

# **FREQUENCY COMPENSATION TECHNIQUES FOR LOW-POWER OPERATIONAL AMPLIFIERS**

**Rudy G. H. Eschauzier  
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**Frequency Compensation Techniques For Low Power  
Operational Amplifiers The Springer International  
Series In Engineering And Computer Science**

**Ron Hogervorst, Johan Huijsing**



## **Frequency Compensation Techniques For Low Power Operational Amplifiers The Springer International Series In Engineering And Computer Science:**

**Frequency Compensation Techniques for Low-Power Operational Amplifiers** Rudy G.H. Eschauzier, Johan Huijsing, 2013-04-17 Frequency Compensation Techniques for Low Power Operational Amplifiers is intended for professional designers of integrated amplifiers emphasizing low voltage and low power solutions The book bridges the gap between the professional designer's needs and available techniques for frequency compensation It does so by explaining existing techniques and introducing several new techniques including Hybrid Nested Miller compensation Multipath Miller Zero cancellation and Multipath Conditionally Stable compensation All compensation techniques are treated in a stage number based order progressing from a single transistor to circuits with six stages and more Apart from discussing the mathematical basis of the compensation methods the book provides the reader with the factual information that is required for practicing the design of integrated feedback amplifiers and many worked out examples What is more many bipolar and CMOS operational amplifier realizations along with their measurement results prove the effectiveness of the compensation techniques in real life circuits The text focuses on low voltage low power integrated amplifiers Many of the presented bipolar circuits operate at supply voltages down to 1V while several CMOS amplifiers that function correctly just slightly above this voltage are demonstrated The lowest measured power consumption amounts to 17 $\mu$ W for a class AB CMOS opAmp with 120dB gain Despite this attention to low voltage and low power the frequency compensation strategies provided are universally applicable The fundamental approach followed leads to efficient compensation strategies that are well guarded against the parameter variations inherent to the mass fabrication of integrated circuits The book is essential reading for practicing analog design engineers and researchers in the field It is also suitable as a text for an advanced course on the subject

**Internally Compensated LDO Regulators for Modern System-on-Chip Design** José María Hinojo, Clara Luján Martínez, Antonio Torralba, 2018-04-19 This book presents a thorough state of the art review for internally compensated Low Dropout Regulators IC LDO It serves as a useful guide for circuit designers The advantages and disadvantages of each cell proposed are highlighted The authors describe an alternative to the classical topology the Flipped Voltage Follower FVF which has been recently applied in the design of internally compensated LDOs to enhance their performances This book provides novel circuits enhancing those parameters of LDO related with frequency behavior and power consumption These solutions as well as their appropriate design methodology are properly described within the text

**Vision Chips** Alireza Moini, 2012-12-06 This chapter presents a set of introductory material which in addition to providing a general view on the topic highlights the importance of research in this area It also presents a short history of the design of smart vision sensors and points out some of the fundamental issues in the design of such sensors 1 1 A General Overview Machine vision is one of the main branches of artificial intelligence The richness of information present in images makes

them the first choice as an input to an artificial system which tries to interact with its environment. A large proportion of the brain of many advanced species is dedicated to visual information processing which illustrates the importance of visual information in biological systems. Biological visual systems have evolved over millions of years and each species has developed a specialized visual system tailored for the essential tasks of survival such as catching a prey or escaping a predator. Implementing electronic hardware for image processing therefore may benefit from the underlying fundamental aspects of biological vision though in no respect should this be regarded as a solid framework for electronic vision systems. Traditionally computer vision algorithms are performed on images captured by conventional cameras and processing is accomplished by means of general purpose digital computers. More advanced systems utilize dedicated hardware to speed up the processing stage.

**Design of Low-Voltage, Low-Power Operational Amplifier Cells** Ron Hogervorst, Johan Huijsing, 2013-03-09. Design of Low Voltage Low Power CMOS Operational Amplifier Cells describes the theory and design of the circuit elements that are required to realize a low voltage low power operational amplifier. These elements include constant gm rail to rail input stages, class AB rail to rail output stages and frequency compensation methods. Several examples of each of these circuit elements are investigated. Furthermore the book illustrates several silicon realizations giving their measurement results. The text focuses on compact low voltage low power operational amplifiers with good performance. Six simple high performance class AB amplifiers are realized using a very compact topology making them particularly suitable for use as VLSI library cells. All of the designs can use a supply voltage as low as 3V. One of the amplifier designs dissipates only 50 W with a unity gain frequency of 1.5 MHz. A second set of amplifiers run on a supply voltage slightly above 1V. The amplifiers combine a low power consumption with a gain of 120 dB. In addition the design of three fully differential operational amplifiers is addressed. Design of Low Voltage Low Power CMOS Operational Amplifier Cells is intended for professional designers of analog circuits. It is also suitable for use as a text book for an advanced course in CMOS operational amplifier design.

**Operational Amplifiers** Johan Huijsing, 2013-03-14. Operational Amplifiers Theory and Design is the first book to present a systematic circuit design of operational amplifiers. Containing state of the art material as well as the essentials the book is written to appeal to both the experienced practitioner and the less initiated circuit designer. It is shown that the topology of all operational amplifiers can be divided into nine main overall configurations. These configurations range from one gain stage up to four or more gain stages. Many famous designs are evaluated in depth. High frequency compensation techniques are presented for all nine configurations. Special emphasis is placed on low power low voltage architectures with rail to rail input and output ranges. Operational Amplifiers Theory and Design also develops on the theme of the design of fully differential operational amplifiers and operational floating amplifiers. In addition the characterization of operational amplifiers by macromodels and error matrices is presented together with measurement techniques for their parameters. Carefully structured and enriched by numerous figures, problems and simulation exercises the book is ideal for the purposes

of self study and self evaluation      **The Design of Low-Voltage, Low-Power Sigma-Delta Modulators** Shahriar Rabii, Bruce A. Wooley, 2012-12-06 Oversampling techniques based on sigma delta modulation are widely used to implement the analog digital interfaces in CMOS VLSI technologies This approach is relatively insensitive to imperfections in the manufacturing process and offers numerous advantages for the realization of high resolution analog to digital A/D converters in the low voltage environment that is increasingly demanded by advanced VLSI technologies and by portable electronic systems In *The Design of Low Voltage Low Power Sigma Delta Modulators* an analysis of power dissipation in sigma delta modulators is presented and a low voltage implementation of a digital audio performance A/D converter based on the results of this analysis is described Although significant power savings can typically be achieved in digital circuits by reducing the power supply voltage the power dissipation in analog circuits actually tends to increase with decreasing supply voltages Oversampling architectures are a potentially power efficient means of implementing high resolution A/D converters because they reduce the number and complexity of the analog circuits in comparison with Nyquist rate converters In fact it is shown that the power dissipation of a sigma delta modulator can approach that of a single integrator with the resolution and bandwidth required for a given application In this research the influence of various parameters on the power dissipation of the modulator has been evaluated and strategies for the design of a power efficient implementation have been identified *The Design of Low Voltage Low Power Sigma Delta Modulators* begins with an overview of A/D conversion emphasizing sigma delta modulators It includes a detailed analysis of noise in sigma delta modulators analyzes power dissipation in integrator circuits and addresses practical issues in the circuit design and testing of a high resolution modulator *The Design of Low Voltage Low Power Sigma Delta Modulators* will be of interest to practicing engineers and researchers in the areas of mixed signal and analog integrated circuit design      Highly Linear Integrated Wideband Amplifiers Henrik Sjöland, 2012-12-06 *Highly Linear Integrated Wideband Amplifiers Design and Analysis Techniques for Frequencies from Audio to RF* deals with the complicated issues involved in the design of high linearity integrated wideband amplifiers for different operating frequencies The book demonstrates these principles using a number of high performance designs New topologies for high linearity are presented as well as a novel method for estimating the intermodulation distortion of a wideband signal One of the most exciting results presented is an enhanced feedback configuration called feedback boosting that is capable of very low distortion Also important is a statistical method for relating the intermodulation distortion of a wideband signal to the total harmonic distortion THD of a single tone The THD as opposed to the intermodulation distortion of the wideband signal is easy to measure and use as a design parameter Three different applications where high linearity is needed are identified namely audio power amplifiers wideband IF amplifiers and RF power amplifiers For these applications high performance integrated amplifier designs using novel topologies are presented together with measurement results The audio amplifiers are built in CMOS and are capable of driving 8Ω loudspeaker loads directly without using any external components One

of the designs can operate on a supply voltage down to 1.5V. Both bipolar and CMOS wideband IF amplifiers are built; they are fully differential and have linearity from DC to 20 MHz. Finally, an RF power amplifier is built in CMOS without using inductors in order to investigate what performance can be achieved without them. Highly Linear Integrated Wideband Amplifiers: Design and Analysis Techniques for Frequencies from Audio to RF is an excellent reference for researchers and designers of integrated amplifiers and may be used as a text for advanced courses on the topic.

*Design of Low-Voltage Low-Power CMOS Delta-Sigma A/D Converters* Vincenzo Peluso, Michiel Steyaert, Willy M.C. Sansen, 2013-03-09. Design of Low Voltage Low Power CMOS Delta Sigma A/D Converters investigates the feasibility of designing Delta Sigma Analog to Digital Converters for very low supply voltage lower than 1.5V and low power operation in standard CMOS processes. The chosen technique of implementation is the Switched Opamp Technique which provides Switched Capacitor operation at low supply voltage without the need to apply voltage multipliers or low  $V_t$  MOST devices. A method of implementing the classic single loop and cascaded Delta Sigma modulator topologies with half delay integrators is presented. Those topologies are studied in order to find the parameters that maximise the performance in terms of peak SNR. Based on a linear model, the performance degradations of higher order single loop and cascaded modulators compared to a hypothetical ideal modulator are quantified. An overview of low voltage Switched Capacitor design techniques such as the use of voltage multipliers, low  $V_t$  MOST devices and the Switched Opamp Technique is given. An in depth discussion of the present status of the Switched Opamp Technique covers the single ended Original Switched Opamp Technique, the Modified Switched Opamp Technique which allows lower supply voltage operation and differential implementation including common mode control techniques. The restrictions imposed on the analog circuits by low supply voltage operation are investigated. Several low voltage circuit building blocks, some of which are new, are discussed. A new low voltage class AB OTA especially suited for differential Switched Opamp applications together with a common mode feedback amplifier and a comparator are presented and analyzed. As part of a systematic top down design approach, the non ideal charge transfer of the Switched Opamp integrator cell is modeled based upon several models of the main opamp non ideal characteristics. Behavioral simulations carried out with these models yield the required opamp specifications that ensure that the intended performance is met in an implementation. A power consumption analysis is performed. The influence of all design parameters, especially the low power supply voltage, is highlighted. Design guidelines towards low power operation are distilled. Two implementations are presented together with measurement results. The first one is a single ended implementation of a Delta Sigma ADC operating with 1.5V supply voltage and consuming 100  $\mu$ W for a 74 dB dynamic range in a 3.4 kHz bandwidth. The second implementation is differential and operates with 900 mV. It achieves 77 dB dynamic range in 16 kHz bandwidth and consumes 40  $\mu$ W. Design of Low Voltage Low Power CMOS Delta Sigma A/D Converters is essential reading for analog design engineers and researchers.

**Integrated Video-Frequency Continuous-Time Filters** Scott D. Willingham, Kenneth W.

Martin,2012-12-06 Advances in the state of the art mean the signal processing ICs of ever increasing complexity are being introduced While the typical portion of a large IC devoted to analog circuits has diminished the performance of those surviving analog signal processing circuits remains vital and their design challenging Moreover the emerging high definition TV technology has created a new area for IC development one with formidable signal processing requirements The antialiasing filters needed for one proposed HDTV decoder motivated the research documented in this book Sharply selective filters place tight constraints on the permitted excess phase shifts of their constituent circuits Combined with stringent requirements for low distortion at video frequencies these constraints challenge the IC filter designer Integrated Video Frequency Continuous Time Filters High Performance Realizations in BiCMOS deals with what is arguably the mainstay of analog signal processing circuits Prominent applications in computer disk drive read channels video receivers rf circuits and antialiasing and reconstruction in data converters testifies to their importance Moreover they are excellent benchmarks for more general analog signal processors Bipolar and MOSFET transistors freely combined at the lowest circuit levels provide the designer with an opportunity to develop potent variations on the standard idioms The book considers the general principles of BiCMOS circuit design through to a demanding design problem This case study approach allows a concrete discussion of the justification for and practical trade offs of each design decision Audience A reference work for experienced IC designers and a text for advanced IC design students      *Proceedings of the International Conference on Data Engineering and Communication Technology* Suresh Chandra Satapathy,Vikrant Bhateja,Amit Joshi,2016-08-23 This two volume book contains research work presented at the First International Conference on Data Engineering and Communication Technology ICDECT held during March 10 11 2016 at Lavasa Pune Maharashtra India The book discusses recent research technologies and applications in the field of Computer Science Electrical and Electronics Engineering The aim of the Proceedings is to provide cutting edge developments taking place in the field data engineering and communication technologies which will assist the researchers and practitioners from both academia as well as industry to advance their field of study      **Distortion Analysis of Analog Integrated Circuits** Piet Wambacq,Willy M.C. Sansen,2013-04-17 The analysis and prediction of nonlinear behavior in electronic circuits has long been a topic of concern for analog circuit designers The recent explosion of interest in portable electronics such as cellular telephones cordless telephones and other applications has served to reinforce the importance of these issues The need now often arises to predict and optimize the distortion performance of diverse electronic circuit configurations operating in the gigahertz frequency range where nonlinear reactive effects often dominate However there have historically been few sources available from which design engineers could obtain information on analysis techniques suitable for tackling these important problems I am sure that the analog circuit design community will thus welcome this work by Dr Wambacq and Professor Sansen as a major contribution to the analog circuit design literature in the area of distortion analysis of electronic circuits I am personally looking forward to having a copy

readily available for reference when designing integrated circuits for communication systems

**Low-Voltage Low-Power Analog Integrated Circuits** Wouter A. Serdijn, 2012-12-06 Low Voltage Low Power Analog Integrated Circuits brings together in one place important contributions and state of the art research results in this rapidly advancing area Low Voltage Low Power Analog Integrated Circuits serves as an excellent reference providing insight into some of the most important issues in the field

**VLSI — Compatible Implementations for Artificial Neural Networks** Sied Mehdi Fakhraie, Kenneth C. Smith, 2012-12-06 This book introduces several state of the art VLSI implementations of artificial neural networks ANNs It reviews various hardware approaches to ANN implementations analog digital and pulse coded The analog approach is emphasized as the main one taken in the later chapters of the book The area of VLSI implementation of ANNs has been progressing for the last 15 years but not at the fast pace originally predicted Several reasons have contributed to the slow progress with the main one being that VLSI implementation of ANNs is an interdisciplinary area where only a few researchers academics and graduate students are willing to venture The work of Professors Fakhraie and Smith presented in this book is a welcome addition to the state of the art and will greatly benefit researchers and students working in this area Of particular value is the use of experimental results to backup extensive simulations and in depth modeling The introduction of a synapse MOS device is novel The book applies the concept to a number of applications and guides the reader through more possible applications for future work I am confident that the book will benefit a potentially wide readership M I Elmasry University of Waterloo Waterloo Ontario Canada Preface Neural Networks NNs generally defined as parallel networks that employ a large number of simple processing elements to perform computation in a distributed fashion have attracted a lot of attention in the past fifty years As the result many new discoveries have been made

**Neuromorphic Systems Engineering** Tor Sverre Lande, 2007-08-26 Neuromorphic Systems Engineering Neural Networks in Silicon emphasizes three important aspects of this exciting new research field The term neuromorphic expresses relations to computational models found in biological neural systems which are used as inspiration for building large electronic systems in silicon By adequate engineering these silicon systems are made useful to mankind Neuromorphic Systems Engineering Neural Networks in Silicon provides the reader with a snapshot of neuromorphic engineering today It is organized into five parts viewing state of the art developments within neuromorphic engineering from different perspectives Neuromorphic Systems Engineering Neural Networks in Silicon provides the first collection of neuromorphic systems descriptions with firm foundations in silicon Topics presented include large scale analog systems in silicon neuromorphic silicon auditory ear and vision eye systems in silicon learning and adaptation in silicon merging biology and technology micropower analog circuit design analog memory analog interchipcommunication on digital buses LIST Neuromorphic Systems Engineering Neural Networks in Silicon serves as an excellent resource for scientists researchers and engineers in this emerging field and may also be used as a text for advanced courses on the subject

**Characterization Methods for Submicron MOSFETs**

Hisham Haddara, 2012-12-06 It is true that the Metal Oxide Semiconductor Field Effect Transistor MOSFET is a key component in modern microelectronics. It is also true that there is a lack of comprehensive books on MOSFET characterization in general. However, there is more than that as to the motivation and reasons behind writing this book. During the last decade, device physicists, researchers, and engineers have been continuously faced with new elements which made the task of MOSFET characterization more and more crucial as well as difficult. The progressive miniaturization of devices has caused several phenomena to emerge and modify the performance of scaled-down MOSFETs. Localized degradation induced by hot carrier injection and Random Telegraph Signal (RTS) noise generated by individual traps are examples of these phenomena. Therefore, it was inevitable to develop new models and new characterization methods or at least adapt the existing ones to cope with the special nature of these new phenomena. The need for more deep and extensive characterization of MOSFET parameters has further increased as the applications of this device have gained ground in many new fields in which its performance has become more and more sensitive to the properties of its Si/SiO<sub>2</sub> interface. MOS transistors have crossed the borders of high-speed electronics where they operate at GHz frequencies. Moreover, MOSFETs are now widely employed in the subthreshold regime in neural circuits and biomedical applications.

*CMOS Current Amplifiers* Giuseppe Palmisano, Gaetano Palumbo, Salvatore Pennisi, 2012-12-06 CMOS Current Amplifiers presents design strategies for high-performance current amplifiers based on CMOS technology. After an introduction to various architectures of operational amplifiers, the operating principles of the current amplifier are outlined. This book provides the reader with simple and compact design equations for use in a pencil-and-paper design and the following simulation step. Chapter 1 introduces the general aspects of current amplifiers. After a preliminary classification of operational amplifiers, ideal blocks and models are discussed for different architectures, and a first high-level comparison is made between traditional amplifiers and current amplifiers. Analysis and examples of basic circuits as well as signal processing applications involving current amplifiers are also given. Non-idealities and second-order effects causing limitations in performance are then discussed and evaluated. Chapter 2 focuses on low-drive current amplifiers. Several design examples for current conveyors and class-A current amplifiers are discussed in detail, and design equations are presented for the main performance parameters, which allows a good trade-off between requirements. High-performance solutions for high bandwidth and low voltage capability are also considered, and finally current comparators with progressively enhanced performance are reported and analyzed critically. Chapter 3 deals with current amplifiers for off-chip loads. Several class-AB current-mode output stages are discussed, and design strategies which improve performance are presented. A detailed analysis of non-ideal effects is carried out with particular emphasis on linearity. Design examples are given, and circuit arrangements for further developments are included. CMOS Current Amplifiers serves as an excellent reference for researchers and professionals of analog IC design and may also be used as an advanced text on current amplifiers.

*Compact Low-Voltage and High-Speed CMOS, BiCMOS*

*and Bipolar Operational Amplifiers* Klaas-Jan de Langen, Johan Huijsing, 2013-03-14 Compact Low Voltage and High Speed CMOS BiCMOS and Bipolar Operational Amplifiers discusses the design of integrated operational amplifiers that approach the limits of low supply voltage or very high bandwidth. The resulting realizations span the whole field of applications from micro power CMOS VLSI amplifiers to 1 GHz bipolar amplifiers. The book presents efficient circuit topologies in order to combine high performance with simple solutions. In total twelve amplifier realizations are discussed. Two bipolar amplifiers are discussed: a 1 GHz operational amplifier and an amplifier with a high ratio between the maximum output current and the quiescent current. Five amplifiers have been designed in CMOS technology: extremely compact circuits that can operate on supply voltages down to one gate source voltage and two saturation voltages which equals about 1.4 V and ultimate low voltage amplifiers that can operate on supply voltages down to one gate source voltage and one saturation voltage which amounts to about 1.2 V. In BiCMOS technology five amplifiers have been designed. The first two amplifiers are based on a compact topology. Two other amplifiers are designed to operate on low supply voltages down to 1.3 V. The final amplifier has a unity gain frequency of 200 MHz and can operate down to 2.5 V. Compact Low Voltage and High Speed CMOS BiCMOS and Bipolar Operational Amplifiers is intended for the professional analog designer. Also it is suitable as a text book for advanced courses in amplifier design.

Top-Down Design of High-Performance Sigma-Delta Modulators Fernando Medeiro, Belén Pérez Verdú, Angel Rodríguez-Vázquez, 2013-04-18 The interest for  $\Delta\Sigma$  modulation based NO converters has significantly increased in the last years. The reason for that is twofold. On the one hand, unlike other converters that need accurate building blocks to obtain high resolution,  $\Delta\Sigma$  converters show low sensitivity to the imperfections of their building blocks. This is achieved through extensive use of digital signal processing, a desirable feature regarding the implementation of NO interfaces in mainstream CMOS technologies which are better suited for implementing fast dense digital circuits than accurate analog circuits. On the other hand, the number of applications with industrial interest has also grown. In fact, starting from the earliest in the audio band, today we can find  $\Delta\Sigma$  converters in a large variety of NO interfaces ranging from instrumentation to communications. These advances have been supported by a number of research works that have led to a considerably large amount of published papers and books covering different sub-topics from purely theoretical aspects to architecture and circuit optimization. However, so much material is often difficult to digest by those unexperienced designers who have been committed to developing a  $\Delta\Sigma$  converter mainly because there is a lack of methodology. In our view, a clear methodology is necessary in  $\Delta\Sigma$  modulator design because all related tasks are rather hard.

**Feed-Forward Neural Networks** Jouke Annema, 2012-12-06 Feed Forward Neural Networks: Vector Decomposition Analysis, Modelling and Analog Implementation presents a novel method for the mathematical analysis of neural networks that learn according to the back propagation algorithm. The book also discusses some other recent alternative algorithms for hardware implemented perception-like neural networks. The method permits a simple analysis of the learning behaviour of neural networks, allowing

specifications for their building blocks to be readily obtained Starting with the derivation of a specification and ending with its hardware implementation analog hard wired feed forward neural networks with on chip back propagation learning are designed in their entirety On chip learning is necessary in circumstances where fixed weight configurations cannot be used It is also useful for the elimination of most mismatches and parameter tolerances that occur in hard wired neural network chips Fully analog neural networks have several advantages over other implementations low chip area low power consumption and high speed operation Feed Forward Neural Networks is an excellent source of reference and may be used as a text for advanced courses      Design of Modulators for Oversampled Converters Feng Wang,Ramesh Harjani,2012-12-06

Oversampled A/D converters have become very popular in recent years Some of their advantages include relaxed requirements for anti alias filters relaxed requirements for component matching high resolution and compatibility with digital VLSI technology There is a significant amount of literature discussing the principle theory and implementation of various oversampled converters Such converters are likely to continue to proliferate in the foreseeable future Additionally more recently there has been great interest in low voltage and low power circuit design New design techniques have been proposed for both the digital domain and the analog domain Both trends point to the importance of the low power design of oversampled A/D converters Unfortunately there has been no systematic study of the optimal design of modulators for oversampled converters Design has generally focused on new architectures with little attention being paid to optimization The goal of Design of Modulators for Oversampled Converters is to develop a methodology for the optimal design of modulators in oversampled converters The primary focus of the presentation is on minimizing power consumption and understanding and limiting the nonlinearities that result in such converters Design of Modulators for Oversampled Converters offers a quantitative justification for the various design tradeoffs and serves as a guide for designing low power highly linear oversampled converters Design of Modulators for Oversampled Converters will serve as a valuable guide for circuit design practitioners university researchers and graduate students who are interested in this fast moving area

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