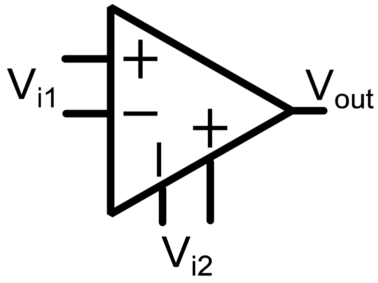
Offset compensation using an additional input port

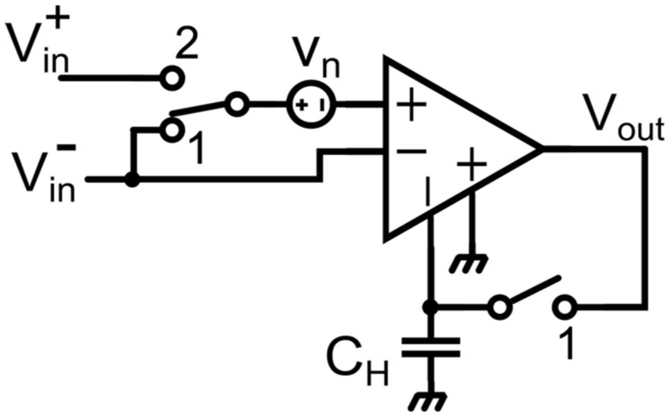


$$V_{out} = A\left(V_{i1} - v_n\right) + BV_{i2}$$

V_{i1} is the input signal port, V_{i2} is the offset calibration port

(offset and noise are referred to the input signal port)

AZ compensation:



Phase 1:

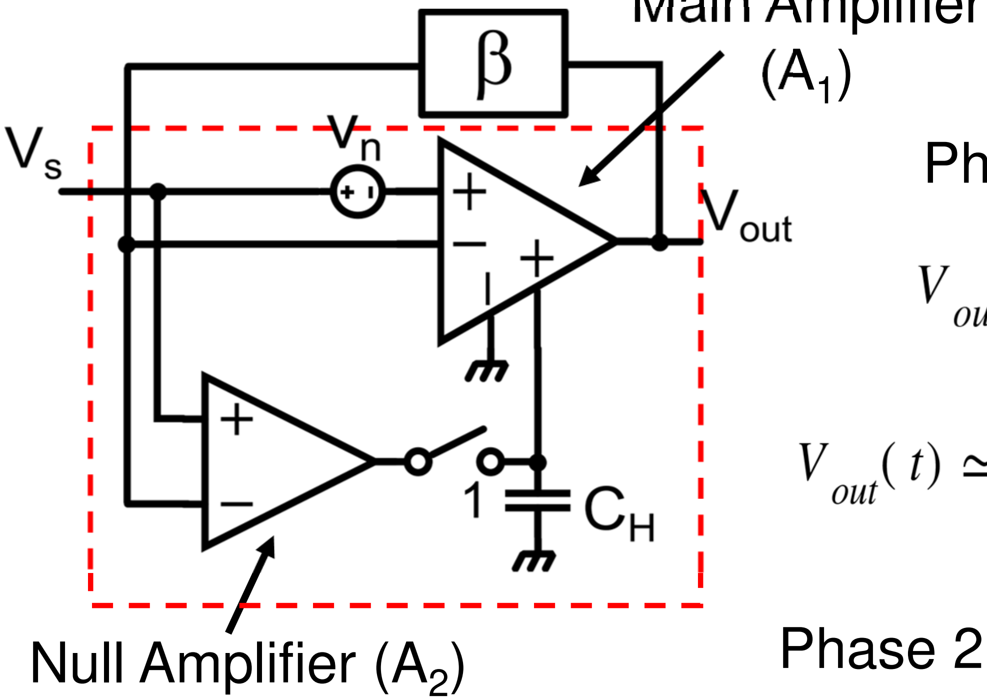
$$V_{out}(t) = -Av_n(t) - BV_{out}(t) \Rightarrow V_{out}(t) = -\frac{A}{1+B}v_n(t)$$

$$V_{C_H}(t) = V_{out}(t)$$

Phase 2:

$$V_{out}(t) = A\left(V_{in}^{+}(t) - V_{in}^{-}(t) - v_n(t)\right) - BV_{C_H}^{(1)} \Rightarrow V_{out}(t) \simeq A\left(V_{in}^{+}(t) - V_{in}^{-}(t) - \underbrace{\left(v_n(t) - v_n^{(1)}\right)}_{v_{n-eff}(t)}\right)$$

Continuous-time AZ amplifiers



Hp.: Null Amplifier without offset

Phase 1:

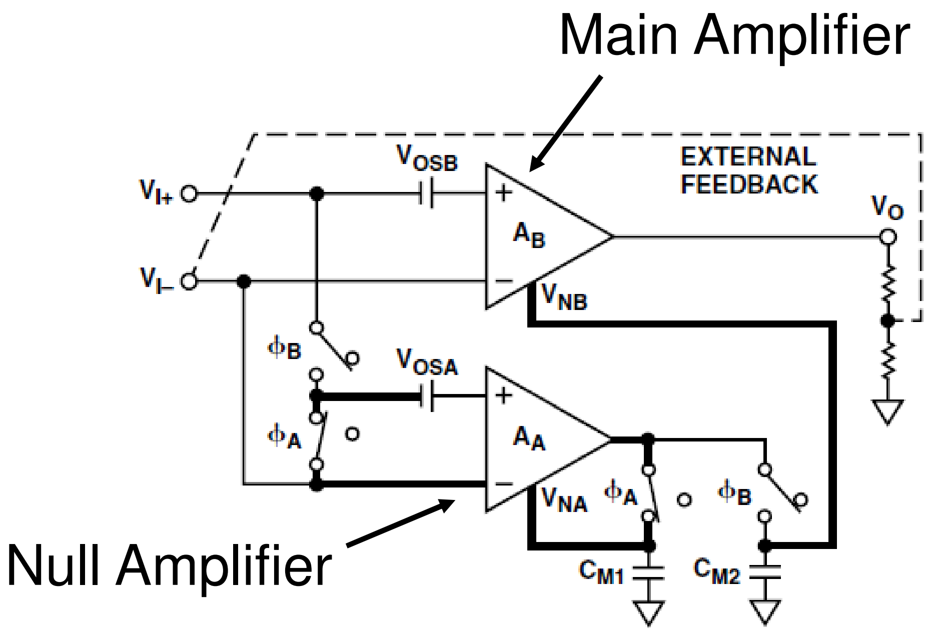
$$V_{out}(t) = A_1\left(V_s - \beta V_{out} - v_n\right) + B_1 A_2\left(V_s - \beta V_{out}\right)$$

$$V_{out}(t) \simeq \frac{V_s}{\beta} - \frac{v_n A_1}{\beta\left(A_1 + B_1 A_2\right)} \Rightarrow v_{n-eff}(t) \simeq \frac{v_n(t) A_1}{B_1 A_2}$$

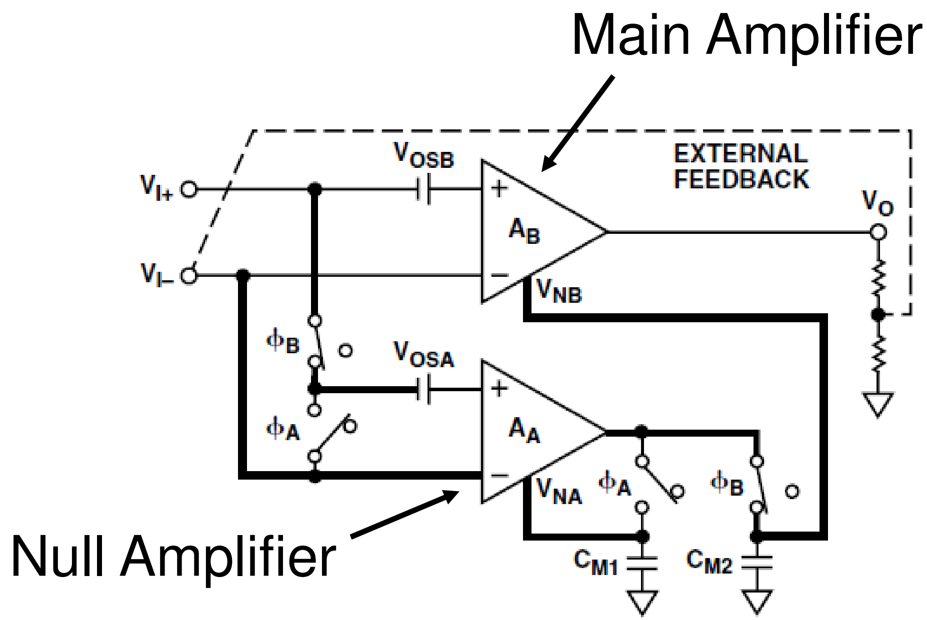
Phase 2:

$$V_{out}(t) = A_1\left(V_s - \beta V_{out} - v_n\right) + B_1 A_2 V_{C_H}^{(1)} \Rightarrow V_{out}(t) \simeq \frac{V_S}{\beta} - A_1\overbrace{\left(v_n(t) - v_n^{(1)}\right)}^{v_{n-eff}(t)}$$

Commercial Zero-Drift Operational Amplifiers based on AZ (AD8551, TLC2654, OPA335…)

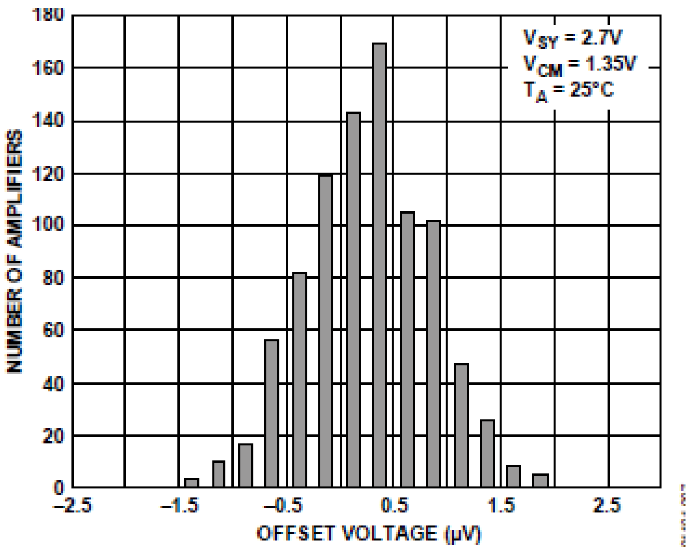


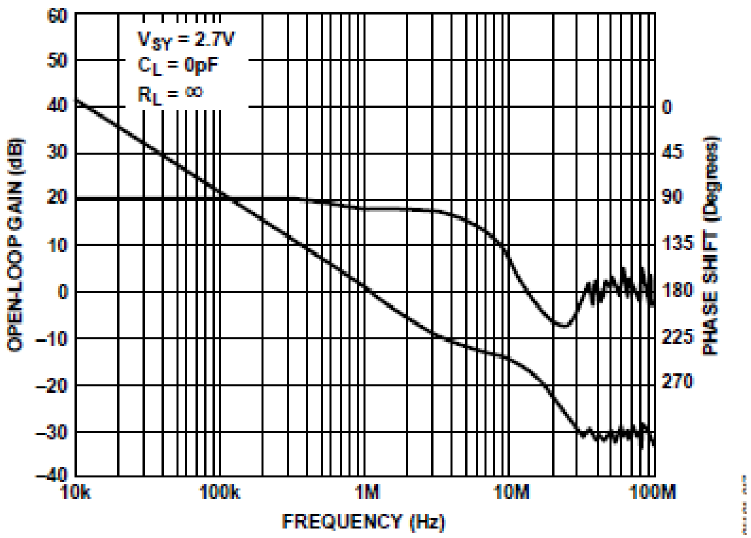
a. Auto-Zero Phase A: null amplifier nulls its own offset.

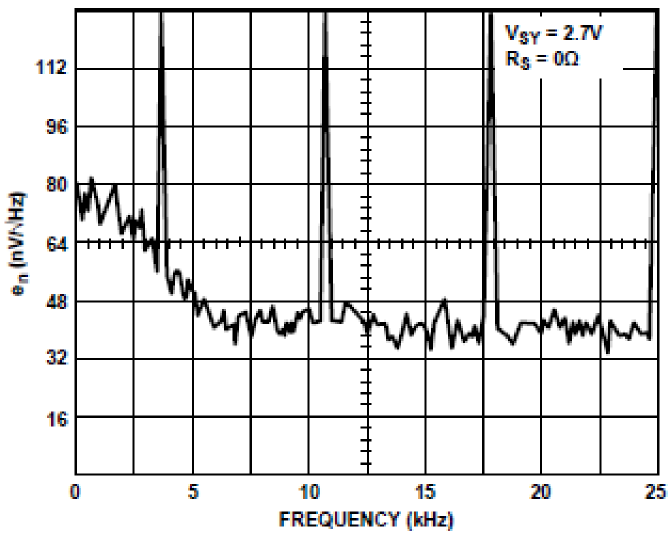


b. Output Phase B: null amplifier nulls the main amplifier offset.

Commercial Zero-Drift Operational Amplifiers based on AZ (AD8551)





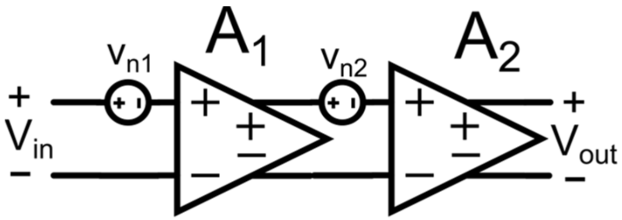


$f_{AZ} = 4$ kHz

Commercial Zero-Drift Operational Amplifiers based on AZ (AD8551, TLC2654, OPA335…)

Parameter	Symbol	Conditions	Min	Typ	Max	Unit
POWER SUPPLY						
Power Supply Rejection Ratio	PSRR	V_S = 2.7 V to 5.5 V	120	130		dB
		−40°C ≤ T_A ≤ +125°C	115	130		dB
Supply Current/Amplifier	I_{SY}	V_O = 0 V		850	975	µA
		−40°C ≤ T_A ≤ +125°C		1000	1075	µA
DYNAMIC PERFORMANCE						
Slew Rate	SR	R_L = 10 kΩ		0.4		V/µs
Overload Recovery Time				0.05	0.3	ms
Gain Bandwidth Product	GBP			1.5		MHz
NOISE PERFORMANCE						
Voltage Noise	e_n p-p	0 Hz to 10 Hz		1.0		µV p-p
	e_n p-p	0 Hz to 1 Hz		0.32		µV p-p
Voltage Noise Density	e_n	f = 1 kHz		42		nV/√Hz
Current Noise Density	i_n	f = 10 Hz		2		fA/√Hz

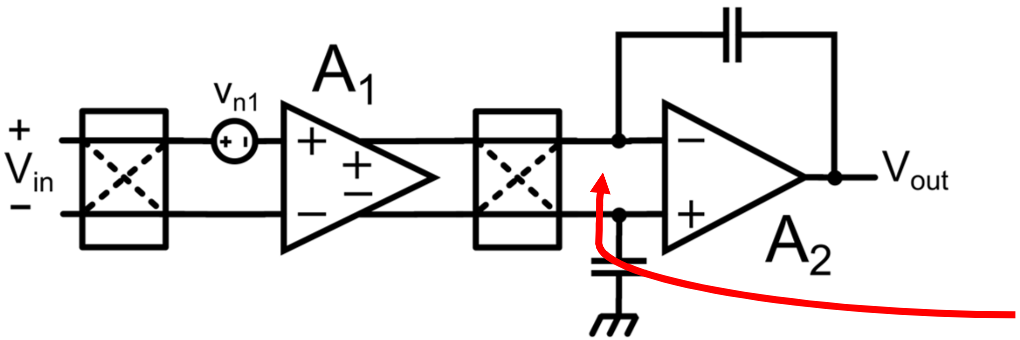
Chopper Amplifier



$$v_{n-out} = A_1 A_2 v_{n1} + A_2 v_{n2}$$

$$v_{n-eff} = v_{n1} + \frac{v_{n2}}{A_1}$$

RTI offset of the second stage is attenuated by A_1

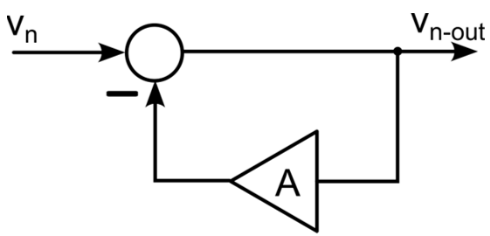


We can apply CHS only to the first stage and use the second stage as 1° order LPF (e.g. Miller Compensation)

Offset ripple is too large to be rejected by a 1° order LPF

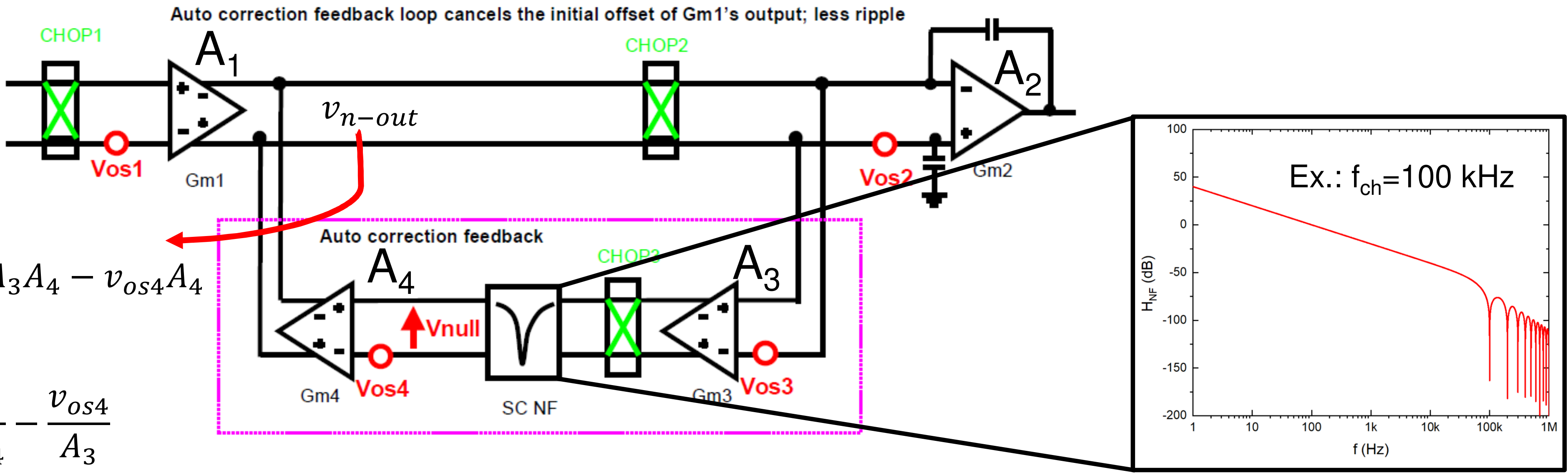
* Y. Jusuda, "Auto Correction Feedback for Ripple Suppression in a Chopper Amplifier" – IEEE JSSC 2010

Auto-Correction Feedback for Ripple Suppression*



$$v_{n-out} = v_n - A v_{n-out} \Rightarrow v_{n-out} = \frac{v_n}{1+A}$$

Amplifier A must be without offset and input signal must not be attenuated!

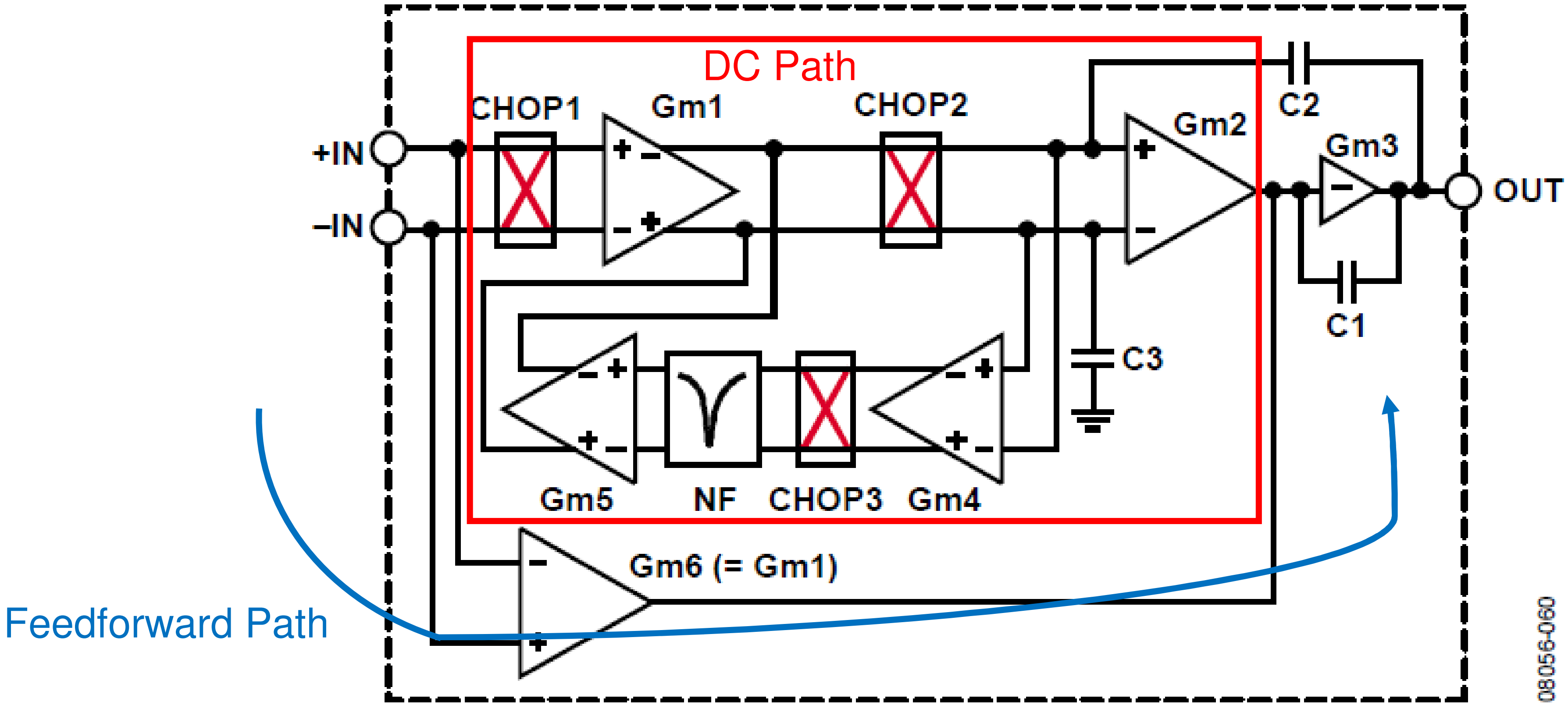


$$v_{n-out} = v_{os1}A_1 - v_{n-out}A_3A_4 - v_{os4}A_4$$

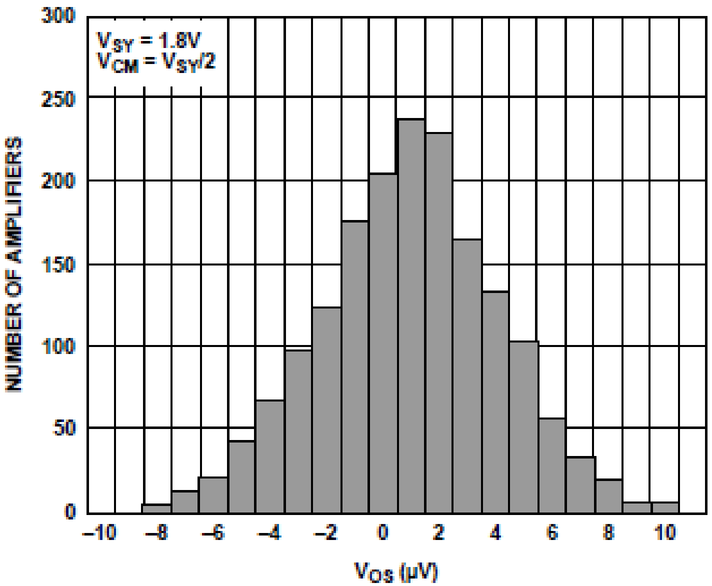
$$v_{n-out} = \frac{v_{os1}A_1}{1 + A_3A_4} - \frac{v_{os4}}{A_3}$$

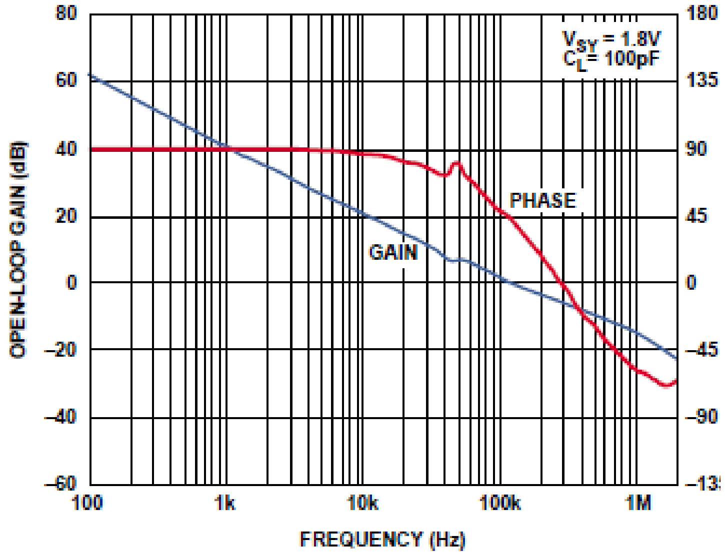
* Y. Jusuda, "Auto Correction Feedback for Ripple Suppression in a Chopper Amplifier" – IEEE JSSC 2010

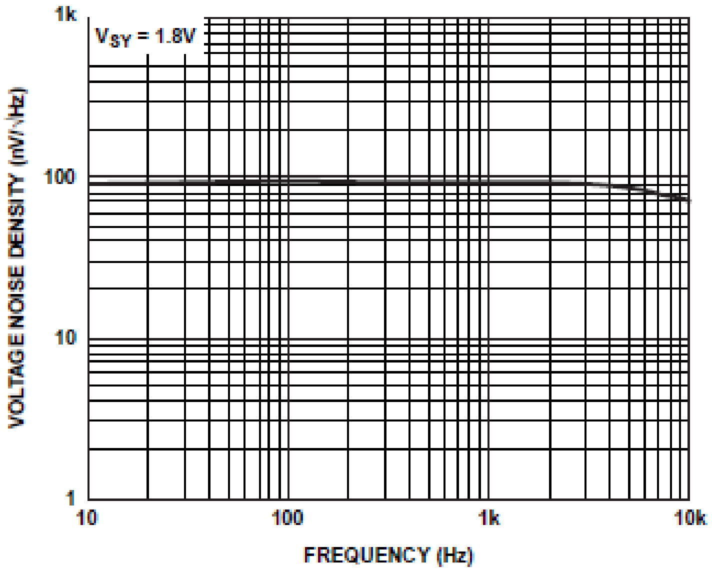
Commercial Zero-Drift Operational Amplifiers based on CHS (ADA4051)



Commercial Zero-Drift Operational Amplifiers based on CHS (ADA4051)







f_{ch} = 40 kHz

Commercial Zero-Drift Operational Amplifiers based on CHS (ADA4051)

Parameter	Symbol	Test Conditions/Comments	Min	Typ	Max	Unit
POWER SUPPLY						
Power Supply Rejection Ratio	PSRR	$1.8\ V \le V_{SY} \le 5.5\ V$	110	135		dB
		$-40°C \le T_A \le +125°C$	106			dB
Supply Current per Amplifier	I_{SY}					
ADA4051-2		$V_{OUT} = V_{SY}/2$		13	17	µA
ADA4051-1		$V_{OUT} = V_{SY}/2$		15	18	µA
		$-40°C \le T_A \le +125°C$			20	µA
DYNAMIC PERFORMANCE						
Slew Rate	SR+	$R_L = 10\ k\Omega$, $C_L = 100\ pF$, $G = 1$		0.04		V/µs
	SR−	$R_L = 10\ k\Omega$, $C_L = 100\ pF$, $G = 1$		0.03		V/µs
Settling Time	t_S	To 0.1%, $V_{IN} = 1\ V$ p-p, $R_L = 10\ k\Omega$, $C_L = 100\ pF$		120		µs
Gain Bandwidth Product	GBP	$C_L = 100\ pF$, $G = 1$		115		kHz
Phase Margin	Φ_M	$C_L = 100\ pF$, $G = 1$		40		Degrees
Channel Separation	CS	$V_{IN} = 1.7\ V$, $f = 100\ Hz$		140		dB
NOISE PERFORMANCE						
Voltage Noise	e_n p-p	$f = 0.1\ Hz$ to $10\ Hz$		1.96		µV p-p
Voltage Noise Density	e_n	$f = 1\ kHz$		95		nV/√Hz
Current Noise Density	i_n	$f = 1\ kHz$		100		fA/√Hz