## Dynamic Response, Bandwidth and Resonance

All sensors can only respond to a limited range of frequencies.

Sensors measuring position, velocity and acceleration are largely limited by the mass of the sensor being moved. A one-gram sensor can be much more easily vibrated than, say, a large truck. Stiffness of the materials is the other major factor.

Sound sensors and actuators are similarly limited, which is why the "woofer" speakers are so much larger than the "tweeters"

Light-based sensors have similar limitations, based on the electrical or optical resistance of the material rather than its mass.

Accelerometers are force sensors that include a small *seismic mass* which can move very rapidly. The forces on the mass reflect the acceleration of the system. (Newton's $2^{nd}$ law; $F = m\ a$)

**Resonance**

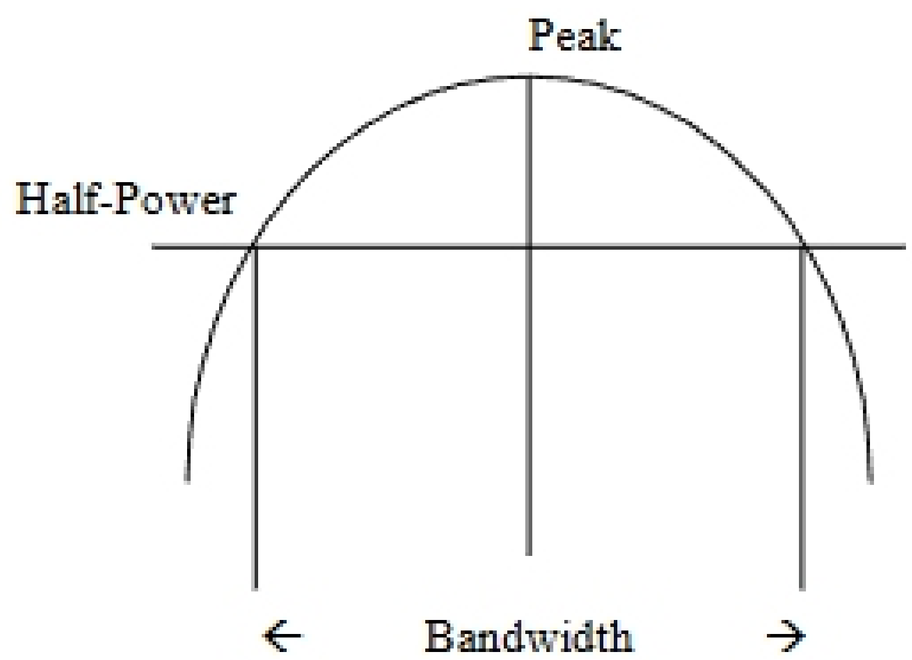
Many natural systems, including sensors have a particular frequency at which they naturally vibrate. (Plastic ruler over the edge of a table). This frequency is called the *resonant* frequency for the system.

A sensor that is designed to operate over a range of frequencies is seldom, if ever, used at or near its resonant frequency. For example accelerometers are usually used well below their resonant frequency. Piezo-electric crystals rely on resonance for the very strong frequency reference signal they provide. By feeding the output back to the input the system resonates very strongly at a single frequency. (Resonating composite demo). Sensors can be developed which monitor how the resonant frequency shifts when stimulated by, for example, temperature.

The response curve of a piezoelectric transducer is illustrated by fig 9.18. This diagram shows us that the system has no useful response to steady pressure (Response = 0 at low frequencies). As the frequency rises the response increases until it achieves a plateau. The response remains constant over a range of frequencies in this plateau region. As the frequency increases further the response increases again to a peak value. This is resonance. After that the response declines steadily as the frequency increases.

**Bandwidth**

The useful range of frequencies that a device can be used over is called the *bandwidth*. If a sensor has a simple peaked response such as that shown below then the bandwidth is the frequency between the half-power points.




It is useful to remember with electrical frequency responses that Power = $V^2/R$ and that the voltage at half-power is therefore $(V)^2/2R = (V/\sqrt{2})^2/R$. Since $1/\sqrt{2}=0.707$, we look for the point where the voltage has dropped to 0.707 x the peak voltage to find the half-power point.

The above response is typical of that for ultrasonic transducers.

In the case of the piezoelectric sensor the useful bandwidth is that range of frequencies over which the response is flat. We can't use the resonant peak, nor the low frequencies where the response is too low.

**Testing the frequency response of a sensor**
Oscillate the sensor with a sine wave. The peak size of the sine wave source must be constant. Measure the response. Look for a peak or resonant value. Look for plateaus. Note that some systems are not designed to operate near resonance and can be damaged by operating near resonant frequencies. The point where the response drops to half the peak (power) value is the bandwidth edge.

Note that the above discussion for mechanical systems applies equally well to light systems