Order determination for frequency compensation of negative-feedback systems

Arie van Staveren and Chris J.M. Verhoeven
Delft University of Technology, Electronics Research Laboratory, Delft, The Netherlands
e-mail: A.vStaveren@its.tudelft.nl

Abstract

To maximize the bandwidth of dedicated negative-feedback amplifiers by passive frequency compensation, the order of the amplifier needs to be known. Here a method is introduced to determine the order of a circuit with negative feedback. It is shown that the sum of poles in the negative-feedback loop, i.e. the loop poles, can be used to determine the order of the amplifier. These loop poles can be found relatively easily from the circuit diagram and thus the order of the circuit is also relatively easily found.

1. Introduction

The design of the dynamic behavior (or frequency compensation) of an amplifier is the design of the characteristic polynomial (CP). For *general purpose amplifiers* the order of the circuit is reduced to one to guarantee stability for a wide range of load and source impedances. This is, however, at the cost of bandwidth. For *dedicated amplifiers* source and load conditions are known, and a higher-order dynamic behavior can be designed, making full use of the bandwidth capabilities: a larger bandwidth is obtained compared with a first-order behavior for the same amplifier.

2. Characteristic polynomial

On the one hand, the CP of a negative feedback system can be described in terms of the required system poles (p_{s_i}) (or *closed loop poles*) as:

$$CP(s) = s^n - s^{n-1}\sum_{i=1}^{n} p_{s_i} + \cdots + \prod_{i=1}^{n} |p_{s_i}|. \quad (1)$$

in which s is the Laplace variable. On the other hand it can be expressed in the *loop parameters*, as:

$$CP(s) = s^n - s^{n-1}\sum_{i=1}^{n} p_{l_i} + \cdots + [1 - LG(0)]\prod_{i=1}^{n} |p_{l_i}|. \quad (2)$$

in which p_{l_i} are the poles found in the *open loop* and $LG(0)$ is the DC loop gain. From equating the lowest-order terms of equation (1) and (2), the LP product (loop-gain-poles product) [1], [2] can be found. This LP product gives an upper limit of the attainable bandwidth after frequency compensation of the closed-loop system. For calculating a realistic LP product, the order of the system needs to be known.

3. Order determination

The order of a system is defined here as the maximum number of system poles that can be moved, by means of frequency compensation, into a predefined pole pattern, for instance Butterworth. This order can be found by inspecting again equation (1) and (2). From the fact that the corresponding terms are equal, it follows from the (n-1)-order terms:

$$\sum_{i=1}^{n} p_{s_i} = \sum_{i=1}^{n} p_{l_i} \quad (3)$$

Thus, the sum of the *loop poles* equals the sum of the *system poles*. Commonly used frequency compensation techniques can only reduce the sum of the poles [2] and thus the following procedure can be used to determine the order:

1. Start with the loop pole closest to the origin;
2. Determine the LP product;
3. Determine the sum of *required system poles* from the LP product and the specified frequency response;
4. If $\sum$*loop poles* $>$ $\sum$ *required system poles*: take next loop pole into account, go to step 2;
5. If $\sum$*loop poles* = $\sum$ *required system poles*: order is obtained, finished;
6. If $\sum$*loop poles* $<$ $\sum$*required system poles*: leave out pole farthest from the origin: order is obtained.

References

[1] E. Nordholt. *Design of High-Performance Negative-Feedback Amplifiers*. Elsevier,Amsterdam, 1983.

[2] A. van Staveren, C. Verhoeven, and A. van Roermund. *Structured Electronic Design: High-Performance Harmonic Oscillators and Bandgap References*. Kluwer, Dec. 2000.