SA56 DESIGN IDEAS

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The SA56 is a 5-ampere PWM Amplifier designed for motor-control applications. It operates at up to 60 volts, and can deliver up to 10 amperes, peak. The SA56 enables powering and controlling DC brush-type motors of ¼ horsepower or more from a single 48-volt bus.

1. INTRODUCTION

1.1 MOTOR CONTROL OVERVIEW

Designers of motor control systems commonly use Pulse Width Modulation (PWM) techniques to drive DC motors because of the great efficiencies that can be achieved. Single-chip PWM-controller/motor drivers enable system level engineers to integrate sophisticated motion control into their designs without being experienced in analog or power circuitry. Single-chip solutions, as we discuss below, provide analog or digital control of the motor-drive output H-bridge and commonly include features, such as thermal protection, short-circuit protection and programmable current limit. However, until recently, the upper threshold for drive current in a single-chip motor driver was 3A. This translates as a motor of approximately 1/6 HP on a 48-volt bus.

But with the introduction of Apex Microtechnology's SA56 Pulse Width Modulation Amplifier, able to continuously deliver 5A, designers can now power and control DC motors of 1/4 HP or more from a single 48-volt bus.

1.2 THE SA56 5A PWM AMPLIFIER

The SA56 is a 5A, PWM Amplifier designed for motion control applications (Figure 1). The device is fabricated using a modular (multi-technology) process that combines bipolar and CMOS control circuitry with DMOS power devices in a single monolithic structure. Ideal for driving DC motors, the SA56 operates at voltages up to 60V, delivering up to 5A continuously, and accommodates peak output currents up to 10A. An innovative circuit that facilitates low-loss sensing of the output current has been implemented.

The on-board PWM oscillator and comparator are employed to convert an analog signal into PWM direction and magnitude for motor-control applications. Or as will be described, the internal ramp generator and PWM oscillator can be disabled if the designer chooses to employ an external microprocessor with an on-board PWM source as the controller.

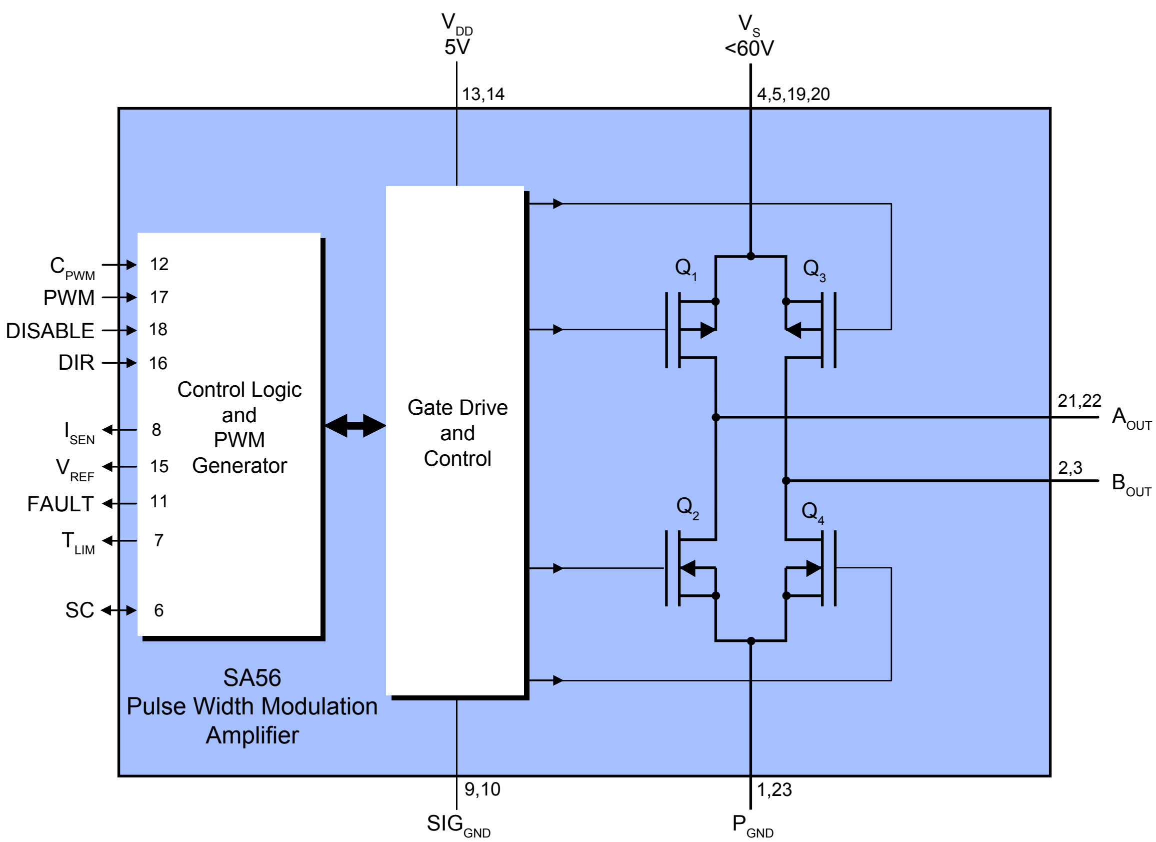

Figure 1. **The SA56 Pulse Width Modulation Amplifier –** This versatile IC is well suited for driving motors, position and velocity for servomechanisms, factory automation robots — as well as for computer printers and plotters.

2. H BRIDGE MOTOR CONTROL FUNDAMENTALS

2.1 H-BRIDGES

An H-Bridge can be used to control the speed, the direction of rotation and the torque of brush-type DC motors. The bridge comprises four SPST switches connected in an "H" configuration, as shown in Figure 2a. If each switch is thought of as a 'quadrant', and a DMOS FET replaces each single-pole, single-throw (SPST) switch, as shown in Figure 2b, then the supply voltage can be alternately connected, disconnected and reconnected at high speeds to the load in various ways via the four DMOS FETs, as we shall discuss in detail in this Design Idea.

Because the ON resistance of a FET device is purely resistive, the voltage can be of either polarity, and consequently, the current at any instant, will flow in the direction governed by the polarity of the voltage across it, thereby enabling motor reversal and braking. The low ON resistance, in combination with high-speed Schottky diodes connected in shunt, as we recommend in Section 9, enables the safe discharge of the power stored in the motor's inductive load, thereby protecting the MOSFETs.

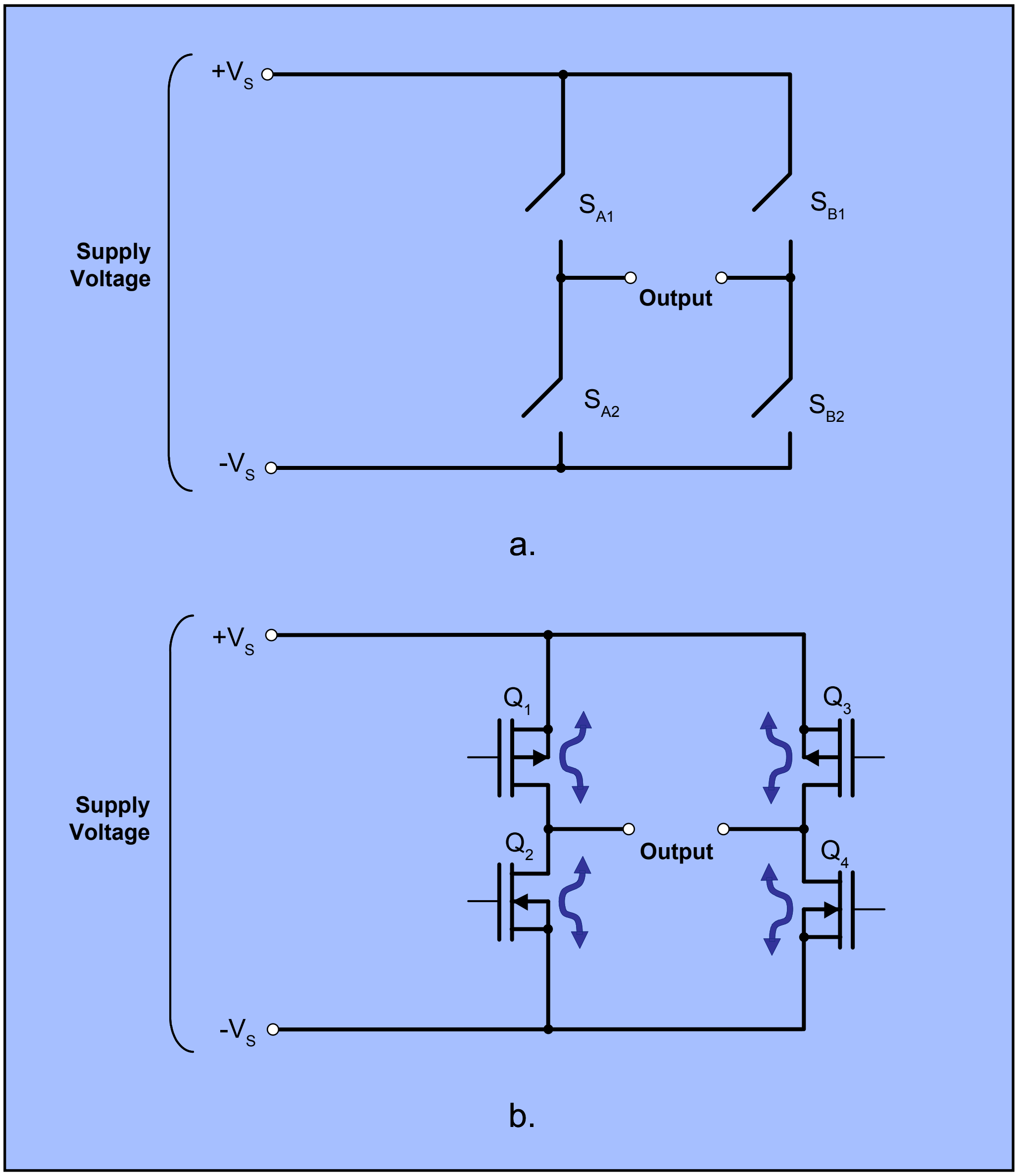

Figure 2. **A DMOS version of an H-Bridge –** The basic H-bridge circuit is shown in a. When DMOS FETs are substituted, as shown in b, they enable four-quadrant behavior, as well as bidirectional current flow (blue arrows) when the FETs are in the ON state.

The distinction between two- and four-quadrant mode is that in the former only two quadrants, or MOSFETs, are active at any one time when driving a brush-type motor; whereas in four-quadrant operation all four MOSFETs are active. Four-quadrant operation provides smoother speed transitions at low speeds. However, the trade-off is that power dissipation is higher because four, rather than two, MOSFETs are switching all the time, so switching losses are doubled.

2.2 GENERATING A PWM WAVEFORM

To generate a PWM waveform, an analog input signal is compared to the PWM ramp reference, as shown in Figure 3. (This sawtooth ramp signal can be viewed by applying an oscilloscope probe to pin 12 of the SA56. The output V_{REF} at pin 15 corresponds to the mid-point — 2.5V — of the ramp.) When the input signal is greater than the ramp voltage, the A_{OUT} side of the H-bridge switches to V_S and the B_{OUT} side to P_{GND}. Similarly, when the input signal is less than the ramp, the B_{OUT} side switches to V_S, as depicted in Figure 3. So long as the input is within the peak-to-peak ramp voltage, then an infinitely variable duty cycle can be achieved. (If the input signal is outside the peak-to-peak ramp voltage there is no switching.)

Preventing Shoot Though - For the safety of the amplifier and the load, it is important that the two switches on the same side of the H-bridge are never on at the same time. For this would create a short from $+V_S$ to $-V_S$. 'Dead Time' is the solution to this potential problem. During the transition from the A_{OUT} side to the B_{OUT} side of the H-bridge, or vice-versa, there is a period of time in which neither side is high. This dead time, in the case of the SA56 is approximately 100 nanoseconds. Though dead time introduces a small non-linear region in the variable duty cycle near 0% and 100%, its contribution to inefficiency is negligible.

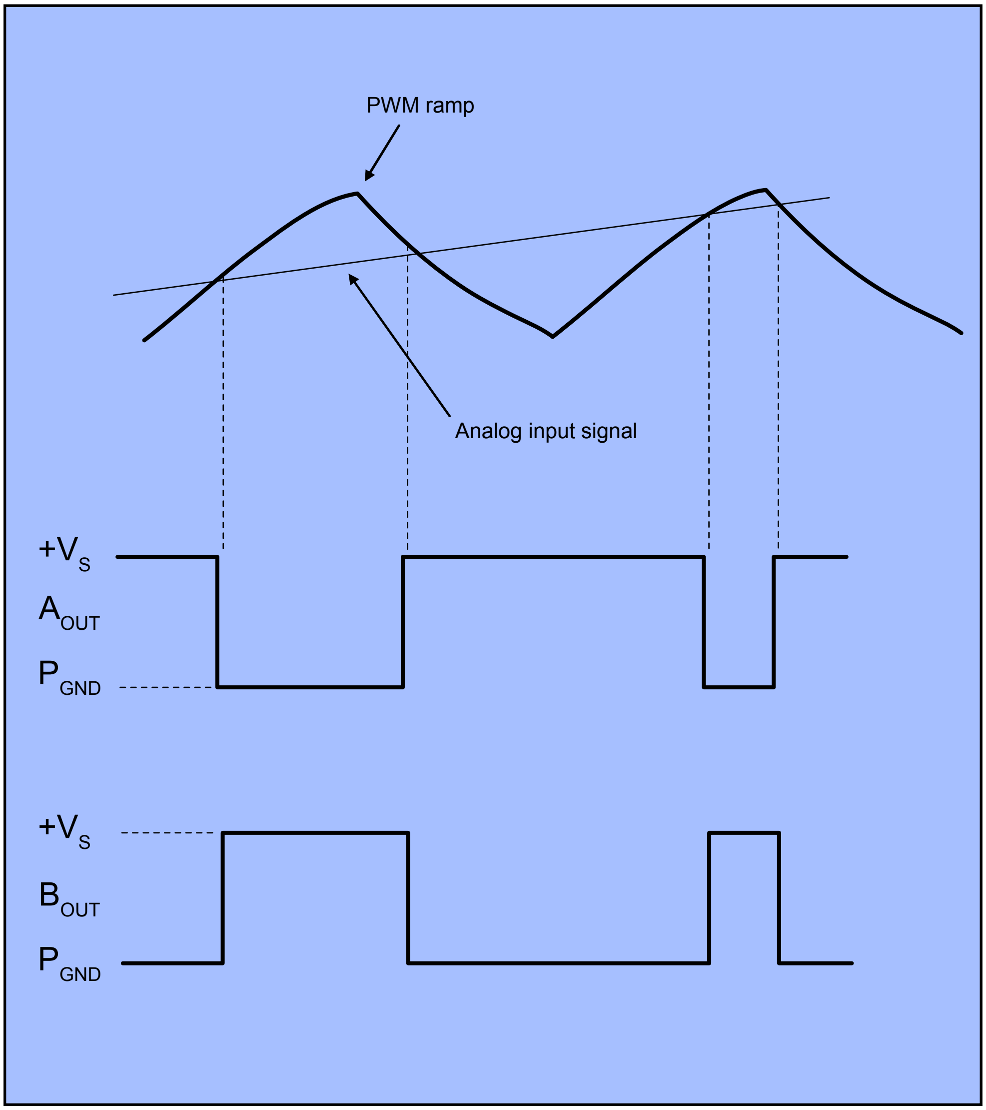

Figure 3. **Generating a PWM Waveform —** An analog input signal is continuously compared with the PWM ramp, toggling A_{OUT} and B_{OUT}.

2.3 TWO-QUADRANT OPERATION

Shown in Figure 4 is two-quadrant operation. Note that in the forward direction — which assumes the average value of the current flowing from A_{OUT} to B_{OUT} is positive — MOSFETs Q_1 and Q_2 are cycled by a PWM signal while MOSFET Q3 remains ON all the time. MOSFET Q4 remains off. The waveforms developed at the MOSFET terminals A_{OUT} and B_{OUT} are depicted in Figure 4, as well as the net voltage applied to the motor terminal (A_{OUT} - B_{OUT}).

If the motor is to be driven in the reverse direction then the roles of MOSFETs Q_1, Q_2, and Q_4 are simply interchanged, bilaterally.

Start-Up — During two quadrant operation start-up a slow start-algorithm must be employed to prevent excessive current. This is due to the fact that the back EMF, which is a function of the velocity in RPMs, is at zero volts when the motor is at rest. The back EMF will rise as the motor accelerates, gradually reducing the current flow. Once the back EMF is high enough, full power (a higher duty cycle) can be applied to the motor. However, deceleration and the re-application of power to drive the motor in the opposite direction requires careful programming including a "Soft-Start" algorithm, in the case of a digital drive and an RC network in the case of an analog drive. These topics are discussed in detail in Section 7.

Braking — To brake the motor in two-quadrant operation requires turning the two P-channel MOSFETS, Q_1 and Q_3, ON at the same time. This can be accomplished by setting the PWM pin 17 to LOW.

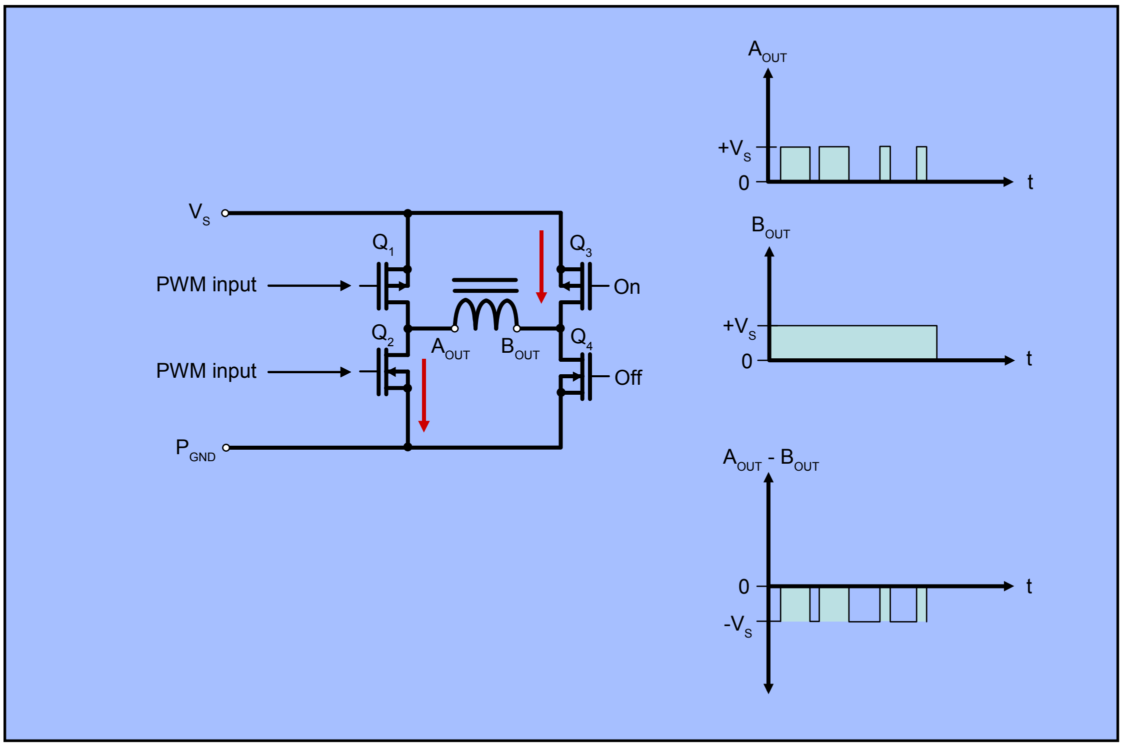

Figure 4. **Two Quadrant Operation —** Only two MOSFETs are active at any one time.

2.4 FOUR-QUADRANT OPERATION

In four-quadrant operation all four switches are active all of the time, because the Q_1–Q_4 pair and Q_2–Q_3 pair will switch in a complementary fashion, as depicted in Figure 5. What governs the direction of the motor is the polarity of the current. When the duty cycle is exactly 50% - 50%, then the average current is zero and the motor will be stopped. Shifting the duty cycle so that the ON interval of either the Q_1–Q_4 or the Q_2–Q_3 pair is greater than 50% will cause the current flow to rise above zero so that average current will be higher in the MOSFET pair that is ON greater than 50% of the time. See also Section 4.1

Start-Up — As is the case in two-quadrant operation, during start-up a soft-start algorithm must be employed to prevent excessive current. This is due to the fact that the back EMF is a function of the velocity in RPMs and acts to gradually diminish the current as the motor speed gradually builds up. Once the back EMF is high enough, then full power (a higher duty cycle) can be applied to the motor. However, deceleration and the re-application of power to drive the motor in the opposite direction requires careful programming including a "Soft-Start" algorithm, in the case of a digital drive, and an RC network in the case of an analog drive. These topics are discussed in detail in Section 7.

Braking — Pull DIR and PWM (pins 16 and 17 respectively) low to turn on both upper MOSFETs and apply regenerative braking techniques. The motor winding current will rapidly circulate through these MOSFET devices until it decays to zero.

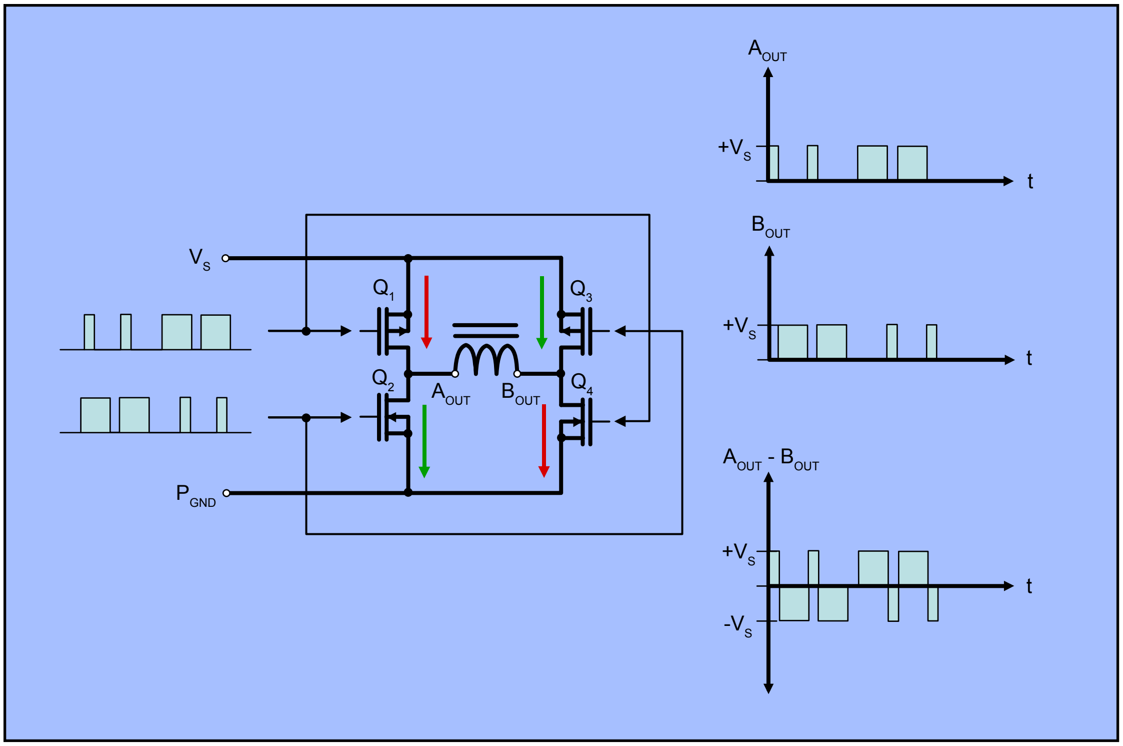

Figure 5. **Four-Quadrant Operation —** All four MOSFETs are active.

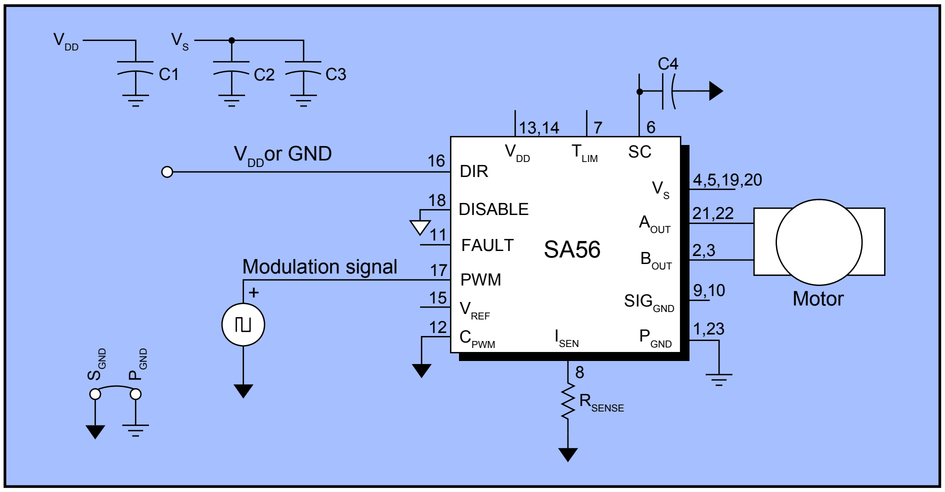

Figure 6. **Digital Mode - Two Quadrant – Schematic —** The binary input to DIR controls which output (A_{OUT} or B_{OUT}) of the SA56 is active while the other is held HIGH, as depicted in Figure 7.

3. TWO-QUADRANT CONTROL APPLICATION

3.1 TWO QUADRANT – DIGITAL MODE

Two-quadrant operation of the FETs is realized by driving PWM pin 17 of the SA56 with a digital PWM signal supplied by a microcontroller or DSP, as depicted in Figure 6. When using a digital modulation signal, tie the C_{PWM} pin to GND, as shown in Figure 6, to disable the internal oscillator and its companion ramp generator. When operating in the digital mode, pulse widths should be no less than 100ns and the switching frequency should remain below 500kHz. This will allow enough time for the output MOSFETs to reach their full ON and OFF states before receiving the subsequent command to reverse state.

A digital PWM signal applied to the PWM pin, as shown in Figure 6, controls the output duty cycle at one output pin while the other output pin is held "HIGH". The input at the DIR pin (V_{CC} or GND) governs the output behavior. If DIR is a logic "HIGH", the A_{OUT} output will be held high, as shown in Figure 7, and the B_{OUT} output will be switched as the complement of the PWM input signal. The average output at A_{OUT} will always be greater than at B_{OUT}. Whereas if DIR is a logic "LOW", the B_{OUT} output will be held "HIGH" and the A_{OUT} output will be switched.

Operating in two-quadrant mode reduces switching noise and power dissipation, but limits the ability to control the motor at very low speed.

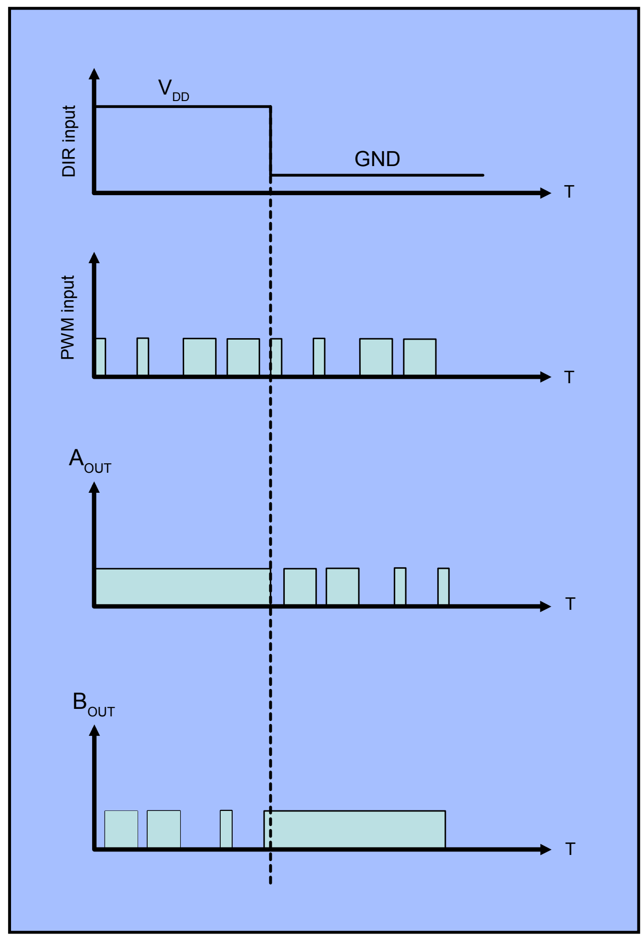

Figure 7. **Two Quadrant – Digital Mode Waveforms** – Depending on the setting of DIR either A_{OUT} or B_{OUT} will be held high.

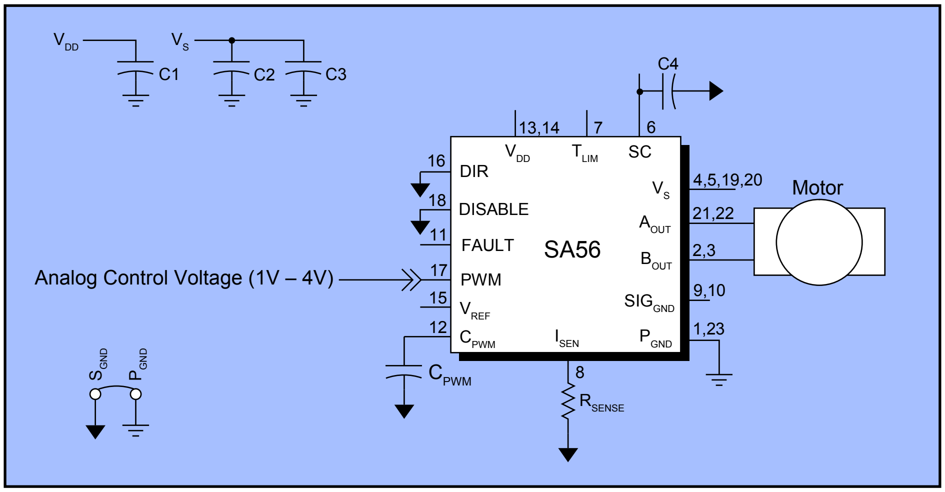

Figure 8. **Four Quadrant — Analog Input –** By applying an analog voltage between 1 and 4 volts to the PWM pin, the duty cycle of the PWM signal generated internally within the SA56 can be controlled.

4. FOUR-QUADRANT CONTROL APPLICATIONS

4.1 FOUR QUADRANT – ANALOG MODE

In Four Quadrant – Analog Mode the capacitor C_{PWM}, connected between C_{PWM} and SIG_{GND}, as shown in Figure 8, sets the frequency of the internal triangular ramp signal. The value of C_{PWM} is governed by the following:

$$C_{PWM}\,(pF) = \frac{4.05 \times 10^7}{F_{SW}} \qquad (1)$$

Where F_{SW} is the frequency of the PWM signal.

When operating in the analog mode, the analog control voltage applied to the PWM pin is continuously compared with the internally-generated ramp in the SA56 which, in turn, modulates the duty cycle of the PWM output that appears at pins A_{OUT} and B_{OUT}. (Refer also to Section 2.2.) In analog mode, the DIR pin is tied to signal ground, as shown in Figure 8. Duty cycle versus the applied voltage for different input voltages are depicted in Figure 9. These values correspond with the information depicted in the figure entitled "DUC vs Analog Input" found on page 3 of the SA56 Data Sheet[1].

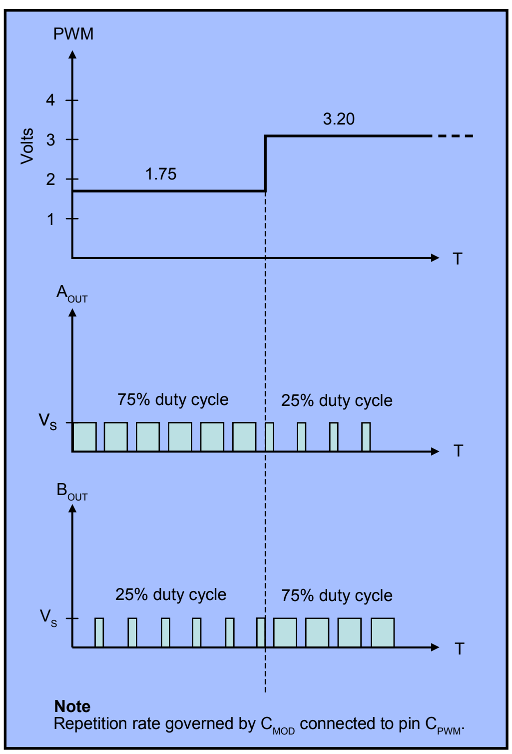

Figure 9. **Four Quadrant - Analog Input Wave Forms —** The duty cycle at pins A_{OUT} and B_{OUT}, for two analog input values at pin 17, 1.75V and 3.2V, are depicted here.

4.1 FOUR QUADRANT – ANALOG MODE (CONT.)

As depicted in Figure 10, the analog voltage applied to pin 17 of the SA56 governs the duty cycle of the PWM signals driving the MOSFETs. Note that zero RPM occurs at 2.5 V which corresponds to the reference voltage available at pin 15. Consequently, to drive the motor in the forward direction in which the $A_{OUT} - B_{OUT}$ will be positive, the applied voltage is gradually lowered below 2.5V so as to bring the motor to full speed. Likewise to drive the motor in the opposite direction ($A_{OUT} - B_{OUT}$ below zero voltage) requires that the analog voltage be gradually raised above 2.5V.

Refer to the graph entitled "Maximum Duty Cycle for Linear Operation in Analog Mode", p.3 of the SA56 Data Sheet. It denotes a maximum recommended duty cycle for a certain frequency of operation. For motor control frequencies the maximum specified duty cycle is approximately 95%. At duty cycles above the specified maximum, the duty cycle will snap to 100%. If this behavior is likely to occur in your design, then the circuit can be made more noise robust by adding the snubber kit discussed in the EK22 Evaluation Board Data Sheet[2].

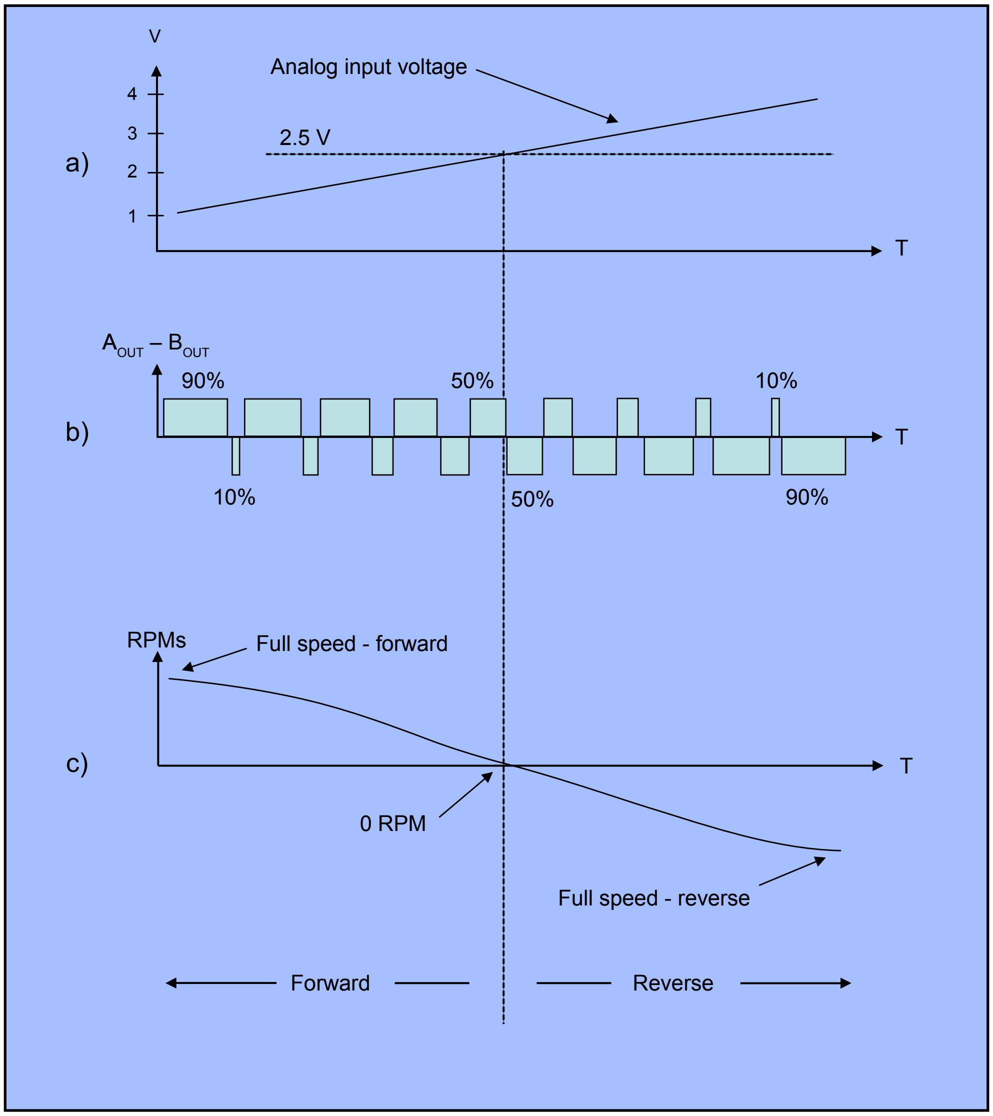

Figure 10. **Four Quadrant – Analog Mode —** In a) is shown the analog input voltage. Note that at 2.5V the motor is at rest because the pulse widths are equal (50% - 50%), so the average power applied is zero, as shown in b). As shown in c) the speed accelerates when the analog voltage is varied above or below 2.5V.

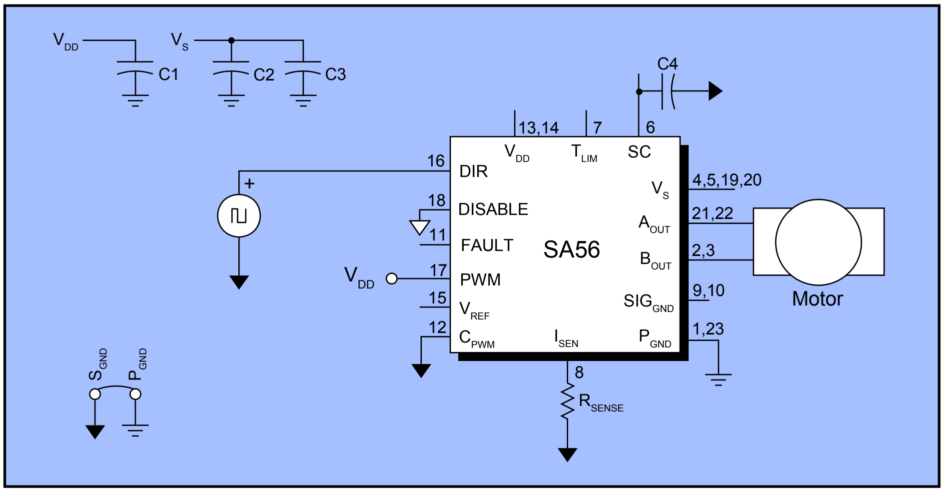

Figure 11. **Four Quadrant – Digital Mode Schematic –** The PWM is applied to the DIR pin with both MOSFETS switching in a locked complementary fashion.

4.2 FOUR QUADRANT - DIGITAL MODE

During four-quadrant operation a single digital PWM input includes magnitude and direction information. The digital PWM input signal is applied to the DIR pin, as shown in Figure 11, and the PWM pin is tied HIGH to V_{DD}. Both pairs of output MOSFETs will switch in a locked, complementary fashion, delivering the outputs depicted in Figure 12.

With a 50% duty cycle the average voltage of outputs A_{OUT} and B_{OUT} will be the same, which is half of V_S so that the average differential voltage over each period applied to the load will therefore be zero, as discussed in Section 4.1.

Four-quadrant operation allows for smooth transitions through zero current for low-speed applications. However, power dissipation is slightly higher than in two-quadrant operation since all four output MOSFETs must switch every cycle.

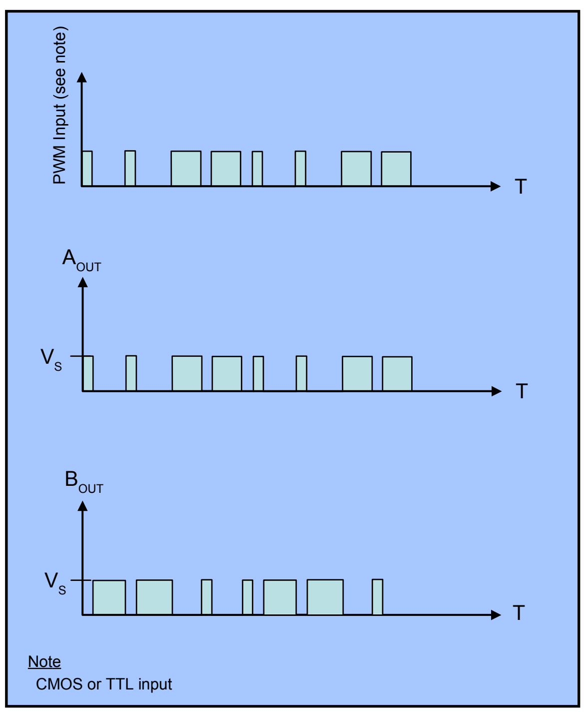

Figure 12. **Four Quadrant – Digital Mode Waveforms –** Both outputs A_{OUT} and B_{OUT} will operate in a locked complementary fashion. A_{OUT} will mirror the PWM input at DIR and B_{OUT} will deliver the complement of A_{OUT}.

5. MICROPROCESSOR CONTROL

Shown in Figure 13 is a Microchip PIC18F2331 microcontroller driving a SA56. As an example, the Microchip PIC18F2331 has been selected to control SA56 because it can be programmed very easily for motor-control applications. It is covered in Reference 3.

Soft-Start Algorithm – This algorithm enables controlling the rate of acceleration and consequently the maximum current. As depicted in Figure 14, there are two parameters to be programmed: 'increment' and 'delay'. The delay is the time interval between the successive incremental changes in the duty cycle. Whereas the increment is the percent increase in duty cycle which is implemented at the end of each delay. After each increase in duty cycle that is slightly higher than the last one, there is a delay, or time interval, until the next incremental change occurs. The effect of Soft-Start is to ramp up the motor speed without exceeding the maximum allowable current, until the specified speed is reached.

Handling Reversals - When the motor is to be reversed, the motor will gradually decelerate through zero RPM – 50% duty cycle— automatically and then gradually accelerate in the opposite direction. During development it is essential to reduce the duty cycle, holding the duty-cycle start-up current before attempting to rotate the motor in the opposite direction. Once the motor begins to rotate in the opposite direction and the back EMF begins to build up, the duty cycle may be increased.

Input to the Microchip - For prototyping purposes, the designer may want to employ the signals, depicted by the dotted lines in Figures 13 and 15.

V_{FREQ} – The PWM frequency can be varied from 4 kHz to 118 kHz by changing the voltage applied between V_{FREQ} and microcontroller ground.

V_{DUC} – The duty cycle can be varied from 0% to 98% by varying the applied voltage between V_{DUC} and ground.

Forward/Reverse (F/R) – The Forward(HIGH)/Reverse (LOW) pin is provided to control the direction of rotation of the motor.

Run/Stop (R/S) – The Run(LOW)/Stop(HIGH) enables starting and stopping the motor by changing the applied binary voltage between V_{DUC} and D_{GND}.

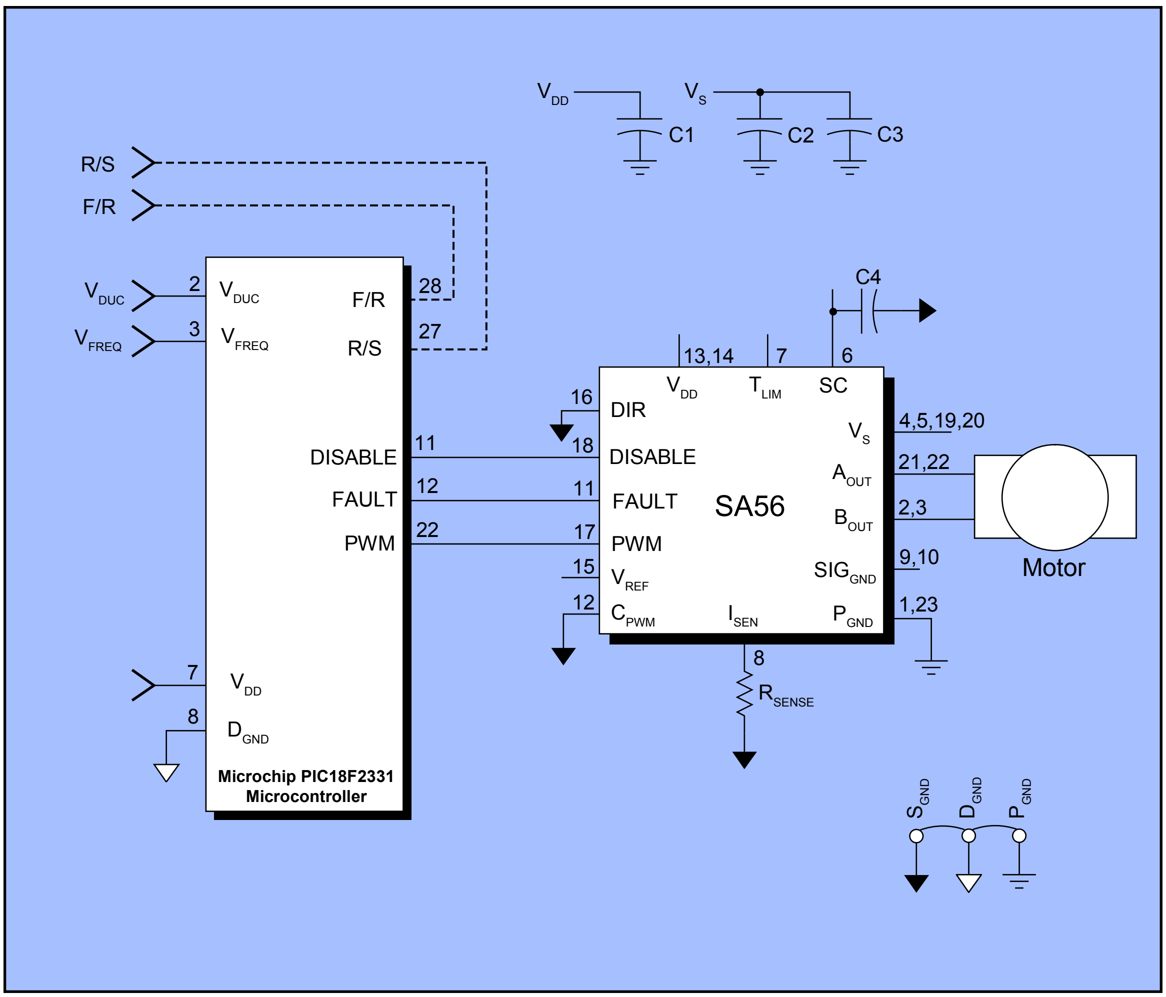

Figure 13. **Microprocessor Controlled –** By driving the SA56 with a microcontroller such as the Microchip PIC18F2331, essential parameters of the motor – such as rate of acceleration, final speed and direction of rotation – can be easily controlled.

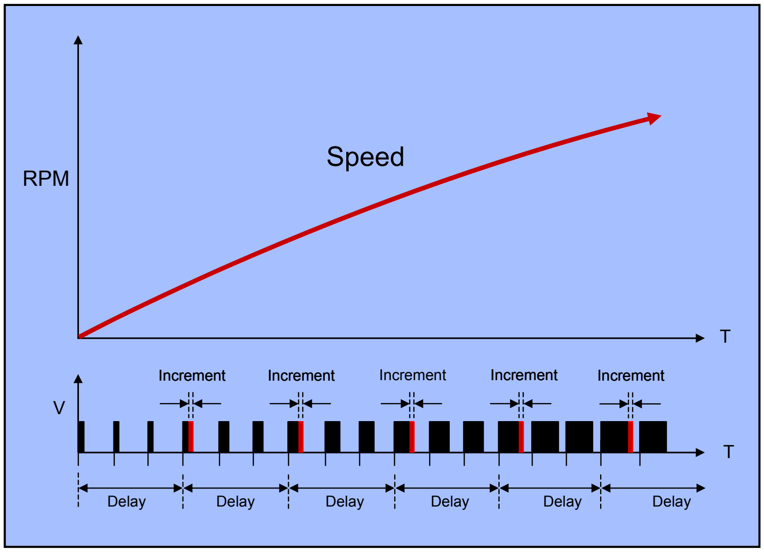

Figure 14. **Increment and Delay —** Principal parameters in the 'Slow-Start' Algorithm.

6. TORQUE CONTROL

6.1 CLOSED-LOOP TORQUE CONTROL - DIGITAL MODE

Monitoring Current – Since torque is a function of current, monitoring the DC motor current enables closed-loop torque control. The sensed motor current is delivered at the I_{SEN} pin of the SA56, as shown in Figure 15. The SA56 Data Sheet specifies the ratio of the sensed current to output (motor) current that is governed by the plot shown on page 3 of the SA56 Data Sheet[1]. The op amp A_1 should be a low-offset, rail-to-rail device such as the Maxim 2375 or the Texas Instruments TLC081. A typical value for R_{SENSE} is 1k Ohm. As an example, for an A_1 op amp gain of 10, the values of R_{IN} and R_F could be 10k Ohms and 90k Ohms, respectively.

Within the microcontroller the two values – the torque T_{REF} and a voltage corresponding to the motor current delivered at I_{SEN} – are compared and applied to a Proportional Integral Derivative (PID) controller algorithm, to alter the duty cycle of the PWM outputs, as necessary, to maintain a constant motor torque. PID controllers are discussed in the Appendix of this document.

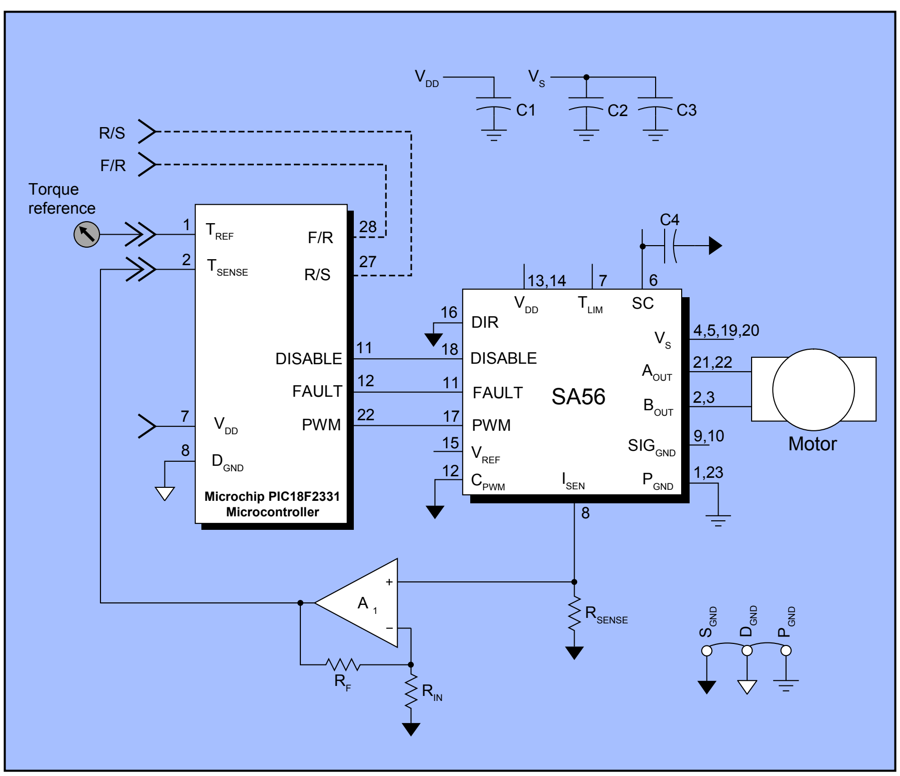

Figure 15. **Torque Control - Digital Mode –** Note the feedback signal, via op amp A_1, back to the microcontroller.

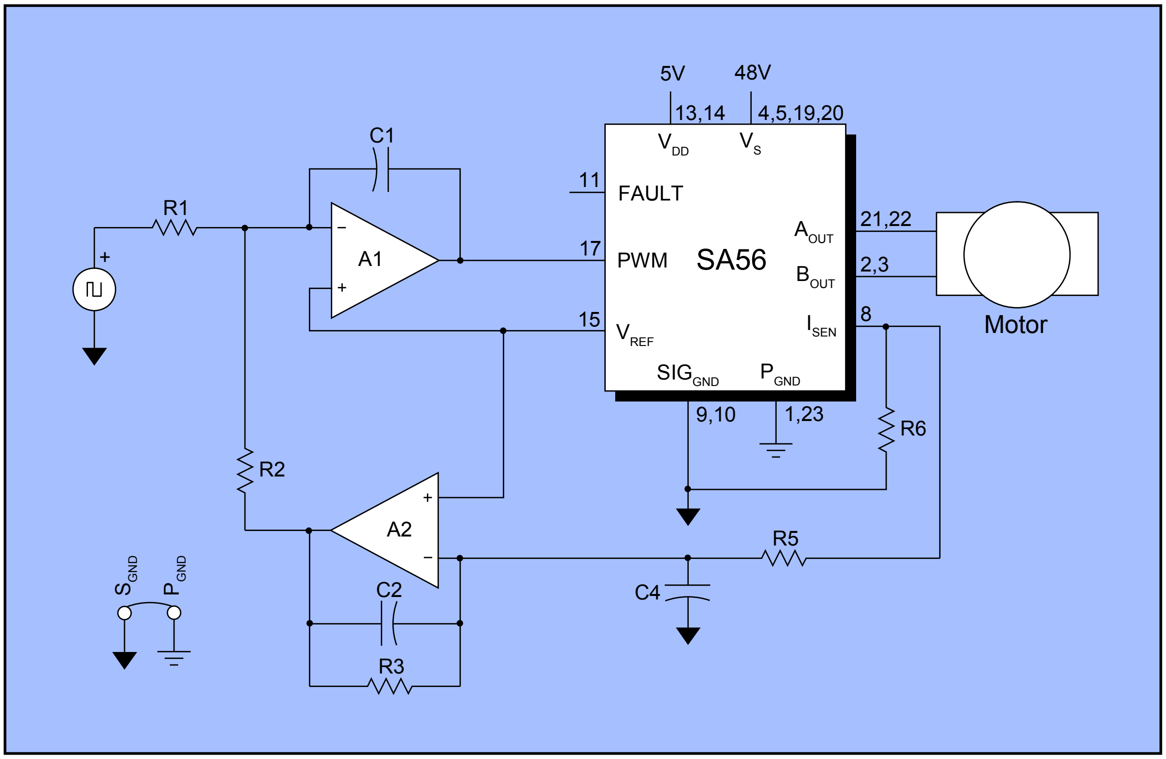

Figure 16. **Torque Control – Analog Mode —** The current sensed at the I_{SEN} terminal is compared with the reference voltage supplied by the PWM source. Refer to Apex Application Note 41 for details.

6.2 CLOSED LOOP TORQUE CONTROL – ANALOG MODE

In Figure 16, a schematic of a closed-loop torque control is shown that's employing an analog source for the SA56. Details with regard to the selection of the operational amplifier and component selection can be found in Apex Microtechnology's Application Note 41[4].

7. SOFT-START CIRCUIT

As shown in Figure 17, an RC delay is added to the analog input for controlling the duty cycle at start up, thereby gradually ramping up the motor speed. The RC time constant will determine the delay. In this example, with a $R_{S\text{-}S}$ of 100k Ohms and a $C_{S\text{-}S}$ of 2 Nanofarads, a time constant of 0.2 millisecond is established – and assuming a rise time of 5 time constants (1 millisecond), the motor reaches the specified speed in 1 millisecond. The analog input and the corresponding PWM duty cycle are depicted in Figure 18.

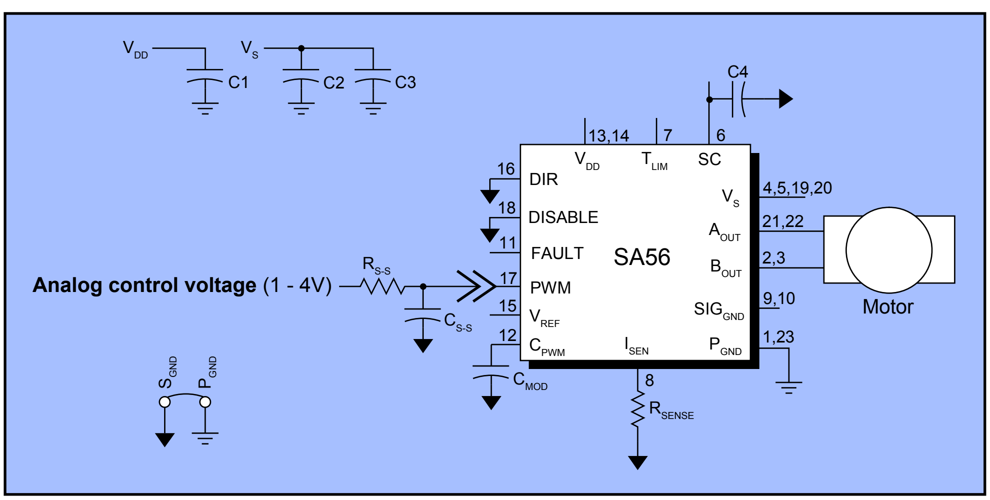

Figure 17. **Slow-Start – Analog Mode —** The current sensed at the I_{SEN} terminal is compared with the reference voltage supplied by the PWM source. Refer to Apex Application Note 41 for details.

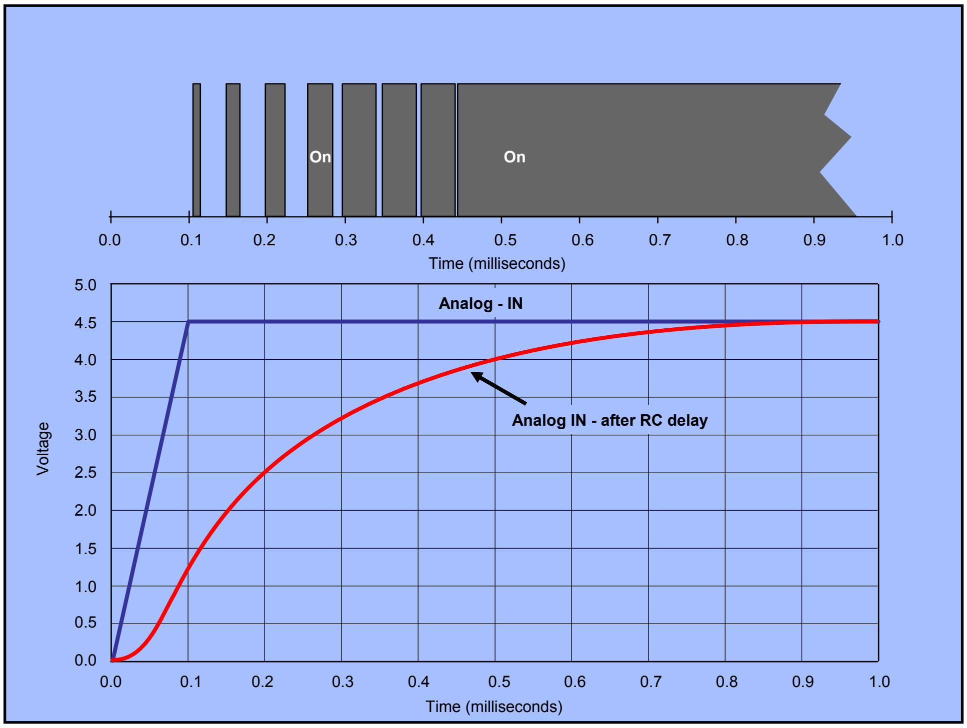

Figure 18. **Soft-Start Acceleration —Analog Mode -** As the reference voltage climbs, the PWM duty cycle, which is initially very low, reaches 100% in approximately 0.5 millisecond.

8. PROTECTION CIRCUITS

Introduction – The most severe condition for any power device is a direct, hard-wired ("screwdriver") short from an output to ground. While the short-circuit protection will latch the output MOSFETs within 500ns (typical), the die and package may be required to dissipate up to 500 Watts of power until the protection circuits are activated.

This energy can be destructive, particularly at higher operating voltages, so sound thermal design is critical if such fault tolerance is to be established in the design. The V_S and P_{GND} pins may become very hot during this period of high current.

THe SA56 is designed with thermal and short-circuit protection to prevent damage in the event that faults occur as described below:

Short-circuit protection – The short-circuit protection circuits will sense a direct short from either output (A_{OUT} or B_{OUT}) to GND or V_S — as well as across the load. If the high-current protection circuit engages, it will place all four MOSFETs in the tristate condition (high-impedance output). The SC output, pin 6, will go "HIGH", though not latch, thereby denoting that this protection feature has been triggered.

Over-current protection – When the current on the high side goes above 10A peak, the over-current circuit tristates so that the four MOSFETs go into a latched fault condition.

Thermal protection - The thermal protection circuits will engage if the temperature of any of the four MOSFETs reaches approximately 160°C. If this occurs, the FAULT output pin will go HIGH. If the thermal protection circuit engages, it will place all four MOSFETs in tristate condition (high-impedance output). The T_{LIM} output which is normally LOW will go HIGH, though not latch, thereby denoting which of the protection features has been triggered.

FAULT pin – This pin latches high whenever the four MOSFETs have been placed in the tristate condition when either the high-current or the thermal protection has engaged.

Defeating thermal protection – Grounding pin T_{LIM} defeats the over-temperature protection. Normally this pin should be left unconnected if over-temperature protection is desired.

SC and T_{LIM} outputs - The SC or T_{LIM} output will go "HIGH", though will not latch, thereby denoting which of the protection features has been triggered. Both pins go low once the MOSFETs go into tristate condition, which means that the circuit has been able to protect itself. To reset the tristate condition, cycle the V_{DD} power or bring the DISABLE pin HIGH, then LOW.

Bypassing the SC pin – It is essential that the SC pin be bypassed to signal ground with a ceramic capacitor C4 ranging in value between 14 and 45pF, as shown in Figure 15. This will add a delay to the short-circuit response, but the SA56 will still be able to protect itself against short circuit and overcurrent.

Reset following a fault – Pulling the DISABLE pin HIGH and then LOW will reset a latched fault condition. (When pulled HIGH, all four output MOSFETs are disabled. A logic LOW on this pin allows the four output FETs to function normally.)

Reset when employing a microcontroller – When the DISABLE and FAULT pins are tied to the microcontroller, as shown in Figures 13 and 15, the FAULT pin will generate an interrupt in the microcontroller, so that the interrupt, can in turn, generate a pulse on the DISABLE pin. When a fault occurs, the SA56 fault circuitry will be reset.

Keep in mind that if thermal shutdown occurs repeatedly, the programmer must decide how many times reset of the SA56 will be allowed to reoccur and therefore should program a limit before human intervention is required.

9. SCHOTTKY DIODES IN SHUNT

Given that a motor presents an inductive load to the MOSFETs, the voltage across terminals A_{OUT} and B_{OUT} is Ldi/dt. If the motor is drawing 5A to 10A peak and there is a high rate of repetition of rise and fall times due to the PWM switching applied to the MOSFETs, the rise and fall time will be in the range of 60 to 70 nanoseconds, as can be confirmed by consulting the SA56 Data Sheet[1]. If the motor inductance is approximately 1 millihenry and the current swing is on the order of 10A, the magnitude of the voltage that would kick back to the drivers would be quite large, on the order of 10,000 volts. This would destroy the MOSFET drivers. However, by connecting Schottky diodes as shown in Figure 19, the drain-to-source terminals will never be subjected to more than the forward conduction voltage of the diode which is 0.3V. So effectively the drivers see no more than V_S plus the voltage drop V_D.

SB560 Schottky Diodes Recommended - Low-voltage-drop, high-current Schottky diodes such as the Diodes, Inc. SB560 are recommended.

The principal reason Schottky diodes are employed instead of employing the internal body diodes is that they exhibit faster reverse recovery. The Schottky diode has a forward conduction voltage V_D of 0.3V rather than the 0.7V as is the case with the internal diodes in the MOSFETs. Consequently, the Schottky diodes will turn on before the body diode, thereby protecting the body diode.

Operating with only the internal body diode with its slower reverse recovery may be satisfactory at lower currents, on the order of 2A to 3A. However, to be safe, and to avoid damaging the SA56 device even at these lower currents, Apex recommends the use of Schottky diodes connected as shown in Figure 19. With the Schottkys connected as shown, they will carry virtually all the current whenever the MOSFET is off and a kickback current is delivered by the motor.

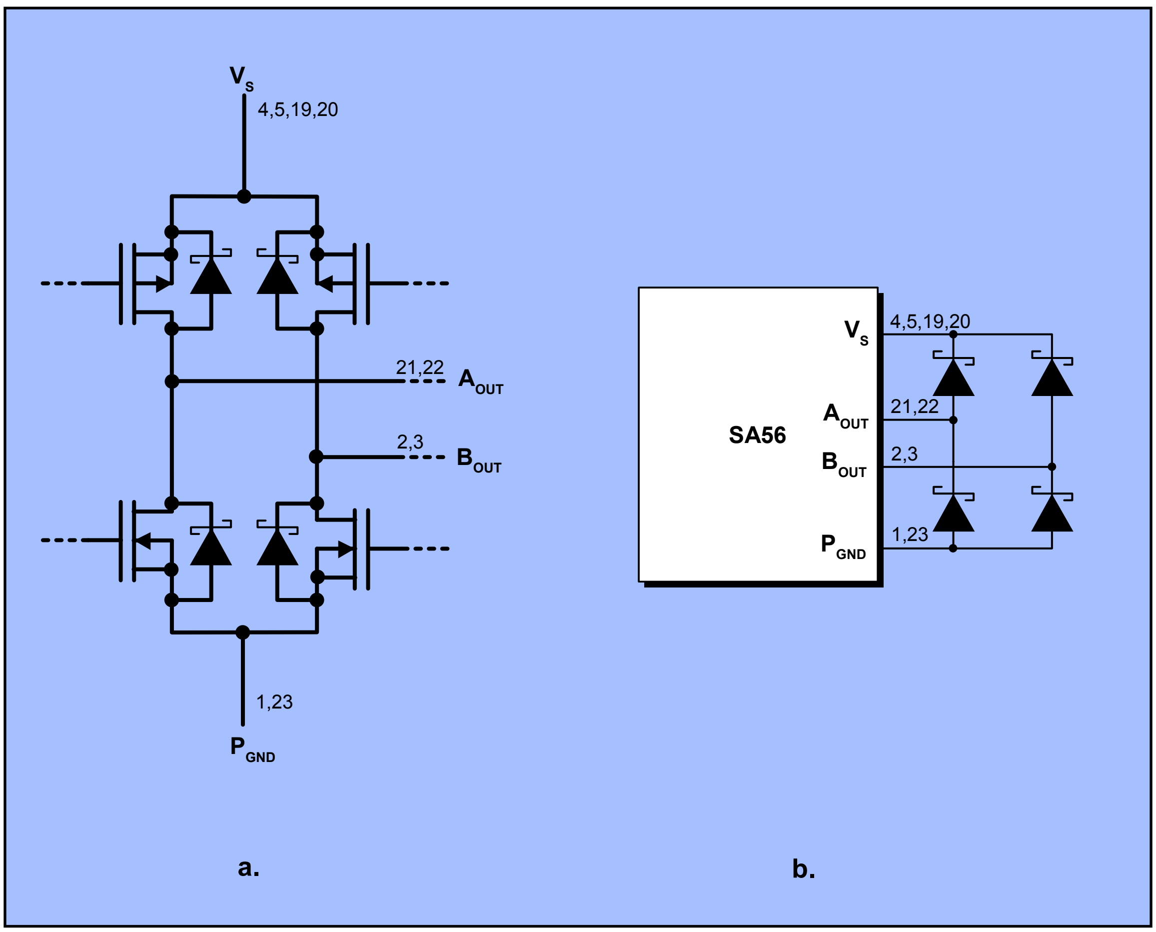

Figure 19. **Schottky Diodes –** a) High-speed Schottky diodes provide a reverse current path shunting each FET. Connect the four SB560 Schottky diodes as shown in b).

10. PROGRAMMABLE CURRENT LIMIT

The I_{SEN} pin sources a current proportional to the forward output current of the active P channel output MOSFET. The proportionality is approximately 300 µA per ampere of output current. Note that the I_{SEN} output is blocked during the switching transitions when current spikes are likely to be significant.

To create a programmable current limit, connect a resistor from I_{SEN} to S_{GND}. If the voltage across this resistor exceeds an internally-generated 2.75V threshold, all four output MOSFETs will be turned off for the remainder of the switching cycle. A 1.8k-Ohm resistor will set the current limit at approximately 5A.

The I_{SEN} output can also be used for maintaining a current control loop in torque motor applications, as discussed in Sections 6.1 and 6.2 of this Application Note.

11. DESIGN TIPS

11.1 GROUNDING AND BYPASSING

Grounds – The signal grounds (SIG_{GND}) for the SA56 are pins 9 and 10; the power grounds (P_{GND}) are 1 and 23. The package TAB should be tied to P_{GND}.

Signal and Power Grounds – Keep the microcontroller signal ground and power ground separate, but tie them together at a single point. When employing a microcontroller, establish three separate grounds, assigning the microprocessor ground to the ground plane. Then connect the power ground and the signal ground to the microprocessor ground, as depicted in Figures 13 and 15.

Power Supply Bypassing – For the SA56, bypass capacitors (C1, C2, C3) between the power-supply terminals V_S and V_{DD} and ground must be mounted close to the pins to prevent erratic, low-efficiency operation and excessive ringing at the outputs. Electrolytic capacitors of at least 10µF-per-output ampere are required for suppressing V_S to P_{GND} noise. High-quality ceramic capacitors (X7R), 1µF or greater, should also be used. Only capacitors rated for switching applications should be considered.

Mount these bypass capacitors as close to the power supply pins as possible, due to the very fast switching times of the outputs. Keep in mind that an inductance of just 1 inch of circuit trace can cause a significant degradation in performance. The bypassing requirements of V_{DD} are less stringent, but still necessary. A 0.1µF to 0.47µF capacitor connected directly between the V_{DD} (13,14) and S_{GND} (9,10) pins will suffice.

Please refer to Reference 5 for guidelines on power-supply terminal bypassing.

11.2 OPTIONAL EXTERNAL SNUBBER CIRCUITS

In high-switching noise scenarios a 4.7nF, 100V capacitor in series with a 50ohm 5W resistor should be connected between A_{OUT} and B_{OUT}. Depending on the PWM frequency and the resistance and inductance of the motor being driven, other values may be more effective.

The power dissipated in the snubber components can be estimated by:

$$P = V^2 C(F_{SW}) \qquad (2)$$

Where:

P = power dissipated
V = V_S supply voltage
C = snubber capacitor value
F_{SW} = switching frequency.

11.3 HEATSINKING

Refer to the SA56 Data Sheet for maximum power dissipation and power derating specifications. Based upon your power calculations, heat sinking requirements can be determined. If a heatsink is required, please refer to the Apex Microtechnology Website for available options. References 6 and 7 provide information on power dissipation and thermal calculations.

12. APPENDIX

A Proportional-integral-derivative controller (PID controller) is a feedback loop technique employed in control systems. It can be thought of as a form of a phase lead-lag compensator. A PID controller has one pole at the origin and the other at infinity[8]. It is used to compare a measured value with a reference value. When employed in motor control, the values may be either speed or torque. The difference value is then employed to calculate a new value to restore the value – be it speed or torque – to the setpoint value. A PID loop produces accurate, stable control in cases, whereas a simple proportional control would be likely to induce a steady-state error or would induce oscillation. Unlike more complicated control algorithms based on optimal control theory, PID controllers do not require advanced mathematics to develop a design.

A standard PID controller is also known as a "three-term" controller and can be expressed in the “parallel form” by (3) or the "ideal form" by equation (4):

$$G(s) = K_P + K_I \frac{1}{s} + K_D s \qquad (3)$$

$$= K_P \left(1 + \frac{1}{T_I s} + T_D s\right) \qquad (4)$$

Where K_P is the proportional gain, K_I the integral gain, K_D the derivative gain, T_I the integral time constant and T_D the derivative time constant.

- The proportional term provides an overall control response that is proportional to the error signal through the all-pass gain factor.
- The integral term reduces steady-state errors through low-frequency compensation by an integrator.
- The derivative term improves the transient response through high-frequency compensation by a differentiator.

The effects of each of these three terms on closed-loop performance are summarized in Table A.

Table A. **The Effects of Independent P, I and D Tuning**

Closed-Loop Response	Rise Time	Overshoot	Settling Time	Steady-State Error	Stability
Increasing K_P	Decrease	Increase	Small Increase	Decrease	Degrade
Increasing K_I	Small decrease	Increase	Increase	Large decrease	Degrade
Increasing K_D	Small decrease	Decrease	Decrease	Minor change	Improve

13. REFERENCES

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3. Microchip PIC18F2331/2431/4331/4431 Data Sheet, 28/40/44-Pin Enhanced Flash Microcontrollers, www.microchip.com
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7. Application Note 11, *Thermal Techniques*, www.apexmicrotech.com
8. "PID Control System Analysis, Design, and Technology," by Kiam Heong Ang, Gregory Chong and Yun Li, *IEEE Transactions on Control Systems Technology*, Vol. 13, No. 4, July 2005, pages 559 - 576

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