

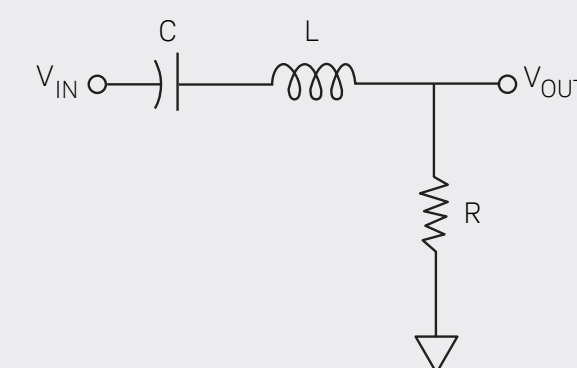
Bode Plots and Frequency Response Measurements

Bode Plots

A Bode plot is a graph of the frequency response of a mechanical or electrical system. It consists of the combination of a magnitude plot and phase plot and is based on asymptotic straight-line approximations as a function of theoretical poles and zeros. Both quantities (magnitude and phase) are plotted against a horizontal axis proportional to the logarithm of frequency. The vertical axis of magnitude is typically plotted logarithmically as well in units of dB; thus a log-log magnitude plot. The vertical axis of phase is typically plotted linearly in units of degrees; thus a lin-log phase plot.

Series RLC bandpass filter example

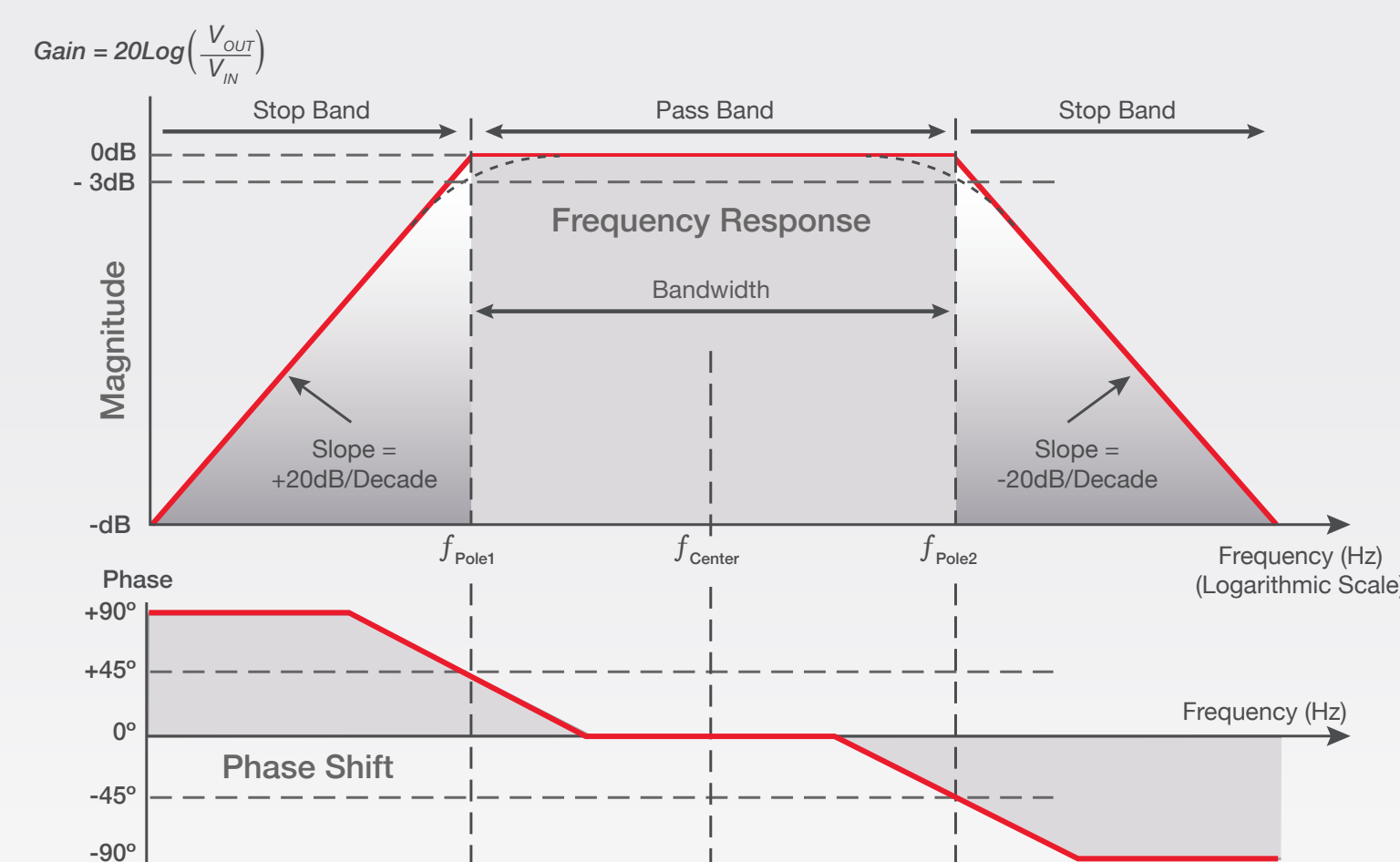
A series RLC circuit will create a bandpass filter consisting of 2 poles and 1 zero (at 0 Hz). The transfer function $T(j\omega)$ for this bandpass filter is:



$$T(j\omega) = \frac{V_{OUT}(j\omega)}{V_{IN}(j\omega)} = \left(\frac{R}{L}\right) \left[\frac{j\omega}{(j\omega)^2 + \left(\frac{R}{L}\right)j\omega + \frac{1}{LC}} \right]$$

$$f_{Pole1}(Hz) = \frac{1}{2\pi} \left(-\frac{R}{2L} + \sqrt{\left(\frac{R}{2L}\right)^2 + \frac{1}{LC}} \right)$$

$$f_{Pole2}(Hz) = \frac{1}{2\pi} \left(\frac{R}{2L} + \sqrt{\left(\frac{R}{2L}\right)^2 + \frac{1}{LC}} \right)$$



Frequency Response Analyzer (FRA)



A Frequency Response Analyzer (FRA), sometimes called a Vector Network Analyzer (VNA), is a test and measurement instrument that can measure and plot the frequency response (gain and phase) of an active or passive electrical system under test. Included in an FRA is a variable-frequency sine wave source and two acquisition input channels for measuring V_{IN} and V_{OUT} at discrete frequencies across a test frequency range. FRAs and/or VNAs are rarely found in university undergraduate EE student labs because they are often considered to be special-purpose instruments. EE students typically use an oscilloscope and function generator to perform multiple time-domain V_{IN} and V_{OUT} measurements at manually-set frequencies.

Keysight's InfiniiVision 1000 X-Series oscilloscope is the first oscilloscope that can perform frequency response analysis automatically in the frequency-domain, if equipped with the optional function generator (WaveGen).

To set up an FRA measurement, first define the following test parameters in the setup menu:

- V_{IN} channel
- V_{OUT} channel
- Minimum test frequency
- Maximum test frequency
- Test amplitude

When "run analysis" is selected, the scope sweeps a sine wave test signal from the minimum to the maximum frequency while measuring the gain ($20\text{Log}V_{OUT}/V_{IN}$) and phase shift and then plots the results as shown here.



Hendrik Wade Bode



Hendrik Wade Bode was born in Madison, Wisconsin (USA) on December 24, 1905. Young Hendrik rapidly advanced through elementary and secondary schools and graduated from high school at the age of 14. Although Hendrik applied to attend the University of Illinois, he was not accepted because of his young age. However, Ohio State University accepted him where he received his B.A. and M.A. degree in Mathematics in 1926.

Soon after graduating, Bode began an illustrious engineering and scientific research career at Bell Labs where he initially designed electronic filters and equalizers but was subsequently assigned to the Mathematical Research Group. While at Bell Labs, Bode successfully completed his PhD in physics at Columbia in 1935.

In 1938, Dr. Bode invented what is famously known today by engineering students as "Bode plots" for his namesake. But that's not what he called them. He simply called them "asymptotic frequency-domain magnitude and phase plots."

During his time at Bell Labs, Dr. Bode received numerous academic medals and awards and held 25 patents in various areas of electrical and communications engineering. He also collaborated closely with other well-known scientists and researchers at Bell Labs, including Claude Shannon and Harry Nyquist.

Dr. Bode retired from Bell Labs in 1967 and soon after accepted a professorship position at Harvard University where he taught and directed graduate engineering students in Systems Engineering.

During his spare time, Bode enjoyed reading, writing, gardening and sailing. He died on June 21, 1982, at the age of 76 at his home in Cambridge, Massachusetts.

