5.5nV/$\sqrt{\text{Hz}}$ Low Noise, 500μA low Power, Rail-to-Rail Output CMOS Operational Amplifier

FEATURES

- Equivalent Input Noise Voltage
  - f=10Hz: 11nV/$\sqrt{\text{Hz}}$
  - f=1kHz: 5.5nV/$\sqrt{\text{Hz}}$
- Supply Current: 500μA typ.
- Gain Bandwidth Product: 4.4MHz
- Slew Rate: 1.1V/μs
- Supply Voltage: Single Supply 1.8V to 5.5V, Dual Supply ±0.9V to ±2.75V
- Rail-to-Rail Output ($R_L=10k\Omega$): 50mV from rail
- Ground Sense
- Common-Mode Input Voltage Range: $V_{SS}-0.1V$ to $V_{DD}+0.9V$
- Input Offset Voltage: 2mV max.
- Input Offset Voltage Drift: 1.5μV/°C typ.
- RF-Noise Immunity
- Package: SC-88A

APPLICATIONS

- Low-noise microphone amplifier
- Photodiode preamplifier
- Shock Sensor application
- Acceleration sensor application
- Security equipment
- Wireless LAN
- Radio systems

DESCRIPTION

The NJU77806 is a single low noise rail-to-rail output CMOS operational amplifier offer a low input voltage noise density of 5.5nV/$\sqrt{\text{Hz}}$ at 1kHz while consuming only 500μA of supply current, and have wide gain bandwidth of 4.4MHz and slew rate of 1.1V/μs. These characteristics makes NJU77806 ideal when excellent performance is required in low noise and low power applications.

The very low noise of 5.5nV/$\sqrt{\text{Hz}}$ at 1kHz and low 1/f noise of 11nV/$\sqrt{\text{Hz}}$ at 10Hz while consuming only 500μA of supply current, give the NJU77806 the wide dynamic range necessary for preamps in microphones, audio amplifiers, active filters and sensor amplifiers.

NJU77806 guaranteed from 1.8V to 5V specifications. In addition to low noise and low supply current, the NJU77806 operate on supplies as low as 1.8V. These features makes NJU77806 ideal for battery powered applications.

The NJU77806 is high RF-immunity to reduce malfunctions caused by RF noises from mobile phones and others.

The NJU77806 is available in space saving 5-pin SC-88A. The small package saves space on PC boards, and enables the design of small portable electronic devices.

TYPICAL CHARACTERISTIC

![Voltage Noise vs. Frequency](chart)

PIN CONFIGURATION

<table>
<thead>
<tr>
<th>Pin Function</th>
<th>Pin</th>
</tr>
</thead>
<tbody>
<tr>
<td>+INPUT</td>
<td>1</td>
</tr>
<tr>
<td>-INPUT</td>
<td>2</td>
</tr>
<tr>
<td>OUTPUT</td>
<td>3</td>
</tr>
<tr>
<td>VSS</td>
<td>4</td>
</tr>
<tr>
<td>VDD</td>
<td>5</td>
</tr>
</tbody>
</table>

Package: SC-88A

Product Name: NJU77806F3
ABSOLUTE MAXIMUM RATINGS

<table>
<thead>
<tr>
<th>PARAMETER</th>
<th>SYMBOL</th>
<th>RATING</th>
<th>UNIT</th>
</tr>
</thead>
<tbody>
<tr>
<td>Supply Voltage</td>
<td>VDD</td>
<td>7</td>
<td>V</td>
</tr>
<tr>
<td>Input Voltage</td>
<td>VICM</td>
<td>VSS - 0.3 to VDD + 0.3</td>
<td>V</td>
</tr>
<tr>
<td>Differential Input Voltage</td>
<td>V_ID</td>
<td>±7 (2)</td>
<td>V</td>
</tr>
<tr>
<td>Power Dissipation (3)</td>
<td>PD</td>
<td>(2-layer)</td>
<td>mW</td>
</tr>
<tr>
<td>SC-88A</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Operating Temperature Range</td>
<td>Topr</td>
<td>-40 to +105</td>
<td>°C</td>
</tr>
<tr>
<td>Storage Temperature Range</td>
<td>Tstg</td>
<td>-55 to +125</td>
<td>°C</td>
</tr>
</tbody>
</table>

(1) Differential voltage is the voltage difference between +INPUT and -INPUT.
(2) For supply voltage less than +7V, the absolute maximum rating is equal to the supply voltage.
(3) Power dissipation is the power that can be consumed by the IC at Ta=25°C, and is the typical measured value based on JEDEC condition.
When using the IC over Ta=25°C subtract the value \[\text{[mW/°C]}=\frac{P_D}{(Tstg(MAX)-25)}\] per temperature.
2-layer: EIA/JEDEC STANDARD Test board (76.2x114.3x1.6mm, 2layers, FR-4) mounting

RECOMMENDED OPERATING CONDITIONS (Ta=25°C)

<table>
<thead>
<tr>
<th>PARAMETER</th>
<th>SYMBOL</th>
<th>TEST CONDITION</th>
<th>MIN.</th>
<th>TYP.</th>
<th>MAX.</th>
<th>UNIT</th>
</tr>
</thead>
<tbody>
<tr>
<td>Supply Voltage</td>
<td>VDD</td>
<td></td>
<td>1.8</td>
<td>-</td>
<td>5.5</td>
<td>V</td>
</tr>
</tbody>
</table>
### ELECTRICAL CHARACTERISTICS

(V<sub>DD</sub>=1.8 to 5.0V, V<sub>SS</sub>=0V, V<sub>ICM</sub>=V<sub>DD</sub>/2, Ta=25°C, unless otherwise noted.)

<table>
<thead>
<tr>
<th>PARAMETER</th>
<th>SYMBOL</th>
<th>TEST CONDITION</th>
<th>MIN.</th>
<th>TYP.</th>
<th>MAX.</th>
<th>UNIT</th>
</tr>
</thead>
<tbody>
<tr>
<td>Supply Current</td>
<td>I&lt;sub&gt;DD&lt;/sub&gt;</td>
<td>No Signal</td>
<td>-</td>
<td>500</td>
<td>650</td>
<td>µA</td>
</tr>
<tr>
<td>Input Offset Voltage</td>
<td>V&lt;sub&gt;IO&lt;/sub&gt;</td>
<td>-</td>
<td>-</td>
<td>0.7</td>
<td>2</td>
<td>mV</td>
</tr>
<tr>
<td>Input Offset Voltage Drift</td>
<td>ΔV&lt;sub&gt;IO&lt;/sub&gt;/ΔT</td>
<td>Ta = -40°C to 105°C</td>
<td>-</td>
<td>1.5</td>
<td>-</td>
<td>µV/ºC</td>
</tr>
<tr>
<td>Input Bias Current</td>
<td>I&lt;sub&gt;B&lt;/sub&gt;</td>
<td>-</td>
<td>-</td>
<td>1</td>
<td>-</td>
<td>pA</td>
</tr>
<tr>
<td>Input Offset Current</td>
<td>I&lt;sub&gt;IO&lt;/sub&gt;</td>
<td>-</td>
<td>-</td>
<td>1</td>
<td>-</td>
<td>pA</td>
</tr>
<tr>
<td>Input capacitance</td>
<td>C&lt;sub&gt;IN&lt;/sub&gt;</td>
<td>-</td>
<td>-</td>
<td>17</td>
<td>-</td>
<td>pF</td>
</tr>
<tr>
<td>Voltage Gain</td>
<td>A&lt;sub&gt;V&lt;/sub&gt;</td>
<td>R&lt;sub&gt;L&lt;/sub&gt;=10kΩ to V&lt;sub&gt;DD&lt;/sub&gt;/2</td>
<td>70</td>
<td>100</td>
<td>-</td>
<td>dB</td>
</tr>
<tr>
<td>Common-Mode Rejection Ratio</td>
<td>CMR</td>
<td>V&lt;sub&gt;ICM&lt;/sub&gt;=-0.1V to V&lt;sub&gt;DD&lt;/sub&gt;-0.9V</td>
<td>70</td>
<td>100</td>
<td>-</td>
<td>dB</td>
</tr>
<tr>
<td>Supply Voltage Rejection Ratio</td>
<td>SVR</td>
<td>V&lt;sub&gt;DD&lt;/sub&gt;=1.8V to 5.5V</td>
<td>70</td>
<td>100</td>
<td>-</td>
<td>dB</td>
</tr>
<tr>
<td>Common-Mode Input Voltage Range</td>
<td>V&lt;sub&gt;ICM&lt;/sub&gt;</td>
<td>CMR&gt;70dB</td>
<td>-0.1</td>
<td>-</td>
<td>-</td>
<td>V</td>
</tr>
<tr>
<td>High-Level Output Voltage</td>
<td>V&lt;sub&gt;OH&lt;/sub&gt;</td>
<td>R&lt;sub&gt;L&lt;/sub&gt;=10kΩ to V&lt;sub&gt;DD&lt;/sub&gt;/2</td>
<td>V&lt;sub&gt;DD&lt;/sub&gt;-0.1</td>
<td>V&lt;sub&gt;DD&lt;/sub&gt;-0.15</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Low-Level Output Voltage</td>
<td>V&lt;sub&gt;OL&lt;/sub&gt;</td>
<td>R&lt;sub&gt;L&lt;/sub&gt;=10kΩ to V&lt;sub&gt;DD&lt;/sub&gt;/2</td>
<td>-</td>
<td>0.05</td>
<td>0.1</td>
<td>V</td>
</tr>
<tr>
<td></td>
<td></td>
<td>I&lt;sub&gt;source&lt;/sub&gt;=1.5mA</td>
<td>V&lt;sub&gt;DD&lt;/sub&gt;-0.05</td>
<td>V&lt;sub&gt;DD&lt;/sub&gt;-0.1</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td></td>
<td>I&lt;sub&gt;sink&lt;/sub&gt;=1.5mA</td>
<td>V&lt;sub&gt;DD&lt;/sub&gt;-0.15</td>
<td>V&lt;sub&gt;DD&lt;/sub&gt;-0.1</td>
<td>-</td>
<td>-</td>
</tr>
</tbody>
</table>

### AC CHARACTERISTICS

<table>
<thead>
<tr>
<th>PARAMETER</th>
<th>SYMBOL</th>
<th>TEST CONDITION</th>
<th>MIN.</th>
<th>TYP.</th>
<th>MAX.</th>
<th>UNIT</th>
</tr>
</thead>
<tbody>
<tr>
<td>Slew Rate</td>
<td>SR</td>
<td>G&lt;sub&gt;V&lt;/sub&gt;=14dB</td>
<td>-</td>
<td>1.1</td>
<td>-</td>
<td>V/µs</td>
</tr>
<tr>
<td>Gain Bandwidth Product</td>
<td>GBP</td>
<td>G&lt;sub&gt;V&lt;/sub&gt;=40dB, f=100kHz</td>
<td>-</td>
<td>4.4</td>
<td>-</td>
<td>MHz</td>
</tr>
<tr>
<td>Unity Gain Frequency</td>
<td>f&lt;sub&gt;T&lt;/sub&gt;</td>
<td>G&lt;sub&gt;V&lt;/sub&gt;=40dB</td>
<td>-</td>
<td>2.4</td>
<td>-</td>
<td>MHz</td>
</tr>
<tr>
<td>Equivalent Input Noise Voltage</td>
<td>V&lt;sub&gt;NI&lt;/sub&gt;</td>
<td>g&lt;sub&gt;V&lt;/sub&gt;=14dB</td>
<td>f=1kHz</td>
<td>5.5</td>
<td>-</td>
<td>nV/√Hz</td>
</tr>
<tr>
<td></td>
<td></td>
<td>f=10Hz</td>
<td>-</td>
<td>11</td>
<td>-</td>
<td>nV/√Hz</td>
</tr>
<tr>
<td></td>
<td>V&lt;sub&gt;NIPP&lt;/sub&gt;</td>
<td>f=0.1Hz to 10Hz</td>
<td>-</td>
<td>0.25</td>
<td>-</td>
<td>µVpp</td>
</tr>
<tr>
<td>Total Harmonic Distortion + Noise</td>
<td>THD+N</td>
<td>G&lt;sub&gt;V&lt;/sub&gt;=20dB, f=1kHz, LPF=80kHz</td>
<td>V&lt;sub&gt;DD&lt;/sub&gt;=5.0V, V&lt;sub&gt;O&lt;/sub&gt;=4Vpp</td>
<td>-</td>
<td>0.005</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td></td>
<td>V&lt;sub&gt;DD&lt;/sub&gt;=1.8V, V&lt;sub&gt;O&lt;/sub&gt;=1.5Vpp</td>
<td>-</td>
<td>0.01</td>
<td>-</td>
<td></td>
</tr>
</tbody>
</table>

**Note**

The closed gain should be 14dB(5V/V) or higher to prevent the oscillation. Unity gain follower application may cause the oscillation. When the closed gain is lower than 14dB, please use a compensation capacitor (CF: about 20pF), parallel with the feedback resistor R<sub>F</sub> to avoid oscillation. Details are shown on Input Capacitance of Application note.
## TYPICAL CHARACTERISTICS

### Supply Current vs. Supply Voltage

- $G_V=0\,$dB
- $V_{DD}=5\,$V
- $V_{DD}=1.8\,$V

### Supply Current vs. Temperature

- $G_V=0\,$dB
- $V_{DD}=5\,$V
- $V_{DD}=1.8\,$V

### Input Offset Voltage Distribution

- $V_{DD}=5.0\,$V, $T_a=25\,$ºC, $n=195$

### Input Offset Voltage Drift Distribution

- $V_{DD}=5.0\,$V, $n=179$

### Input Offset Voltage vs. Temperature

- $V_{DD}=5.0\,$V, $n=80$

### Input Offset Voltage vs. Supply Voltage

- $V_{DD}=V_{DD}/2$

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## TYPICAL CHARACTERISTICS

### Input Offset Voltage
**vs. Common-Mode Input Voltage**

- **$V_{DD}=5.0V$**
  - $T_a=105^\circ C$ (Red)
  - $T_a=25^\circ C$ (Blue)
  - $T_a=-40^\circ C$ (Green)

- **$V_{DD}=1.8V$**
  - $T_a=105^\circ C$ (Red)
  - $T_a=25^\circ C$ (Blue)
  - $T_a=-40^\circ C$ (Green)

### Common-Mode and Supply Voltage Rejection Ratio
**vs. Temperature**

- **$V_{ICM}=V_{DD}/2$**
  - CMR ($V_{DD}=5.0V$) (Red)
  - CMR ($V_{DD}=1.8V$) (Blue)
  - SVR (Green)

### Voltage Gain
**vs. Temperature**

- $R_L=10k\Omega$ to $V_{DD}/2$
  - $V_{DD}=5.0V$ (Red)
  - $V_{DD}=1.8V$ (Blue)

### Maximum Output Voltage
**vs. Output Current**

- $V_{DD}=5.0V$
  - $V_{OL}$ (Black)
  - $V_{OH}$ (Red)

- $V_{DD}=1.8V$
  - $V_{OL}$ (Black)
  - $V_{OH}$ (Red)
## TYPICAL CHARACTERISTICS

### Voltage Gain/Phase vs. Frequency

- **Voltage Gain/Phase vs. Frequency**
- $V_{DD}=5.0V, Gv=40dB, R_S=100\Omega, R_F=10k\Omega$
- $T_a=105^{\circ}C, -40^{\circ}C, 25^{\circ}C$

### Pulse Response

- **Pulse Response**
- $V_{DD}=5.0V, Gv=14dB$
- $C_L=0pF, 100pF, 47pF$

### Voltage Noise vs. Frequency

- **Voltage Noise vs. Frequency**
- $V_{DD}=5.0V$
- $f=0.1Hz$ to $10Hz$

### 0.1Hz to 10Hz Voltage Noise

- **0.1Hz to 10Hz Voltage Noise**
- $f=0.1Hz$ to $10Hz, V_{DD}=5.0V, V_{IN}=2.5V$

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TYPICAL CHARACTERISTICS

THD+N vs. Output Voltage

$V_{DD}=5.0\ V, G_{V}=20dB, R_{F}=10K\Omega, R_{S}=1K\Omega, Ta=25^\circ C, LPF=80kHz$

$V_{DD}=1.8\ V, G_{V}=20dB, R_{F}=10K\Omega, R_{S}=1K\Omega, Ta=25^\circ C, LPF=80kHz$

- $f=20kHz$
- $f=1kHz$
- $f=20Hz$
APPLICATION NOTE

■ Transimpedance amplifier

NJU77806 is CMOS input operational amplifier, and have high input impedance. And also very low power and low noise makes NJU77806 ideal for transimpedance amplifier requiring low supply current applications.

A typical transimpedance amplifier is shown in Figure1. The output voltage of amplifier is given by the equation $V_{\text{OUT}} = -I_{\text{IN}} \times R_F$. Since the output voltage swing of amplifier is limited, $R_F$ should be selected such that all possible values of $I_{\text{IN}}$ can be detected.

The following parameters are used to design a transimpedance amplifier: the photodiode capacitance, $C_D$; the amplifier input capacitance, $C_{\text{IN}}$. These capacitance and $R_F$ generate a phase lag which causes gain-peaking and can destabilized circuit.

The essential component for obtaining a maximally flat response is feedback capacitor, $C_F$. A feedback capacitance $C_F$ is usually added in parallel with $R_F$ to maintain circuit stability and to control the frequency response. To maximally flat, 2nd order response, $R_F$ and $C_F$ should be chosen by using below equation.

$$C_F = \frac{C_{\text{IN}} + C_D}{\sqrt{GBP \times 2\pi \times R_F}}$$

■ Audio preamplifier with band pass filtering

With 11nV/√Hz at 10Hz low input voltage noise and 500μA low supply current, the NJU77806 is ideal for audio applications. In addition, low supply voltage operation, wide gain bandwidth and low harmonic distortion can be used to design a preamplifier in microphone and portable battery powered audio applications.

Two amplifier circuits are shown in Figure2 and Figure3. Figure2 is an inverting amplifier, with a 10kΩ feedback resistor, $R_2$, and 1kΩ input resistor, $R_1$, and hence provides a gain of -10. Figure3 is a non-inverting amplifier, using the same values of $R_1$ and $R_2$, and provides a gain of 11. In either of these circuits, the coupling capacitor $C_1$ and feedback resistor $R_1$ decides the lower frequency at which the circuit starts providing gain, while the feedback capacitor $C_2$ and feedback resistor $R_2$ decides the frequency which the gain starts dropping off.
APPLICATION NOTE

Input Capacitance

The NJU77806 has a very low input bias current and low voltage noise while consuming only 500µA of supply current, however, to obtain this performance a large CMOS input stage is used, which adds to the input capacitance of 17pF. At high frequency the input capacitance interacts with the input and the feedback impedances to create a pole, which results in lower phase margin and gain peaking. This can be controlled by being selective in the use of feedback resistors, as well as by using a feedback capacitance.

Figure 4 is an inverting amplifier. As shown in Figure 5, as the values of \( R_F \) and \( R_S \) are increased, gain peaking are increased, which in turn decreases the bandwidth of the amplifier. Whenever possible, it is best to choose smaller feedback resistors.

Next, adding a capacitor to the feedback path will decrease the peaking. Figure 6 shows the frequency response with different values of \( C_F \). Adding the capacitance of 20pF removes the peak. The value of \( C_F \) should be chosen by used feedback resistors, \( R_F \) and input capacitance, \( C_{IN} \).

The NJU77806 recommend to operate gain of 14dB (5V/V). However by using these techniques as shown Figure 7, it is enable to improve the stability less than the gain of 14dB.
APPLICATION NOTE

Capacitive load

The unity gain follower is the most sensitive configuration to capacitive loading. The combination of capacitive load placed directly on the output of an amplifier along with the output impedance of the amplifier creates a phase lag which in turn reduces the phase margin of the amplifier. If phase margin is significantly reduced, the response will be either underdamped or the amplifier will oscillate. Since NJU77806 has large CMOS input stage to obtain the low input voltage noise, it can directly drive capacitive loads of up to 33pF without oscillating at unity gain follower. So NJU77806 recommend a gain of 5 (14dB).

To use unity gain follower or drive heavier capacitive loads, an isolation resistor, $R_{ISO}$ as shown Figure8, should be used. This resistor and capacitive load, $C_L$ form a pole and hence delay the phase lag or increase the phase margin of the overall system. The larger the value of $R_{ISO}$, the more stable the output voltage will be. However, larger values of $R_{ISO}$ result in reduced output swing and reduced output current drive.

The typical isolation resistor is 330Ω. Figure9 shows the pulse response with 330Ω $R_{ISO}$, and Figure10 shows $R_{ISO}$ values at unity gain follower without oscillating.

![Figure8. Isolating capacitive load](image)

![Figure9. Frequency response with 330Ω $R_{ISO}$](image)

![Figure10. Isolation resistance to improve stability](image)
■ PACKAGE DIMENSIONS

[Diagram of package dimensions]

SC88A Package

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