of applications with the intention that these circuits will form the starting point for a users future development in conjunction with the guidelines given in the previous section.

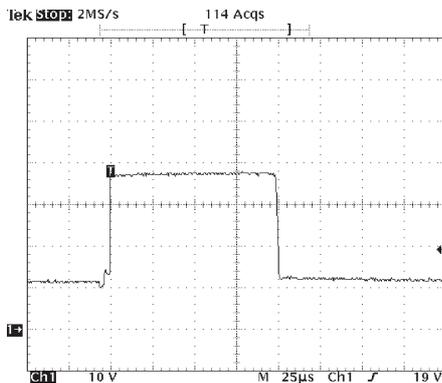


Figure 11
Winding Supply

6V supply with 'naked' hall and bipolar drive

The first example in Figure 13 is for a 6V axial fan driver. The design uses an unbuffered Hall sensor and bipolar drive transistors. The Zetex FMMT619 transistor will furnish output powers up to 2W with the SOT23 package, however, in excess of this the SOT89 package (FCX619) might be more suitable if driver temperature is excessive. Measurements of the fan speed versus the thermistor temperature is shown in the accompanying graph in Figure 14.

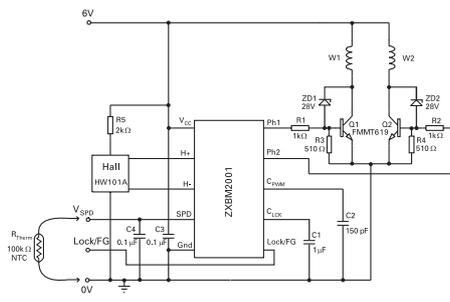


Figure 13
6V Axial Fan using bipolar drive.

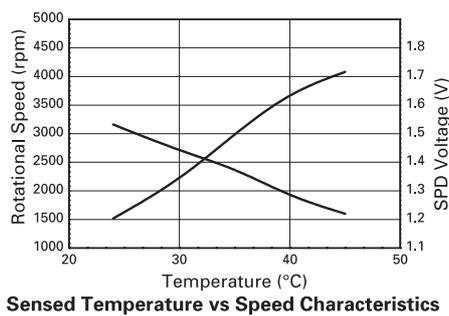


Figure 14.

12V Supply with buffered Hall and MOSFET drivers

This second example in Figure 15 shows a complete circuit using MOSFET drivers and a 12V supply. It also makes use of the more common buffered Hall sensor. The output devices are the Zetex ZXMN6A11G MOSFETs which are rated at 60V so the clamping is achieved with 56V Zeners. Avalanche problems are averted by not attempting to turn the MOSFETs off too quickly and 1kΩ for R3 and R4 meets those aims. It should be suitable for powers up to 20W. The speed response is shown in Figure 16.

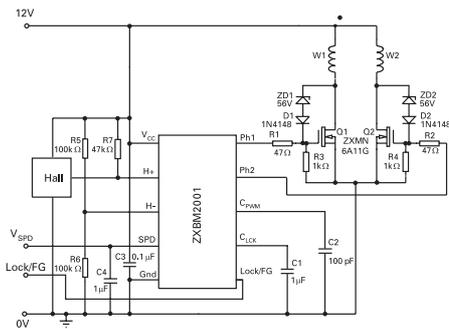


Figure 15
12V motor with MOSFET drive.

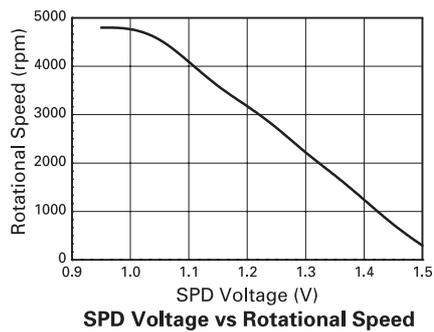


Figure 16.

12V Supply with Reverse Supply Protection

This following circuit in Figure 17 is similar to that in Figure 15 except that it has the reverse polarity protection feature added. This is achieved with D3 providing protection to the ZXBM2001 and D4 providing protection to the motor windings. C5 is also added to smooth out the excessive supply disturbance as discussed in previous sections.

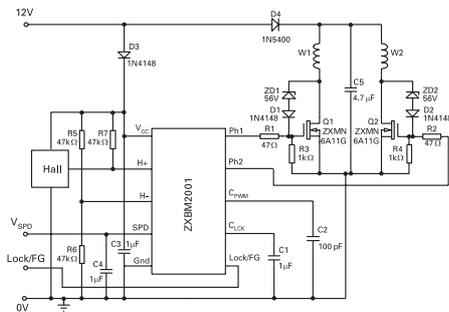


Figure 17
12V Supply with Reverse Supply Protection.

Another point of note with this circuit is that the PWM frequency was set to run at 34kHz by making C1 the more readily available 100pF value. Running at this higher frequency has not been seen to be a problem with MOSFETs where the on and off switching is clean and thus gives minimal switching losses.

24V Supply with Reverse Supply Protection

The final circuit example in Figure 18 is used to illustrate the supply provision for a 24 V application. Again MOSFETs are used with reverse supply protection incorporated. The ZXBM2001 takes its supply from the same protection diode as the windings, however, because C4 is large and the supply to the ZXBM2001 regulated by ZD3 and C3 the supply commutation ripple is not a problem.

The higher voltage, 100V, Zetex ZXMN10N11G MOSFETs are used with 75V Zener active clamping.

The circuit in Figure 18 has also been used for a motor design with an input supply of 48V. In this case higher voltage rating components were selected to withstand the higher winding avalanche voltages.

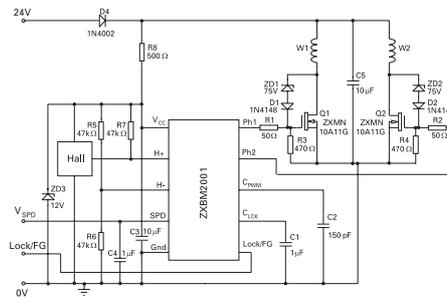


Figure 18
24V motor with Reverse Polarity Protection.

USEFUL APPLICATION IDEAS

Failsafe dual fan systems

In high reliability systems there is a need to ensure the cooling scheme is also reliable. This is often achieved by the use of 2 fans that will ensure there is still a degree of cooling should one fan fail. An improvement to this is to run each of the two fans at half speed and in the event of a failure of one fan to speed up the remaining fan to full speed. Figure 19 illustrates such a system where two fans using the ZXBM2001 are connected together.

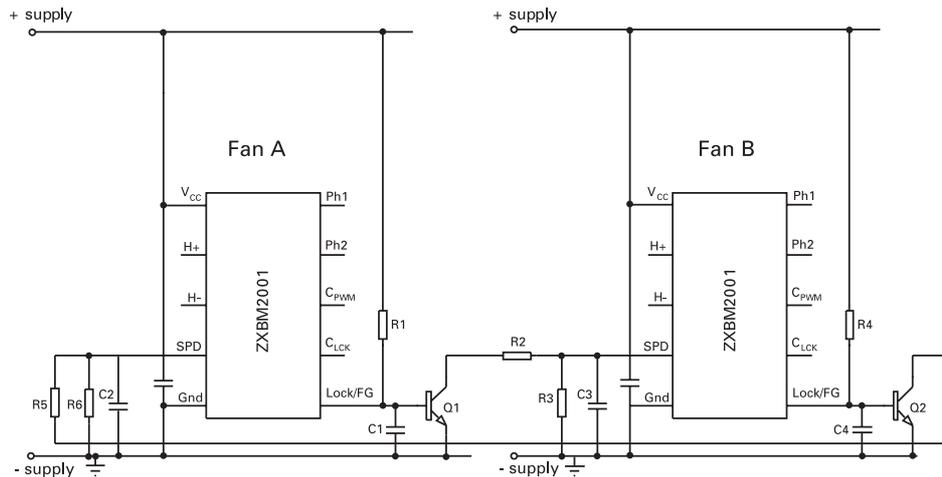


Figure 19
Failsafe dual fan system.

In Figure 19 the SPD pin on both fans is arranged such that they run at half speed, or perhaps a little faster with R6 and R3. Consider Fan A, R1 and C1 integrate out the FG frequency pulses such that Q1 is always kept off. If a lock condition is then encountered with the fan the Lock/FG pin will go permanently high and switch on Q1. This in turn will send a signal to Fan B such that it will switch R2 to ground. With the value of R2 chosen such that the SPD voltage of Fan B is <1V it will ensure Fan B is set to full speed to compensate to the now stopped Fan A.

Conversely R4, C4, Q2 and R5 will ensure that if Fan B stops Fan A will be set to full speed.

By careful selection of the values of R1/C1 and R4/C4 it is possible to only partially take out the FG speed pulses. This will make one fan speed up should the other slow down sufficiently but not actually stop. To remove the need for C1 and C4 the ZXBM2002 variant with the Lock only output can be used so the FG pulses do not need to be removed.

SPD Voltage Conversion

There may be situations where the SDP input control voltage range will be incompatible with the application requirements perhaps because the motor is to be controlled from an already defined and different voltage source. Figure 20 provides a simple voltage range conversion for a control signal where a higher voltage represents a higher speed.

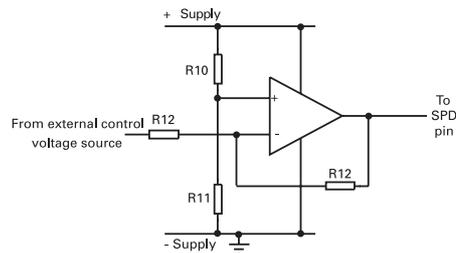


Figure 20
SPD control voltage level conversion.

Bipolar driver active switch off

The problems of base turn off when driving bipolar devices has been mentioned previously. Figure 21 is an active turn off circuit that can be added to each phase drive transistor of the circuits shown in Figures 7 or 8. The transistor Q3A and Q3B can be of the multi-pack type and forms a simple double inverter function to actively discharge the base charge of Q1.

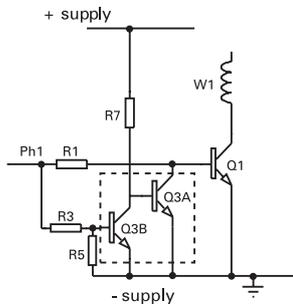


Figure 21
Active switch-off circuit for bipolar driver devices

Removal of Speed Variation with Supply Voltage

It has already been discussed that when using a 10kΩ NTC thermistor and an external potential divider an increase in supply voltage results in a slower speed. It is therefore possible when using a 10kΩ NTC thermistor to remove supply voltage variation by feeding a percentage of the supply voltage change into the SPD pin.

To do this the circuit in Figure 22 is used. In this circuit a Zener diode is used to partly remove supply voltage variation. A Zener voltage half that of the supply voltage should suffice. R1 and R2 should be small in relation to R3 and R4 and provides a partly regulated voltage that in turn is used for the potential divider for the Thermistor network. A raising of the supply voltage would normally put a higher voltage across the windings and so increase the speed. This is now countered by the fact that a small percentage of the supply increase appears at the R1/R2 junction. This percentage increase also appears at the R3/R4 junction - the SPD pin. An increase in the control voltage on the SPD causes a lowering of the PWM drive and thus a lower speed. Careful manipulation of the R1/R2 and R3/R4 ratios will enable constant speed to be attained over a wide supply voltage range but still allowing speed variation with temperature.

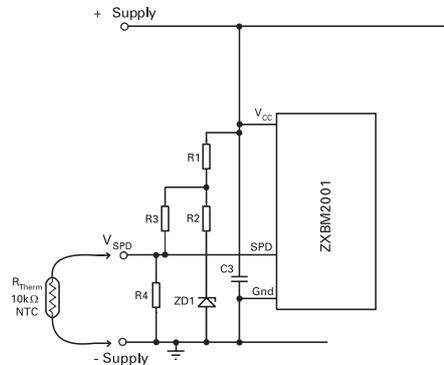


Figure 22
Constant Speed versus Supply Voltage

Applications Note AN36 Issue 1 - JULY 2002

LAYOUT CONSIDERATIONS

Whilst it is understandable that the circuit layout is likely to be severely compromised in the restricted environment of small 2-Phase brushless Fan and Blowers a number of points are worth mentioning.

The capacitors for C_{LCK} and C_{PWM} (C1 and C2 respectively in all the Figures) need to be positioned as close to the device as possible with the latter being the more important. The decoupling capacitor (C3 in all the Figures) also needs to be as close to the device as possible.

As much area as possible should be kept as copper for the tracks associated with the output stage and ground rail with the technique of laying out the gaps rather than laying out the tracks being preferred. Allotting as much copper to the tab of the winding driver transistors is beneficial when using surface mount packages as they rely upon the copper of the PCB to dissipate as much of the heat as possible with the PCB itself in effect becoming the heatsink.

The power rails to the device and to the windings should be kept separate where possible. Where the power comes onto the PCB it should go in one direction to the windings and in the other direction to the controller and its associated components, in effect to form a star connection.

APPLICATIONS ASSISTANCE

Zetex Applications Engineers have a wealth of experience in using the ZXBM200n series of variable speed, 2-phase, DC brushless motor controllers and are always available to help with customer applications. Should help be sought please contact your nearest Zetex office for assistance.

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