Analysis and Design of Operational Amplifier Stability Based on Control Theory

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In the control theory field, Nyquist stability criterion and Routh-Hurwitz (R-H) stability criterion are widely utilized for judging the stability of the feedback system. However, according to our survey of the related texts about analog electronic circuits [1], the Routh-Hurwitz method is rarely mentioned in analysis and design of the operational amplifier stability. On this account, we have made attempts to introduce the R-H stability criterion into electronic circuit design field and begin with used for judging stability of operational amplifier.

We proposed to use the Routh-Hurwitz stability criterion for operational amplifier (Fig.1) stability analysis and design, to obtain explicit stability conditions(Eq.(1)) for operational amplifier circuit parameters[2]; this has not been described in any operational design book/paper, to our knowledge. In this paper, we demonstrate that the respective mathematical foundations of Nyquist and Routh-Hurwitz stability criteria are equivalent as show in Eq.(2)and Eq.(3), and we deduce the relationship as show in Fig.2 between Routh-Hurwitz stability criterion parameters with phase margin of the operational amplifier with a voltage follower configuration, as theoretical support and perfection for the proposed method, and then, we verify our proposed method with some amplifier models. Our SPICE simulation results show good agreements with our theoretical analysis based on the proposed method.

Explicit stability condition:

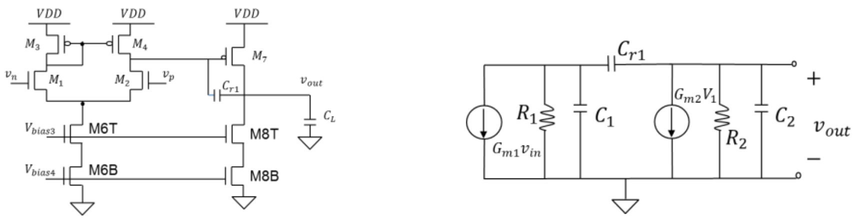
$$\theta = R_1C_1 + R_2C_2 + (R_1 + R_2)C_{r1} + (G_{m2} - fG_{m1})R_1R_2C_{r1} \tag{1}$$

Stability condition based on Nyquist criterion:

$$K < -\frac{a_1}{b_1}, \text{ in case } b_1 < 0; \quad K > -\frac{a_1}{b_1}, \text{ in case } b_1 > 0 \tag{2}$$

Stability condition based on Routh-Hurwitz criterion:

$$-\frac{a_1}{b_1} < K < \frac{a_1}{b_1}, \text{ in case } a_1b_1 > 0; \quad \frac{a_1}{b_1} < K < -\frac{a_1}{b_1}, \text{ in case } a_1b_1 < 0 \tag{3}$$



(a) Transistor level circuit (b) Small-signal model

Fig. 1 Two-stage amplifier with inter-stage capacitance

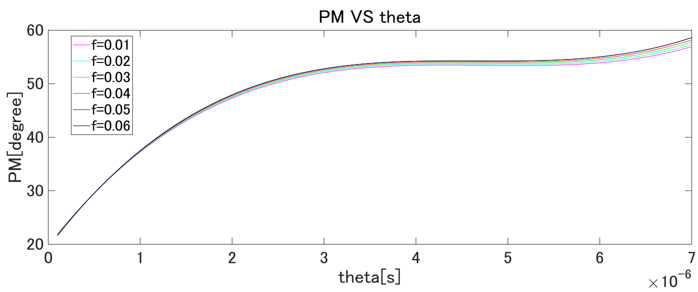


Fig.2 Relationship between PM and parameter θ at various feedback factor conditions.

[1]B. Razavi, Design of Analog CMOS Integrated Circuits, McGraw-Hill (2003).[2]J. Wang, G. Adhikari, H. Kobayashi, et al, "Analysis and Design of Operational Amplifier Stability Based on Routh-Hurwitz Method", IEEE 13th ICSICT, Hangzhou, China (Oct. 2016).