LMH6624/LMH6626
Single/Dual Ultra Low Noise Wideband Operational Amplifier

General Description
The LMH6624/LMH6626 offer wide bandwidth (1.5GHz for single, 1.3GHz for dual) with very low input noise (0.92nV/√Hz, 2.3pA/√Hz) and ultra low dc errors (100µV VOS, ±0.1µV/˚C drift) providing very precise operational amplifiers with wide dynamic range. This enables the user to achieve closed-loop gains of greater than 10, in both inverting and non-inverting configurations.

The LMH6624 (single) and LMH6626’s (dual) traditional voltage feedback topology provide the following benefits: balanced inputs, low offset voltage and offset current, very low offset drift, 81dB open loop gain, 95dB common mode rejection ratio, and 88dB power supply rejection ratio.

The LMH6624/LMH6626 operate from ±2.5V to ±6V in dual supply mode and from +5V to +12V in single supply configuration.

LMH6624 is offered in SOT23-5 and SOIC-8 packages.

Features
- VS = ±6V, TA = 25˚C, AV = 20, (Typical values unless specified)
- Gain bandwidth (LMH6624) 1.5GHz
- Input voltage noise 0.92nV/√Hz
- Input offset voltage (limit over temp) 700µV
- Slew rate 350V/µs
- Slew rate (AV = 10) 400V/µs
- HD2 @ f = 10MHz, RL = 100Ω −63dBc
- HD3 @ f = 10MHz, RL = 100Ω −80dBc
- Supply voltage range (dual supply) ±2.5V to ±6V
- Supply voltage range (single supply) +5V to +12V
- Improved replacement for the CLC425 (LMH6624)
- Stable for closed loop |AV| ≥ 10

Applications
- Instrumentation sense amplifiers
- Ultrasound pre-amps
- Magnetic tape & disk pre-amps
- Wide band active filters
- Professional Audio Systems
- Opto-electronics
- Medical diagnostic systems

Connection Diagrams

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### Absolute Maximum Ratings (Note 1)
If Military/Aerospace specified devices are required, please contact the National Semiconductor Sales Office/Distributors for availability and specifications.

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### ±2.5V Electrical Characteristics

Unless otherwise specified, all limits guaranteed at T<sub>A</sub> = 25˚C, V<sup>+</sup> = 2.5V, V<sup>−</sup> = −2.5V, V<sub>CM</sub> = 0V, A<sub>V</sub> = +20, R<sub>F</sub> = 500Ω, R<sub>L</sub> = 100Ω. **Boldface** limits apply at the temperature extremes. See (Note 12).

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### ±2.5V Electrical Characteristics

Unless otherwise specified, all limits guaranteed at $T_A = 25°C$, $V^+ = 2.5V$, $V^- = 2.5V$, $V_{CM} = 0V$, $A_V = +20$, $R_F = 500Ω$, $R_L = 100Ω$. **Boldface** limits apply at the temperature extremes. See (Note 12).

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### ±6V Electrical Characteristics

Unless otherwise specified, all limits guaranteed at $T_A = 25°C$, $V^+ = 6V$, $V^- = −6V$, $V_{CM} = 0V$, $A_V = +20$, $R_F = 500Ω$, $R_L = 100Ω$. **Boldface** limits apply at the temperature extremes. See (Note 12).

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### ±6V Electrical Characteristics (Continued)

Unless otherwise specified, all limits guaranteed at $T_A = 25^\circ C$, $V^+ = 6V$, $V^- = -6V$, $V_{CM} = 0V$, $A_V = +20$, $R_F = 500\Omega$, $R_L = 100\Omega$. **Boldface** limits apply at the temperature extremes. See (Note 12).

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### Distortion and Noise Response

- $e_n$ Input Referred Voltage Noise
  - $f = 1$ MHz (LMH6624): 0.92 nV/$\sqrt{\text{Hz}}$
  - $f = 1$ MHz (LMH6626): 1.0 nV/$\sqrt{\text{Hz}}$

- $I_n$ Input Referred Current Noise
  - $f = 1$ MHz (LMH6624): 2.3 pA/$\sqrt{\text{Hz}}$
  - $f = 1$ MHz (LMH6626): 1.8 pA/$\sqrt{\text{Hz}}$

- HD2 2nd Harmonic Distortion $f_C = 10$ MHz, $V_O = 1V_{PP}$, $R_L = 100\Omega$
  - $-63$ dBc

- HD3 3rd Harmonic Distortion $f_C = 10$ MHz, $V_O = 1V_{PP}$, $R_L = 100\Omega$
  - $-80$ dBc

### Input Characteristics

- $V_{OS}$ Input Offset Voltage
  - $V_{CM} = 0V$
  - Average Drift (Note 7): $-0.5$ to $+0.5$ mV

- $I_{OS}$ Input Offset Current Average Drift (Note 7)
  - (LMH6624) $V_{CM} = 0V$
    - $-1.1$ to $+1.1$ µA
  - (LMH6626) $V_{CM} = 0V$
    - $-2.0$ to $+2.0$ µA

- $I_B$ Input Bias Current
  - $V_{CM} = 0V$
  - Average Drift (Note 7): $13$ +20 µA

- $R_{IN}$ Input Resistance (Note 10)
  - Common Mode: 6.6 MΩ
  - Differential Mode: 4.6 kΩ

- $C_{IN}$ Input Capacitance (Note 10)
  - Common Mode: 0.9 pF
  - Differential Mode: 2.0 pF

- CMRR Common Mode Rejection Ratio
  - Input Referred, $V_{CM} = -4.5$ to $+5.25V$
    - 90 dB
  - $V_{CM} = -4.5$ to $+5.0V$
    - 87 dB

### Transfer Characteristics

- $A_{VOL}$ Large Signal Voltage Gain
  - (LMH6624) $R_L = 100\Omega$, $V_O = -3V$ to $+3V$
    - 77 dB
  - (LMH6626) $R_L = 100\Omega$, $V_O = -3V$ to $+3V$
    - 74 dB

- $X_c$ Crosstalk Rejection
  - $f = 1$ MHz (LMH6626)
    - $-75$ dB

### Output Characteristics

- $V_O$ Output Swing
  - (LMH6624) $R_L = 100\Omega$
    - $\pm4.4$ to $\pm4.9$ V
  - (LMH6624) No Load
    - $\pm4.3$ to $\pm4.8$ V
  - (LMH6626) $R_L = 100\Omega$
    - $\pm4.3$ to $\pm4.8$ V
  - (LMH6626) No Load
    - $\pm4.2$ to $\pm4.65$ V

- $R_O$ Output Impedance
  - $f \leq 100$ kHz
    - 10 mΩ
±6V Electrical Characteristics

Unless otherwise specified, all limits guaranteed at $T_A = 25^\circ C$, $V^+ = 6V$, $V^- = -6V$, $V_{CM} = 0V$, $A_V = +20$, $R_F = 500\Omega$, $R_L = 100\Omega$. **Boldface** limits apply at the temperature extremes. See (Note 12).

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<th>Typ (Note 5)</th>
<th>Max (Note 6)</th>
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<td>(LMH6624)</td>
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<th>Conditions</th>
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<td>(LMH6626)</td>
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**Power Supply**

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**Ordering Information**

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<td>A94A</td>
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<td>LMH6626MMX</td>
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<td>3.5k Units Tape and Reel</td>
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Typical Performance Characteristics

Open Loop Frequency Response Over Temperature

Frequency Response with Cap. Loading

Frequency Response with Cap. Loading

Frequency Response with Cap. Loading

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Typical Performance Characteristics (Continued)

Non-Inverting Frequency Response Varying $V_{IN}$

- **LMH6624**
  - $V_S = \pm 2.5V$
  - $A_V = +10$
  - $R_F = 500\Omega$

- **LMH6626**
  - $V_S = \pm 6V$
  - $A_V = +10$
  - $R_F = 500\Omega$

$V_{IN} = 200mV$

FREQUENCY (Hz) | 100k | 1M | 10M | 100M | 1G
---|---|---|---|---|---
Normalized Gain (dB) | -2 | 0 | 2 | 4 | 5

Non-Inverting Frequency Response Varying $V_{IN}$ (LMH6624)

- **LMH6624**
  - $V_S = \pm 2.5V$
  - $A_V = +20$
  - $R_F = 500\Omega$

$V_{IN} = 200mV$

Non-Inverting Frequency Response Varying $V_{IN}$ (LMH6626)

- **LMH6626**
  - $V_S = \pm 6V$
  - $A_V = +20$
  - $R_F = 500\Omega$

$V_{IN} = 200mV$

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Typical Performance Characteristics (Continued)

Sourcing Current vs. \( V_{OUT} \) (LMH6624)

\[
I_{SOURCE} \text{ (mA)}
\]
\[
V_{OUT} \text{ (V)}
\]

\( V_S = \pm 2.5 \text{V} \)

Sourcing Current vs. \( V_{OUT} \) (LMH6626)

\[
I_{SOURCE} \text{ (mA)}
\]
\[
V_{OUT} \text{ (V)}
\]

\( V_S = \pm 2.5 \text{V} \)

VOS vs. \( V_{SUPPLY} \) (LMH6624)

\[
V_{OS} \text{ (\text{\textmu}{V})}
\]
\[
V_{SUPPLY} \text{ (V)}
\]

\( V_S = \pm 6 \text{V} \)

VOS vs. \( V_{SUPPLY} \) (LMH6626)

\[
V_{OS} \text{ (\text{\textmu}{V})}
\]
\[
V_{SUPPLY} \text{ (V)}
\]

\( V_S = \pm 6 \text{V} \)
Typical Performance Characteristics (Continued)

Sinking Current vs. \( V_{OUT} \) (LMH6624)

\[ I_{SINK} (mA) \]

\[ V_S = \pm 2.5V \]

\[ V_S = \pm 6V \]

Sinking Current vs. \( V_{OUT} \) (LMH6626)

\[ I_{SINK} (mA) \]

\[ V_S = \pm 2.5V \]

\[ V_S = \pm 6V \]

Crosstalk Rejection vs. Frequency (LMH6626)

\[ I_{OS} (\mu A) \]

\[ V_S = \pm 6V \]

\[ V_S = \pm 2.5V \]

\[ V_{IN} = 60mV_{PP} \]

\[ A_V = +20 \]

\[ R_L = 100\Omega \]
Typical Performance Characteristics

Distortion vs. Frequency

- $A_v = +10$
- $R_L = 100\Omega$
- $V_S = \pm 6V, V_O = 2V_{PP}$
- $V_S = \pm 2.5V, V_O = 1V_{PP}$

Distortion vs. Frequency

- $A_v = +20$
- $R_L = 100\Omega$
- $V_S = \pm 6V, V_O = 2V_{PP}$
- $V_S = \pm 2.5V, V_O = 1V_{PP}$

Distortion vs. V$_{OUT}$ Peak to Peak

- $A_v = +20$
- $V_S = \pm 2.5V$
- $R_L = 100\Omega$
- $V_O = 2V_{PP}$
- $f_C = 10MHz$
- $f_C = 1MHz$

Distortion vs. V$_{OUT}$ Peak to Peak

- $A_v = +20$
- $V_S = \pm 6V$
- $R_L = 100\Omega$
- $f_C = 10MHz$
- $f_C = 1MHz$

Distortion vs. Gain

- $V_S = \pm 6V$
- $V_O = 2V_{PP}$
- $V_S = \pm 2.5V$
- $V_O = 1V_{PP}$
- $f_C = 1MHz$
- $R_L = 100\Omega$
Typical Performance Characteristics (Continued)

Non-Inverting Large Signal Pulse Response

![Graph showing Non-Inverting Large Signal Pulse Response]

- $V_S = \pm 2.5V$
- $V_O = 1V_{PP}$
- $A_V = +10$
- $R_L = 100\Omega$

200 mV/DIV

10 ns/DIV

Non-Inverting Small Signal Pulse Response

![Graph showing Non-Inverting Small Signal Pulse Response]

- $V_S = \pm 2.5V$
- $V_O = 200mV$
- $A_V = +10$
- $R_L = 100\Omega$

50 mV/DIV

10 ns/DIV

PSRR vs. Frequency

![Graph showing PSRR vs. Frequency]

- $V_S = \pm 2.5V$
- $+PSRR, A_V = +10$
- $+PSRR, A_V = +20$

PSRR (dB)

FREQUENCY (Hz)

1k 10k 100k 1M 10M 100M 1G

0 -20 -40 -60 -80 -100

-120 -140

Non-Inverting Large Signal Pulse Response

![Graph showing Non-Inverting Large Signal Pulse Response]

- $V_S = \pm 5V$
- $V_O = 1V_{PP}$
- $A_V = +20$
- $R_L = 100\Omega$

200 mV/DIV

10 ns/DIV

Non-Inverting Small Signal Pulse Response

![Graph showing Non-Inverting Small Signal Pulse Response]

- $V_S = \pm 5V$
- $V_O = 500mV$
- $A_V = +20$
- $R_L = 100\Omega$

100 mV/DIV

10 ns/DIV

PSRR vs. Frequency

![Graph showing PSRR vs. Frequency]

- $V_S = \pm 5V$
- $+PSRR, A_V = +10$
- $+PSRR, A_V = +20$

PSRR (dB)

FREQUENCY (Hz)

1k 10k 100k 1M 10M 100M 1G

0 -20 -40 -60 -80 -100

-120 -140
Typical Performance Characteristics (Continued)

Input Referred CMRR vs. Frequency

![Graph showing CMRR vs. Frequency](image1)

Amplifier Peaking with Varying $R_F$

![Graph showing Amplifier Peaking](image2)
INTRODUCTION

The LMH6624/LMH6626 are very wide gain bandwidth, ultra low noise voltage feedback operational amplifiers. Their excellent performances enable applications such as medical diagnostic ultrasound, magnetic tape & disk storage and fiber-optics to achieve maximum high frequency signal-to-noise ratios. The set of characteristic plots in the “Typical Performance” section illustrates many of the performance trade offs. The following discussion will enable the proper selection of external components to achieve optimum system performance.

BIAS CURRENT CANCELLATION

To cancel the bias current errors of the non-inverting configuration, the parallel combination of the gain setting (Rg) and feedback (Rf) resistors should equal the equivalent source resistance (Rseq) as defined in Figure 1. Combining this constraint with the non-inverting gain equation also seen in Figure 1, allows both Rf and Rg to be determined explicitly from the following equations:

\[
R_f = \frac{A_v}{R_{\text{seq}}} \quad \text{and} \quad R_g = \frac{R_f}{(A_v - 1)}
\]

When driven from a 0Ω source, such as the output of an op amp, the non-inverting input of the LMH6624/LMH6626 should be isolated with at least a 25Ω series resistor.

As seen in Figure 2, bias current cancellation is accomplished for the inverting configuration by placing a resistor (Rb) on the non-inverting input equal in value to the resistance seen by the inverting input (Rf/(Rg+Rs)). Rb should to be no less than 25Ω for optimum LMH6624/LMH6626 performance. A shunt capacitor can minimize the additional noise of Rb.

TOTAL INPUT NOISE vs. SOURCE RESISTANCE

To determine maximum signal-to-noise ratios from the LMH6624/LMH6626, an understanding of the interaction between the amplifier’s intrinsic noise sources and the noise arising from its external resistors is necessary.

Figure 3 describes the noise model for the non-inverting amplifier configuration showing all noise sources. In addition to the intrinsic input voltage noise (εn) and current noise (i_n = i_n^+ = i_n^-) source, there is also thermal voltage noise (εv = \sqrt{4KTR}) associated with each of the external resistors. Equation 1 provides the general form for total equivalent input voltage noise density (εni).

Equation 2 is a simplification of Equation 1 that assumes

\[
ε_n = \frac{R_f}{R_{\text{seq}}}
\]

FIGURE 1. Non-Inverting Amplifier Configuration

FIGURE 2. Inverting Amplifier Configuration

FIGURE 3. Non-Inverting Amplifier Noise Model
Application Section (Continued)

\[ e_{ni} = \sqrt{e_n^2 + 2Tr_{Rseq} + 4kT(2R_{seq})^2} \]  

\[ R_{seq} \] for bias current cancellation. Figure 4 illustrates the equivalent noise model using this assumption. Figure 5 is a plot of eni against equivalent source resistance (Rseq) with all of the contributing voltage noise source of Equation 2. This plot gives the expected eni for a given (Rseq) which assumes Rf||Rg = Rseq for bias current cancellation. The total equivalent output voltage noise (eni) is eni^2/AV.

\[ \frac{e_{ni}}{\sqrt{2}} \] for Rf||Rg = Rseq.

FIGURE 4. Noise Model with Rf||Rg = Rseq

\[ e_{ni} = \sqrt{e_n^2 + 2(i_n R_{seq})^2 + 4kT(2R_{seq})^2} \]

As seen in Figure 5, eni is dominated by the intrinsic voltage noise (e_n) of the amplifier for equivalent source resistances below 33.5Ω. Between 33.5Ω and 6.43kΩ, eni is dominated by the thermal noise (e_t = \sqrt{4kT(2R_{seq})}) of the external resistor. Above 6.43kΩ, eni is dominated by the amplifier’s current noise (i_n). When Rseq = 464Ω (ie., e_n/\sqrt{2} i_n) the contribution from voltage noise and current noise of LMH6624/LMH6626 is equal. For example, configured with a gain of +20V/V giving a −3dB of 90MHz and driven from Rseq = 25Ω, the LMH6624 produces a total equivalent input noise voltage (eni x \sqrt{HZ}) 1.57*90MHz of 16.5µVrms.

\[ NF = 10\log\left(\frac{S_i}{N_i}\right) = 10\log\left(\frac{e_{ni}^2}{e_{n}^2}\right) \]

The Noise Figure formula is shown in Equation 3. The addition of a terminating resistor R_T reduces the external thermal noise but increases the resulting NF. The NF is increased because R_T reduces the input signal amplitude thus reducing the input SNR.

\[ NF = 10\log\left(\frac{e_n^2 + 2R_{seq}^2 + 4kT(2R_{seq})^2}{4kT(2R_{seq})^2}\right) \]

The noise figure is related to the equivalent source resistance (Rseq) and the parallel combination of Rf and Rg. To minimize noise figure.

• Minimize Rf||Rg
• Choose the Optimum R_B (ROPT)
ROPT is the point at which the NF curve reaches a minimum and is approximated by:

\[ ROPT = \frac{e_n}{i_n} \]

NON-INVERTING GAINS LESS THAN 10V/V
Using the LMH6624/LMH6626 at lower non-inverting gains requires external compensation such as the shunt compensation as shown in Figure 6. The compensation capacitors are chosen to reduce frequency response peaking to less than 1dB.

\[ R_{OPT} = \frac{e_n}{i_n} \]

INVERTING GAINS LESS THAN 10V/V
The lag compensation of Figure 7 will achieve stability for lower gains. It is best used for the inverting configuration because of its affect on the non-inverting input impedance.
SINGLE SUPPLY OPERATION
The LMH6624/LMH6626 can be operated with single power supply as shown in Figure 8. Both the input and output are capacitively coupled to set the DC operating point.

LOW NOISE TRANSIMPEDANCE AMPLIFIER
Figure 9 implements a low-noise transimpedance amplifier commonly used with photo-diodes. The transimpedance gain is set by $R_f$. Equation 4 provides the total input current noise density ($i_{ni}$) equation for the basic transimpedance configuration and is plotted against feedback resistance ($R_f$) showing all contributing noise sources in Figure 10. This plot indicates the expected total equivalent input current noise density ($i_{ni}$) for a given feedback resistance ($R_f$). The total equivalent output voltage noise density ($e_{ni}$) is $i_{ni} * R_f$.

LOW NOISE INTEGRATOR
The LMH6624/LMH6626 implement a deBoo integrator shown in Figure 11. Positive feedback maintains integration linearity. The LMH6624/LMH6626's low input offset voltage and matched inputs allow bias current cancellation and provide for very precise integration. Keeping $R_G$ and $R_S$ low helps maintain dynamic stability.
HIGH-GAIN SALLEN-KEY ACTIVE FILTERS
The LMH6624/LMH6626 are well suited for high gain Sallen-Key type of active filters. Figure 12 shows the 2nd order Sallen-Key low pass filter topology. Using component predistortion methods discussed in OA-21 enables the proper selection of components for these high-frequency filters.

LOW NOISE MAGNETIC MEDIA EQUALIZER
The LMH6624/LMH6626 implement a high-performance low noise equalizer for such application as magnetic tape channels as shown in Figure 13. The circuit combines an integrator with a bandpass filter to produce the low noise equalization. The circuit's simulated frequency response is illustrated in Figure 14.

LAYOUT CONSIDERATION
National Semiconductor suggests the copper patterns on the evaluation boards listed below as a guide for high frequency layout. These boards are also useful as an aid in device testing and characterization. As is the case with all high-speed amplifiers, accepted-practice RF design technique on the PCB layout is mandatory. Generally, a good high frequency layout exhibits a separation of power supply and ground traces from the inverting input and output pins. Parasitic capacitances between these nodes and ground may cause frequency response peaking and possible circuit oscillations (see Application Note OA-15 for more information). Use high quality chip capacitors with values in the range of 1000pF to 0.1F for power supply bypassing. One terminal of each chip capacitor is connected to the ground plane and the other terminal is connected to a point that is as close as possible to each supply pin as allowed by the manufacturer's design rules. In addition, connect a tantalum capacitor with a value between 4.7µF and 10µF in parallel with the chip capacitor. Signal lines connecting the feedback and gain resistors should be as short as possible to minimize inductance and microstrip line effect. Place input and output termination resistors as close as possible to the input/output pins. Traces greater than 1 inch in length should be impedance matched to the corresponding load termination.
Symmetry between the positive and negative paths in the layout of differential circuitry should be maintained to minimize the imbalance of amplitude and phase of the differential signal.

These free evaluation boards are shipped when a device sample request is placed with National Semiconductor.

Component value selection is another important parameter in working with high speed/high performance amplifiers. Choosing external resistors that are large in value compared to the value of other critical components will affect the closed loop behavior of the stage because of the interaction of these resistors with parasitic capacitances. These parasitic capacitors could either be inherent to the device or be a by-product of the board layout and component placement. Moreover, a large resistor will also add more thermal noise to the signal path. Either way, keeping the resistor values low will diminish this interaction. On the other hand, choosing very low value resistors could load down nodes and will contribute to higher overall power dissipation and high distortion.

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2. A critical component is any component of a life support device or system whose failure to perform can be reasonably expected to cause the failure of the life support device or system, or to affect its safety or effectiveness.