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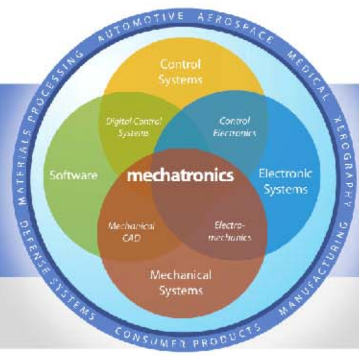
# MECHATRONICS IN DESIGN

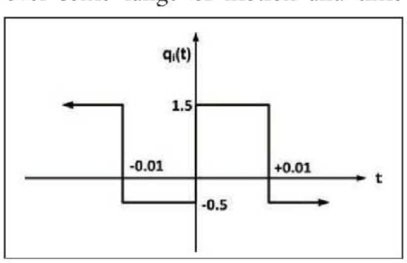


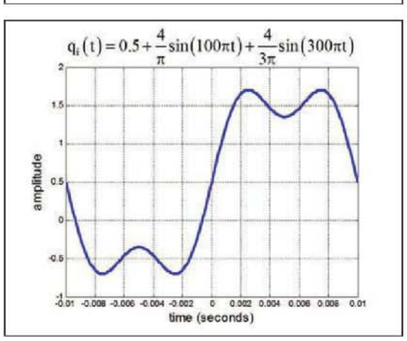

# Frequency Response— The Gold Standard

## Engineers predict real-world response and identify model parameters.

**WHAT DO ENGINEERS,** "see" when they look at a real system or when they conceive a new design? They will look past the hardware and visualize the flow of energy, where it is stored, and where it is dissipated. They will identify the kinetic energy of moving fluids and solid masses; the potential energy of compressible fluids, elastic hoses and tanks, and deformable solids; the energy stored in electric and magnetic fields; and the energy lost through friction generating heat. But they will also "see" how the system might respond to real-world inputs by understanding the frequency response of the system and the frequency spectrum of the probable inputs.

A real system often can be modeled, over some range of motion and time duration, as a stable, linear, time-invariant system. If the input to this system is a sine wave, the steady-state output (after the transients have died out) is also a sine wave with the same frequency, but with an amplitude and phase angle that are both frequency-dependent. Plots of the input-output amplitude ratio vs. frequency and the phase angle vs. frequency are called the Bode plots. If the system being excited were a nonlinear or time-varying system, the output might contain frequencies other than the input frequency and the amplitude ratio might be dependent on the input magnitude. Any real-world device or process will only need to function properly for a certain range of frequencies; outside this range we don't care what happens. When one has the frequency-response curves for any system and is given a specific sinusoidal input, it is an easy calculation to get the sinusoidal output. What is not obvious, but extremely important, is that the frequency-response curves are really a complete description of the system's dynamic behavior and allow one to compute the response for any input, not just sine waves.




Two hundred years ago, Jean Baptiste Fourier showed that any periodic waveform that exists in nature can be generated by adding up sine waves. By picking the amplitudes, frequencies, and phases of these sine waves, one can generate a waveform identical to the desired signal. A periodic function qi(t) can be represented by an infinite series of terms called a Fourier series. The figures show a square wave and a plot of the first few terms of the Fourier series. The more terms used in the series, the better the fit.

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Using the principle of superposition for linear systems, we can combine the frequency spectrum of a real-world signal with the system's frequency response and calculate the system time response. The device used to experimentally determine a system's frequency response is called a dynamic signal analyzer (DSA) and there are many excellent application notes available on its use.

Frequency response testing plays a most significant role in grey-box modeling, discussed here last month. For example, once one has the model structure for a device, such as a solenoid-operated proportional valve used in fluid power applications, the measured frequency-response data can be used with optimization algorithms to determine the model parameters. And we all know that a model is worth a thousand tests! This exact situation is presented by The MathWorks at http://dn.hotims.com/45109-506. **DN**