ANALOG DEVICES

AN-136
APPLICATION NOTE

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An Ultra Low Noise Preamplifier

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Achieving the maximum usable dynamic range from low output level transducers such as audio microphones, magnetic pick-ups, or low impedance strain gauges requires a preamplifier with very low input-referred voltage noise. The circuit shown in Figure 1 has extremely low noise, 0.5nV/$\sqrt{Hz}$, and can provide a gain of 1000 over a 200kHz bandwidth.

This amplifier's low noise characteristics are attributable to the SSM-2220's matched PNP transistor pair. Operating with 2mA collector current in each transistor, the SSM-2220 forms a differential input stage with a DC gain of 385, approximately 50µV of offset voltage, and only 0.5nV/$\sqrt{Hz}$ of broadband noise. When multiplied by the stage gain of 385, the input noise of the SSM-2220 appears as 192.5nV/$\sqrt{Hz}$ differentially at the inputs of the OP-27. This makes the 3.8nV/$\sqrt{Hz}$ of the op amp an insignifi-cant contribution to the overall noise of the circuit. In this example, the input stage compensation, C_1 and R_7, optimizes noise performance over the audio frequency range by allowing the differential pair to have a flat frequency response to 20kHz before being rolled-off for stability criteria. Input stage gain is reduced 20dB from 20kHz to 200kHz and then remains constant until the SSM-2220's gain-bandwidth limit is reached at about 8MHz. This compensation ensures the preamplifier's stability for gains from 100 to over 2000. Gain is set with resistors R_5 and R_6 where $A_{VCL} = 1 + R_5/R_6$. To limit the thermal noise contributed by the feedback loop impedance, R_6 should be no more than 10Ω (a 10Ω resistor creates about 0.4nV/$\sqrt{Hz}$ at +25°C).

The input stage current, 4mA, is established by the current source of Q_2, R_1, and a GaAsP LED. The LED is used as a 1.6V "zener" whose temperature coefficient is nearly identical to that of Q_2's base-emitter junction. This produces a temperature stable 1V drop across R_1 forcing 4mA to flow from Q_2's collector. The 4mA splits to 2mA in each side of the differential pair. With $h_{fe} = 150$ in the SSM-2220, input bias current will be about 13µA. Because the bias current is relatively large, the offset voltage created as it flows through unbalanced source impedances will quickly surpass the differential pair's offset, making necessary the offset trim, R_8. Low source impedances will reduce the offset drift as h_{fe} changes over temperature.

A low source impedance is also critical to maintain a low overall input noise. The 0.5nV/ $\sqrt{Hz}$ noise of the SSM-2220 input is equivalent to the thermal noise of a 15Ω resistor at +25°C.

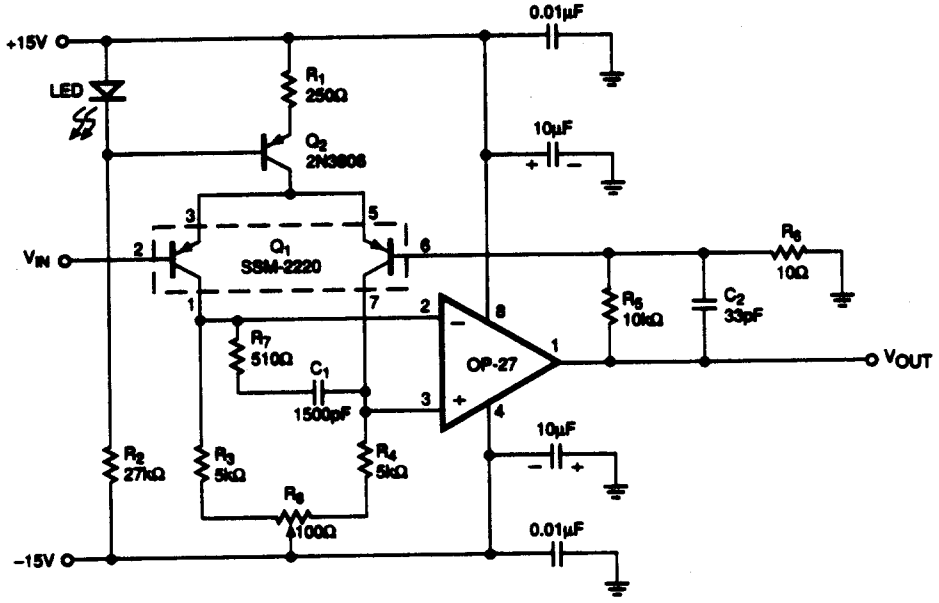

FIGURE 1: *This ultra low noise preamplifier shines new light on high-gain, low noise applications such as microphones, thermocouples, strain gauges, and magnetic pick-ups.*

Therefore, any transducer with a sourcing impedance greater than 15Ω will produce a noise which dominates that of the preamplifier. Figure 2 shows the total output noise of the preamplifier driven through a 10Ω source impedance. The analyzer displays total RMS noise voltage measured in a 0.03Hz bandwidth. The average broadband measurement is roughly 0.13μV on the vertical scale. Divided by the amplifier's closed-loop gain of 1000, this corresponds to 0.13nV at the preamp input, or expressed in nV/ Hz,

$$e_n = \frac{0.13nV}{\sqrt{0.03Hz}} = 0.75nV/\sqrt{Hz}$$

Taking into account the noise of two 10Ω source resistors, the noise attributable to the SSM-2220 is then,

$$0.75nV/\sqrt{Hz} = \sqrt{(e_{SSM})^2 + (0.4nV/\sqrt{Hz})^2 + (0.4nV/\sqrt{Hz})^2}$$

$$e_{SSM} = 0.49nV/\sqrt{Hz}$$

The 1/f noise corner frequency is also remarkably low, only about 0.25Hz. In the 20kHz audio bandwidth, the total RMS input-referred noise voltage contributed by the SSM-2220 differential pair is,

$$e_n = (0.5nV/\sqrt{Hz})(\sqrt{20kHz - 20Hz}) = 70.5nV_{RMS}$$

The thermal noise of a 10Ω source impedance in the same bandwidth is,

$$e_t = 1.28 \times 10^{-10}\sqrt{(10\Omega)(20kHz - 20Hz)} = 57nV_{RMS}$$

The total input referred noise of the preamplifier with 10Ω source impedances on each input is,

$$e_{total} = \sqrt{(70.5nV)^2 + (57nV)^2 + (57nV)^2} + 106nV_{RMS}$$

This is lower than the thermal noise of a single 50Ω resistor over the same bandwidth, $126nV_{RMS}$.

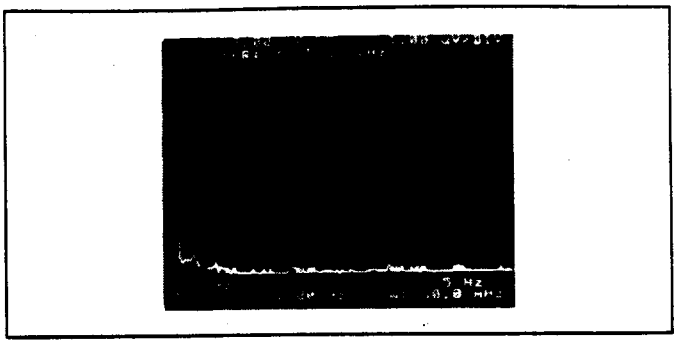

FIGURE 2: *The spectrum analyzer shows that, in a gain of 1000 with 10Ω source impedances, the SSM-2220 preamplifier has less than 0.5nV √Hz broadband noise and a 1/f noise corner of about 0.25Hz. Total harmonic distortion is less than 0.005% of a $10V_{p-p}$ signal from 20Hz to 20kHz.*