Operational Amplifiers

High Speed Operational Amplifiers

Operational amplifiers with 3 dB bandwidths of up to 1.5 GHz are now available, such operational amplifiers are used in consumer applications like hard disk drives and computer monitors, industrial and medical applications, such as CAT scanners. In addition one can use these operational amplifiers for IF amplifiers in many communication receiver applications.

These high speed amplifiers fall into three categories:

Voltage Feedback Amplifiers

Current Feedback Amplifiers

Dual Feedback Amplifiers

The Voltage Feedback amplifiers have the same properties as the LF356 or 741 operational amplifiers, used at low frequencies.

The Voltage feedback amplifiers have lower noise, better dc performance and more freedom in feedback configuration. The Current Feedback amplifiers have faster slew rates, lower distortion but restrictions on feedback configurations.

If an operational amplifier has input voltages V_1 and V_2 at the input terminals, then for a voltage feedback amplifier the output voltage is:

$$V_{out} = A(s)\,(V_1 - V_2)\ ,$$

where A(s) is the open loop gain, which is frequency dependent. Consider the noninverting amplifier configuration:

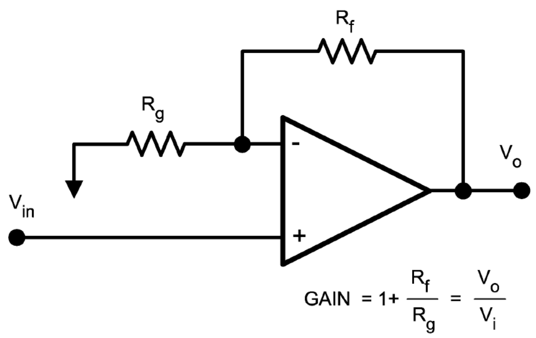


Figure 1. Noninverting Amplifier (National Semiconductor Appl Note OA-30)

If one makes: $G = \dfrac{R_f + R_g}{R_g}$ then $V_o = V_{in}\left[\dfrac{G}{1 + \dfrac{G}{A(s)}}\right]$

Since G(s) decreases with frequency as shown in figure 2, the bandwidth of the amplifier will depend on the gain as is also shown in figure 2.

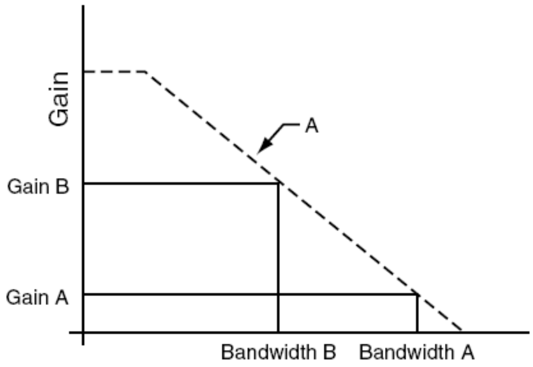


Figure 2. Open loop and Closed loop gain of Voltage Feedback Amplifier (National Semiconductor Appl Note OA-30)

The Current feedback amplifier

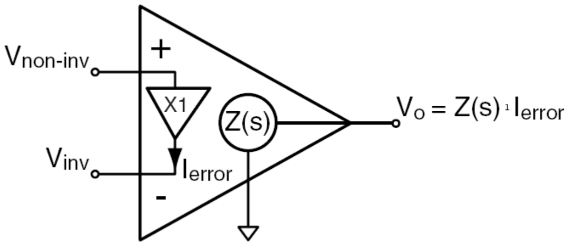


Figure 3 Current Feedback amplifier configuration (National Semiconductor Appl Note OA-30)

For the inverting amplifier configuration, the equations for the amplifier are:

$$i_{error} = \frac{V_{in} - V_o}{R_f} + \frac{V_{in}}{R_g}$$

Since $V_o = Z(s) I_{error}$, substituting for Ierror in the above equation after manipulation leads to:

$$V_o = \frac{R_g}{\frac{Z(s) + R_f}{Z(s)}} V_{in}$$

The current feedback amplifier will thus have a transfer function of:

$$V_o = V_{in} \left[\frac{G}{1 + \frac{R_f}{Z(s)}} \right]$$ compared with a transfer function of :

$$V_o = V_{in} \left[\frac{G}{1 + \frac{G}{A(s)}} \right]$$ for the voltage feedback amplifier.

Where $G = \frac{R_f + R_g}{R_g}$ is the ideal amplifier gain, which is the same for both amplifiers.

The difference is thus in the way G/A(s) and R_f/Z(s) behave with frequency. Halving both R_f and R_g will double the bandwidth and keep the gain the same for the current feedback amplifier, but not change the gain for the voltage feedback amplifier. Doubling the gain by halving R_g will halve the bandwidth of the Voltage feedback amplifier but will not change the bandwidth of the current feedback amplifier. The use of low impedances will allow current amplifiers with high bandwidths to be obtained. Current feedback amplifers have higher input currents and that makes them less suitable for integrators.

There is basically no slew rate limit for the current feedback amplifier, so that much higher slew rates can be obtained. Current feedback amplifiers generally result in have a lower distortion than Voltage Feedback amplifiers, as can be seen in the table 1.

Current and Voltage Feedback Amplifier Comparison

	Current Feedback	Voltage Feedback
Device	LMH 6702	LMH6624
3dB Bandwidth	720 MHz	1.5 GHz
Slew rate	3100 V/µs	350 V/µs
Noise Voltage	1.83 nV/√Hz	0.92 nV/√Hz
Noise Current	3.0 pA/√Hz	2.3 pA/√Hz
Distortion (HD2)	-79 dBc (20 MHz, 2Vpp)	-63 dBc (10 MHz, 1Vpp)
Distortion (HD3)	-88 dBc (20 MHz, 2Vpp)	-80 dBc (10 MHz, 1Vpp)
Input Offset Voltage	1 mV	0.1 mV
Input Offset Current	13 µA	0.1 µA
Load Resistor test circ	100 Ω	100 Ω
Feedback Resistor test circ	237 Ω	500 Ω
Feedback Resistor range	Narrow	Very wide
Supply Voltage	± 5V to ±6 V	±2.5 V to ±6 V
Supply Current	12.5 mA	12 mA
Cost (US$/1000)	$1.49	$1.67

Table 1. Current and Voltage Feedback performance comparison

Low Noise designs using Operational Amplifiers:

The noise associated with a resistor is

$$E_{NR} = \sqrt{4kTBR}$$

Where:

K = Boltzman's constant 1.38E-23 Joules/°Kelvin
T = Absolute temperature Kelvin
B = Bandwidth in Hz
R = Resistance in Ω

In a circuit each resistor is then associated with its own noise source which has a random noise voltage of E_{NR}.

In addition the operational amplifier produces noise which can most accurately be represented as voltage (e_{ni}) and current noise sources (i_{ni+} and i_{ni-}) at the inputs, as shown in figure 4.

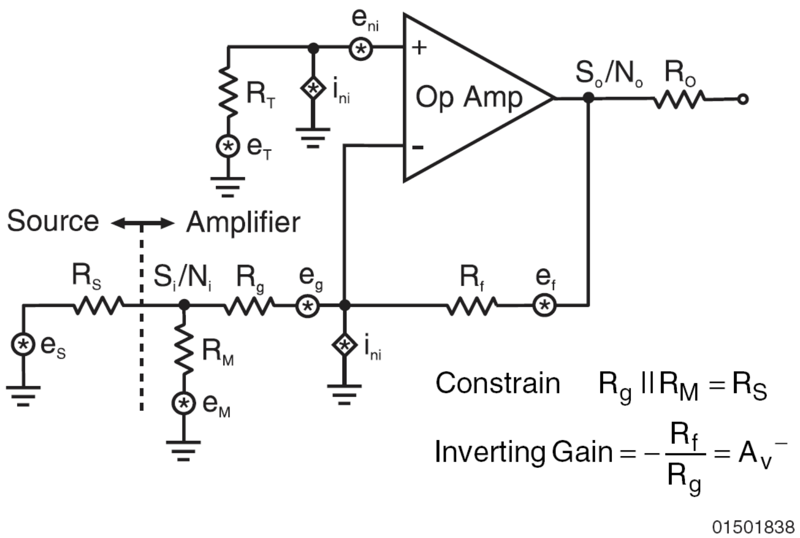


Figure 4 Noise sources in an operational amplifier configuration (National Semiconductor Appl Note OA-11)

The values for e_{ni} and for i_{ni+} and i_{ni-} are normally obtained from manufacturers data sheets. The table 2 shows the noise performance of some low noise amplifiers from different manufacturers. The noise of operational amplifiers will rise at low frequency, as shown in figures 5 to 8, and is inversely proportional to frequency at low frequencies, due to flicker noise or 1/f noise. The corner frequency of that 1/f noise may be important in a design. For example is a microphone amplifier is required, the noise performance at less than 1 kHz is important and the LMH6622 has a better noise performance at those frequencies than the LMH6624, which has a better noise performance at higher frequencies only.

Manufacturer	Part	nV/sqrtHz	1/f Hz	GBWP MHz	VinOffset mV
Texas Instruments	TLE2037	2.5		50	0.1
Texas Instruments	OPA2300	3		150	5
Analog Devices	AD8028	4.3	300Hz	190	0.9
Analog Devices	AD8099	0.85		500	0.2
Analog Devices	AD797	0.9	100 Hz	110	0.025
National Instruments	LMH6624	1	10kHz	1500	0.5
National Instruments	LMH6622	2	1kHz	160	1.2
National Instruments	LF356	12	100Hz	5	3

Table 2. Low Noise Operational Amplifiers.

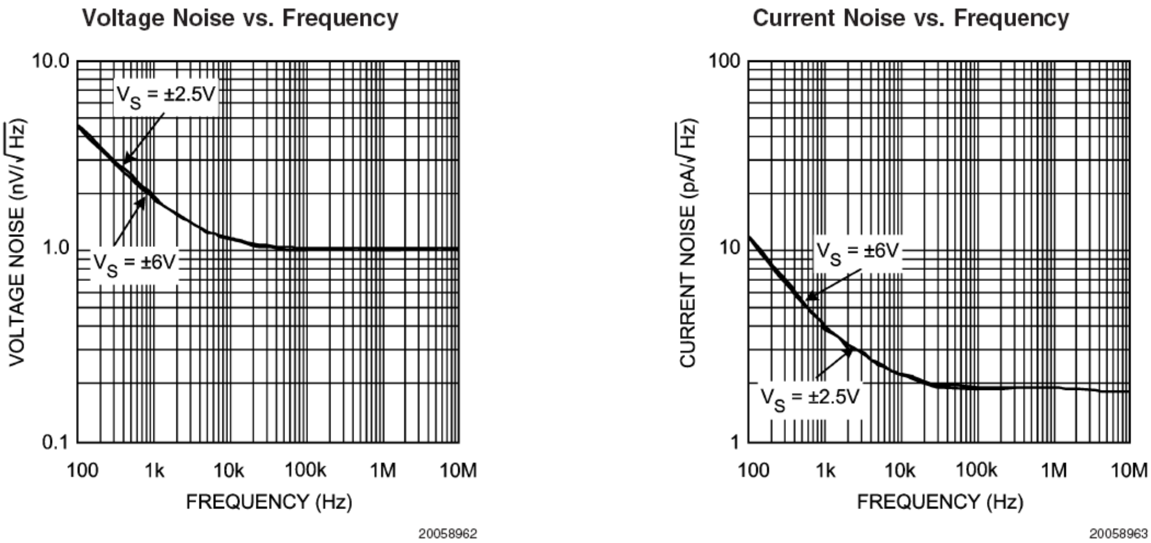


Figure 5. Noise of LMH6624L versus frequency

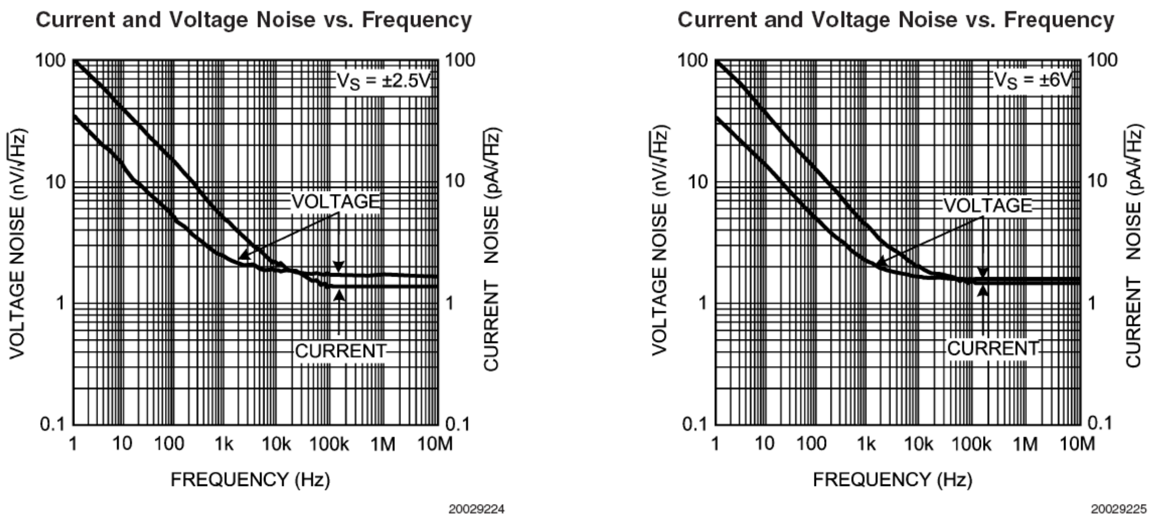
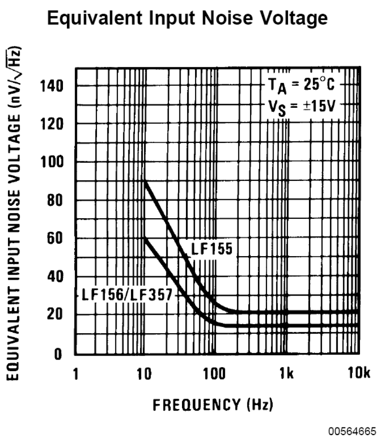


Figure 6. Noise of LMH6622 versus frequency



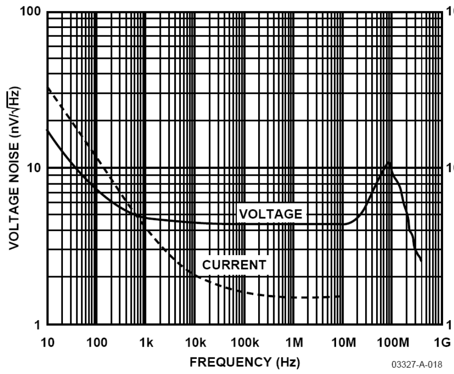


Figure 19. Voltage and Current Noise vs. Frequency

Figure 7. Noise of LF356 and AD8027/AD8028 versus frequency

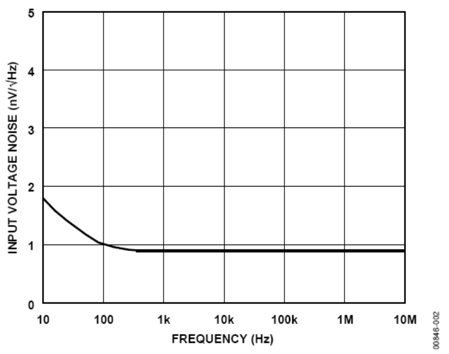


Figure 2. AD797 Voltage Noise Spectral Density

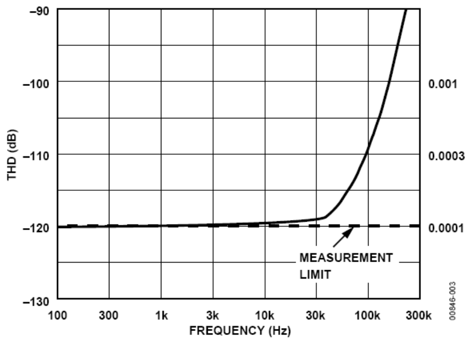


Figure 3. THD vs. Frequency

Figure 8. Noise and Distortion of AD797

Note the lower 1/f point of the AD8027/8028, but the higher noise voltage of the AD8027.

Example

A microphone has a 100 Ω source impedance and requires a load resistance larger than 1 kΩ for the microphone to operate correctly. The output from the microphone is 3mV. An amplifier with a voltage gain of 1000 is required.

The noise obtained from an operational amplifier circuit for a microphone amplifier using an inverting and noninverting amplifier configuration is shown in table 3.

Operational amplifer Noise calculation

4kT	1.60E-20
Microphone, 10mV out, Rl 1k,	
Bandwidth (Hz)	20000
Op Amp	LMH6624L
Rs	Source resistance
Rg	Input resistance series with inverting input
Rf	Feedback resistor

	Non Inverting Op Amp			Inverting Amp		
	Value	Noise Power/Hz	Output Noise Power/Hz	Value	Noise Power/Hz	Output Noise Power/Hz
en V	1.00E-09	1.00E-18	1.00E-12	1.00E-09	1.00E-18	1.00E-12
in+ A	2.3E-12	1.90E-18	1.91E-12	2.3E-12	0.00E+00	0.00E+00
in- A	2.3E-12	5.28E-22	5.29E-16	2.3E-12	6.84E-17	6.86E-11
Rs	600	9.60E-18	9.62E-12	0	0.00E+00	0.00E+00
Rg	10	1.60E-19	1.60E-13	3600	5.76E-17	5.76E-11
Rf	10000	1.60E-16	1.60E-16	3600000	5.76E-14	5.76E-14
Gain	1001			1001		
				1000		
Total Power/Hz			1.27E-11			1.27E-10
Total Noise Power			2.54E-07			2.54E-06
Noise Voltage mV		5.04E-01			1.60E+00	
Mic Output mV	2.5		2502.5			2500
SNR			73.92			63.90
Noise figure			1.20			6.45

Table 3. Noise for inverting and noninverting amplifier configurations.

References:

Noise: National data sheet: "LMH6624/LMH6626 Single/Dual Ultra Low Noise Wideband Operational Amplifier"

"Current vs. Voltage Feedback Amplifiers" National Semiconductor Application Note OA-30