Electronics in (some) particle detectors

https://en.wikipedia.org/wiki/Charge_amplifier

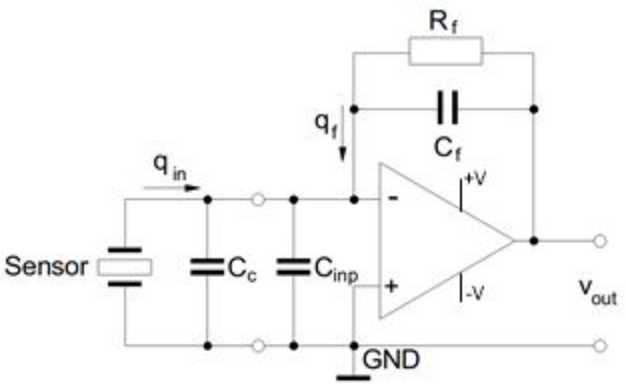
Reminder: HPGe and Charge amplifier

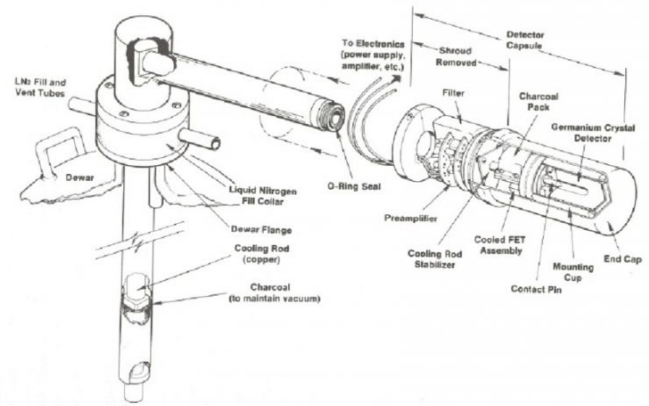
- Detector design is often integrated with readouts
- Charge detector:
  - Collecting charge on its capacitance
  - Amplifying via “charge amplifier”
  - Discharge via feedback resistor

$$q_{in} = q_f$$

$$V_{out} = q_f / C_f = q_{in} / C_f$$

    Decay time: R_f*C_f
- Detector capacitance critical for noise
  - Voltage noise (v_n) amplified by C_{in}/C_f

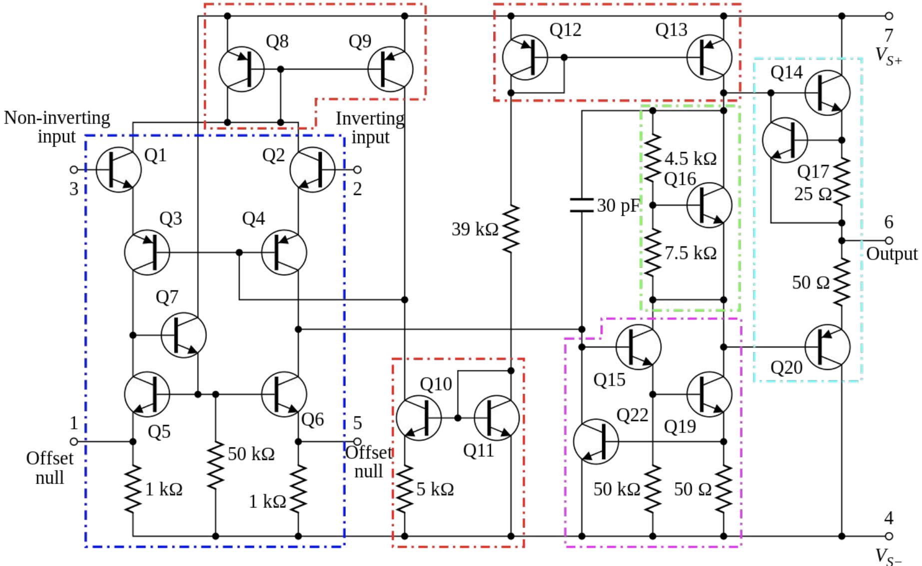




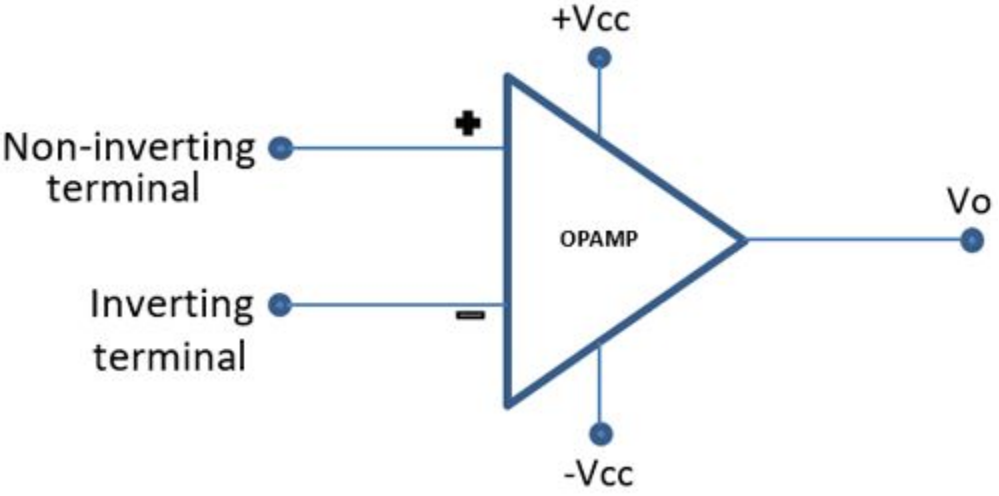
Operational Amplifiers

Operational amplifiers ("op amps") are probably the most important active components in analog electronic circuits. These integrated circuits have a complex internal structure, but their ideal operation is relatively simple.

Circuit diagram for the LM741 op-amp internal structure. - 20 transistors, 11 resistors, 1 capacitor. (Credit: Wikipedia)

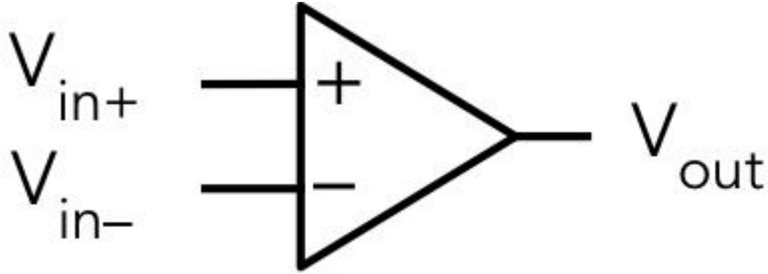


Op-amp



Op-amp symbol

Ideal Op-amp



An ideal op-amp is a voltage source that supplies an output voltage

$$V_{out} = A_{open} (V_{in+} - V_{in-})$$

where A_{open} is the “open-loop” gain without feedback

- Infinite **gain**
- Infinite **input impedance**, so the input draw no current
- Zero **output impedance**, so the output can supply infinite current

For an op-amp in a closed loop with feedback, the output adjusts itself to make the voltage difference between the inputs zero.

Input and Output Impedance

- The **input impedance** of a circuit is the ratio of input voltage to input current:

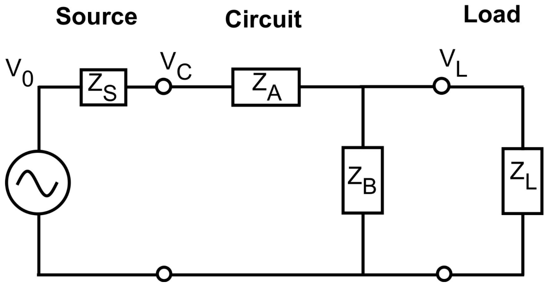
$$Z_{in} = \frac{V_{in}}{I_{in}}$$

  - To evaluate this for an isolated circuit, assume that its output is open (i.e. connected to infinite impedance).
- The output impedance of a circuit is the ratio of output voltage to output current:

$$Z_{out} = \frac{V_{out}}{I_{out}}$$

  - To evaluate this for an isolated circuit, assume that its output is short-circuited.

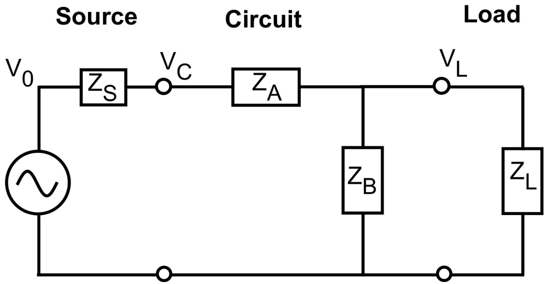
Input/Output Impedance example



A Source producing a signal that passes through a Circuit that delivers it to a Load that can be another circuit or instrument.

- Output impedance ("internal resistance") of the Source is Z_S.
    - Max current that could flow out of the Source is V_0/Z_S, which would happen if Z_A=Z_B=Z_L=0
- Input impedance of the Circuit is $Z_A + Z_B$.
    - Max current that could flow into the Circuit if $Z_L = \infty$ is $V_C/(Z_A + Z_B)$.
- Output impedance of the Circuit is Z_A.
    - Maximum current out of the Circuit is V_C/Z_A, if $Z_L = 0$.
- Input impedance of the Load is Z_L.
    - Maximum current that could flow into the Load is V_L/Z_L.

Input/Output Impedance example



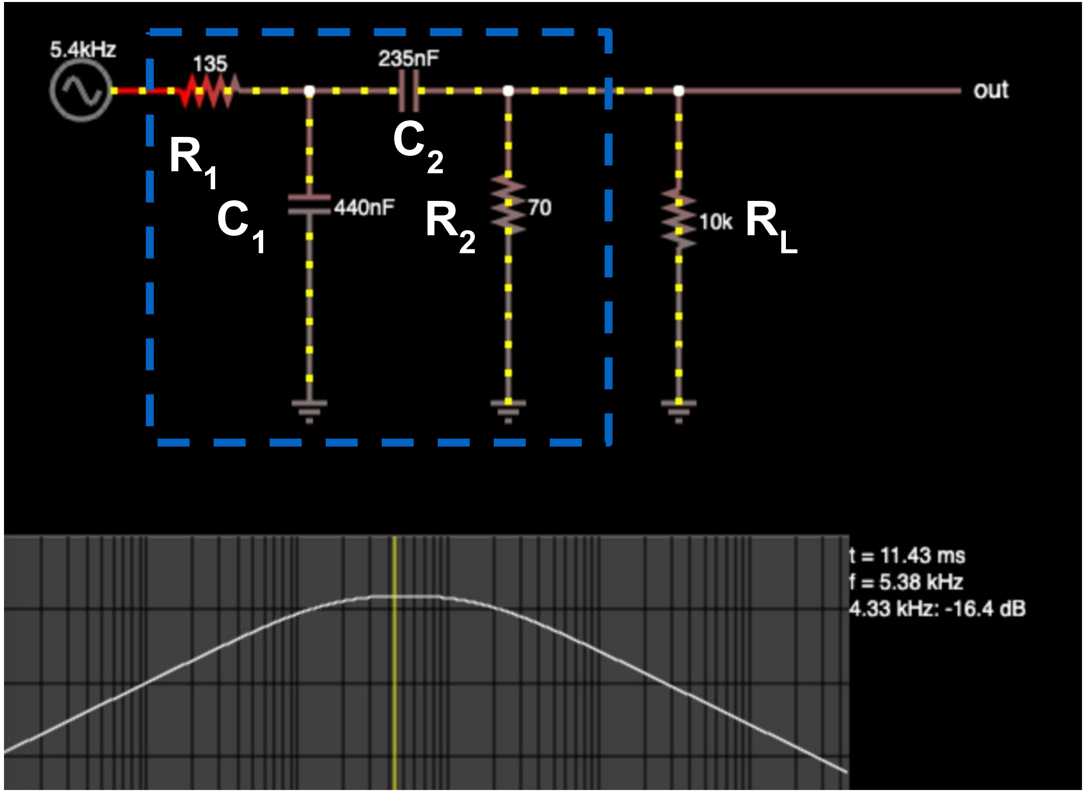
A Source producing a signal that passes through a Circuit that delivers it to a Load that can be another circuit or instrument.

- If Z_L is infinite, the ratio of output to input voltage for a circuit is

$$\frac{V_{out}}{V_{in}} = 1 - \frac{Z_{out}}{Z_{in}}$$

- Filters are circuits whose input and output impedances have different frequency dependencies

Band pass filter impedances



$$\frac{V_{out}}{V_{in}} = 1 - \frac{Z_{out}}{Z_{in}}$$

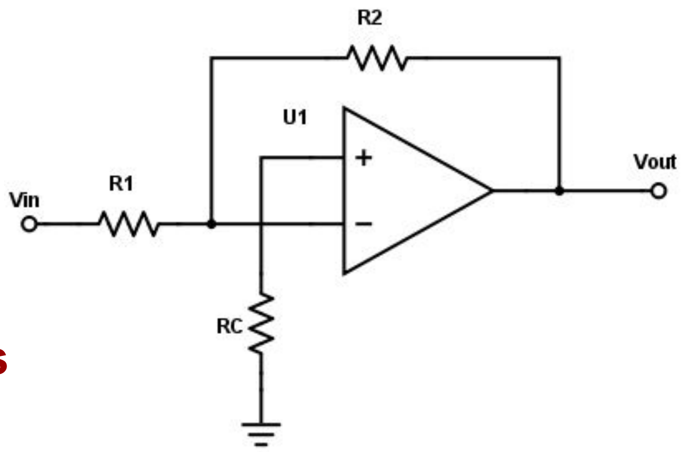
$$Z_{in} = R1 + C1//(C2 + R2)$$

$$Z_{out} = R1 + C1//(C2)$$

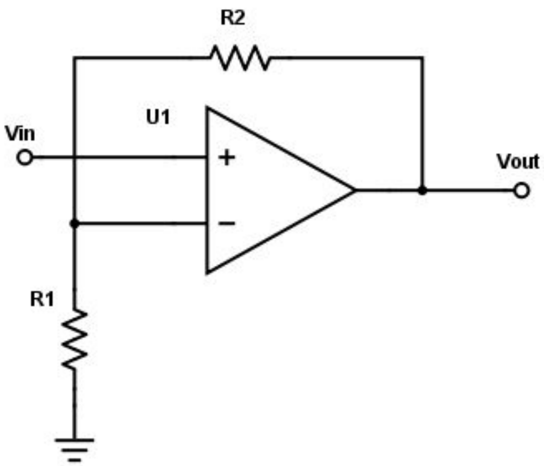
Ideal Op-amp working rules

https://www.allaboutcircuits.com/tools/non-inverting-op-amp-resistor-calculator/

1. **V+ = V-**
2. **No current flows through op-amp**



Inverting Op-amp

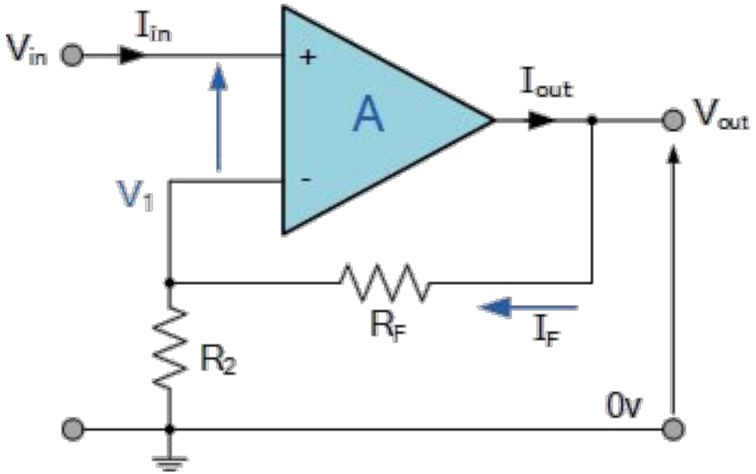


Non-inverting Op-amp

https://www.electronics-tutorials.ws/category/opamp

Non-inverting Amplifier

1. **V+ = V-**
2. **No current flows through op-amp**



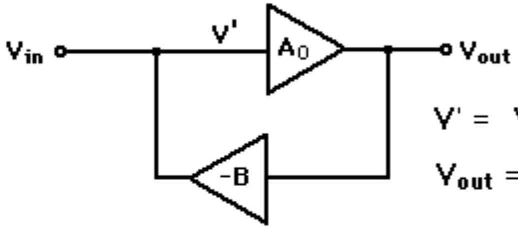
$$V_{in} = V_+ = V_-$$
$$I_{in} = 0$$
$$I_{out} = 0$$
$$I_- = 0$$
$$I_F = I_2$$
$$V_- = I_F * R_2$$
$$V_{out} = I_F * (R_F + R_2)$$

$$\frac{V_{out}}{V_{in}} = \frac{R_F + R_2}{R2}$$
$$\frac{V_{out}}{V_{in}} = 1 + \frac{R_F}{R2}$$

Input and output impedances?

Ideal vs realistic op-amps

- Infinite gain
  - Real op-amps typically have A_{open} ~ $10^5 - 10^6$
- Infinite input impedance, so the inputs draw no current
  - Real op-amps have Z_{input} ~ $10^6 - 10^{12}\ \Omega$
  - their inputs draw I_{input} ~ $10^{-9} - 10^{-12}\ A$
- Zero output impedance, so the output can supply infinite current
  - Real op-amps have Z_{output} ~ $10 - 1000\ \Omega$
- Realistic modeling of feedback



$$V' = V_{in} - BV_{out}$$

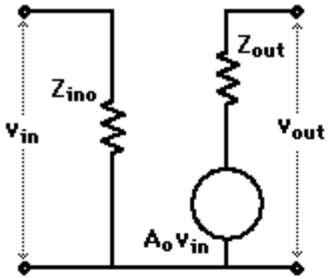
$$V_{out} = A_0 V'$$

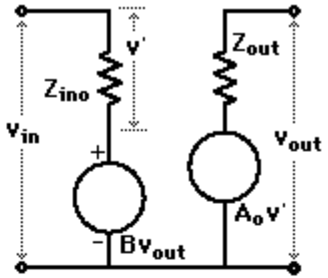
Substituting: $V_{out} = A_0(V_{in} - BV_{out})$

$$V_{out}[1 + A_0 B] = A_0 V_{in}$$

$$A_f = \frac{V_{out}}{V_{in}} = \frac{A_0}{1 + A_0 B} \approx \frac{1}{B}$$

Input/Output impedance in realistic Non-inverting amplifier





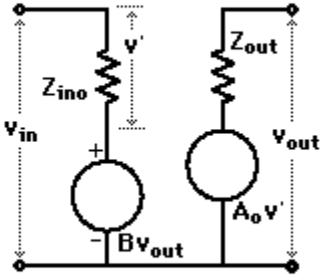
Using the gain expression $v_{out} = v_{in}\dfrac{A_o}{1+A_oB}$ gives $i_{in} = \dfrac{v_{in}\left[1 - \dfrac{BA_o}{1+A_oB}\right]}{Z_{ino}}$

so the effective impedance is $Z_{inf} = \dfrac{v_{in}}{i_{in}} = (1 + A_oB)Z_{ino}$

$$Z_{outf} = \frac{v_{out}}{i_{out}} = \frac{A_o v' - i_{out}Z_{out}}{i_{out}}$$

$$= \frac{A_o(v_{in} - Bv_{out}) - i_{out}Z_{out}}{i_{out}}$$

This gives $v_{out} = \dfrac{A_o v_{in} - i_{out}Z_{out}}{1 + A_oB}$

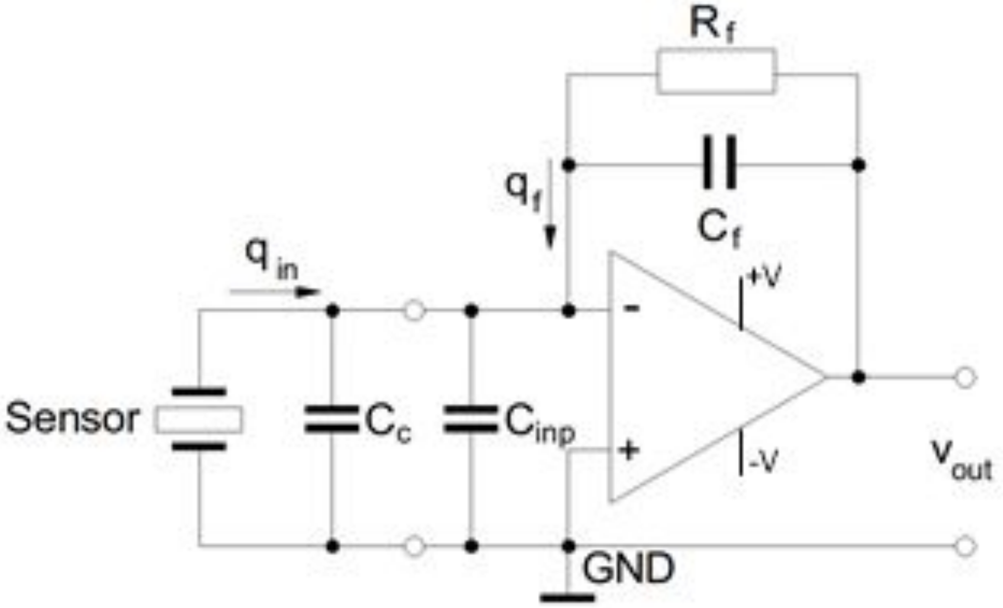


$$Z_{outf} = -\frac{\partial v_{out}}{\partial i_{out}} = \frac{Z_{out}}{1 + A_oB}$$

This decreases the impedance by a factor of 10 to 100 in transistor circuits and to practically zero in op-amps.

https://en.wikipedia.org/wiki/Charge_amplifier

Coming back to Charge amplifier



- Inverting amplifier

$$q_{in} = q_f$$
$$V_{out} = q_f / C_f = q_{in} / C_f$$

- Near zero input impedance
- Discharge via feedback resistor

  Decay time: R_f*C_f

Not all op-amps are the same…

ANALOG DEVICES

Ultralow Distortion, Ultralow Noise Op Amp

Data Sheet **AD797**

FEATURES

Low noise
0.9 nV/√Hz typical (1.2 nV/√Hz maximum) input voltage noise at 1 kHz
50 nV p-p input voltage noise, 0.1 Hz to 10 Hz
Low distortion
−120 dB total harmonic distortion at 20 kHz
Excellent ac characteristics
800 ns settling time to 16 bits (10 V step)
110 MHz gain bandwidth (G = 1000)
8 MHz bandwidth (G = 10)
280 kHz full power bandwidth at 20 V p-p
20 V/μs slew rate
Excellent dc precision
80 μV maximum input offset voltage
1.0 μV/°C V_{OS} drift
Specified for ±5 V and ±15 V power supplies
High output drive current of 50 mA

APPLICATIONS

Professional audio preamplifiers
IR, CCD, and sonar imaging systems
Spectrum analyzers
Ultrasound preamplifiers
Seismic detectors
Σ-Δ ADC/DAC buffers

GENERAL DESCRIPTION

The AD797 is a very low noise, low distortion operational amplifier ideal for use as a preamplifier. The low noise of 0.9 nV/√Hz and low total harmonic distortion of −120 dB in audio bandwidths give the AD797 the wide dynamic range necessary for preamps in microphones and mixing consoles.

Furthermore, the AD797 has an excellent slew rate of 20 V/μs and a 110 MHz gain bandwidth, which makes it highly suitable for low frequency ultrasound applications.

The AD797 is also useful in infrared (IR) and sonar imaging applications, where the widest dynamic range is necessary. The low distortion and 16-bit settling time of the AD797 make it ideal for buffering the inputs to Σ-Δ ADCs or the outputs of high resolution DACs, especially when the device is used in critical applications such as seismic detection or in spectrum analyzers. Key features such as a 50 mA output current drive and the specified power supply voltage range of ±5 V to ±15 V make the AD797 an excellent general-purpose amplifier.

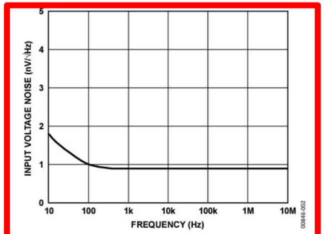


Figure 1. AD797 Voltage Noise Spectral Density

Parameter	Conditions	Supply Voltage (V)	AD797A Min	AD797A Typ	AD797A Max	AD797B Min	AD797B Typ	AD797B Max	Unit
INPUT CHARACTERISTICS									
Input Resistance									
Differential				7.5			7.5		kΩ
Common Mode				100			100		MΩ
Input Capacitance									
Differential[4]				20			20		pF
Common Mode				5			5		pF
OUTPUT RESISTANCE	$A_V = 1$, f = 1 kHz			3				3	mΩ

TEXAS INSTRUMENTS

LF155, LF156, LF256, LF257
LF355, LF356, LF357

SNOSBH0D – MAY 2000 – REVISED NOVEMBER 2015

LFx5x JFET Input Operational Amplifiers

1 Features

- Advantages
  - Replace Expensive Hybrid and Module FET Op Amps
  - Rugged JFETs Allow Blow-Out Free Handling Compared With MOSFET Input Devices
  - Excellent for Low Noise Applications Using Either High or Low Source Impedance—Very Low 1/f Corner
  - Offset Adjust Does Not Degrade Drift or Common-Mode Rejection as in Most Monolithic Amplifiers
  - New Output Stage Allows Use of Large Capacitive Loads (5,000 pF) Without Stability Problems
  - Internal Compensation and Large Differential Input Voltage Capability
- Common Features
  - Low Input Bias Current: 30 pA
  - Low Input Offset Current: 3 pA
  - High Input Impedance: 10^{12} Ω
  - Low Input Noise Current: 0.01 pA/√Hz
  - High Common-Mode Rejection Ratio: 100 dB
  - Large DC Voltage Gain: 106 dB

2 Applications

- Precision High-Speed Integrators
- Fast D/A and A/D Converters
- High Impedance Buffers
- Wideband, Low Noise, Low Drift Amplifiers
- Logarithmic Amplifiers
- Photocell Amplifiers
- Sample and Hold Circuits

3 Description

The LFx5x devices are the first monolithic JFET input operational amplifiers to incorporate well-matched, high-voltage JFETs on the same chip with standard bipolar transistors (BI-FET™ Technology). These amplifiers feature low input bias and offset currents/low offset voltage and offset voltage drift, coupled with offset adjust, which does not degrade drift or common-mode rejection. The devices are also designed for high slew rate, wide bandwidth, extremely fast settling time, low voltage and current noise and a low 1/f noise corner.

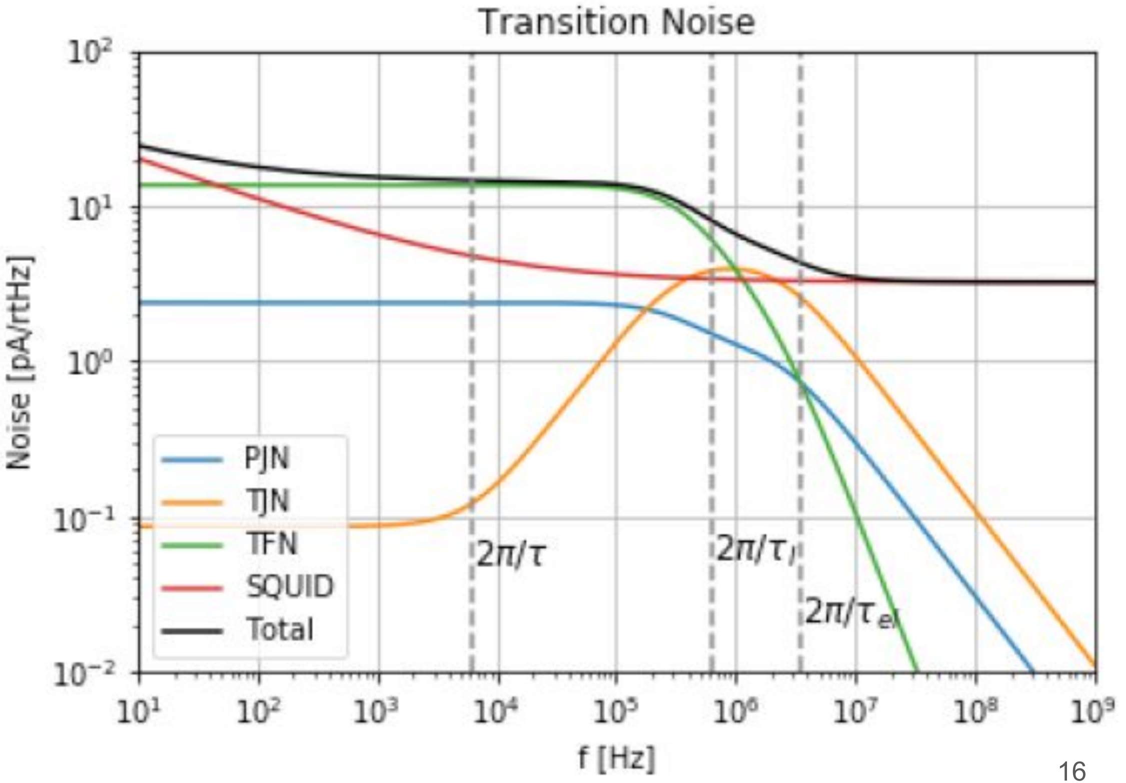
Device Information(1)

PART NUMBER	PACKAGE	BODY SIZE (NOM)
LFx5x	SOIC (8)	4.90 mm × 3.91 mm
	TO-CAN (8)	9.08 mm × 9.08 mm

PARAMETER		TEST CONDITIONS			MIN	TYP	MAX	UNIT
SR	Slew Rate	$LF15x: A_V = 1$		LFx55		5		V/μs
				LFx56, LF356B	7.5			
				LFx56, LF356B		12		
		$LF357: A_V = 5$		LFx57		50		
GBW	Gain Bandwidth Product	LFx55				2.5		MHz
		LFx56, LF356B				5		
		LFx57				20		
t_s	Settling Time to 0.01%(1)	LFx55				4		μs
		LFx56, LF356B				1.5		
		LFx57				1.5		
e_n	Equivalent Input Noise Voltage	$R_S = 100\ \Omega$	f = 100 Hz	LFx55		25		nV/√Hz
				LFx56, LF356B		15		
				LFx57		15		
			f = 1000 Hz	LFx55		20		nV/√Hz
				LFx56, LF356B		12		
				LFx57		12		

First stage amplifier noise is important!

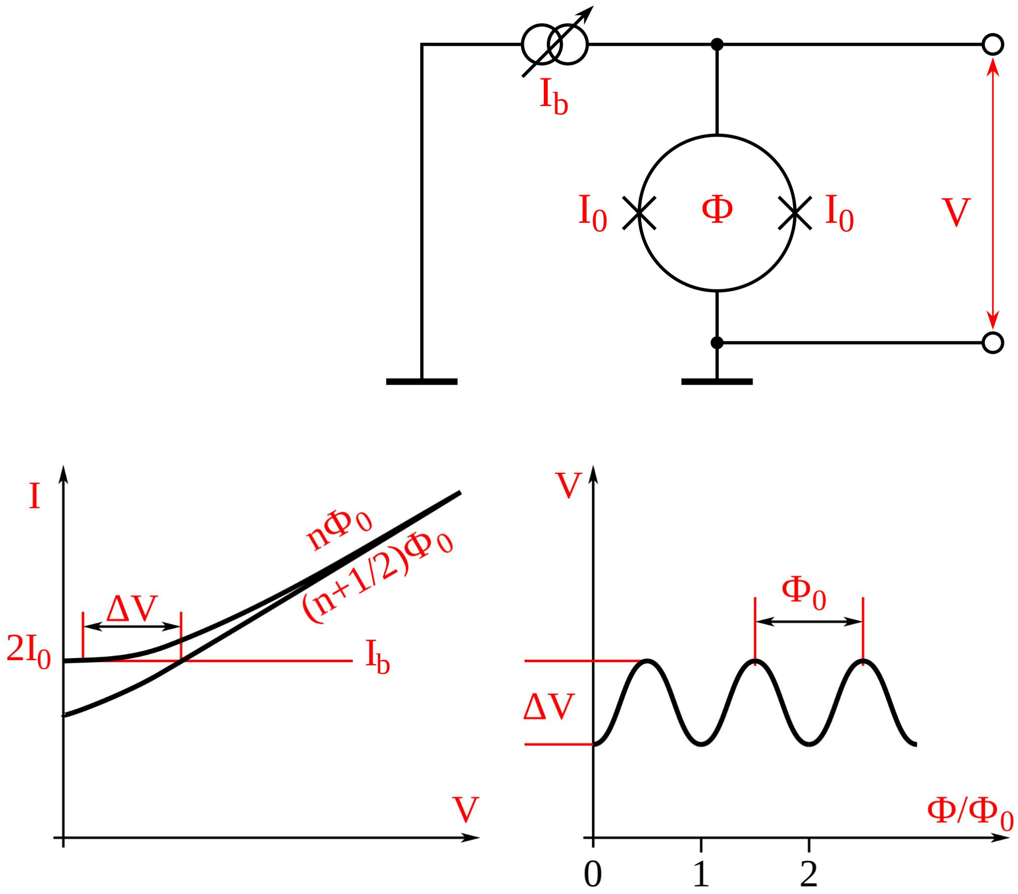
- Usually control first stage amplifier noise to be lower than other intrinsic noise
- Eg SQUID noise lower than TFN for signal bandwidth
- **Early stage noise gets amplified together with signal!**
- Put low noise op-amp in front
  - Later stages can use less expensive op-amp

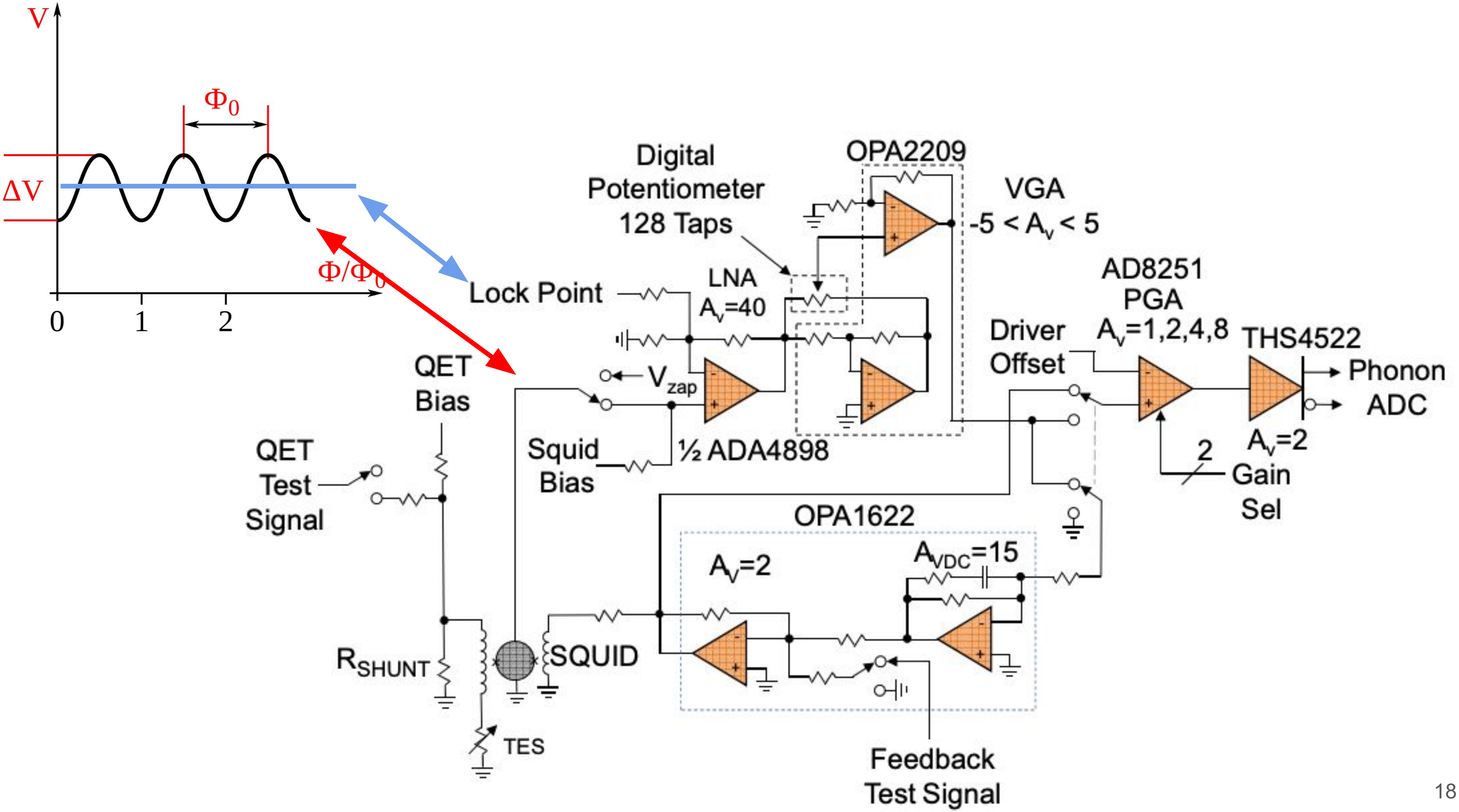


https://en.wikipedia.org/wiki/SQUID

SQUID

- (DC) Superconducting QUantum Interference Device
- Operates based on Joseph Junction magic
- IV curve changes as a function of magnetic flux
- Quantum-limited magnetometer
- Can measure current when coupled with an inductor




V
ΔV
Φ0
Φ/Φ0
0
1
2
Lock Point
Digital
Potentiometer
128 Taps
OPA2209
VGA
-5 < Av < 5
LNA
Av=40
Vzap
½ ADA4898
QET
Bias
QET
Test
Signal
Squid
Bias
AD8251
PGA
Av=1,2,4,8
THS4522
Driver
Offset
Phonon
ADC
Av=2
2
Gain
Sel
OPA1622
Av=2
AVDC=15
RSHUNT
SQUID
TES
Feedback
Test Signal