

# Design Of Low Voltage Low Power Operational Amplifier Cells The Springer International Series In Engineering And Computer Science

**Johan Huijsing, Rudy J. van de Plassche, Willy Sansen**

*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 $\mu$ 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 Amplifier Speed and Accuracy Improvement** Vadim V. Ivanov, Igor M. Filanovsky, 2005-12-30 Operational Amplifier Speed and Accuracy Improvement proposes a new methodology for the design of analog integrated circuits. The usefulness of this methodology is demonstrated through the design of an operational amplifier. This methodology consists of the following iterative steps: description of the circuit functionality at a high level of abstraction using signal flow graphs; equivalent transformations and modifications of the graph to the form where all important parameters are controlled by dedicated feedback loops; and implementation of the structure using a library of elementary cells. Operational Amplifier Speed and Accuracy Improvement shows how to choose structures and design circuits which

improve an operational amplifier's important parameters such as speed to power ratio, open loop gain, common-mode voltage rejection ratio, and power supply rejection ratio. The same approach is used to design clamps and limiting circuits which improve the performance of the amplifier outside of its linear operating region, such as slew rate enhancement, output short circuit current limitation, and input overload recovery.

**Wideband Low Noise Amplifiers Exploiting Thermal Noise Cancellation** Federico Bruccoleri, Eric Klumperink, Bram Nauta, 2006-03-30 Low Noise Amplifiers (LNAs) are commonly used to amplify signals that are too weak for direct processing for example in radio or cable receivers. Traditionally, low noise amplifiers are implemented via tuned amplifiers, exploiting inductors and capacitors in resonating LC-circuits. This can render very low noise but only in a relatively narrow frequency band close to resonance. There is a clear trend to use more bandwidth for communication, both via cables (e.g. cable TV, internet) and wireless links (e.g. satellite links and Ultra Wideband Band). Hence wideband low-noise amplifier techniques are very much needed. *Wideband Low Noise Amplifiers Exploiting Thermal Noise Cancellation* explores techniques to realize wideband amplifiers, capable of impedance matching and still achieving a low noise figure well below 3dB. This can be achieved with a new noise cancelling technique as described in this book. By using this technique, the thermal noise of the input transistor of the LNA can be cancelled while the wanted signal is amplified! The book gives a detailed analysis of this technique and presents several new amplifier circuits. This book is directly relevant for IC designers and researchers working on integrated transceivers. Although the focus is on CMOS circuits, the techniques can just as well be applied to other IC technologies, e.g. bipolar and GaAs, and even in discrete component technologies.

**International Books in Print**, 1997

*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.

*Design of High-Performance CMOS Voltage-Controlled Oscillators* Liang Dai, Ramesh Harjani, 2003 Design of High-Performance CMOS Voltage-Controlled Oscillators presents a phase noise modeling framework for CMOS ring oscillators. The analysis considers both linear and nonlinear operation. It indicates that fast rail-to-rail switching has to be achieved to minimize phase noise. Additionally, in conventional design the flicker noise in the bias circuit can potentially dominate the phase noise at low offset frequencies. Therefore, for narrow bandwidth PLLs, noise up conversion for the bias circuits should be minimized. We define the effective Q factor ( $Q_{eff}$ ) for ring oscillators and predict its increase for CMOS processes with smaller feature sizes. Our phase noise analysis is validated via simulation and measurement results. The digital switching noise coupled through the power supply and substrate is usually the dominant source of clock jitter. Improving the supply and substrate noise immunity of a PLL is a challenging job in hostile environments such as a microprocessor chip where millions of digital gates are present.

**Design of Low-Voltage Bipolar Operational Amplifiers** M. Jeroen Fonderie, Johan Huijsing, 2012-12-06 Design of Low-Voltage Bipolar Operational Amplifiers discusses the sub-circuits necessary to build a low-voltage operational amplifier. These include rail-to-rail input stages, rail-to-rail output stages, intermediate stages, protection circuitry and frequency compensation techniques. Of each of these, various implementations are examined. Furthermore, the book discusses realizations in silicon of the amplifiers. The design and implementation of low-voltage bipolar Operational Amplifiers (OpAmps) is fully presented. A low supply voltage is necessary because the tendency towards chip components of smaller dimensions lowers the breakdown voltage of these components. Further, a low supply voltage is favorable because it enables operation of the OpAmp from just one single battery cell. The bipolar technology is chosen, because it is more suited for operation at low-voltages than the MOS technology. The common-mode input voltage of the OpAmp must be able to have any value that fits within the supply voltage range. Input stages are discussed which are able to realize this at supply voltages down to 1.8 V, as well as down to 1 V. The output voltage of the OpAmp must be able to have any value within the supply voltage range. One of the 1 V output stages that is discussed, the multi-path driven output stage, also has a high bandwidth with a high gain. In addition to the input and output stage, the OpAmp comprises an intermediate stage, between the input

stage and the output stage, to boost the overall gain of the OpAmp, and a class AB current control. A frequency compensation technique is used to split apart the pole frequencies in the transfer function. A disadvantage of this nested Miller compensation, is that the resulting bandwidth is reduced by a factor of two. A new method, multi-path-driven Miller compensation, which does not have this drawback, is therefore introduced. Several realizations are evaluated and a figure of merit is defined for the performance comparison of the OpAmps. One of the OpAmps operates at a 1 V supply, has a 3.4 MHz bandwidth with a 100 pF load and has a 700  $\mu$ A supply current. The book is an excellent reference for professional designers of amplifiers and may be used as a text for advanced courses on the subject.

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.

**High-Speed Photodiodes in Standard CMOS Technology** Sasa Radovanovic, Anne-Johan Annema, Bram Nauta, 2006-10-11 High-speed Photodiodes in Standard CMOS Technology describes high-speed photodiodes in standard CMOS technology which allow monolithic integration of optical receivers for short-haul communication. For short haul communication the cost aspect is important, and therefore it is desirable that the optical receiver can be integrated in the same CMOS technology as the rest of the system. If this is possible then ultimately a single-chip system including optical inputs becomes feasible, eliminating EMC and crosstalk problems, while data rate can be extremely high. The problem of photodiodes in standard CMOS technology is that they have very limited bandwidth, allowing data rates up to only 50 Mbit per second. High-speed Photodiodes in Standard CMOS Technology first analyzes the photodiode behaviour and compares existing solutions to enhance the speed. After this, the book introduces a new and robust electronic equalizer technique that makes data rates of 3 Gb/s possible, without changing the manufacturing technology. The application of this technique can be found in short haul fibre communication, optical printed circuit boards, but also photodiodes for laser disks.

**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.

**Extreme Low-Power Mixed Signal IC Design** Armin Tajalli, Yusuf Leblebici, 2010-09-14 Design exibility and power consumption in addition to the cost, have always been the most important issues in design of integrated circuits (ICs), and are the main concerns of this research, as well. Energy Consumptions: Power dissipation (P) and energy consumption are especially important when there is a limited amount of power budget or limited source of energy. Very common examples

are portable systems where the battery life time depends on system power consumption. Many different techniques have been developed to reduce or manage the circuit power consumption in this type of systems. Ultra-low power (ULP) applications are another examples where power dissipation is the primary design issue. In such applications, the power budget is so restricted that very special circuit and system level design techniques are needed to satisfy the requirements. Circuits employed in applications such as wireless sensor networks (WSN), wearable battery powered systems [1], and implantable circuits for biological applications need to consume very low amount of power such that the entire system can survive for a very long time without the need for changing or recharging battery [2-4]. Using new power supply techniques such as energy harvesting [5] and printable batteries [6], is another reason for reducing power dissipation. Developing special design techniques for implementing low power circuits [7-9], as well as dynamic power management (DPM) schemes [10] are the two main approaches to control the system power consumption. Design Flexibility: Design exibility is the other important issue in modern integrated systems.

*Design of Low-voltage Low-power CMOS Operational Amplifier Cells* Ron Hogervorst, 1996

**Op Amps for Everyone** Ron Mancini, 2003 The operational amplifier (op amp) is the most versatile and widely used type of analog IC, used in audio and voltage amplifiers, signal conditioners, signal converters, oscillators, and analog computing systems. Almost every electronic device uses at least one op amp. This book is Texas Instruments' complete professional-level tutorial and reference to operational amplifier theory and applications. Among the topics covered are basic op amp physics (including reviews of current and voltage division, Thevenin's theorem, and transistor models), idealized op amp operation and configuration, feedback theory and methods, single and dual supply operation, understanding op amp parameters, minimizing noise in op amp circuits, and practical applications such as instrumentation amplifiers, signal conditioning, oscillators, active filters, load and level conversions, and analog computing. There is also extensive coverage of circuit construction techniques, including circuit board design, grounding, input and output isolation, using decoupling capacitors, and frequency characteristics of passive components. The material in this book is applicable to all op amp ICs from all manufacturers, not just TI. Unlike textbook treatments of op amp theory that tend to focus on idealized op amp models and configuration, this title uses idealized models only when necessary to explain op amp theory. The bulk of this book is on real-world op amps and their applications; considerations such as thermal effects, circuit noise, circuit buffering, selection of appropriate op amps for a given application, and unexpected effects in passive components are all discussed in detail. \*Published in conjunction with Texas Instruments \*A single volume, professional-level guide to op amp theory and applications \*Covers circuit board layout techniques for manufacturing op amp circuits.

**Operational Amplifiers** Johan Huijsing, 2016-07-09 This proven textbook guides readers to a thorough understanding of the theory and design of operational amplifiers (OpAmps). The core of the book presents systematically the design of

operational amplifiers, classifying them into a periodic system of nine main overall configurations, ranging from one gain stage up to four or more stages. This division enables circuit designers to recognize quickly, understand, and choose optimal configurations. Characterization of operational amplifiers is given by macro models and error matrices, together with measurement techniques for their parameters. Definitions are given for four types of operational amplifiers depending on the grounding of their input and output ports. Many famous designs are evaluated in depth, using a carefully structured approach enhanced by numerous figures. In order to reinforce the concepts introduced and facilitate self-evaluation of design skills, the author includes problems with detailed solutions, as well as simulation exercises.

**Current Conveyors** Raj Senani, D. R. Bhaskar, A. K. Singh, 2014-10-09 This book serves as a single-source reference to Current Conveyors and their use in modern Analog Circuit Design. The authors describe the various types of current conveyors discovered over the past 45 years, details of all currently available, off-the-shelf integrated circuit current conveyors, and implementations of current conveyors using other, off-the-shelf IC building blocks. Coverage includes prominent bipolar/CMOS/Bi-CMOS architectures of current conveyors, as well as all varieties of starting from third generation current conveyors to universal current conveyors, their implementations and applications. • Describes all commercially available off-the-shelf IC current conveyors, as well as hardware implementations of current conveyors using other off-the-shelf ICs; • Describes numerous variants of current conveyors evolved over the past forty five years; • Describes a number of Bipolar/CMOS/Bi-CMOS architectures of current conveyors, along with their characteristic features; • Includes a comprehensive collection of over 400 application circuits using current conveyors; • Provides an exhaustive catalogue of current conveyor-based circuits for a variety of applications, including instrumentation amplifiers, precision rectifiers, simulated inductors, filters, sinusoidal oscillators, waveform generators, chaos generators, analog multipliers/dividers, memristive emulators and numerous others.

*Low-Voltage CMOS Operational Amplifiers* Satoshi Sakurai, Mohammed Ismail, 2012-12-06 Low-Voltage CMOS Operational Amplifiers: Theory, Design and Implementation discusses both single and two-stage architectures. Opamps with constant-gm input stage are designed and their excellent performance over the rail-to-rail input common mode range is demonstrated. The first set of CMOS constant-gm input stages was introduced by a group from Technische Universiteit, Delft and Universiteit Twente, the Netherlands. These earlier versions of circuits are discussed, along with new circuits developed at the Ohio State University. The design, fabrication (MOSIS Tiny Chips), and characterization of the new circuits are now complete. Basic analog integrated circuit design concepts should be understood in order to fully appreciate the work presented. However, the topics are presented in a logical order and the circuits are explained in great detail, so that Low-Voltage CMOS Operational Amplifiers can be read and enjoyed by those without much experience in analog circuit design. It is an invaluable reference book, and may be used as a text for advanced courses on the subject.

*Design of Low-Voltage CMOS Switched-Opamp Switched-Capacitor Systems* Vincent S.L. Cheung, Howard Cam H. Luong, 2013-03-14 This volume emphasizes the design and development of advanced switched-opamp architectures and techniques for low-voltage low-power switched-capacitor systems. It presents a novel multi-phase switched-opamp technique together with new system architectures that are critical in improving significantly the performance of switched-capacitor systems at low supply voltages.

**Sub-threshold Design for Ultra Low-Power Systems** Alice Wang, Benton Highsmith Calhoun, Anantha P. Chandrakasan, 2006-12-11 Based on the work of MIT graduate students Alice Wang and Benton Calhoun, this book surveys the field of sub-threshold and low-voltage design and explores such aspects of sub-threshold circuit design as modeling, logic and memory circuit design. One important chapter of the book is dedicated to optimizing energy dissipation - a key metric for energy constrained designs. This book also includes invited chapters on the subject of analog sub-threshold circuits.

**Analog Circuit Design** Johan Huijsing, Rudy J. van de Plassche, Willy Sansen, 1992-12-31 This volume of Analog Circuit Design concentrates on three topics: Operational Amplifiers, A-to-D converters and Analog CAD. The book comprises six papers on each topic written by internationally recognised experts. These papers have a tutorial nature aimed at improving the design of analog circuits. The book is divided into three parts. Part I, Operational Amplifiers, presents new technologies for the design of Op-Amps in both bipolar and CMOS technologies. Two papers demonstrate techniques for improving frequency and gain behavior at high voltage. Low voltage bipolar Op-Amp design is treated in another paper. The realization high-speed and high gain VLSI building blocks in CMOS is demonstrated in two papers. The final paper shows how to provide output power with CMOS buffer amplifiers. Part II, Analog-to-Digital Conversion, presents papers which address very high conversion speeds and very high resolution implementations using sigma-delta modulation architectures. Analog to Digital converters provide the link between the analog world of transducers and the digital world of signal processing and computing. High-performance bipolar and MOS technologies result in high-resolution or high-speed convertors which can be applied in digital audio or video systems. Furthermore, the advanced high-speed bipolar technologies show an increase in conversion speed into the gigahertz range. Part III, Analog Computer Aided Design, presents the latest research towards providing analog circuit designers with the tools needed to automate much of the design process. The techniques and methodologies described demonstrate the advances being made in developing analog design tools comparable with those already available for digital design. The papers in this volume are based on those presented at the Workshop on Advances in Analog Circuit Design held in Delft, The Netherlands in 1992. The main intention of the workshop was to brainstorm with a group of about 100 analog design experts on the new possibilities and future developments on the above topics. The result of this brainstorming is contained in Analog Circuit Design, which is thus an important reference for researchers and design engineers working in the forefront of analog circuit design and research.

High Voltage Direct Current Transmission J. Arrillaga, 1998-06-30 This book describes a variety of reasons justifying the use of DC transmission as well as the basic concepts and techniques involved in the AC-DC and DC-AC conversion processes.

Whispering the Techniques of Language: An Psychological Quest through **Design Of Low Voltage Low Power Operational Amplifier Cells The Springer International Series In Engineering And Computer Science**

In a digitally-driven world where monitors reign great and immediate connection drowns out the subtleties of language, the profound secrets and psychological nuances hidden within words usually move unheard. However, set within the pages of **Design Of Low Voltage Low Power Operational Amplifier Cells The Springer International Series In Engineering And Computer Science** a interesting fictional value blinking with fresh emotions, lies an extraordinary quest waiting to be undertaken. Penned by a talented wordsmith, that marvelous opus attracts viewers on an introspective journey, softly unraveling the veiled truths and profound impact resonating within ab muscles fabric of each word. Within the emotional depths with this poignant review, we shall embark upon a heartfelt exploration of the book is primary styles, dissect its captivating writing design, and succumb to the effective resonance it evokes heavy within the recesses of readers hearts.

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