Brush Type DC Motor Drive with Power Op Amps

1.0 AMPLIFIER SELECTION

One of the most entertaining moments as a power op amp applications engineer is when a customer calls up asking for an op amp to drive a 24V, 2A motor and has already settled on a 5 amp amplifier. It's just not that simple. This current rating could have many meanings, and actually there are two current rating conditions to be considered when designing a reliable application: stall current and reversal current.

Reversing a motor is about the most stressful application to which power op amps are subjected. It's important to establish from the outset if it will be necessary to sustain reversals. Some applications can disregard this; a good example being a simple speed control for a motor always rotating the same direction.

1.1 STALL RESISTANCE

Every motor will be stalled. This is the required state of transition to get a motor rotating. And it is doubtful any mechanical system can be devised which is guaranteed to never jam.

A single operating point for the stalled condition can be plotted. The location of the point is defined by several factors: 1) If the product of current limit and stall resistance is greater than maximum output voltage swing ((Ilim*Rs)>Vomax) the amplifier output will be at maximum swing; or 2) If the product of current limit and stall resistance is less than maximum swing, then the amplifier output voltage will be at the value of Ilim*Rs. To calculate dissipation, subtract this voltage from the supply voltage and multiply by current limit: Pd = (Vs-Vo)*Ilim

Alternatively, stall resistance can be plotted as a load line on the SOA graph. On the SOA graph, current limit should also be plotted. This is useful for conditions where the amplifier output will be attempting to go to some other value than full output voltage under stall conditions. Remember, maximum dissipation occurs at an output voltage one half way between zero and the supply rail.

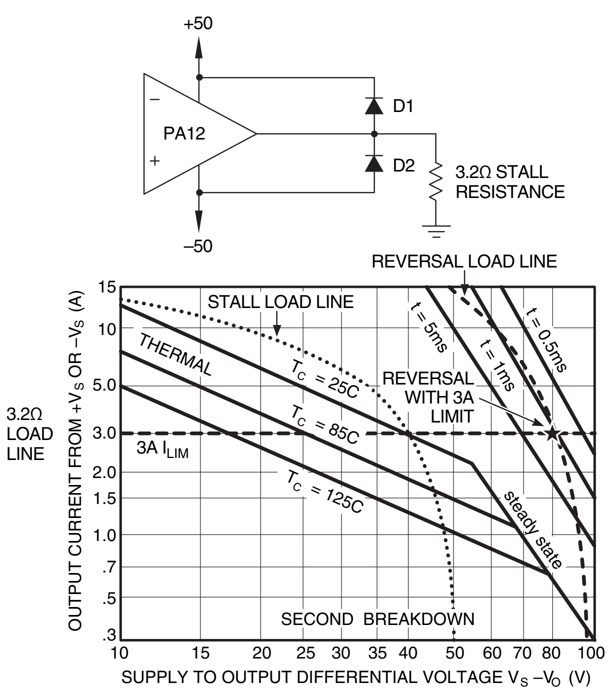

FIGURE 1. EXAMPLE OF MOTOR DRIVE LOAD LINE ANALYSIS

Figure 1 shows just such an example of a calculation. This example uses a PA12A along with a motor which has a 3.2 ohm stall resistance and bipolar ±50V power supplies. If we simply plot the condition where the amplifier is against the rail, we have approximately 44V at the output and 13.8A of current flow. The supply to output differential and current result is a dissipation of 6 * 13.8, or 82.5W, which is within the amplifier SOA. If the amplifier output voltage were commanded to one half supply rail or 25V under a stalled condition, the power dissipation would be 195W, which is beyond the continuous SOA.

This illustrates the value in plotting the stall resistance load line. Both the low output and full output conditions are within the SOA, but intermediate values create excessive dissipation and this is immediately apparent by plotting the load line. The point where the load line exceeds the 25°C continuous SOA is a good value for maximum acceptable current limit.

In summary, design for stalled conditions should at least plot the resistive load line to determine proper setting of current limits. If the load line completely falls within the SOA, then other fault conditions of shorts from output to ground or output to either rail will take precedence in determining current limit values in the event these faults must be accounted for.

1.2 REVERSAL

Reversal brings the back EMF of the motor into the stress equation. The back EMF is equivalent to a new source of voltage with a polarity such that it adds to the supply voltage and increases voltage stress on the output devices. As in the stalled condition, motor resistance also plays a part.

Determining back EMF may seem difficult, but most motor data sheets shed some light on determining its value. Knowing the motor resistance and current draw permits exact calculation of back EMF: it is the applied voltage, less the drop across the motor resistance. Worst case assumption for back EMF should assume it could be equal to applied voltage, and this would be true for any motor drawing negligible current.

The schematic in Figure 2 shows an example of what happens to the circuit in Figure 1 during reversal—assuming the amplifier current limit is set at 3 amps. Motor operating current is a function of load. So for this example, let's assume the motor requires 1A under normal running conditions. Maximum output from the PA12 could be up to 45V. Subtract 3.2V for the drop across the motor resistance for a back EMF of 41.8V. Upon command to reverse the negative half goes into 3A current limit. The resulting voltage drop across the motor resistance subtracts from the back EMF, providing the values shown during the reversal. The dissipation during this event is 246W—clearly outside the PA12 SOA. Motor reversal by nature is a transient condition. If it can be assured the motor can reverse within an amount of time equivalent to transient stress limits on the SOA graph, then the application could be safe.

1.2.1 PLOTTING REVERSAL LOAD LINE

Just as stall load lines can be plotted, so can reversal load lines. The process of plotting a worst-case reversal load line starts with the assumption that back EMF is equal to maximum amplifier output voltage. An even worse assumption is that it is equal to the supply voltage of one of the rails.

Plot the load line by:

1. Calculate the drop across the motor resistance at various currents within the SOA.

2. Subtract that voltage from the back EMF to result in the amplifier output voltage.
3. Take the resulting difference between supply rail and output as the stress point.

Figure 1 also shows its reversal load line. This load line indicates that it is not within the continuous SOA unless current is limited to approximately less than 400mA. If this application were required to tolerate reversal, an amplifier with better SOA should probably be used.

Load lines that exceed the continuous SOA, but are within transient SOA, may be safe if the time conditions are met with certainty. This is difficult to assess, and usually requires a judgement call when any signal other than pulse is present. In general, as in any case, life is simpler and more reliable if we at least make the effort to keep within continuous SOA limits.

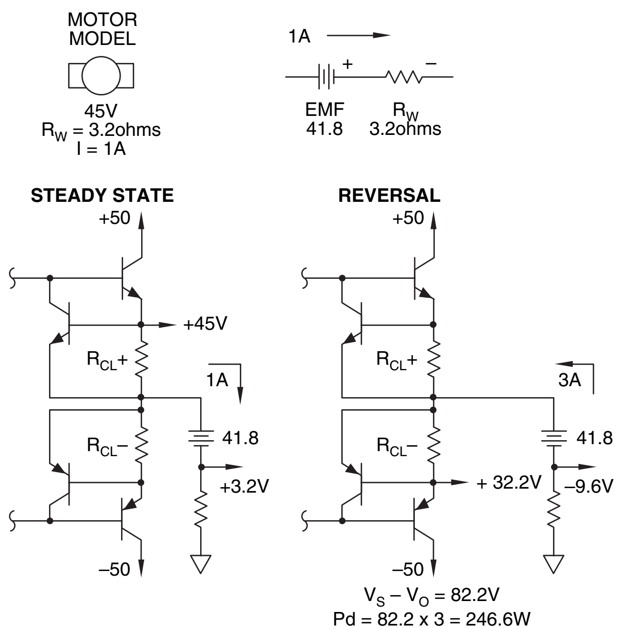

FIGURE 2. MOTOR REVERSAL

1.3 NOMINAL OPERATING CONDITIONS

Nominal operating conditions can only be determined on a by application basis. All motor data sheets shows torque and RPM constants allowing the engineer to determine required voltage and current once the load is known. The worst case normal operating point will be when the amplifier output is halfway between zero and the supply rail.

2.0 AMPLIFIER PROTECTION AND HEATSINKING

As has already been shown, the load lines must be within the amplifiers capabilities or current limit must be configured to restrict operation to within the SOA. However, the SOA shrinks with increasing temperature. Therefore, either adequate (read: generous) heatsinking must be provided for, or SOA analysis should consider limits of higher case temperature curves. Using standard heatsink formulae the exact amplifier case temperature can be determined under any operating condition (as well as junction temperature).

2.1 FOLDBACK CURRENT LIMITING

Current limit, as demonstrated, is truly a good thing and necessary. But designers must not be lured into the attraction of using foldback current limiting as available on PA10, PA12 and can be used on PA04, PA05. Reason being that foldover current limiting causes more problems than it solves when used with nonlinear loads. For instance, with inductive loads (and motors are very inductive), the amplifier can go into relaxation oscillation. And with an inductive load, when the amplifier goes into current limit, it generates a violent pulse all the way up to the supply rail (limited only by flyback diodes, without which it would go beyond the rail).

If a designer insists on experimenting with foldover current limiting, then it would be wise to plot the current limit line on the SOA along with the expected load lines. If the load lines are within the current limit boundaries, then you're OK. Keep in mind that foldover current limiting slope can be varied and sometimes a gentle foldover characteristic can provide adequate protection.

2.2 FLYBACK DIODES

Brush type DC motors generate a continuous pulse train of inductive kick-back due to brush commutation. This inductive kickback must be clamped within the limits set by the power supply rails by flyback diodes as shown in Fig. 1.

Many amplifier schematics show these diodes internally, but this does not mean they can be depended upon in motor drive applications. In most bipolar, darlington, emitter-follower output stages, these diodes are the substrate diodes of the darlington output transistors. This causes the diodes to exhibit slow recovery, which will in turn overheat under the stress of a continuous pulse train of inductive kickback.

Amplifiers with no diodes, or slow recovery diodes, internally must have external fast or ultra-fast recovery diodes added. If these are not available, then standard recovery is better than nothing. The diodes must be rated for voltage well in excess of the total rail-to-rail voltage. Current requirements are not demanding. One amp types will suffice.

All Apex Microtechnology amplifiers require external flyback diodes except the MOSFET output amplifiers PA04, PA05, PA09, PA19; and the PA02 and PA03 which are bipolar amplifiers with built-in high speed flyback diodes. In general, on any Apex Microtechnology data sheet schematic or in the Apex Microtechnology data book, if the flyback diodes have a different part numeral than the output transistor, then they are separate fast recovery diodes. Diodes with the same part number as the output transistor are slow recovery diodes and external additions will be needed. For example in the PA12, the upper output transistor is Q2A and Q2B and the flyback diode is D2. If you're not sure, there is no harm in adding them even if they are not needed.

3.0 AMPLIFIER PERFORMANCE

3.1 VOLTAGE VS CURRENT OUTPUT BEHAVIOR

Voltage output configurations are generally used for speed control. Although a voltage output configuration can be incorporated within a larger current control loop. The importance of voltage output in the amplifier itself relates to output impedance, which will be very low. As such, the output voltage as seen on a scope will generally be quiet and steady under steady state conditions.

Current output can be implemented as mentioned above with a larger current sense loop that incorporates a voltage output power amp. Alternatively, current output circuits can be implemented within the feedback loop around the op amp alone. When this is done, the amplifier apparently exhibits a very high output impedance. A current source should do this by definition. This is mentioned because if the output of such a circuit is scoped, the flyback pulses will be exaggerated by this high impedance — a perfectly normal behavior for current output.

There is no performance advantage in selecting voltage or current output, at least not due to power op amp circuit choice alone. Many other factors will play a part in which choice provides the best performance. In general, without using larger control loops, the voltage output configuration is preferred for speed control, and the current output for torque control.

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