Low Frequency Phase Shift In LIVM Sensors As A Function Of Discharge Time Constant And Frequency

Abstract

Low Impedance Voltage Mode (LIVM) sensors are piezoelectric devices with integral FET impedance converting amplifiers. To bias the amplifier, a high value resistor is placed in parallel with the gate of the FET and the crystal element. The discharge time constant (TC) of the sensor is the product of this resistor and the total shunt capacitance of the crystal element. (See Figure 1). It is the discharge time constant which sets the low frequency amplitude and phase response of the sensor. This article presents a mathematical relationship for phase response as a function of frequency with discharge time constant as a parameter.

The LIVM Sensor

Figure 1 shows schematically, the LIVM sensor.

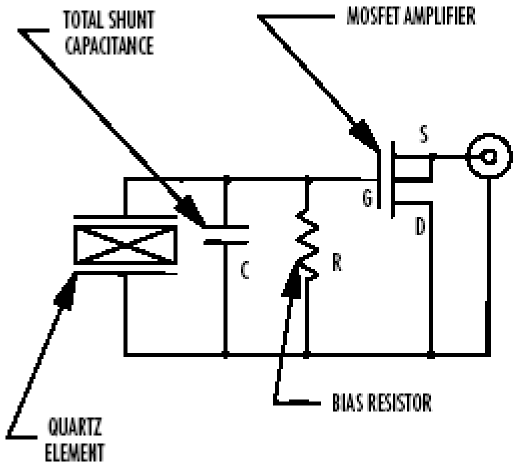

Figure 1

It can be shown that the sensor is actually a first order high pass filter with phase and amplitude parameters established by the discharge TC. The TC is the product of crystal capacitance C (includes stray C and the input capacitance of the FET) times the gate resistor R. The units of TC are seconds. The filter may be represented as shown in Figure 2 below.

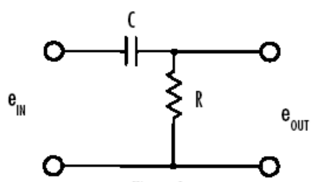

Figure 2

The transfer function of the filter shown in Figure 1 is:

$$\frac{e_{out}}{e_{in}} = \frac{R}{R + jX_C} \qquad \text{Eq. 1}$$

The vector diagram for this circuit is:

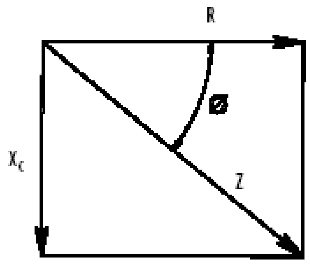

Figure 3

Regarding the phase angle Ø:

From the diagram, Figure 3,
we may write the relationship: $Ø = \tan^{-1} \frac{X_c}{R}$ Eq. 2

In equation 2, X_C is the capacitive reactance.

Capacitive reactance is: $X_C \frac{1}{2\pi fC}$ where: f = frequency (Hz),
C = capacitance (Farads)

Substituting this relationship in Eq. 2,

$$Ø = \tan^{-1} \frac{1}{2\pi fRC}$$

Since RC = TC by definition:

$$Ø = \tan^{-1} \frac{1}{2\pi fTC}$$

reducing further,

$$Ø = \tan^{-1} \frac{0.16}{fTC} \qquad \text{Eq. 3}$$

Using the last equation, knowing the discharge TC of the sensor, this phase shift at any frequency may be calculated easily.

Example:
What is the phase shift of a sensor with a 2 second TC at 2 Hz?

$$\text{Phase shift } Ø = \tan^{-1} \frac{0.16}{2 \text{ x } 2} = \tan^{-1} 0.04 = 2.29 \text{ degrees}$$