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New Small Amplified Automotive Vacuum Sensors A Single Chip Sensor Solution for Brake Booster Monitoring

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BRAKING SYSTEMS

Different types of braking principles can be found in vehicles depending on whether the brake system is only activated by muscular energy or power assisted (partially or completely).

Muscular activated brakes are mostly found on motorcycles and very light vehicles. The driver's effort on the hand lever or pedal is directly transmitted via a hydraulic link to the brake pads.

Power assisted brakes are found on most passenger cars and some light vehicle trucks. In this case, the driver's effort is amplified by a *brake booster* to increase the force applied to the brake pedal.

BRAKE BOOSTER OPERATION PRINCIPLE

The vacuum brake booster is a system using the differential between atmospheric pressure and a lower pressure source (vacuum) to assist the braking operation. The brake booster is located between the brake pedal and the master cylinder. Figure 1 shows a simplified schematic of a vacuum brake booster.

When no brake pressure is applied on the push rod (brake pedal side), the air intake valve is closed and the vacuum valve open. Thus, both the vacuum and working chambers are at the same pressure, typically around –70 kPa (70 kPa below atmospheric pressure). Vacuum is generated by either the engine intake manifold or by an auxiliary vacuum pump.

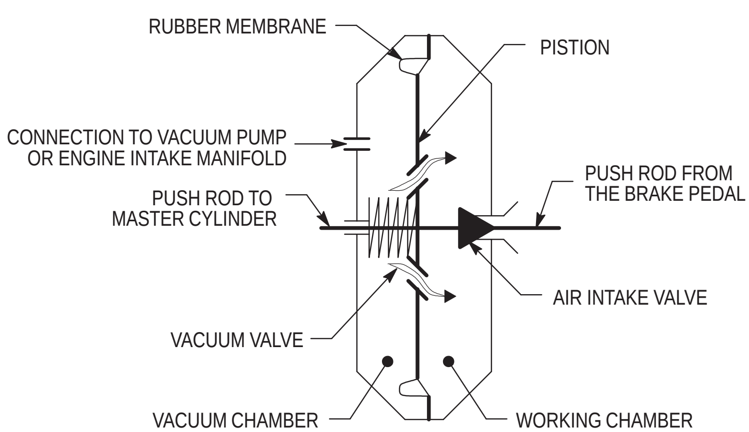

Figure 1. Brake Booster Simplified Schematic

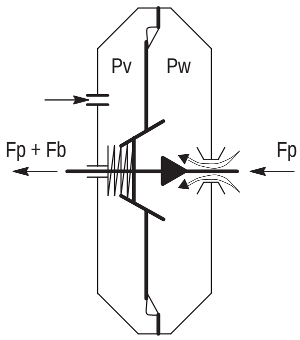

Figure 2. Braking Phase

Once the brake pedal is activated (force Fp), the vacuum valve is closed and the air intake valve is open proportionally to the displacement of the push rod (Figure 2). The working chamber is progressively open to atmospheric pressure, which creates a differential between the vacuum chamber and the working chamber. This differential pressure applied to the surface (S) of the piston results in a force *Fb = (Pw – Pv) x S*. The forces Fb + Fp are then applied to the brake pads through the master cylinder and hydraulic links.

When the brake pedal is released, the spring moves the piston back, closing the air intake valve and opening the vacuum valve to rebalance the pressure between the two chambers.

VACUUM GENERATION

On most passenger cars, vacuum is generated by the engine itself. When the engine throttle valve is closed, the displacement of the pistons produces vacuum in the intake manifold. Thanks to a tube or hose connected between the engine intake manifold and the brake booster, vacuum can be applied to the chambers. A backslash valve inserted between the intake manifold and the booster maintains the vacuum in the booster when the engine throttle valve is open.

This principle has some limitations, however. For example, it can be only used on engines that have the ability to generate enough vacuum. On diesel engines, which have no throttle valve, it is necessary to use an auxiliary pump to generate vacuum. This will also be the case on the Gasoline Direct Injection (GDI) engine, where in some driving conditions (idle, lean burn) the electrically assisted throttle valve will be maintained slightly open. In this situation, the vacuum available on the intake manifold is not sufficient to provide an efficient braking.

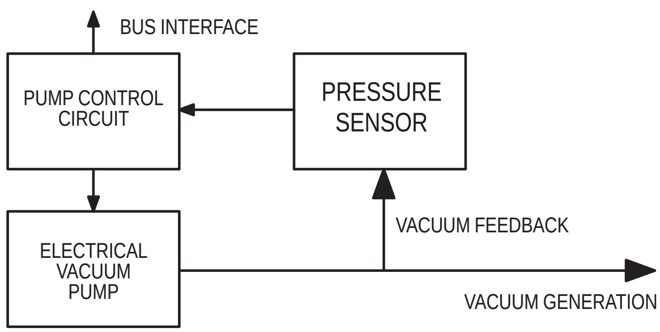

Figure 3. Vacuum Pump Monitoring

Therefore, it is necessary and desirable to use an electrical pump that will generate the vacuum for the brake booster. The use of an auxiliary electrical pump (Figure 3) provides several advantages over the "intake manifold" vacuum.

- Vacuum generation is no longer related to the engine running condition. Vacuum is only generated and controlled by the pump thanks to a vacuum pressure sensor that provides an accurate reading to the pump electrical control circuit.
- The electrical pump can be switched on and off based on the required vacuum. To compensate atmospheric pressure variation in order to maintain a constant booster effect, the pump also can be switched on independently from the atmospheric pressure. Various algorithms for driving the pump can be implemented depending on the required braking conditions.
- Pressure variations during braking can be measured, and the pump can be activated to generated additional vacuum if required to increase the braking force.
- Leakage can be detected by the pressure sensors and the pump can be switched on to compensate them. The driver can be informed of any type of failure thanks to the bus interface. Vacuum level, and thus available braking force can be communicated through the bus to other braking systems such as, for example, ABS or ESP.

Motorola, a worldwide leader in automotive semiconductors, has introduced a new integrate pressure sensor dedicated to vacuum measurements in applications such as brake booster monitoring. The single–chip vacuum sensor may be placed directly onto the pump electronic control unit or integrated as component within the brake booster, thus providing flexibility, system integration and reduced system cost.

Motorola's New MPXV4115V Vacuum Sensor

PIEZORESISTIVE/AMPLIFIED SENSORS

Motorola's pressure sensors are based on a piezoresistive technology that consists of a silicon micromachined diaphragm and a diffused piezoresistive strain gauge. When vacuum or pressure is applied on the die, the diaphragm is deformed and stressed. The resulting constraints create a variation of resistance in the piezoresistive strain gauge. In order to read this variation, an excitation current passes through the gauge, and a voltage proportional to the applied pressure and excitation current appears between the voltage taps. To get an accurate pressure reading, such a sensing element needs usually to be calibrated, temperature compensated and amplified.

In order to solve the inherent limitation of the basic sensing element, Motorola produces an entire family of calibrated, thermally compensated and amplified pressure sensors (Figure 4) called Integrated Pressure Sensors (IPS).

The IPS is a state of the art, monolithic, amplified and signal–conditioned silicon pressure sensor. The sensor combines advanced micromachining techniques, thin film memorization and bipolar semiconductor processing to provide an accurate, high–level analog output that is proportional to the applied pressure. IPS sensors can be directly connected to an A/D converter.

Figure 4. Integrated Pressure Sensor Block Diagram

PRESSURE MEASUREMENT CONVENTION

Pressure measurements can be divided into three different categories: absolute, gage and differential pressure.

Absolute pressure refers to the absolute value of the force per unit area exerted on a surface by a fluid. Therefore, the absolute pressure is the difference between the pressure at a given point in a fluid and the absolute zero of pressure or a perfect vacuum.

Gage pressure is the measurement of the difference between the absolute pressure and the local atmospheric pressure. Local atmospheric pressure can vary depending on ambient temperature, altitude and local weather conditions. The standard atmospheric pressure at sea level and 20°C is 101.325 kPa absolute. When referring to pressure measurement, it is critical to specify what reference the pressure is related to: gage or absolute. A gage pressure by convention is always positive. A 'negative' gage pressure is defined as vacuum. Figure 5 shows the relationship between absolute, gage pressure and vacuum.

Differential pressure is simply the measurement of one unknown pressure with reference to another unknown pressure. The pressure measured is the difference between the two unknown pressures. Since a differential pressure is a measure of one pressure referenced to another, it is not necessary to specify a pressure reference.

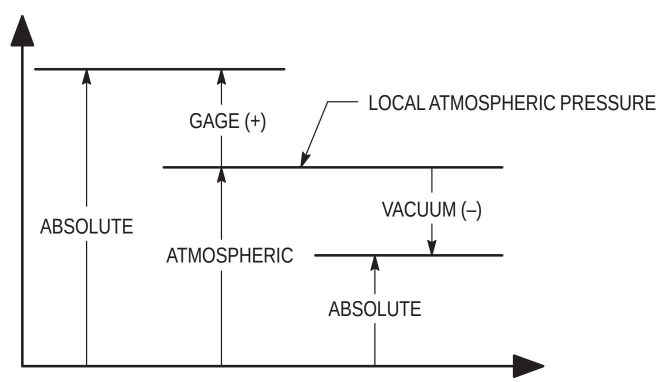

Figure 5. Pressure Convention

TRANSFER FUNCTION

The behavior of an IPS is defined by a linear transfer function. This transfer function applies to all Motorola's Integrated Pressure Sensors whatever the pressure range and type of sensing element (absolute or differential).

$$V_{out} = V_S \times (P \times K1 + K2) \pm (PE \times TM \times V_S \times K1)$$

- V_{out} : Sensor output voltage
- P: Applied pressure in kPa
- Vs: Sensor supply voltage in V
- K1: Sensitivity constant in V/V/kPa
- K2: Offset Constant inV/V
- PE: Pressure error in kPa
- TM: Temperature multiplier

The constants, K1, K2, PE & TM are specific to each device, temperature and pressure encountered in the application.

The variables P and Vs are dependent on the user application but must remain within the operating specification of the device.

THE MPXV4115V INTEGRATED PRESSURE SENSOR

The Motorola MPXV4115V gauge vacuum sensor, designed to measure pressure below the atmospheric pressure, is suitable for automotive application such as vacuum pump or brake booster monitoring. The MXPV4115V is also ideal for non–automotive applications where vacuum control is required.

The MPXV4115V has the following basic characteristics (Note: Detailed characteristics of Motorola's pressure sensors can be found on http://www.mot–sps.com/senseon).

MPXV4115V CHARACTERISTICS

$$V_{out} = V_S \times (P \times 0.007652 + 0.92) \pm (PE \times TM \times V_S \times 0.007652)$$

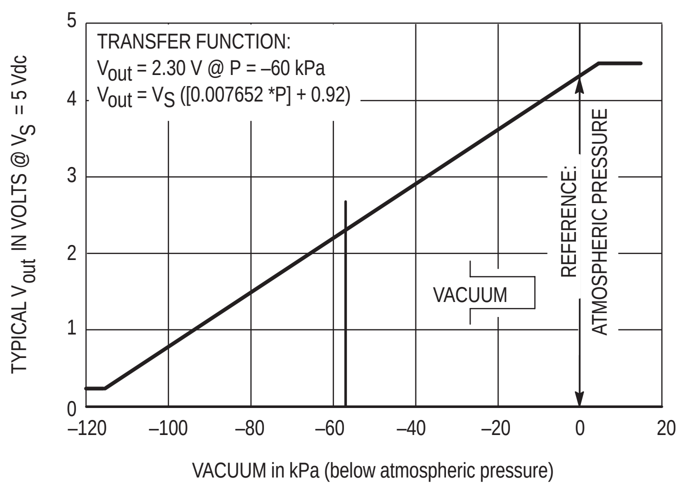

Figure 6. MPXV4115V Transfer Function

- P is the applied vacuum to the sensor pressure port. Pressures below atmospheric pressure have a negative sign. For example, 50 kPa below atmospheric is P = –50 in the transfer function. For pressure higher than the atmospheric pressure, the device will electrically saturate. The sensor is designed to measure vacuum from 0 kPa (Atmospheric pressure applied to the sensor pressure port) down to – 115kPa.

Since the MPXV4115V is using the atmospheric pressure as reference, –115 kPa can only be reached if the atmospheric pressure is higher or equal than 115 kPa. The device will electrically saturate for vacuum below –115 kPa.

- PE = 1.725 kPa (1.5% of full scale span) over the entire pressure range
- TM = 1 between 0 and +85°C, 3 at –40°C and +125°C. TM is a linear response from –40° to 0°C and from 85° to 125°C.

The real intent for the pressure–sensor user is to know the measured pressure. In this case it is preferable to express the transfer function as:

$$P = (V_{out}/V_S - 0.92)\ 0.007652 \pm (PE \times TM)$$

As an example, if V_{out} = 2.30 V for a 5 Vdc power supply and at 25°C ambient temperature, the measured vacuum is P = –60.1 kPa ± 1.725 kPa.

SENSOR PACKAGING

The packaging of a pressure sensor die is critical to achieve optimal performances of the final product. The package must isolate the pressure sensor die from unwanted external stress which can cause undesired drift of the electrical signal while being robust enough to support the pressure applied to the device without cracks, leaks or mechanical failures. It must be media compatible for the same reasons.

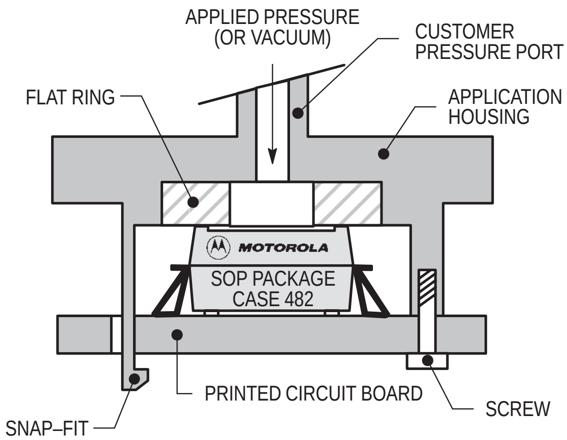

Figure 7. Mounting Suggestion

The new small pressure sensor package from Motorola addresses those requirements and lets designers mount a pressure sensor directly on a printed circuit board, thus providing great flexibility for space saving design. Figure 7 shows a typical assembly using a small outline package (SOP) Case 482–01.

The sensor can be mounted on the printed circuit board by an automatic pick and place machine as with every other surface mount component. Sealing is done by using a silicone flat ring inserted in the application housing. The printed circuit board must be maintained against the flat ring either by a snap fit, or by a screws as shown.

The new small outline package (SOP) is fabricated using poly–phenyl sulfide (PPS), a robust material, which can withstand high temperatures and is highly resistant to chemicals. Consequently, the package is ideal for harsh environment such as automotive, industrial or medical systems.

The small outline package is suitable for any of Motorola’s sensor chips from the basic uncompensated sensor to the fully integrated sensing solution that include amplifiers and other circuitry all on one chip.

Motorola’s sensors using this package are available in both tubes and tape and reel configuration for high productivity on your assembly line.

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