Contents

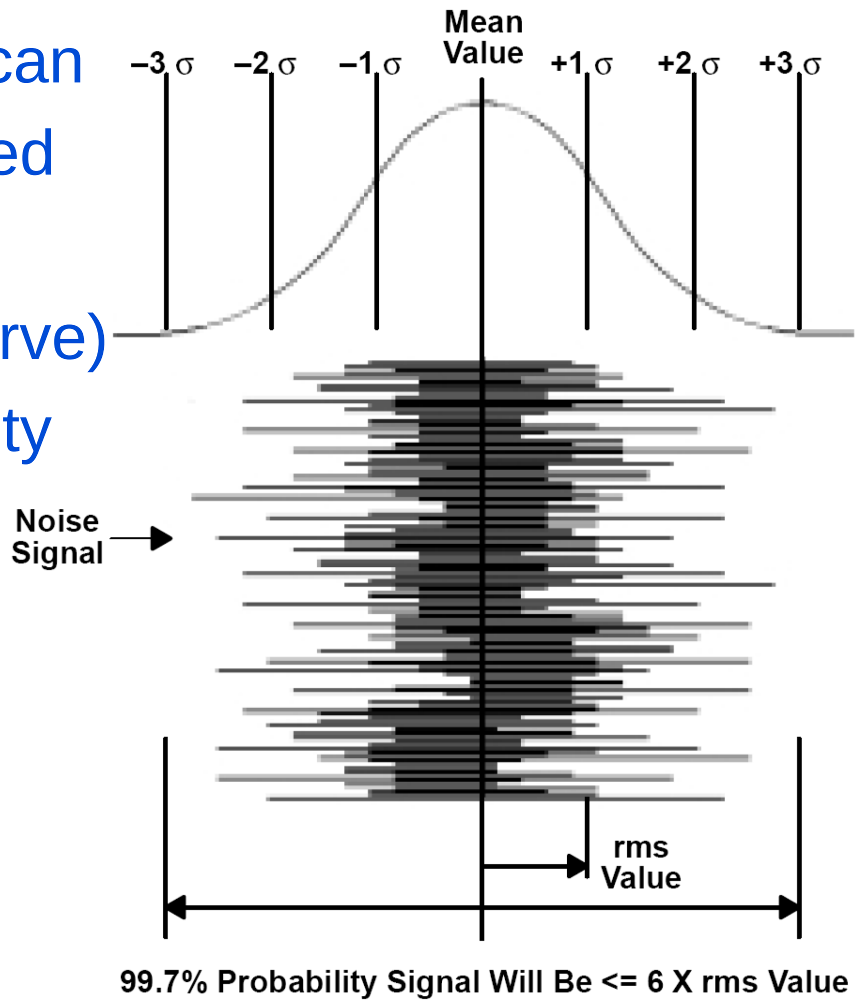
Noise signals

- Are random signals: aperiodic, instantaneous values can never be predicted.
- Can be generated internally in active circuits, e.g. operational amplifiers, in passive components or be injected into a circuit from external sources.
- The signal-to-noise ratio is

$$\frac{S_{(f)}}{N_{(f)}} = \frac{\text{rms signal voltage}}{\text{rms noise voltage}}$$

Noise statistics

- Noise signals can be characterized by histograms (e.g. Gauss curve) or power density spectra (e.g. uniform).



Geometric addition of multiple sources of noise

Independent random signals: rms values do not add linearly but geometrically

$$E_{Totalrms} = \sqrt{e^2_{1rms} + e^2_{2rms} + \ldots e^2_{nrms}}$$

Units of spectral density of noise

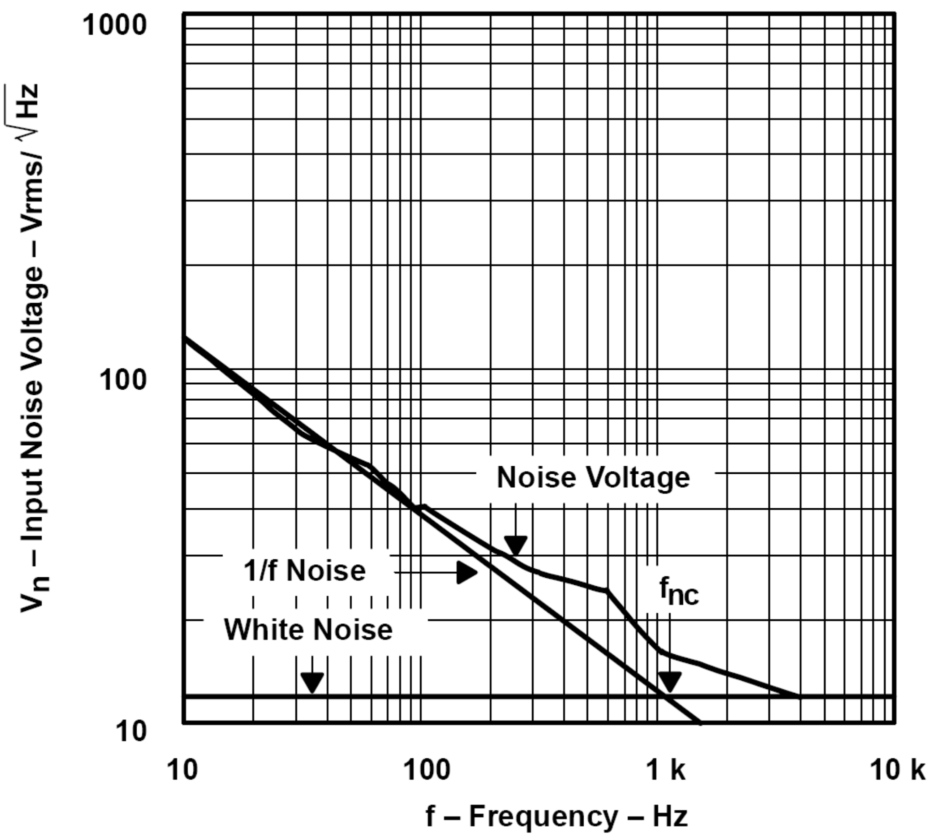
Derived from power spectral density in [V^2/Hz] or [A^2/Hz], referred to a reference resistor (1Ω by default).

$$\frac{V_{rms}}{\sqrt{Hz}} \quad or \quad \frac{A_{rms}}{\sqrt{Hz}}$$

Corner frequency in operational amplifier noise

Here is an example of an input referred voltage noise spectrum:

It can be roughly decomposed in a uniform part above f_{nc}, and a part increasing with 1/rt*f*, below f_{nc}.



Low frequency 1/f power spectral density is measured with many natural signals, in particular temperature, and in all semiconductors.

Attention: Total power diverges, which is a paradox.

Noise corner frequency

If datasheet curves are not in logarithmic scale or corner is not pronounced, determine f_{nc}

Example :

For the TLV2772, the figure shows a noise density of $130\frac{\text{nV}}{\sqrt{\text{Hz}}}$ at 10Hz.

The datasheet of the TLV2772 shows a white noise density of $12\frac{\text{nV}}{\sqrt{\text{Hz}}}$.

On the 1/f noise power curve the product frequency x noise power density is constant:

$$\left[\left(\frac{130\text{nV}}{\sqrt{\text{Hz}}}\right)^2 - \left(\frac{12\text{nV}}{\sqrt{\text{Hz}}}\right)^2\right]\cdot 10\text{Hz} = 167560(\text{nV})^2$$

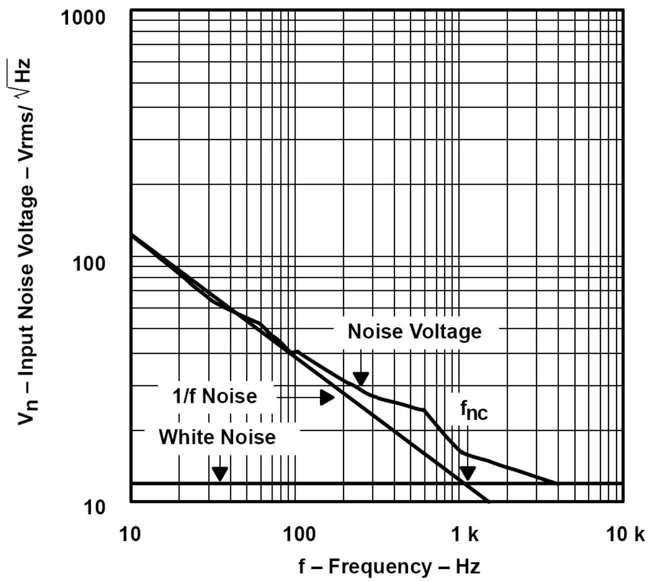
At f_{nc}, the 1/f noise power density is 12nV/rtHz:

$$\frac{167560(\text{nV})^2}{\left(\frac{12\text{nV}}{\sqrt{\text{Hz}}}\right)^2} = 1164\,\text{Hz}$$

Total bandwidth limited noise

Determine the total noise within a given bandwidth, e.g. 10Hz…10kHz

Method: Noise voltage is root of noise power. First integrate power, then determine voltage.

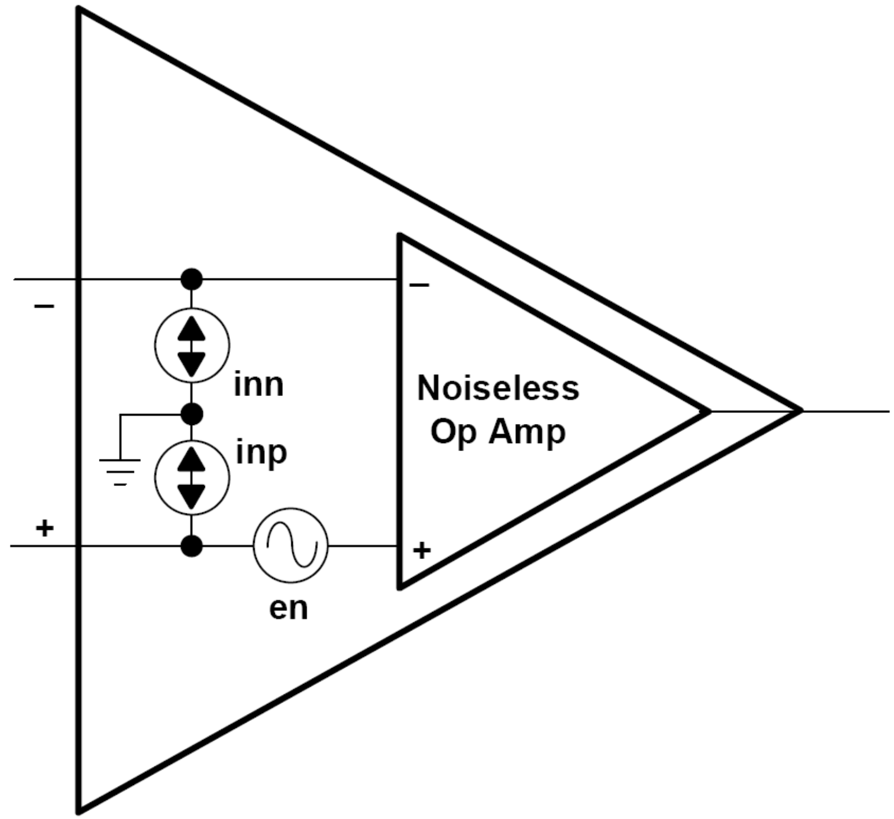


$$E_n = E_{whitenoise} \cdot \sqrt{f_{nc} \cdot \ln\left(\frac{f_{max}}{f_{min}}\right) + (f_{max} - f_{min})}$$

$$E_n = \frac{12\text{nV}}{\sqrt{\text{Hz}}} \cdot \sqrt{1164\text{Hz} \cdot \ln\left(\frac{10^4\,\text{Hz}}{10\text{Hz}}\right) + (10^4\,\text{Hz} - 10\text{Hz})} = 1.61\mu\text{V} = -116\text{dBV}$$

Operational amplifier input referred noise

Noise sources are added to ideal operational amplifier like bias and offset sources at the inputs.
The effect on the output is computed in analogy to that of bias and offset sources, using superposition.



Attention: Superposition of different noise contributions will be geometric.

Exercice
Noise performance data of OP37

Search for noise performance data in the OP37 datasheet.

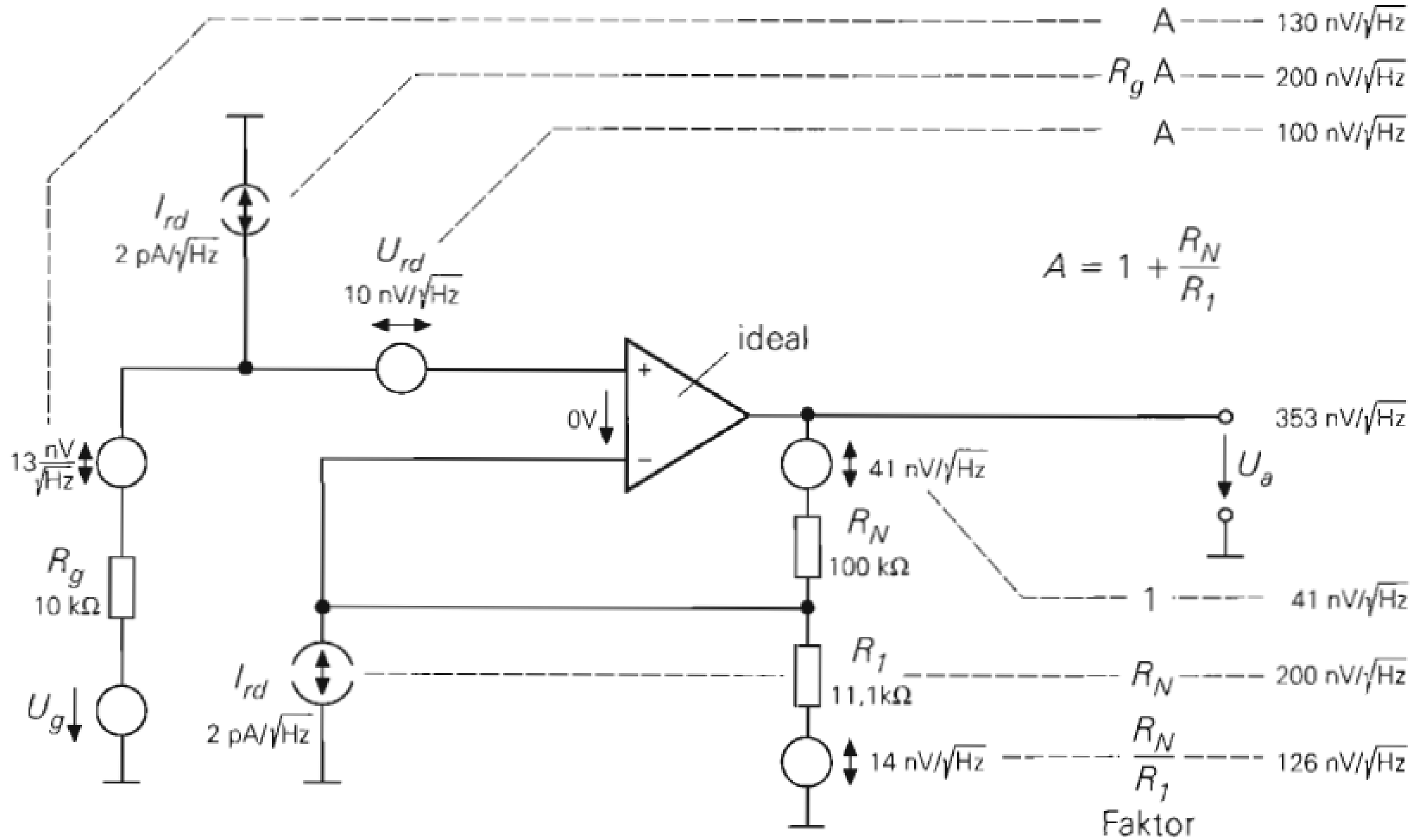
Determine the corner frequencies of voltage and current noise. At which input resistance will voltage and current white noise levels generate equivalent contributions at the output ?

How high will the output noise then be ?

What will the noise corner frequency in this case become ?

Noise sources in a non-inverting amplifier

741 class example:

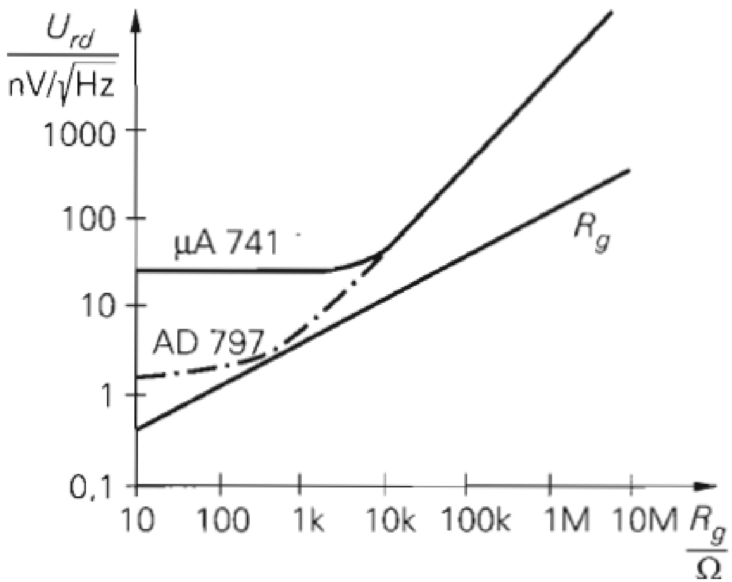


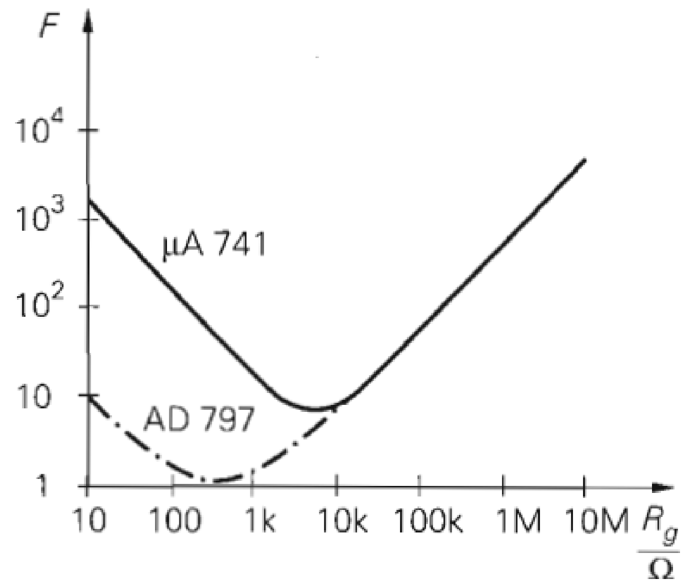
Resistor noise: $U_R = \sqrt{4\,k\,T\,R\left(f_{\max} - f_{\min}\right)}$ k = 1.38·10^{-23}J/K Boltzmann constant

Noise voltage and noise number

$$F = \left(\frac{\text{Noise voltage at real amplifier output}}{\text{Noise voltage at ideal amplifier output}} \right)^2$$

Function of source resistance:

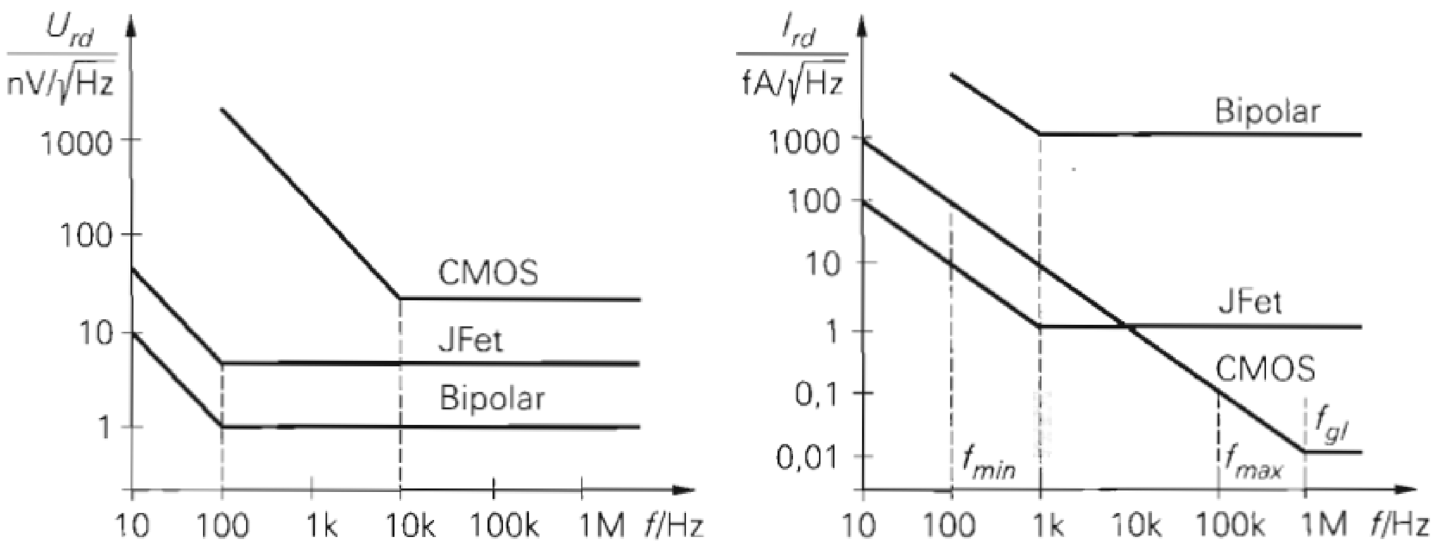




At low R_g, amplifier input referred voltage noise dominates, at high R_g current noise.

Voltage and current noise performances

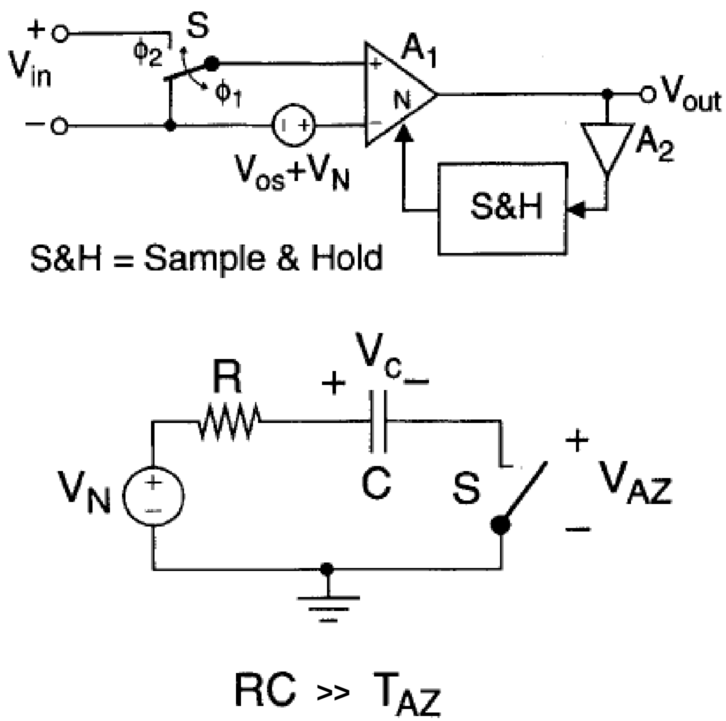
CMOS circuits tend to have less current but more voltage noise.
CMOS circuits also tend to have higher noise corner frequencies.

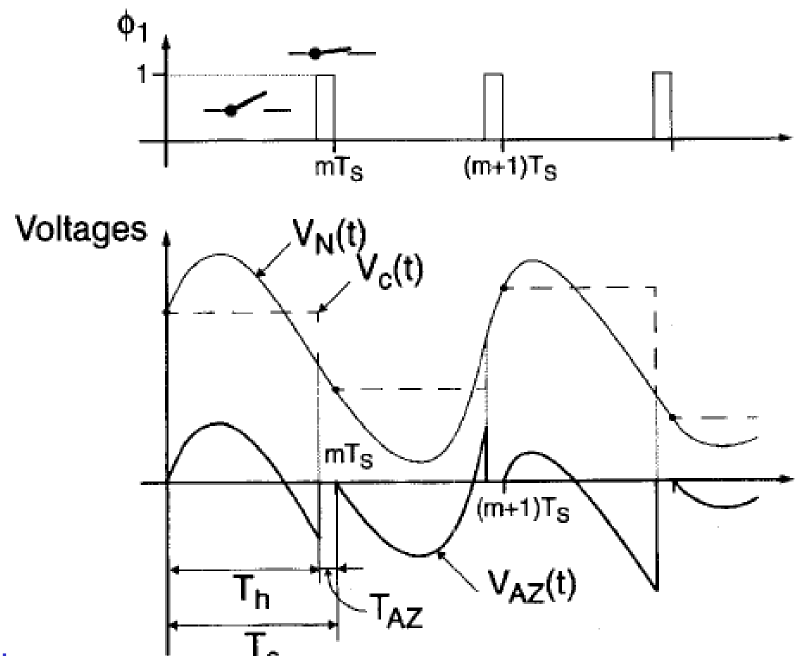


Recall: n(ano) = 10^{-9}, p(ico) = 10^{-12}, f(emto) = 10^{-15}, a(to) = 10^{-18}.

Auto-zero principle

Cancel low frequency noise density increase by auto-measurement of the offset = low frequency noise.
Then subtract measured offset from input.





Usually the measured offset is stored on a capacitor.

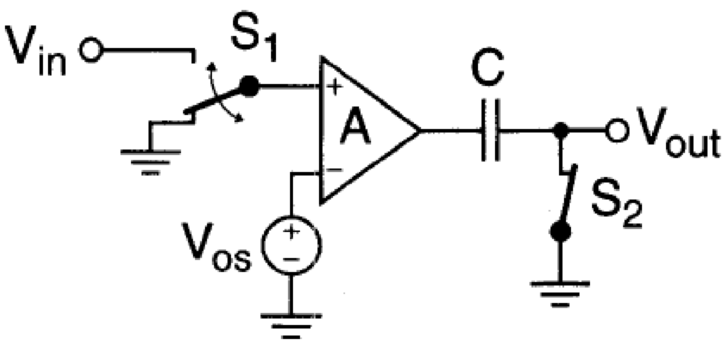
Its discharge must be much slower than the offset mesurement period.

(a) (b)

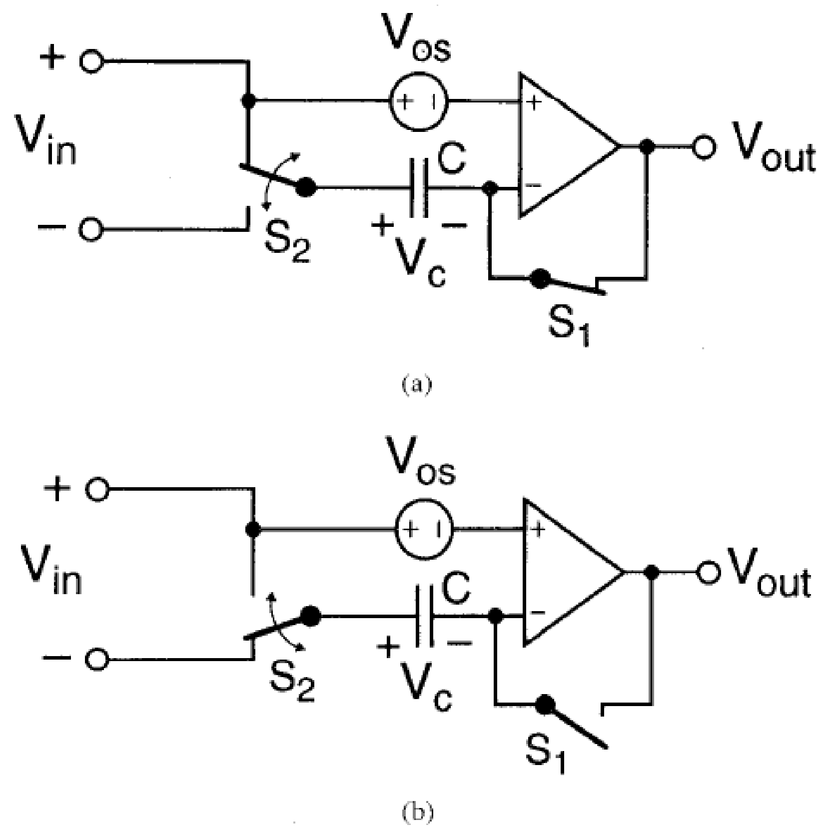
(a) Basic AZ circuit and autozeroed signal: (b) shows voltages in (a).

Auto-zero circuits

Open-loop cancellation



Closed-loop cancellation

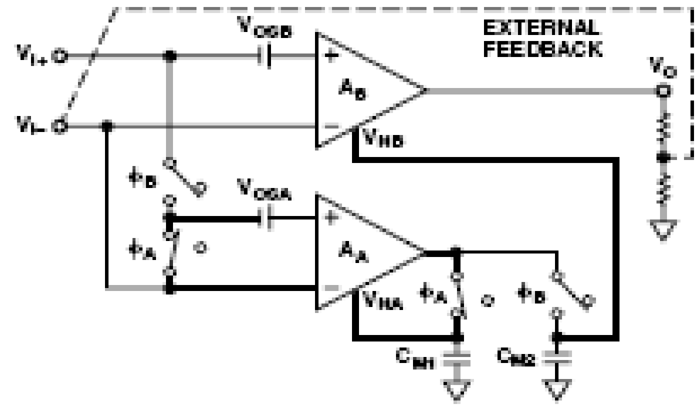


Closed-loop-amplifier offset cancellation principle: (a) offset sampling phase (AZ) and (b) amplification phase.

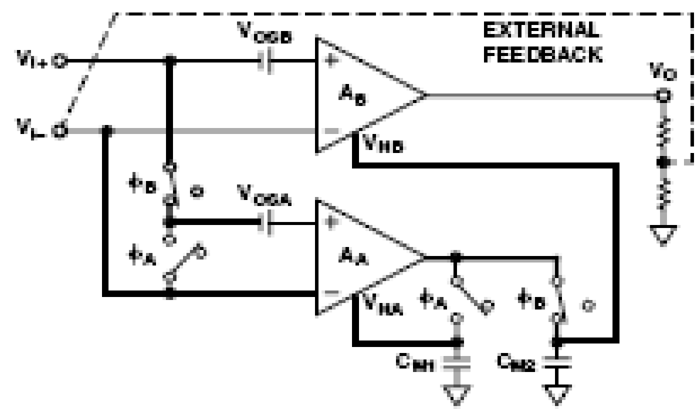
In closed-loop cancellation, the offset is stored on a floating capacitor which is more precise in switched capacitor circuits.

Auto-zero circuit with two amplifiers

The drawback of auto-zeroing is that during the measurement, the principal function of the circuit is not operating.
Two parallel amplifier stages avoid this problem:
The null amplifier measures 'on-line' the main amplifier offset.



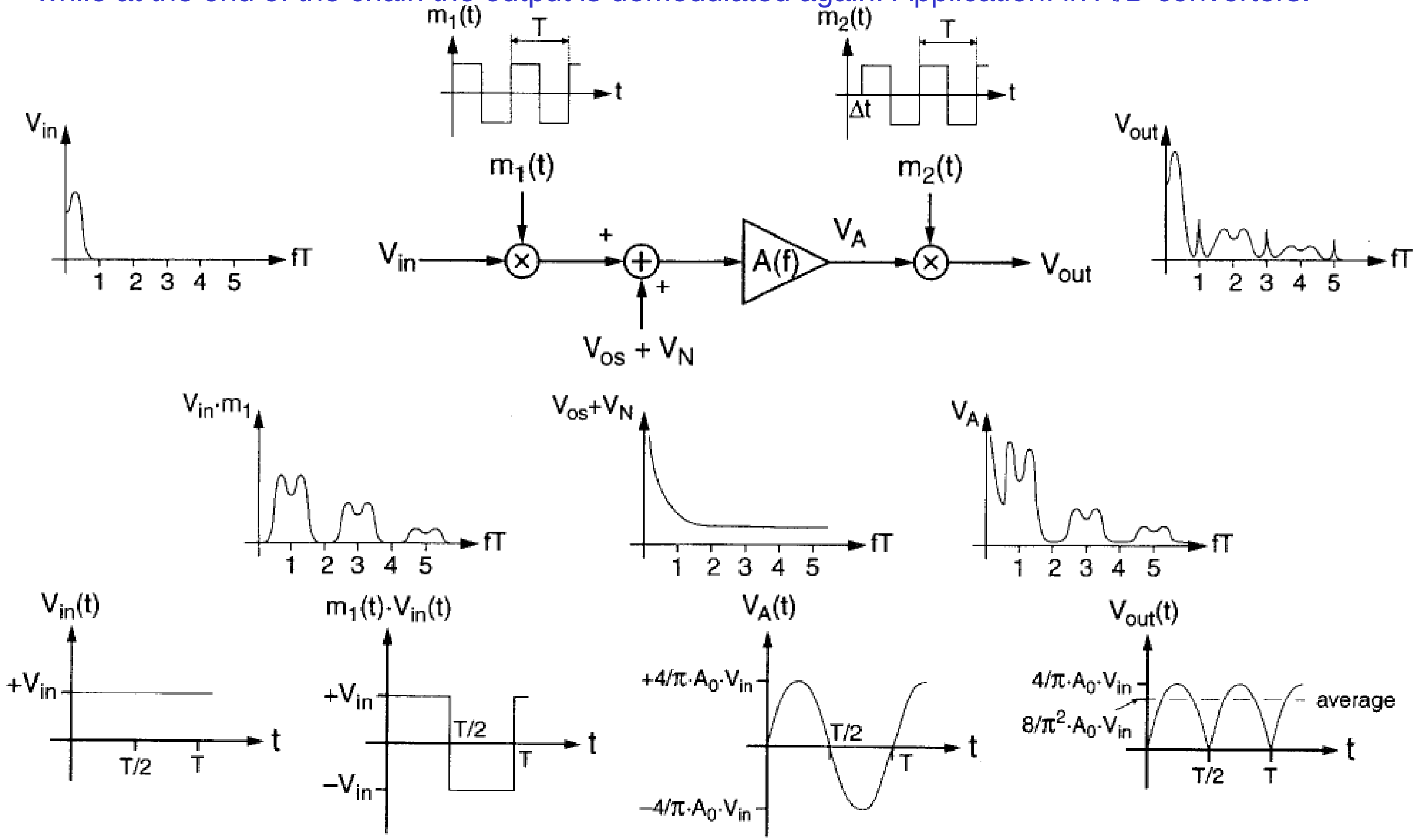
a. Auto-Zero Phase A: null amplifier nulls its own offset.



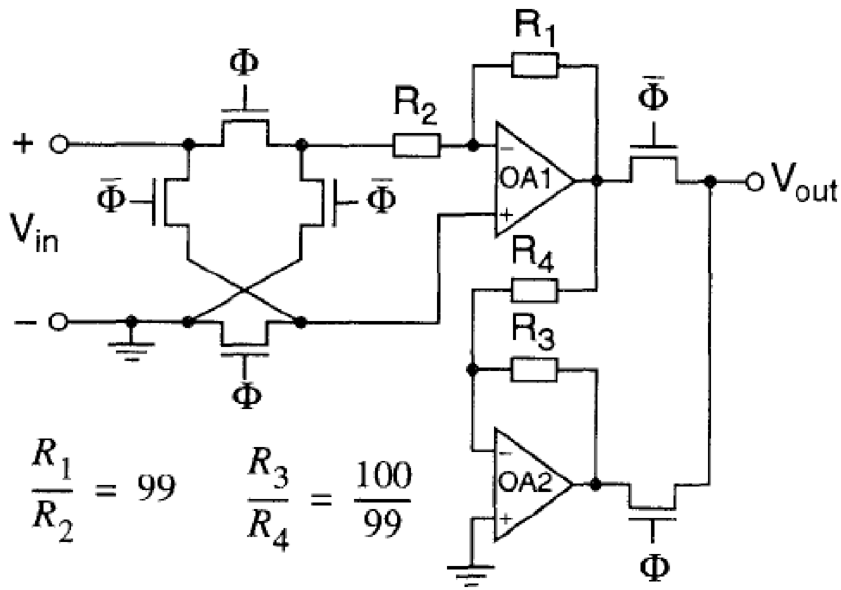
b. Output Phase B: null amplifier nulls the main amplifier offset.

Chopper amplifier principle

Correlated double sampling: The input signal is frequency shifted (modulated),
while at the end of the chain the output is demodulated again. Application: in A/D converters.



Chopper amplifier circuit

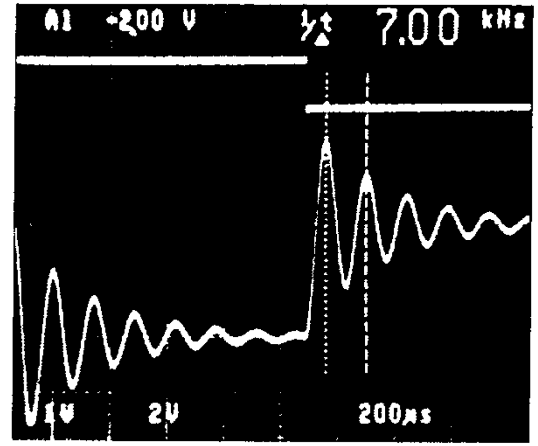


$$\frac{R_1}{R_2} = 99 \qquad \frac{R_3}{R_4} = \frac{100}{99}$$

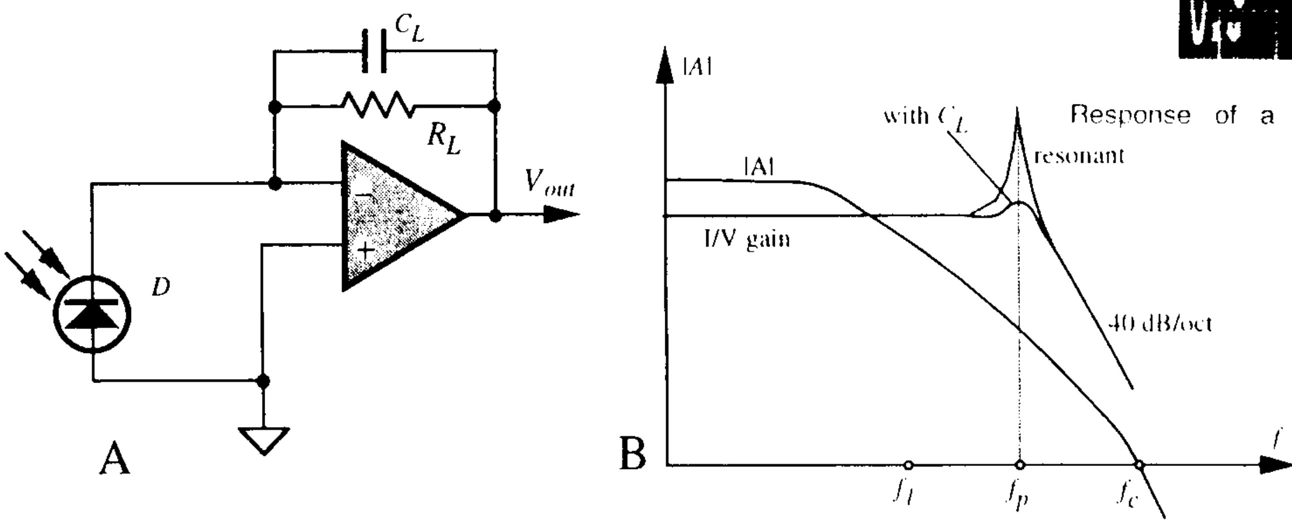
Chopper amplifier switches are generally FETs.
The technique lends itself to use in MOS-FET circuits.
Only two synchronous clocks are used, of opposite phases and with no overlapping.

Exercice:
Noise floor of photodiode current to voltage converter

Determine the transfer function of the circuit below with and without the feedback capacitor C_L.
Explain the improvement realized with C_L.



Response of a photodiode with uncompensated circuit.



Use of current-to-voltage converter (A) and the frequency characteristics (B).

Determine the output noise voltage noise density spectrum for an OP37 amplifier, BPW34 photodiode, R_L = 100kΩ, C_L such that Q = 1.

Exercice:
TIA bandwidth extension

Consider the datasheets of OP470 (VV type) amplifier and 2N4393 FET transistors.

How can a standard VV amplifier be used in TIA configuration?

Propose a discrete difference amplifier stage in front of the operational amplifier.
The differential pair shall be connected in common source configuration.

Estimate the bandwidth of the circuit without and with
the discrete difference amplifier.
The feedback impedance is 3.3pF in parallel with 5.6MΩ. Suppose $I_{DS0} = 0.1\text{mA}$

Determine the noise floor spectrum at the output for a drain impedance
of first 1kΩ and then of 1MΩ.

Stabilization of capacitive load

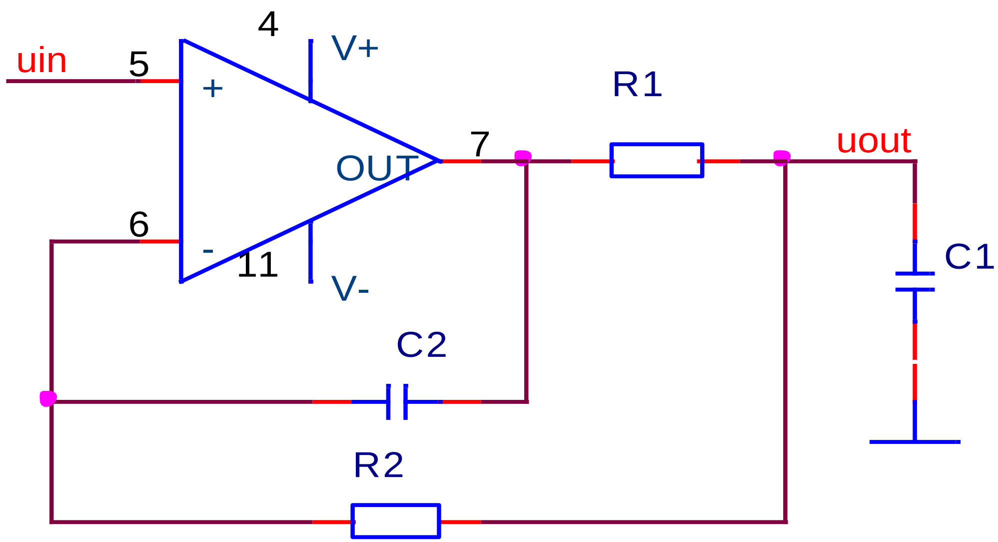
The following circuit represents a voltage follower driving a capacitive load.

Determine its transfer function without and with R1, R2, C2. Use a first order model for the operational amplifier.

What is the use of R2 ?

Suppose an OP37 operational amplifier, and C1= 100nF.

Propose values for R1, R2 and C2, so as to make sure that the amplifier has Q = 1. What bandwidth can be achieved?



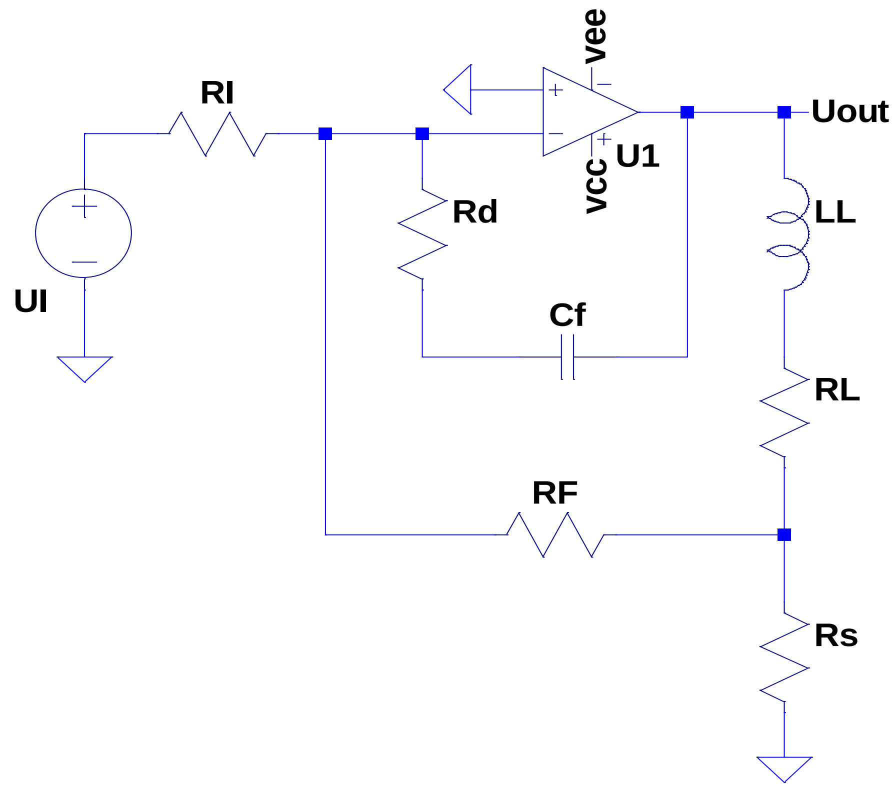
Stabilization of inductive load

The following circuit is a current source driving a voice coil.

Determine its transfer function with and without Rd, Cf. Suppose that all the load current circulates through Rs.

Suppose a PA07 power amplifier, and LL = 159mH, RL = 10Ω, Rs = 1Ω, RI = 5kΩ, RF = 1kΩ.

Propose values for Rd and Cf, so that the amplifier has Q = 1.



Books

Tietze, Schenk: *Halbleiter-Schaltungstechnik*, Springer 2012 (14th ed.), ISBN 3-540-64192-0

Millman: *Microelectronics: Digital and Analog Circuits and Systems*, McGraw-Hill 1984, ISBN 0-07-066410-2

Chatelain, Dessoulavy: *Electronique* , Traité d'électricité: vol VIII, PPUR 1982, ISBN 2-604-00010-5

Gray, Meyer: *Analysis and Design of Analog Integrated Circuits*, Wiley 1984 (2nd ed.), ISBN 0-471-81454-7

Jung: *OpAmp Application Handbook*, Analog Devices 2005, ISBN 0-750-67844-5

Mancini: *OpAmps for everyone*, Texas Instruments 2002