

AN1307

A Simple Pressure Regulator Using Semiconductor Pressure Transducers

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INTRODUCTION

Semiconductor pressure transducers offer an economical means of achieving high reliability and performance in pressure sensing applications. The completely integrated MPX5100 (0–15 PSI) series pressure transducer provides a temperature-compensated and calibrated, high-level linear

output that is suitable for interfacing directly with many linear control systems. The circuit described herein illustrates how this sensor can be used with a simple pressure feedback system to establish pressure regulation.

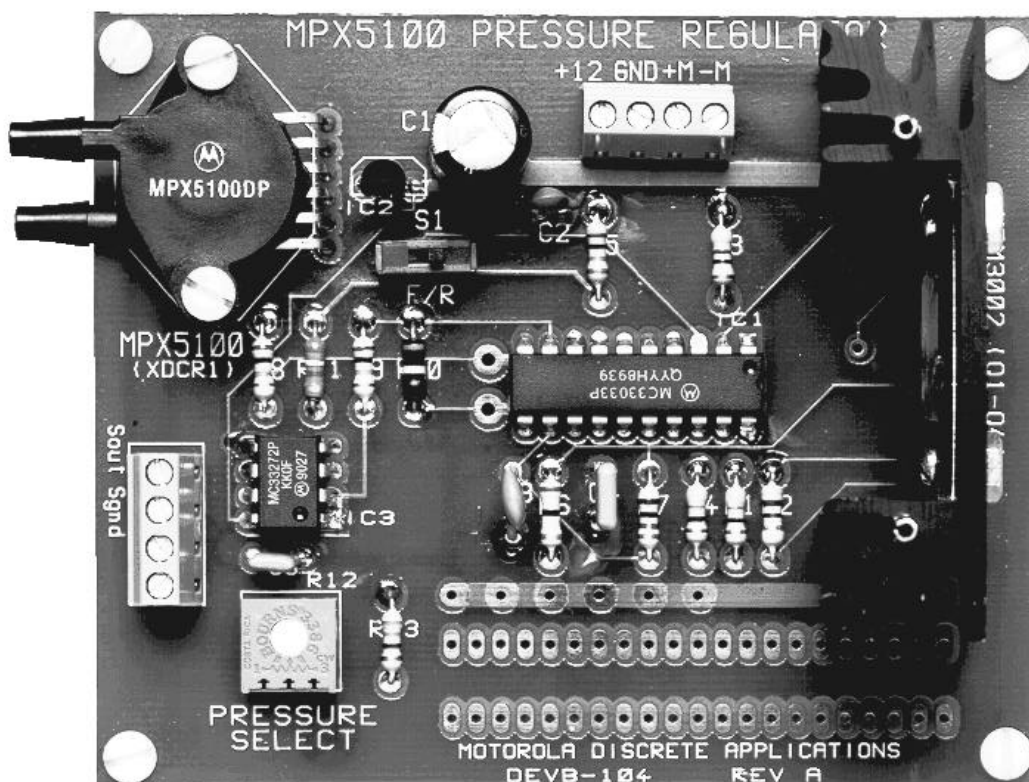


Figure 1. DEVB-104 MPX5100 Pressure Regulator

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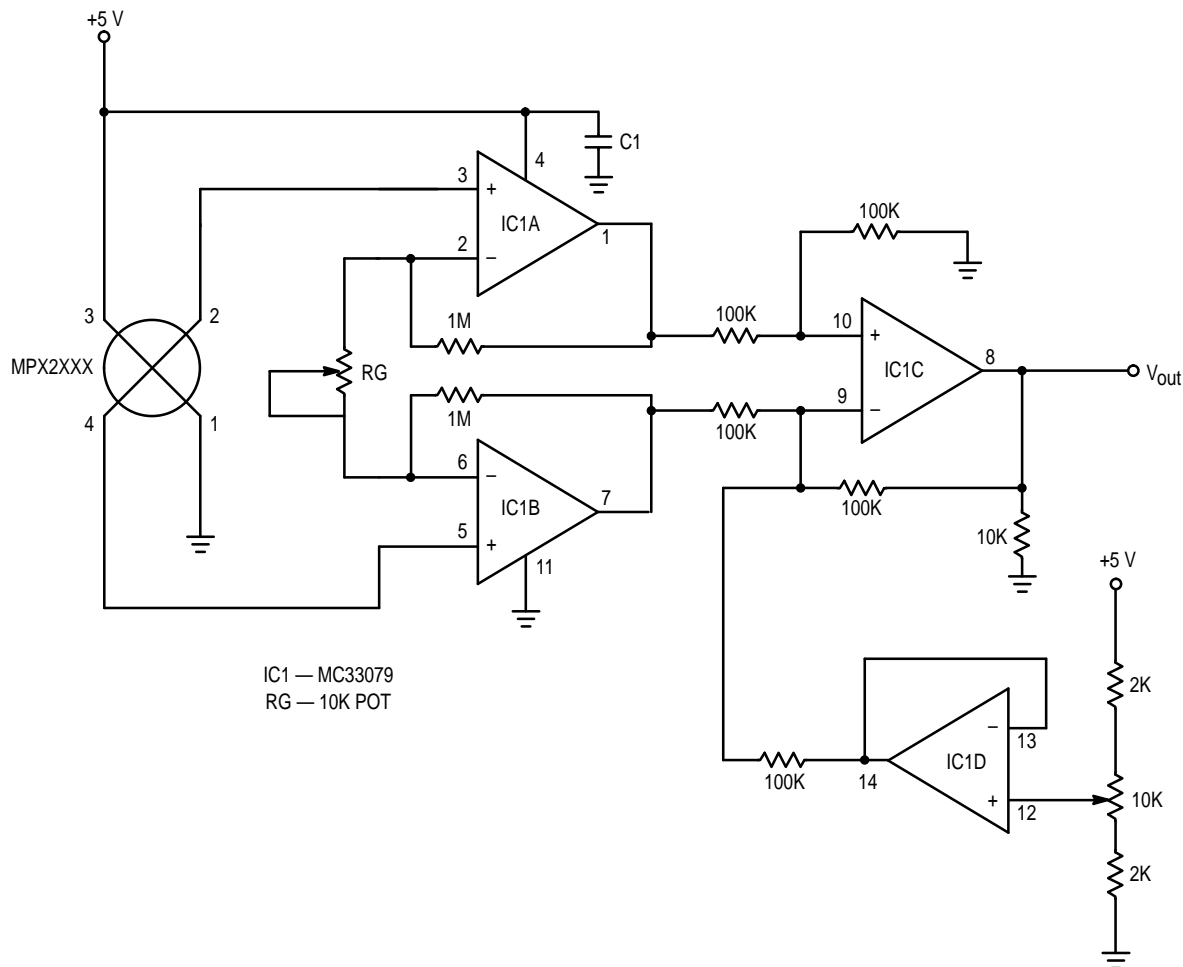


Figure 2. High Level, Ground Referenced Output Using an MPX2000 Series Transducer

THE SENSOR

The MPX5100 is the next level of integration beyond the MPX2000 series. The MPX2000 series of pressure transducers already incorporates, on-chip, more than a dozen external components needed for temperature compensation and offset calibration. Figure 2 shows the basic circuitry required to create a ground referenced output amplified to a high-level from an MPX2100 (0–15 PSI) transducer. For optimum performance, matched metal film resistor pairs and precision operational amplifiers are required.

The MPX5100 goes one step further by adding the differential to ground referenced conversion and the amplification circuitry on-chip. Therefore, the eighteen-component circuit shown in Figure 2 can be reduced to one signal-conditioned sensor, as shown in Figure 3.

All of the MPX devices contain a single piezoresistive implant which replaces the four-element Wheatstone bridge circuit found in most semiconductor-based transducers. The MPX5100 transducer uses an interactively laser-trimmed, four-stage network to perform signal conditioning. Figure 4 is an internal block diagram of the MPX5100 showing these four stages.

The first stage compensates for the temperature coefficient of offset while the second stage performs the differential to single-ended conversion. Stage three is a precision voltage reference that calibrates the zero pressure offset of the entire system, which comprises the sensor offset and the input offset voltages of the other three operational amplifiers. The final stage provides the full-scale span calibration. The MPX5100 is compensated for operation over 0 to 85°C with a response time (10% to 90%) of 1.0 msec.

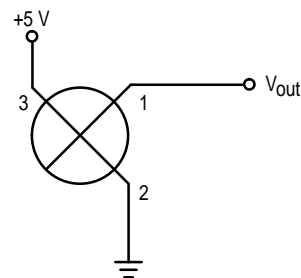


Figure 3. High Level, Ground Referenced Output Using an MPX5100

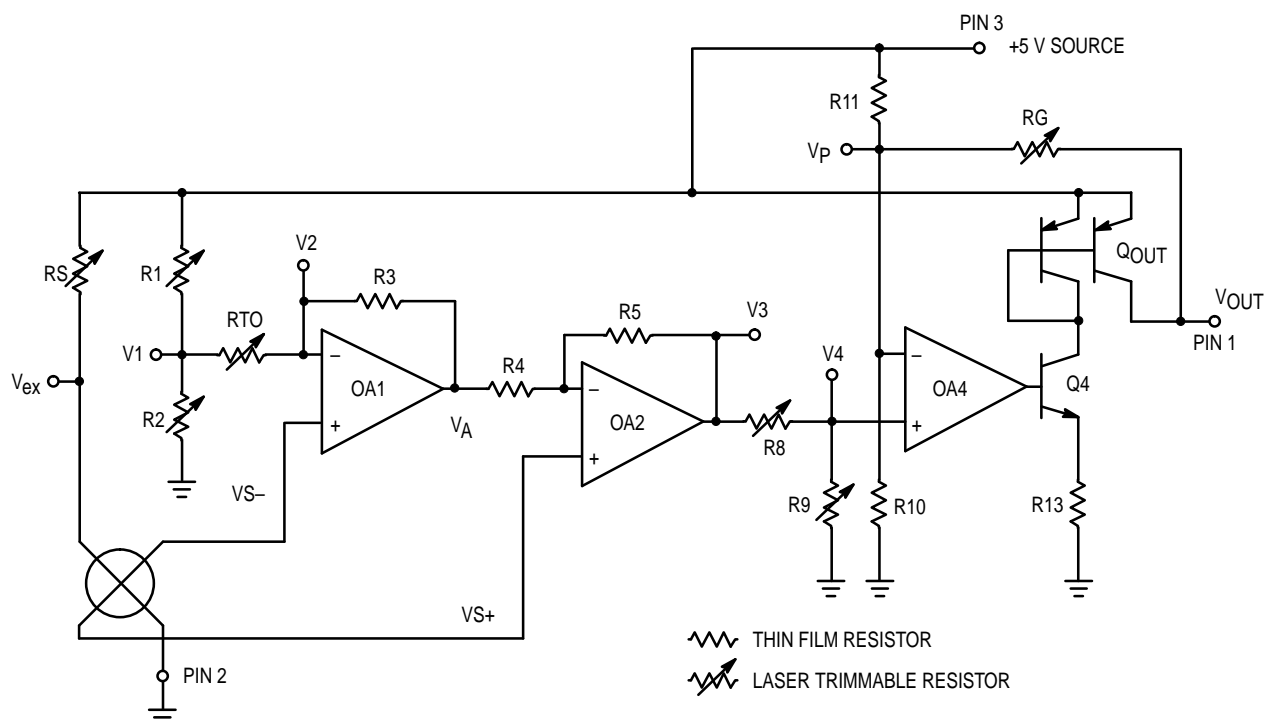


Figure 4. Fully Integrated Pressure Sensor Schematic

Some terms commonly used when discussing pressure sensors are:

- **V_{FSS}** (Full Scale Span) — the output voltage variation between zero differential pressure applied to the sensor and the maximum recommended operating pressure applied to the sensor, with a given supply voltage.
- **V_{OFF}** (Offset) — the voltage output given by a sensor with zero differential pressure applied, with a given supply voltage.
- **Sensitivity** — the amount of output voltage variation per unit pressure input variation.
- **Linearity** — the maximum deviation of the output from a straight line relationship over the operating pressure range.

Motorola specifies linearity using an “end-point straight line” method.

Each transducer is laser trimmed to provide the specified V_{FSS} with the supply voltage indicated on the data sheet. For example, V_{FSS} for the MPX5100 is trimmed to 4.0 V with a supply voltage of +5.0 Vdc.

For the MPX5100, V_{OFF} = 0.5 V with a 5.0 Vdc supply. Therefore, the output of the sensor varies from 0.5 V to 4.5 V for differential pressures from 0 kPa to 100 kPa, respectively. This is ideal for interfacing directly with many linear devices such as the MC33033 motor controller described in this application note or the A/D of a microprocessor controlled system.

THE CIRCUIT

Figure 5 is a block diagram of a simple pressure regulator feedback system. The motor/pump is used to fill a reservoir as required. The pressure created in this reservoir is monitored with a gauge and fed back to the MPX5100 sensor. The sensor provides an output voltage to the Motor Drive Circuitry which is proportional to the monitored pressure.

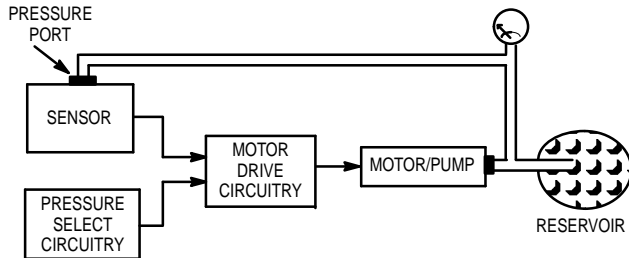


Figure 5. System Block Diagram

The Pressure Select Circuitry allows the user to choose a desired pressure by creating a reference voltage. This reference voltage is equivalent to the sensor output when the desired pressure exists in the system. A comparison is made between the sensor output and the reference voltage. When the system pressure is below the selected pressure, the motor is turned on to increase the pressure. When the system pressure reaches the selected pressure, the motor/pump turns off. Hysteresis is used to set different trip voltages for turn-off and turn-on to allow for noise and pressure fluctuations.

For particular applications that only require one fixed regulated pressure, the Pressure Select Circuitry can be reduced to a single voltage reference. Additionally, the Motor Drive Circuitry can be simplified depending on the application requirements and the motor to be used. Since a +5.0 Vdc supply to the sensor provides an output that is ideal for interfacing with an A/D converter, this comparison could easily be converted to a software function, allowing for a digital pressure select input as well as controlling a digital display.

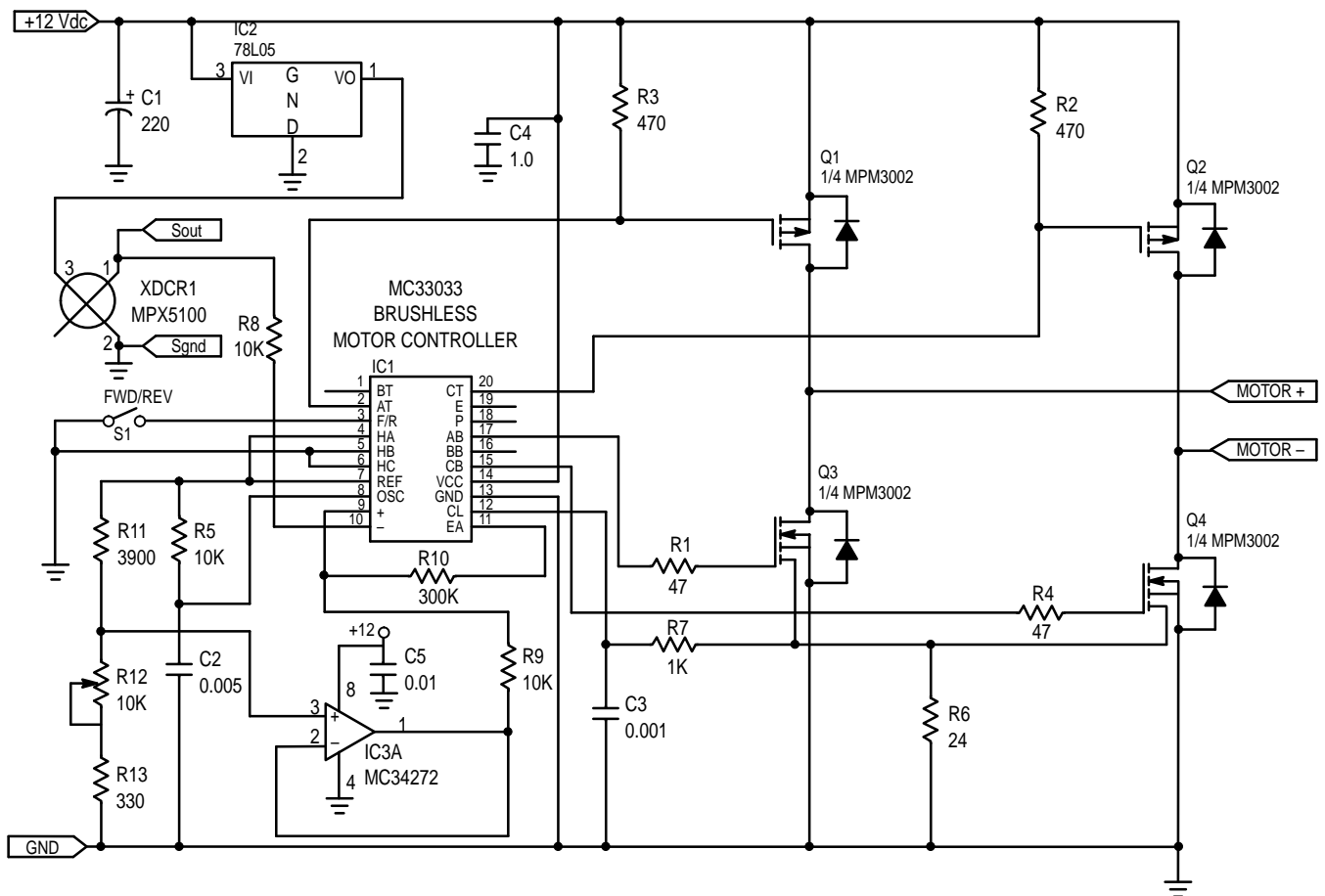


Figure 6. MPX5100 Pressure Regulator

DETAILED CIRCUIT DESCRIPTION

The Supply Voltage

Figure 6 is a schematic of the control electronics for this pressure regulator system. The +12 Vdc supply is used by the MPM3002 power transistors, the MC33033 motor controller and the MC34272 operational amplifier. In addition, this voltage is regulated down to +5.0 Vdc for the sensor supply.

The Pressure Select Circuitry

R11, R12 and R13 provide a variable reference from 0.5 V to 4.5 V. By adjusting R12, the reference voltage can be set to the desired pressure turn-off point. The error amplifier internal to the MC33033, along with R8, R9 and R10, is configured as a comparator with hysteresis. The sensor output voltage and the reference voltage are inputs to the comparator and are used to determine when the motor is turned on or turned off. When the sensor output is less than the reference voltage the motor is on. Pressure in the system increases until the sensor output is equal to the reference voltage plus the hysteresis voltage then the motor is turned off. If the pressure decreases while the motor is off, the sensor output will decrease until it is equal to the reference voltage at which time the motor turns on.

Hysteresis is set to prevent the motor from turning off and on due to small voltage variations such as noise or small pressure fluctuations in the system. The ratio of R10 to both R8 and R9 can be adjusted to provide the hysteresis required in a particular application. The resistor values shown in Figure 6 provide a ratio of 300 k Ω to 10 k Ω . This corresponds to a hysteresis of 300 mV or 7.5 kPa between the turn-off and turn-on trip points. The operational amplifier (MC34272) is used to provide a low impedance output to isolate the divider network from the comparator circuit.

The Motor Drive Circuitry

In a brush motor drive, the primary function of the controller IC is to translate speed and direction inputs into appropriate drive for the power transistors. This can be done efficiently by using the MC33033 Brushless DC controller as shown in Figure 6. In a brushless application, two of six output transistors are switched on in response to Hall sensor inputs H_A, H_B and H_C. In order to drive a brush motor, all that is required is to select a single Hall code that will drive a four transistor H-bridge in a way that is suitable for brush motors. By using phase A and phase C outputs, a 1-0-0 Hall code produces the correct drive for brush motors. A_T, B_T and C_T are open collector outputs, therefore, a logic 0 represents the on state. Conversely, A_B, B_B and C_B are totem pole drivers, and a logic 1 turns on the corresponding output transistor.

Generating the Hall code is easy. Since it is fixed at 1-0-0, tying the Hall inputs to DC levels is sufficient. Logic 1 is obtained from V_{REF}, and logic 0 from ground. The result is the

connections for pins 4, 5 and 6 that are shown in Figure 6. In addition to providing drive to the output transistors, the MC33033 has a current limit function and controls speed by pulse width modulating the lower output transistors, Q3 and Q4. The current limit operates on a 100 mV threshold. Once tripped, it latches the lower transistor drive off until the next clock cycle begins. The latching feature prevents high frequency oscillations which would otherwise overheat the power transistors. Compatibility with SENSEFETs™ is provided by the 100 mV threshold and allows the lossless current sensing configuration that is also shown in Figure 6.

For low-power, low-voltage motors, level shifting the gate-drain for Q1 and Q2, the upper output transistors, is not a problem. Open collector top-side outputs in the MC33033 interface directly to P-Channel MOSFETs. All that is required in the way of top-side drive circuitry is gate-to-source resistors on the P-Channel transistors, such as R2 and R3 in Figure 6.

Since an H-Bridge motor drive uses four power transistors, a power module can considerably simplify the output stage. The MPM3002 that is shown as Q1, Q2, Q3 and Q4 in Figure 6 is ideally suited to fractional horsepower motor drives. It consists of two P-Channel MOSFETs and two N-Channel SENSEFETs connected in an H-Bridge configuration, and housed in an isolated 12-pin, single, in-line package. The P-Channels have a maximum on-resistance of 0.4 ohms, and the N-Channels 0.15 ohms. All four transistors have 100 V breakdown ratings.

The MPM3002's P-Channel/N-Channel configuration makes interfacing to an MC33033 control IC especially easy. The schematic shows an example. The SENSEFETs are connected to outputs A_B and C_B through series gate resistors, and the P-Channels are connected directly to A_T and C_T and tied to the +12 V rail through pull-up resistors. If the source voltage is greater than +12 V, a divider can be used to keep gate voltage on the P-Channels within reasonable limits.

In the schematic, the mirror outputs of both SENSEFETs are tied together. They are then fed into the MC33033's current limit input through a noise suppression filter consisting of R7 and C3. Since only one SENSEFET is on at any given time, this connection is a logic wired-OR. It provides overcurrent protection for both directions of motor rotation, and does not alter trip points for the individual legs. The trip point is calculated with the aid of the following expression.

$$I_{LIMIT} = V_{SENSE} (R_{SENSE} - r_{m(on)}) / (r_{a(on)} \cdot R_{SENSE})$$

Where:

V_{SENSE} is sense voltage

R_{SENSE} is the mirror-to-source sense resistor

r_{m(on)} is mirror-active resistance = 112 ohms

r_{a(on)} is source-active resistance = 0.14 ohms

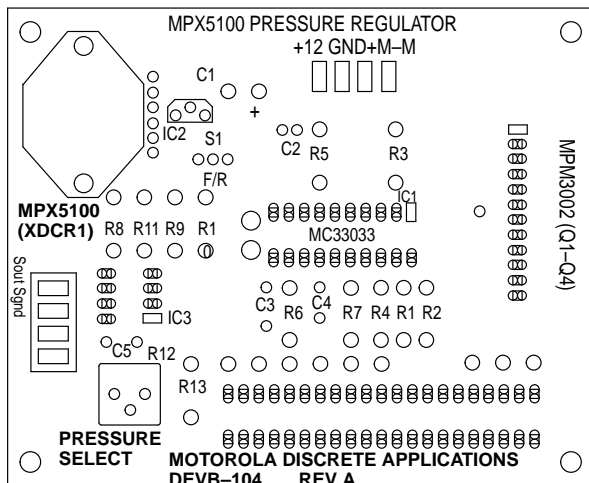


Figure 7. PCB Component Layout

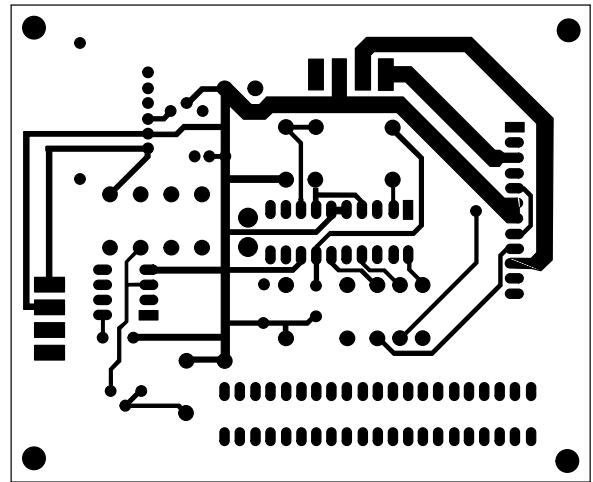


Figure 8. PCB Component Side Artwork

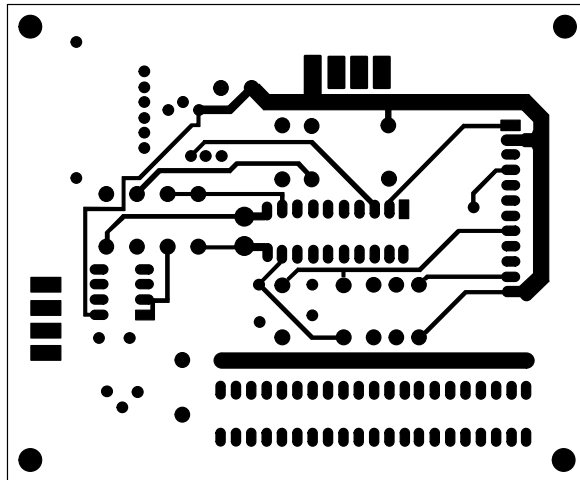


Figure 9. PCB Solder Side Artwork

Since the current limit threshold in the MC33033 is 100 mV, current limiting will occur when V_{SENSE} reaches 100 mV. For the circuit in Figure 6, using 100 mV for V_{SENSE} , and with $R_{SENSE} = R_6 = 24$ ohms then:

$$I_{LIMIT} = 0.1(24 + 112)/(0.14 \cdot 24) = 4.1 \text{ Amps}$$

By using SENSEFETs in the lower half bridge in lieu of a power sense resistor in series with the motor, about 1/2 watt ($4.1 \text{ A} \cdot 0.1 \text{ V}$) of dissipation is saved.

Figures 7, 8, and 9 show a printed circuit board and component layout for the electronics portion of this pressure regulator system, and Table 1 is the corresponding parts list.

System Performance

The entire system draws 4.0 Amps with all but 50 mA used to drive the motor/pump. The pressure sensor provides a sensitivity to regulate well within a few kPa. However, most applications can allow far greater fluctuations in pressure. The system performance, therefore, depends mostly on the motor/pump selected and the hysteresis set in the control circuitry. Using a well-sealed pump will help ensure the motor turns off when the desired pressure is reached. Many pumps are designed to leak to prevent over inflation. In this case, the circuit will turn the motor off until the pressure is reduced, through leakage, by the designed hysteresis amount, then turn on and continue cycling to hold the pressure in the desired range.

Table 1. Parts List for Pressure Regulator PC Board


Reference Designator	Qty	Description	Comments
S1	1	MISCELLANEOUS	
	2	PC Board	See Figures 7–9
	1	Input/Output Terminals	PHX CONT #1727036
	4	Heat Sink	for ICePAK™
	6	1/2" nylon standoffs, threaded	
	2	1/2" nylon screws	
	1	4–40 nylon nuts	
	1	switch	SS-12SDP2
R1, R4	2	RESISTORS, FIXED	
R2, R3	2	Comp., $\pm 5\%$, 1/4 W	
R5, R8, R9	3	47 Ω	
R6	1	470 Ω	
R7	1	10 k Ω	
R10	1	24 Ω	
R11	1	1 k Ω	
R13	1	300 k Ω	
	1	3900 Ω	
	1	330 Ω	
R12	1	RESISTORS, VARIABLE	
		10 k Ω , one turn	3386P-1-103-T
IC1	1	INTEGRATED CIRCUITS	
IC2	1	Motor Controller	MC33033P
IC3	1	Reference	78L05
Q1–Q4	1	Operational Amplifier	MC33272P
	1	Integrated H-Bridge	MPM3002
XDCR1	1	SENSOR	
		MPX5100DP	
C1	1	CAPACITORS	
C2	1	220 μ F, 25 V	
C3	1	0.005 μ F, ceramic, 25 V	
C4	1	0.001 μ F, ceramic, 25 V	
C5	1	1 μ F, ceramic, 50 V	
	1	0.01 μ F, ceramic, 25 V	

CONCLUSION

This circuit is one example of how the MPX5100 with its high level output can directly interface with linear systems. It provides a simple design alternative where pressure measurement or control is required.

REFERENCE

1. Schultz, Warren. "ICs Simplify Brush DC Motor Drives," *Motion*, November 1989.

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