

Preface for Analog IC Design by D. Johns and K. Martin

For the past twenty years, numerous people have predicted there soon would be little need for analog circuitry because the world would rely on digital circuits. However, although many applications have indeed replaced much analog circuitry with their digital counterparts (such as digital audio), the need for good analog circuit design remains strong. For example, when digitizing physical signals, analog-to-digital and digital-to-analog converters are always needed, together with their associated antialiasing and reconstruction filters. In addition, new applications continue to appear in which speed and power-consumption requirements often demand the use of highspeed analog front ends, such as digital communications over copper wires or wireless communication channels. Also as integrated circuits become larger due to system integration, it is much more likely that at least some portion of a modern integrated circuit will include analog circuitry required to interface to the real world. Often this analog circuitry, although it constitutes only a small portion of the total chip area, may be the limiting factor on overall system performance and the most difficult part of the IC to design. As a result, a strong industrial need for analog circuit designers continues. The purpose of this book is to help develop excellent analog circuit designers by presenting a concise treatment of the wide array of knowledge required by an integrated circuit designer.

Many refer to the designing and testing of high-performance analog circuits as a "mystical art". In other words, whereas digital design is relatively systematic, analog design appears to be much more confusing and based on gut feelings. In addition, analog testing may sometimes seem to depend more on the time of day and phase of the moon rather than on concrete electrical properties. These thoughts about analog circuits usually occur when one is not familiar with the many fundamentals required to create high-performance analog circuits. A major goal of this book is to help take the mystery out of analog integrated circuit design. The authors believe that most experienced electrical engineers are capable of good design if they are familiar with the most important design principles. We have attempted to highlight these principles throughout this text. Although many circuits and techniques are described, we have emphasized the most important and fundamental principles involved in realizing state-of-the-art analog circuits. Throughout this book, we give physical and intuitive explanations, and, although mathematical quantitative analyses of many circuits have necessarily been presented, we have attempted not to miss seeing the forest because of the trees. In other words, this book attempts to present the critical underlying concepts without becoming entangled in tedious and over complicated circuit analyses.

Intended Audience

This book is primarily intended for use as a graduate level textbook and as a reference for practicing engineers, although portions of this text are also useful for senior-level undergraduate courses. To appreciate the material in this book, it is expected that the reader has had at least one basic course in analog circuits. Specifically, the reader should be familiar with the concept of small signal analysis and have been exposed to basic transistor amplifier circuits. In addition, the reader should be comfortable working in the frequency domain (ie. Should be familiar with the Laplace transform) with possibly some knowledge of discrete-time signals.

Contents

3.11	Frequency Response	154
3.12	SPICE Simulation Examples	
3.13	References	176
3.14	Problems	176

CHAPTER 1 INTEGRATED-CIRCUIT DEVICES AND MODELLING

1.1	Semiconductors and pn Junctions	1
1.2	MOS Transistors	16
1.3	Advanced MOS Modelling	39
1.4	Bipolar-Junction Transistors	42
1.5	Device Model Summary	56
1.6	SPICE-Modelling Parameters	61
1.7	Appendix	65
1.8	References	78
1.9	Problems	78

CHAPTER 2 PROCESSING AND LAYOUT

82

2.1	CMOS Processing	82
2.2	Bipolar Processing	95
2.3	CMOS Layout and Design Rules	96
2.4	Analog Layout Considerations	105
2.5	Latch-Up	118
2.6	References	121
2.7	Problems	121

CHAPTER 3 BASIC CURRENT MIRRORS AND SINGLE-STAGE AMPLIFIERS

125

3.1	Simple CMOS Current Mirror	125
3.2	Common-Source Amplifier	128
3.3	Source-Follower or Common-Drain Amplifier	129
3.4	Common-Gate Amplifier	132
3.5	Source-Degenerated Current Mirrors	135
3.6	High-Output-Impedance Current Mirrors	137
3.7	Cascode Gain Stage	140
3.8	MOS Differential Pair and Gain Stage	142
3.9	Bipolar Current Mirrors	146
3.10	Bipolar Gain Stages	149

CHAPTER 4 NOISE ANALYSIS AND MODELLING

4.1	Time-Domain Analysis	181
4.2	Frequency-Domain Analysis	
4.3	Noise Models for Circuit Element	
4.4	Noise Analysis Examples	20
4.5	References	216
4.6	Problems	217

CHAPTER 5 BASIC OPAMP DESIGN AND COMPENSATION

5.1	Two-Stage CMOS Opamp	
5.2	Feedback and Opamp Compensation	
5.3	SPICE Simulation Examples	
5.4	References	252
5.5	Problems	253

CHAPTER 6 ADVANCED CURRENT MIRRORS

6.1	Advanced Current Mirrors	
6.2	Folded-Cascode Opamp	
6.3	Current-Mirror Opamp	21
6.4	Linear Settling Time Revisited	
6.5	Fully Differential Opamps	
6.6	Common-Mode Feedback in	
6.7	Current-Feedback Opamps	
6.8	SPICE Simulation Examples	
6.9	References	299
6.10	Problems	300

CHAPTER 7 COMPARATORS

7.1	Using an Opamp for a Comparator	
7.2	Charge-Injection Errors	3
7.3	Latched Comparators	31
7.4	Examples of CMOS and Bipolar Comparators	
7.5	Examples of Bipolar Comparators	
7.6	References	330
7.7	Problems	331

CHAPTER 8 SAMPLE AND HOLDS, VOLTAGE REFERENCES, AND TRANSLINEAR CIRCUITS

8.1	Performance of Sample-and-Hold Circuits	334
8.2	MOS Sample-and-Hold Basics	336
8.3	Examples of CMOS S/H Circuits	343
8.4	Bipolar and BiCMOS Sample and Holds	349
8.5	Bandgap Voltage Reference Basics	353
8.6	Circuits for Bandgap References	357
8.7	Translinear Gain Cell	364
8.8	Translinear Multiplier	366
8.9	References	368
8.10	Problems	370

334**CHAPTER 9 DISCRETE-TIME SIGNALS**

9.1	Overview of Some Signal Spectra	373
9.2	Laplace Transforms of Discrete-Time Signals	374
9.3	z-Transform	377
9.4	Downsampling and Upsampling	379
9.5	Discrete-Time Filters	382
9.6	Sample-and-Hold Response	389
9.7	References	391
9.8	Problems	391

373**CHAPTER 10 SWITCHED-CAPACITOR CIRCUITS**

10.1	Basic Building Blocks	394
10.2	Basic Operation and Analysis	398
10.3	First-Order Filters	409
10.4	Biquad Filters	415
10.5	Charge Injection	423
10.6	Switched-Capacitor Gain Circuits	427
10.7	Correlated Double-Sampling Techniques	433
10.8	Other Switched-Capacitor Circuits	434
10.9	References	441
10.10	Problems	443

394**CHAPTER 11 DATA CONVERTER FUNDAMENTALS**

11.1	Ideal D/A Converter	445
11.2	Ideal A/D Converter	447
11.3	Quantization Noise	448
11.4	Signed Codes	452

445

11.5	Performance Limitations	
11.6	References	461
11.7	Problems	461

CHAPTER 12 NYQUIST-RATE D/A CONVERTERS

12.1	Decoder-Based Converters	
12.2	Binary-Scaled Converters	4
12.3	Thermometer-Code Converters	
12.4	Hybrid Converters	481
12.5	References	484
12.6	Problems	484

CHAPTER 13 NYQUIST-RATE A/D CONVERTERS

13.1	Integrating Converters	48'
13.2	Successive-Approximation Cc	
13.3	Algorithmic (or Cyclic) A/D C	
13.4	Flash (or Parallel) Converters	
13.5	Two-Step A/D Converters	
13.6	Interpolating A/D Converters	
13.7	Folding A/D Converters	f
13.8	Pipelined A/D Converters	
13.9	Time-Interleaved A/D Convei	
13.10	References	527
13.11	Problems	528

CHAPTER 14 OVERSAMPLING CONVERTERS

14.1	Oversampling without Noise	
14.2	Oversampling with Noise Sfo	
14.3	System Architectures	54'
14.4	Digital Decimation Filters	
14.5	Higher-Order Modulators	
14.6	Bandpass Oversampling Con'	
14.7	Practical Considerations	
14.8	Multi-Bit Oversampling Con'	
14.9	Third-Order A/D Design Exa	
14.10	References	571
14.11	Problems	572

CHAPTER 15 CONTINUOUS-TIME FILTERS

15.1	Introduction to G_m -C Filters	
15.2	Bipolar Transconductors	