

## FREQUENCY RESPONSE ANALYSIS

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**ABSTRACT:** This is one of a series of white papers on systems modelling, analysis and control, prepared by Control Systems Principles.co.uk to give insights into important principles and processes in control. In control systems there are a number of generic systems and methods which are encountered in all areas of industry and technology. These white papers aim to explain these important systems and methods in straightforward terms. The white papers describe what makes a particular type of system/method important, how it works and then demonstrates how to control or use it. The demonstrations are performed using models of real systems developed by our senior partner Peter Wellstead and manufactured by TQ Education and Training Ltd in their CE range of equipment. This white paper describes the popular and important technique of frequency response analysis and uses the CE2000 control and simulation tool to show how frequency response analysis works and how to implement it.

### 1. What is a Frequency Response and why is it Important?

When we want to use or control a real system we must know how it behaves when different signals are applied to it. This will give a measure of the dynamic response of the system. One way to find the response of a system is to apply a test signal to the input and look at the output to see how it responds. Many test signals are possible, but a simple and useful test signal is the sine wave. This is because the output of a system with a sine wave input is also a sine wave, but with a different amplitude and phase. By measuring the output amplitude and phase of a system over a range of frequencies of the input sine wave, a particular version of the dynamic response is built – this is called the frequency response.



Figure 1. Linear transfer function with sinewave input.

If a system has transfer function  $G(s)$ , then the output response at a particular frequency  $\omega = 2\pi f$  is given by the gain and phase of the frequency response  $G(j\omega)$  at that frequency  $\omega$ . For the system shown in Figure 1 the input and output signals (after initial transients have gone) are:

$$u(t) = U \sin(\omega t), \quad y(t) = Y \sin(\omega t + \phi) \quad (1)$$

The corresponding gain and phase are given by:

$$\text{Gain at } \omega = |G(j\omega)| = \frac{Y}{U}, \quad \text{Phase at } \omega = \angle G(j\omega) = \phi \quad (2)$$

By measuring the gain and phase over a range of frequencies, the full frequency response of the system can be plotted.

Figure 2 shows typical frequency response measurements plotted in two ways – the first is a diagram of the imaginary part (Im on Figure 2a) of the frequency response  $G(j\omega)$ , against the Real part (Re on the Figure 2a) of the frequency response  $G(j\omega)$ . The second diagram, Figure 2b, shows a plot of the logarithm of the frequency response gain ( $\log|G(j\omega)|$  on Figure 2b) and the phase ( $\phi(j\omega)$  on Figure 2b). The two figures are referred to as, respectively, the Nyquist plot and Bode plot. These are alternative ways of presenting the measurements that are named in acknowledgement of two great engineer/mathematicians who laid the foundations for frequency domain control systems analysis.

# Frequency Response Analysis Control Systems Principles

**D Kirk**

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