Operational Amplifier Stability Research

Research Objective

Our proposal

<table>
<thead>
<tr>
<th>For</th>
<th>Analysis and design of operational amplifier stability</th>
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</thead>
<tbody>
<tr>
<td>Use</td>
<td>Routh-Hurwitz stability criterion</td>
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</tbody>
</table>

We can obtain

Explicit stability condition for circuit parameters

which can NOT be obtained only with Bode plot.

We can verify

Equivalence between Nyquist and Routh-Hurwitz stability criteria

Stability Criteria

<table>
<thead>
<tr>
<th>Nyquist stability Criteria</th>
<th>Routh-Hurwitz stability Criteria</th>
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<tbody>
<tr>
<td>$\mathcal{G}(s)$ precedes $\mathcal{P}(s)$ Feedback system is stable</td>
<td></td>
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<tr>
<td>Greater spacing between $\mathcal{G}(s)$ and $\mathcal{P}(s)$ More stable</td>
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Characteristic equation:

$$\mathcal{H}(s) = a_0 + a_1 s + a_2 s^2 + \cdots + a_n s^n = 0$$

Sufficient and necessary condition:

(i) $a_i > 0$ for $i = 0, 1, \ldots, n$

(ii) All values of Routh table’s first columns are positive.

Example Verification

Two Examples

Ex.1 $\mathcal{G}(s) = \frac{K(1 + b_1 s)}{s^2 + a_1 s + a_2}$ One Zero, Two Poles

Ex.2 $\mathcal{G}(s) = \frac{K(1 + b_1 s)}{s^2 + a_1 s + a_2 + a_3 s^3}$ One Zero, Three Poles

Based on Routh-Hurwitz Criterion

$R(s) + \frac{1}{G(s)} = \frac{K(1 + b_1 s)}{s^2 + a_1 s + a_2}$

Based on Nyquist Criterion

Sketch chart of Nyquist plot

Ex.1 Two-stage amplifier with C compensation

Ex.2 Two-stage amplifier with C, R compensation

Simulation Verification

Example I

Closed-loop transfer function:

$$\mathcal{H}(s) = \frac{A_0(1 + b_1 s)}{1 + f_0 A_0(1 + f_0 A_0) + a_2 s^2}$$

Explicit stability condition of parameters:

$$a_3 + f_0 A_0 R_1 C_3 + R_2 C_1 + (f_0 A_0) R_2 C_3 > 0$$

Case (1) $C_3 = 1900 \text{ pF}$

Case (2) $C_3 = 795.7 \text{ pF}$

Case (3) $C_3 = 100 \text{ pF}$

Example II

Closed-loop transfer function:

$$\mathcal{H}(s) = \frac{A_0(1 + b_1 s)}{1 + f_0 A_0 + (a_1 + f_0 A_0) s + a_2 s^2 + a_3 s^3}$$

Explicit stability condition of parameters:

$$(a_3 + f_0 A_0) R_3 > 0$$

$$X = R_3 C_3 + R_2 C_2 + R_1 C_1 + (f_0 A_0) R_2 C_3$$

$$Y = X$$

Case (1) $X > Y$

Case (2) $X > Y$

Case (3) $X = Y$

Conclusion

- Equivalence between Nyquist and R-H stability criteria
- Equivalence of mathematical foundations
- R-H method, explicit circuit parameter conditions
- Consistency with Bode plot method, LTspice simulation

Discussion

- Depict small signal equivalent circuit
- Derive open-loop transfer function
- Derive closed-loop transfer function & obtain characteristics equation
- Apply R-H stability criterion & obtain explicit stability condition

Use this stability condition for circuit parameters.