

CMOS CURRENT AMPLIFIERS

Speed versus Nonlinearity

Kimmo Koli and Kari Halonen

Contents

1	Introduction to current-mode circuit techniques	1
1.1	Development of integration technologies	1
1.2	Motivation for current-mode circuit design	2
1.3	Evolution of current-mode building blocks	3
1.4	Adjoint principle	4
1.5	Scope of this book	6
2	Basic current amplifiers	11
2.1	Current-mirror	12
2.1.1	Nonidealities due to the channel length modulation	13
2.1.2	Nonidealities due the V_T mismatch	16
2.1.3	High frequency nonidealities	18
	Linear effects	18
	Nonlinearity in limited frequency ranges	20
	Mirror as a feedback amplifier	22
2.1.4	Distortion reduction methods	27
	Transconductance linearisation	27
	Nonlinear current reduction	28
	Nonlinear current cancellation	28
2.1.5	Noise and dynamic range	31
2.1.6	Other mirror topologies	33
	Accurate current-mirror topologies for large signal amplitudes	33
	Resistively compensated mirror	35
2.2	Current buffer	38
2.2.1	Linear nonidealities	39
2.2.2	Nonlinearity	40
2.2.3	Noise	41
2.2.4	Alternative topologies	41

3 Open-loop current amplifiers	45
3.1 First generation current-conveyor CCI	45
3.1.1 Linear nonidealities	46
3.1.2 Nonlinearity	49
3.1.3 Applications of the CCI	49
3.1.4 Push-pull CCI topologies	50
3.1.5 Low voltage CCI topologies	54
3.2 Second generation current-conveyor CCII	55
3.2.1 Linear nonidealities	57
3.2.2 CCII macromodel	59
3.2.3 Applications of the CCII	61
3.2.4 Nonlinearity of the class-A CCII	67
3.2.5 Alternative class-A CCII topologies	68
3.2.6 Push-pull CCII topologies	72
Basic operation of a push-pull CCII+	72
Basic operation of a push-pull CCII-	74
X-terminal impedance	75
Current gain nonlinearity	76
3.3 Third generation current-conveyor CCIII	80
4 Current-mode feedback amplifiers	85
4.1 Current-feedback operational amplifier	85
4.1.1 Closed loop bandwidth	87
4.1.2 Integrator implementations	90
4.1.3 Self-compensation of voltage followers	92
4.1.4 Common-mode rejection	93
4.1.5 CMOS implementations	95
4.2 Operational floating conveyor	97
4.2.1 Applications	98
4.2.2 Composite conveyors	99
4.3 Current-mode operational amplifiers	101
4.3.1 Distortion	102
4.3.2 Slew rate and full power bandwidth	104
4.3.3 Alternative topologies	105
4.4 High-gain current-conveyor CCII ∞	107
4.4.1 Linear nonidealities	108
4.4.2 Applications	110
4.4.3 Distortion	113
4.4.4 Design example	115

5 System aspects of current-mode circuits	123
5.1 Input voltage-to-current conversion	123
5.2 Output current-to-voltage conversion	126
5.3 Differential voltage input structures	129
5.3.1 CMRR enhancement techniques	130
Common-mode bootstrapping	131
Output current subtraction	131
Composite conveyors	135
5.4 Differential current input structures	137
5.5 Single-ended to differential conversion	138
5.6 Noise in current-mode circuits	141
5.6.1 Class-A CMOS CCII+	141
5.6.2 Other low-gain conveyor topologies	145
5.6.3 High-gain current-conveyor	145
5.6.4 Other current-mode feedback amplifiers	148
5.6.5 General notes on current amplifier noise	149
6 Current-mode continuous-time filters	153
6.1 Integrator quality factor	154
6.2 Voltage-mode active-RC integrators	155
6.3 OTA-based integrators	157
6.3.1 The effects of process variation and temperature drift	158
6.3.2 Transconductance linearity	160
6.4 Integrators with MOS-resistors	162
6.5 Current-conveyor based filters	163
6.6 Current-mirror based filter	167
6.7 High-gain current-conveyor based filters	172
6.8 Multi-output current integrator with a linearised transconductor	176
6.8.1 Linearization by drain current difference	177
6.8.2 Linearisation by dynamic biasing	181
6.9 Design case: A 1 MHz current-mode low-pass filter	183
6.9.1 Filter building blocks	183
The transimpedance driver amplifier	184
Multiple-output linearised transconductance element	187
Temperature drift compensation of the integrator time constant	187
6.9.2 The first filter realisation	190
Integrator Q-enhancement	192
Experimental results	195
6.9.3 The second test chip	198

Alternate driver implementation	201
Experimental results	205
6.10 Final remarks	208
7 Current-mode logarithmic amplifiers	213
7.1 Diode-feedback logarithmic amplifiers	214
7.1.1 Voltage-mode operational amplifier based realizations	214
7.1.2 Design case: CCII ∞ based logarithmic peak detector	216
BiCMOS implementation of a CCII ∞	217
Logarithmic peak detector implementation	217
Post processing of the logarithmic output voltage	222
Final remarks on the design	229
7.2 Pseudologarithmic amplifiers	230
7.2.1 Limiting CMOS voltage amplifiers	231
7.2.2 Limiting CMOS current amplifiers	233
7.2.3 Accuracy of the pseudologarithmic amplifier	235
7.2.4 Amplitude detection in pseudologarithmic amplifiers	236
CMOS rectifiers	236
CMOS squarers	238
CMOS peak detectors	238
7.2.5 Design case: A 2.5 V CMOS pseudologarithmic current amplifier	242
Limiting amplifier	243
Current reference	245
Current peak detector	247
Experimental results	247
7.3 Other approaches	252
Current peak detector with enhanced discharging time constant adjustment	252
Conclusions	259
A Basic distortion definitions	261
A.1 Harmonic distortion	261
A.2 Intermodulation distortion	262
A.3 Distortion in feedback amplifiers	263
A.3.1 Distortion in quasi-static feedback amplifiers	263
A.3.2 Distortion in dynamic feedback amplifiers	264

B Distortion in push-pull current amplifiers	269
B.1 Class-A operation	269
B.2 Class-AB operation	271
C Distortion in CMOS operational amplifiers	275
C.1 Miller-compensated unbuffered operational amplifier	275
C.2 Folded cascode operational transconductance amplifier	279
D Distortion in a dual current-mirror integrator	283
D.1 Single-ended integrator	283
D.2 Differential integrator	286