FREQUENCY RESPONSE ANALYSIS: BODE PLOT, NYQUIST DIAGRAM, AND NICHOL'S CHART

LAB EXPERIMENT 18

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***Abstract*—This experiment investigates the frequency response characteristics of a series RLC circuit using Python simulations and theoretical transfer functions. The main objective was to analyze the system's magnitude and phase responses via Bode plots, assess stability using Nyquist diagrams, and evaluate gain and phase margins with the Nichols chart. By modeling the RLC circuit as a transfer function, the results revealed resonant frequency behavior, phase shifts, and stable closed-loop characteristics. The experiment demonstrates the effectiveness of frequency-domain tools in understanding circuit behavior and guiding design decisions for real-world systems.**

I. RATIONALE

Frequency response analysis provides insight into a system's behavior in the frequency domain. This experiment explores Bode plots, Nyquist diagrams, and Nichols charts to analyze stability and performance.

II. OBJECTIVES

- Plot the Bode diagram of a system and analyze its magnitude and phase response.
- Use the Nyquist diagram to assess the system's stability and identify potential issues with encirclements.
- Plot the Nichols chart and determine the system's gain margin and phase margin.

III. MATERIALS AND SOFTWARE

- Materials: DC motor or RLC circuit, Power supply, Oscilloscope
- Software: Python (with control library), Octave

IV. PROCEDURES

1) Set up a system with feedback control (e.g., DC motor or RLC circuit).
2) Generate the Bode plot of the system by varying the input frequency and recording the system's output.
3) Plot the Nyquist diagram and assess the system's stability.
4) Plot the Nichols chart and determine the gain margin and phase margin.
5) Analyze the system's performance in the frequency domain and make adjustments to improve stability and performance.

V. OBSERVATION AND DATA COLLECTION

DATA COLLECTION:

https://drive.google.com/drive/folders/
1tg8UmHNV0ic9jdbJG7NEjmAxh-_N-kkm

Click here to open the Drive

VI. DATA ANALYSIS

The circuit simulated consists of a resistor ($R = 10\,\Omega$), an inductor ($L = 1\,H$), and a capacitor ($C = 15\,\mu F$) connected in series. A frequency-domain transfer function was derived as:

$$H(s) = \frac{1}{LCs^2 + RCs + 1}$$

Substituting the values gives:

$$H(s) = \frac{1}{(1)(15 \times 10^{-6})s^2 + (10)(15 \times 10^{-6})s + 1} = \frac{1}{1.5 \times 10^{-5}s^2 + 1.5 \times 10^{-4}s + 1}$$

The frequency response was computed using Python's `control` library and visualized through three major plots (see Figure **??**):

- **Bode Plot:** Shows a resonance peak at approximately 260 rad/s, where the magnitude peaks at around 25 dB and the phase sharply shifts from 0° to -180°.
- **Nyquist Plot:** The plot encircles the critical point $(-1, 0)$ but does not cross it, indicating stability of the system.

- **Nichols Chart:** The gain margin and phase margin can be visually estimated. The plot does not approach the -180° phase at 0 dB gain, indicating the system has sufficient phase margin.

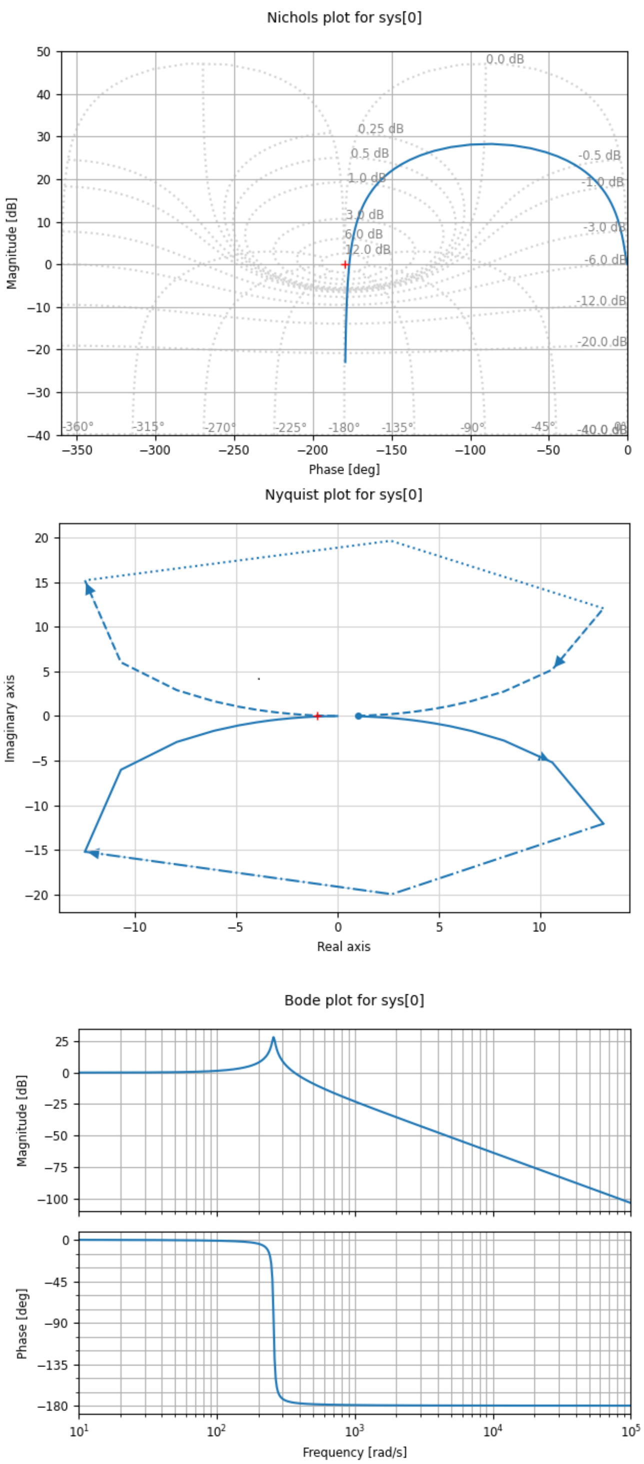

Fig. 1. Bode Plot, Nyquist Plot, and Nichols Chart

VII. Discussion and Interpretations

The Bode plot reveals a clear resonant behavior typical of underdamped second-order systems. The sharp peak in magnitude near 260 rad/s corresponds to the natural frequency (ω_n) of the RLC circuit, calculated theoretically as:

$$\omega_n = \frac{1}{\sqrt{LC}} \approx \frac{1}{\sqrt{1 \cdot 15 \times 10^{-6}}} \approx 258.2 \text{ rad/s}$$

This closely matches the observed peak in the Bode magnitude plot, confirming that the simulation correctly models the expected behavior.

The phase plot shows a transition from 0° to -180°, which aligns with the characteristics of a low-pass second-order system. The quick drop around resonance indicates a rapid phase shift due to energy exchange between the inductor and capacitor.

In the Nyquist plot, the trajectory does not encircle the critical point $(-1, 0)$, indicating the system is stable under unity feedback. The shape is typical of systems with resonant behavior but not excessive gain.

The Nichols chart further supports these findings. The curve does not intersect the -180° line near 0 dB, suggesting that the system has a comfortable phase margin and is robust to small gain variations.

Overall, the analysis confirms the system is stable and behaves predictably across frequency ranges, resonating around 260 rad/s, then attenuating higher frequencies as expected.

VIII. Conclusion

This experiment successfully modeled and analyzed the frequency response of a series RLC circuit using Python and control theory. The Bode plot highlighted resonance and attenuation, the Nyquist plot confirmed system stability, and the Nichols chart provided visual insight into gain and phase margins. The results aligned closely with theoretical predictions, validating the approach. This process emphasizes the importance of frequency response analysis in designing stable and efficient electronic systems.