# Design of High-Performance Negative-Feedback Amplifiers

# *Design of High-Performance Negative-Feedback Amplifiers*

E.H. Nordholt

*Catena Microelectronics*

VSSD

.



First edition 1983-2006

Published by:
Delft Academic Press / VSSD
Leeghwaterstraat 42, 2628 CA Delft, The Netherlands
tel. +31 15 27 82124, e-mail: dap@vssd.nl
www.delftacademicpress.nl/e022.php
A collection of digital pictures and an elctronic version can be made available for lecturers who adopt this book. Please send a request by e-mail to hlf@vssd.nl



ISBN 9789040712470
NUR 959

# Preface

Amplifier design is very often regarded as making a selection from the large arsenal of known amplifier circuits and then adapting it for a specific purpose, possibly with the aid of computer-aided-design programs. Now and then designers are surprised by the introduction of a new amplifier circuit performing better in some respect than the others.

Each aspiring designer has to find his own way in this jungle. He has to choose from a rather chaotic and scattered collection of amplifier circuits rather than apply a systematic and straightforward design sequence that enables him to design his special-purpose amplifier circuit. A great deal of experience is essential.

This work is an attempt to make a useful contribution to the extensive literature on the subject of amplifier design. It can be justified on the grounds that the approach is believed to be unique in a number of respects. Many works that promise to cover the subject are instead concerned with analysis. Moreover, they frequently deal specifically or separately with particular design aspects, characterised by descriptions such as ‘wide-band’, ‘low-noise’, ‘low-distortion’, etc.

A treatment of the various design aspects and their interconnections, however, is necessary for fruitful amplifier design. At the basis of such a treatment lies the observation — usually easily overlooked — that amplifier design is concerned in the first place with obtaining an adequate quality of information transfer. Amplifiers are more than electronic circuits merely bringing the source power up to a higher level.

Quality requirements are imposed on the signal transfer relative to the type of information and to the manner of perception, registration, or processing. The quality of information transfer is determined by a large number of quality aspects such as linearity, accuracy, efficiency, signal-to-noise ratio, etc. Unfortunately, it cannot be expressed as a quantitative figure of merit

Trade-offs between various quality aspects are likely to emerge. Sometimes they will be of a fundamental nature and are imposed by physical and technological limitations, but frequently they will result from the nature of a specific amplifier circuit itself, which — on second thoughts — might not be the most appropriate one to fulfil the desired function.

A systematic, straightforward design approach is presented in this work. It is more or less inspired by the work of Cherry and Hooper[1] which I consider one of the finest design treatises. The present work is more concerned with basic design considerations. Preference was given to a qualitative rather than to a quantitative approach.

Finding the proper configurations for the basic amplifier and of the amplifier stages is considered of primary importance and is emphasised here. This book is therefore largely concerned with the design phase preceding the phase in which existing computer aids can be helpful.

The approach is characterised best by describing it as a systematic and consistent arrangement of design considerations regarding various quality aspects of information transfer. Via the classifications of amplifier configurations, a systematic design method for negative-feedback amplifiers is developed.

A short description of the main lines along which the design method has been developed is given below.

In chapter 1, criteria are given for the adaptation of the input and output impedances to the source and the load, respectively (usually transducers). The purpose of these adaptations is the realisation of optimum information transfer from the signal source to the amplifier and from the amplifier to the load. Next, criteria are deduced for optimum information transfer of the amplifier, preserving signal-to-noise ratio and efficiency by the application of feedback. Classifications are given of basic amplifier configurations with up to four negative-feedback loops, providing the designer with the complete set of fundamentally different two-port amplifier types. The characteristic properties and the practical merits of these configurations are discussed.

A similar classification is given in chapter 2 for configurations with a single active device. A uniform description of these single-device configurations will appear to be of great help in finding suitable stage configurations in the active part of an amplifier with overall negative feedback. The balanced versions of these single-device stages are mentioned but not studied in detail.

In chapter 3, design criteria regarding random noise are formulated. These criteria relate mainly to the selection of the most favourable input-stage configuration and the active device to be used in this stage for a given signal source.

In chapter 4, those configurations of amplifier stages that are best suited to realising optimum accuracy and linearity of information transfer are arrived at.

Thereafter, bandwidth and stability considerations are taken into account in chapter

---

1 E.M. Cherry and D.E. Hooper, Amplifying Devices and Low-Pass Amplifier Design, John Wiley and Sons, New York, 1968.

5. The requirements for optimum performance in this respect fortunately appear to be to a large extent compatible with the requirements regarding the other quality aspects.

The design of bias circuitry is considered in chapter 6. It will be shown that this part of the design can be done in such a way that the signal-path performance of the amplifier is scarcely affected.

Finally, an outline of the design method is given in chapter 7. For examples of amplifiers designed according to the design procedure developed in this book reference is made to the literature.

This book is a revised and reviewed version of my Ph.D. thesis, which was published in June 1980 under the supervision of Prof.Dr.Ir. J. Davidse. The results of the work that he has encouraged me to carry out in the Laboratory of Electronics at the Delft University of Technology, The Netherlands, can be found here.

Writing such a thesis is perhaps even more of a burden to those in an author's environment than to himself. Without the aid of many others, it would not be possible to obtain a Ph.D. degree. As an acknowledgement of their support, this book is dedicated to all who contributed in some way.

Susan Masotty reviewed the text and corrected my numerous linguistic errors. Wim van Nimwegen drew the figures. Josette Verwaal and Hilda Verwest typed the manuscript. They thus contributed to the mere physical existence of this book, which happens to bear my name. This may, however, veil the fact that an author is no more than a person who is lucky enough to be able to write down the ideas he would never have had without a stimulating environment.

It is to this environment — which usually cannot be adequately indicated by names but includes the above — in all its abstraction that I am deeply indebted.

Delft, 1983 Ernst Nordholt

# Contents

# 1 Basic amplifier configurations for optimum transfer of information from signal sources to loads

## 1.1 Introduction

One of the aspects of amplifier design most treated — in spite of its importance — like a stepchild is the adaptation of the amplifier input and output impedances to the signal source and the load. The obvious reason for neglect in this respect is that it is generally not sufficiently realised that amplifier design is concerned with the transfer of signal information from the signal source to the load, rather than with the amplification of voltage, current, or power.
The electrical quantities have, as a matter of fact, no other function than representing the signal information. Which of the electrical quantities can best serve as the information representative depends on the properties of the signal source and load. It will be pointed out in this chapter that the characters of the input and output impedances of an amplifier have to be selected on the grounds of the types of information representing quantities at input and output.
Once these selections are made, amplifier design can be continued by considering the transfer of electrical quantities. By speaking then, for example, of a voltage amplifier, it is meant that voltage is the information representing quantity at input and output. The relevant information transfer function is then indicated as a voltage gain.
After the discussion of this impedance-adaptation problem, we will formulate some criteria for optimum realisation of amplifiers, referring to noise performance, accuracy, linearity and efficiency. These criteria will serve as a guide in looking for the basic amplifier configurations that can provide the required transfer properties. The suitability of some feedback models will be discussed. The rather unusual, so-called asymptotic-gain model, will be selected for use in all further considerations.
Thereafter, we will present a classification of basic negative-feedback configurations. First, a rather theoretical approach is given, where the active amplifier part is considered as a nullor, while the feedback network is realised with ideal transformers and gyrators. A class of *non-energic* negative-feedback amplifiers

Note that each feedback loop essentially fixes the value of one transfer parameter. The properties of the amplifiers will be studied in some detail by inserting them between a signal source and a load as shown in figures 1.8a and 1.8b, where the signal sources are given as voltage and current sources, respectively.

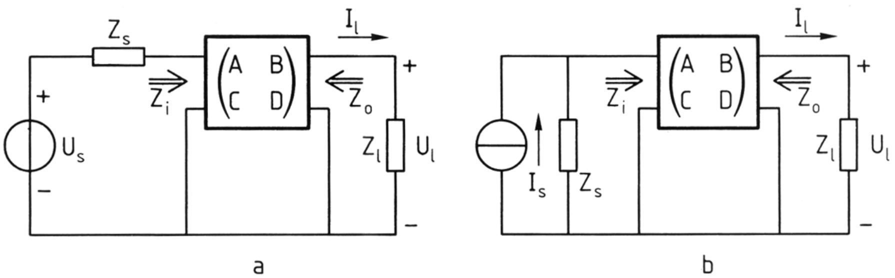


*Figure 1.8* *Amplifiers inserted between signal sources and loads.*

The voltage transfer function of figure 1.8a is given by:

$$\frac{U_\ell}{U_s} = \frac{Z_\ell}{AZ_\ell + B + CZ_s + DZ_s} = A_u \tag{1.27}$$

where $A, B, C$ and $D$ are the transmission parameters of the amplifier. The other transfer functions are related to $A_u$ as:

$$\backslash f(I_\ell,U_s) = \frac{A_u}{Z_\ell} \qquad \text{(figure 1.8a)}$$

$$\backslash f(U_\ell,I_s) = A_u Z_s \qquad \text{(figure 1.8b)}$$

$$\backslash f(I_\ell,I_s) = A_u \frac{Z_s}{Z_\ell} \qquad \text{(figure 1.8b)}$$

The input impedance $Z_i$ and the output impedance $Z_o$ are given respectively by:

$$Z_i = \frac{AZ_\ell + B}{CZ_\ell + D} \quad \text{and} \quad Z_o = \frac{B + DZ_s}{A + CZ_s}$$

The specific properties with respect to the information-transfer aspects of the various configurations will be discussed in the following.

*(i) The nullor*

Without external circuitry, the nullor is obviously not suitable for the transfer of signal information.

*(ii) Single-loop configurations (4)*

The four single-loop amplifiers have either zero or infinite input and output