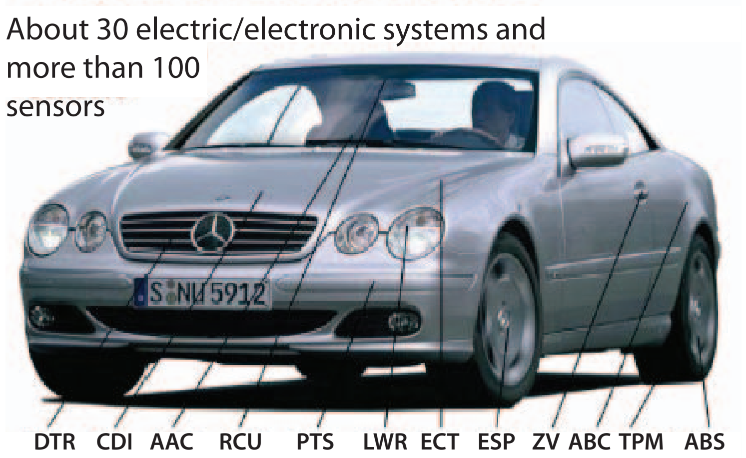
Technology Brief 7: Resistive Sensors

An ***electrical sensor*** is a device capable of responding to an applied ***stimulus*** by generating an electrical signal whose voltage, current, or some other attribute is related to the intensity of the stimulus. The family of possible stimuli encompasses a wide array of physical, chemical, and biological quantities, including temperature, pressure, position, distance, motion, velocity, acceleration, concentration (of a gas or liquid), blood flow, etc. The sensing process relies on measuring resistance, capacitance, inductance, induced electromotive force (emf), oscillation frequency or time delay, among others. Sensors are integral to the operation of just about every instrument that uses electronic systems, from automobiles and airplanes to computers and cell phones (Fig. T7-1). This technology brief covers resistive sensors. ***Capacitive***, ***inductive***, and ***emf sensors*** are covered separately (here and in later chapters).



System	Abbrev.	Sensors	System	Abbrev.	Sensors
Distronic	DTR	3	Common-rail diesel injection	CDI	11
Electronic controlled transmission	ECT	9	Automatic air condition	AAC	13
Roof control unit	RCU	7	Active body control	ABC	12
Antilock braking system	ABS	4	Tire pressure monitoring	TPM	11
Central locking system	ZV	3	Elektron. stability program	ESP	14
Dyn. beam levelling	LWR	6	Parktronic system	PTS	12

Figure TF7-1: Most cars use on the order of 100 sensors. (Courtesy Mercedez Benz.)

Piezoresistivity

According to Eq. (4.70), the resistance of a cylindrical resistor or wire conductor is given by $R = l/\sigma A$, where l is the cylinder's length, A is its cross-sectional area, and σ is the conductivity of its material. Stretching the wire by an applied external force causes l to increase and A to decrease. Consequently, R increases (Fig. T7-2). Conversely, compressing the wire causes R to decrease. The Greek word ***piezein*** means to press, from which the term piezoresistivity is derived. This should not be confused with piezoelectricity, which is an emf effect. (See EMF Sensors in Technology Brief 12.)

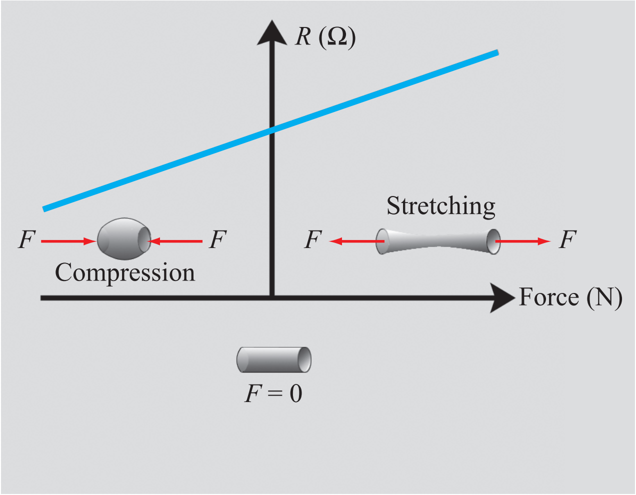


Figure TF7-2: Piezoresistance varies with applied force.

The relationship between the resistance R of a piezoresistor and the applied force F can be modeled by the approximate linear equation

$$R = R_0 \left(1 + \frac{\alpha F}{A_0}\right),$$

where R_0 is the unstressed resistance (@ $F = 0$), A_0 is the unstressed cross-sectional area of the resistor, and α is the piezoresistive coefficient of the resistor material. The force F is positive if it is causing the resistor to stretch and negative if it is compressing it.

An elastic resistive sensor is well suited for measuring the deformation z of a surface (Fig. T7-3), which can be related to the pressure applied on the surface; and if z is recorded as a function of time, it is possible to derive the velocity and acceleration of the surface's motion. To realize high longitudinal piezoresistive sensitivity (the ratio of the normalized change in resistance, $\Delta R/R_0$, to the corresponding change in length, $\Delta l/l_0$, caused by the applied force), the piezoresistor is often designed as a serpentine-shaped wire [Fig. T7-4(a)] bonded on a flexible plastic substrate and glued onto the surface whose deformation is to be monitored. Copper and nickel alloys are commonly used for making the sensor wires, although in some applications silicon is used instead [Fig. T7-4(b)], since it has a very high piezoresistive sensitivity. By connecting the piezoresistor to a Wheatstone bridge circuit (Fig. T7-5) in which the other three resistors are all identical in value and equal to R_0, the resistance of the piezoresistor when no external force is present, the voltage output becomes directly proportional to the normalized resistance change: $\Delta R/R_0$.

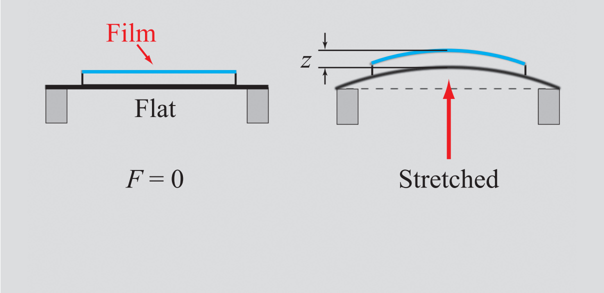


Figure TF7-3: Piezoresistor films.

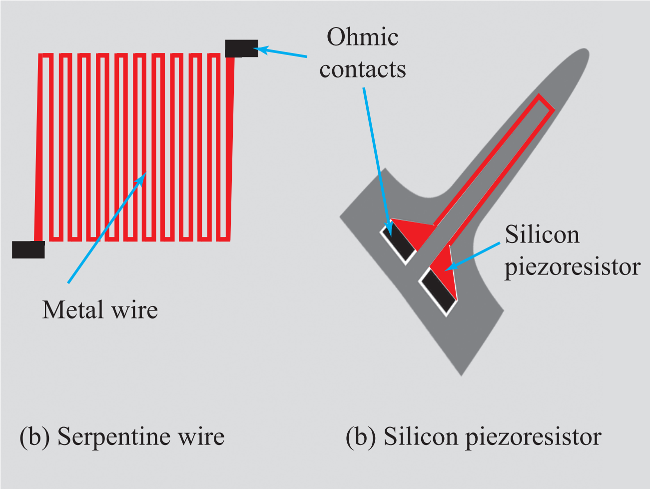
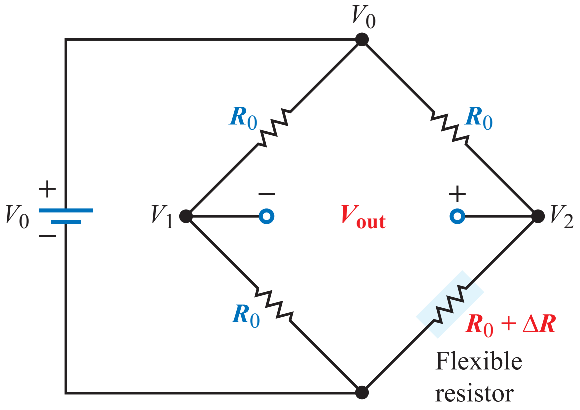


Figure TF7-4: Metal and silicon piezoresistors.



$$V_{\text{out}} = \frac{V_0}{4}\left(\frac{\Delta R}{R_0}\right)$$

Figure TF7-5: Wheatstone bridge circuit with piezoresistor.