Frequency Response Compensation for Resonant Sensors

With REZCOMP®, the usable bandwidth of resonant sensors can be extended via real-time analog frequency response correction

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Introduction

The frequency response of many sensors, such as accelerometers, pressure sensors, and microphones, can be affected by resonance. Whether the resonant response is due to sensor mounting, packaging, or the mechanical design of the sensor itself, such resonance can significantly amplify the in-band signal of interest and distort the output waveform. Even when resonant frequencies are outside the band of interest, removing the resonant response often requires aggressive application of a conventional filter that limits the usable bandwidth and rise time characteristics of the sensor.

Often the resonant response of a sensor can be effectively characterized in terms of the resonant frequency f_r and damping factor ξ (conventionally defined as the quality factor Q). Using these characteristics, the patented resonance compensation technology, or REZCOMP, corrects the sensor frequency response in real-time, increasing the usable bandwidth and reducing phase distortion without the need for extensive data post-processing.

Resonance Compensation (REZCOMP®)

Figure 1 shows the typical amplitude response of a pressure sensor that is affected by an aerodynamically-driven cavity (packaging) resonance. This resonance is generally well-characterized by a second-order transfer function defined by f_r and Q (blue line in Fig. 1). Notice that the resonant peak is 20 dB, and the customary usable bandwidth of the transducer is 20% of the resonant frequency (0.2 f_r) where less than 5% response peaking occurs. To compensate for this resonance, the inverse of the sensor's transfer function must be applied to the input signal. With REZCOMP, this is accomplished by implementing an electrical filter with response characteristics that match the reciprocal of the sensor's transfer function (red line in Fig. 1). If the f_r and Q of the compensating filter match those of the sensor's resonant response, the combined response is flat (green line in Fig. 1): amplification due to resonant peaking will be effectively removed from the signal. In practice, REZCOMP has been shown to extend the usable transducer frequency response to 0.8 f_r and beyond.

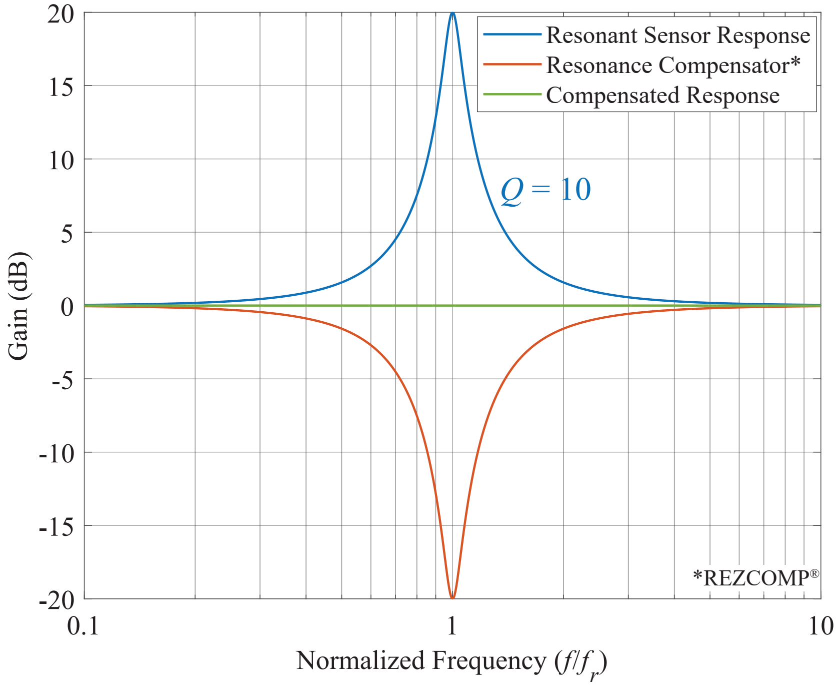
Figure 1. *Frequency response characterization of real-time analog resonance compensation. The resonant sensor response (blue trace) is described by a second order transfer function,*

$$H(s) = \frac{s^2 + s\omega_r + \omega_r^2}{s^2 + (\omega_r/Q)s + \omega_r^2}$$

where ω_r is the resonant frequency (= $2\pi f_r$), Q is the quality factor, and $s = j\omega = j2\pi f$. With REZCOMP, the sensor output is passed through an electrical filter whose response $G(s)$ (red trace) is designed to match the multiplicative inverse of $H(s)$:

$$G(s) = \left(H(s)\right)^{-1}$$

The combined response $H(s)G(s)$ is flat (green trace): the resonant peaking is removed from the sensor's amplitude response.



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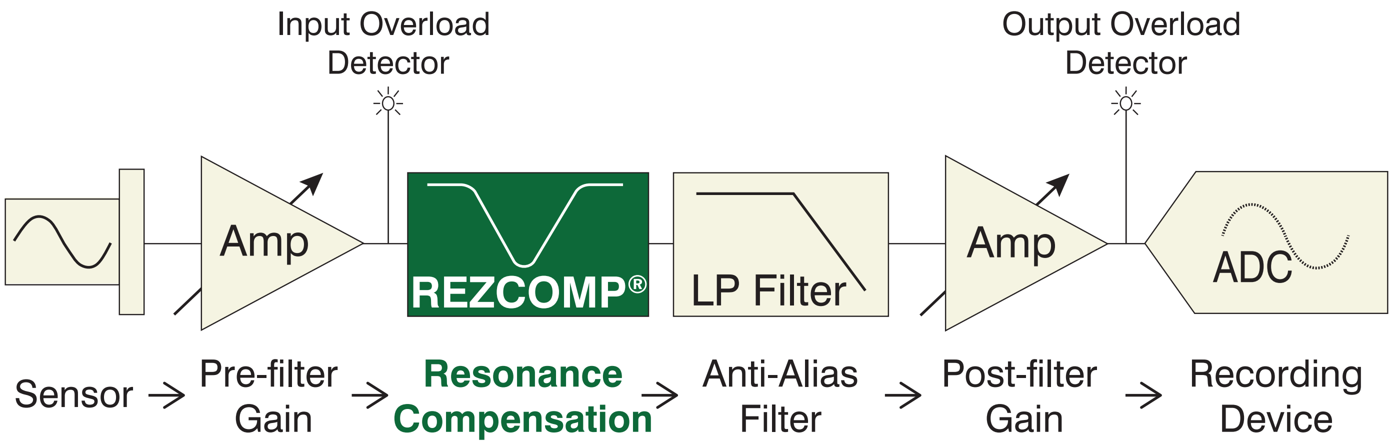

***Figure 2.** Schematic illustration of the signal flow through a Precision Filters analog signal conditioner equipped with REZCOMP.*

Precision Filters has implemented REZCOMP as part of a complete analog signal conditioning system that provides sensor excitation, amplification, and filtering, along with numerous testing, verification, and other quality control features. The generalized signal flow for such a system is depicted in Figure 2. Sensor output is first amplified by a pre-filter gain stage to maintain the signal-to-noise ratio of the in-band signal while preserving headroom for out-of-band signals to prevent an overload condition. Next, the REZCOMP frequency response correction is applied to compensate for the resonant response of the sensor. A programmable low-pass filter is then applied to the compensated signal to remove out-of-band energy and prevent aliasing. A final post-filter gain stage is applied to ensure the full dynamic range of the analog-to-digital converter (ADC) is realized.

While it is possible to remove unwanted resonant energy in a sampled signal using digital signal processing, this approach will often lead to poor signal-to-noise ratios (SNR). If resonant energy is not suppressed using analog circuitry, then the input limits of the ADC must accommodate both the in-band signal of interest and the resonant peaking. This requires reduced amplification of the in-band signal, increasing the relative magnitude of self-noise generated by the signal conditioner and ADC. Consequently, relying solely on digital post-processing to correct for signal resonance results in a signal with a lower SNR, regardless of the ADC's resolution.

REZCOMP was developed in collaboration with Kulite Semiconductor Products and is available on signal conditioning cards for PFI's 28000 system (Fig. 3) and on Kulite's KSC line of signal conditioners. All REZCOMP-equipped products feature programmable Q and f_r, allowing for adjustment of the compensation that is applied to match the connected sensor's resonance characteristics.

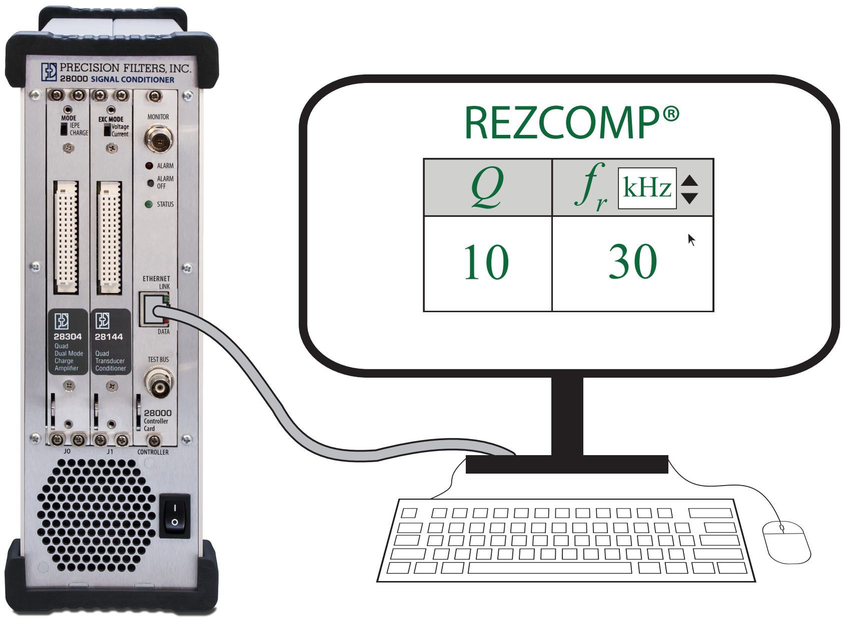

***Figure 3.** Depiction of Precision Filters 28000 signal conditioner with programmable (via GUI PC interface) REZCOMP. The user can specify the quality factor Q and resonant frequency f_r. These parameters determine the compensating frequency response implemented by the signal conditioner's REZCOMP circuitry. (The system shown at left is the Precision 28002 mainframe with two signal conditioner cards – along with the backplane interface (BIF) controller card – installed.)*

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