VERY LOW NOISE OPERATIONAL AMPLIFIER

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Applications

- High Precision Instrumentation
- Microphone Preamplifier
- Tape-Head Preamplifier
- Strain-Gage Amplifier

Features

- Very Low Voltage Noise .... $500pV/\sqrt{Hz}$
- High Gain-Bandwidth Product 150MHz
- High Open-Loop Gain .... 3×10^7
- High CMRR 130dB
- Very Low Offset Voltage Drift .... $<0.1\mu V/°C$

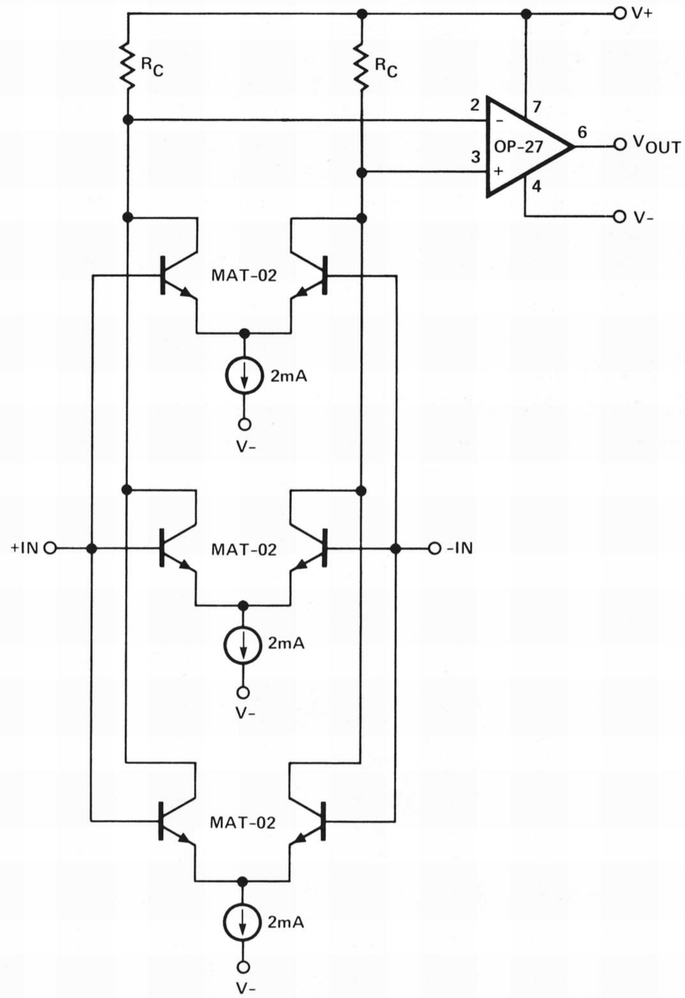
General Description

In situations where low output, low-impedance transducers are used, amplifiers must have very low voltage noise to maintain a good signal-to-noise ratio. The design presented in this application note is an operational amplifier with only $500pV/\sqrt{Hz}$ of broadband noise. The front end uses MAT-02 low-noise dual transistors to achieve this exceptional performance. The op amp has superb DC specifications compatible with high-precision transducer requirements, and AC specifications suitable for professional audio work.

Principle of Operation

The design configuration in Figure 1 uses an OP-27 op amp (already a low-noise design) preceded by an amplifier consisting of three parallel-connected MAT-02 dual transistors. Base spreading resistance (R_{bb}) generates thermal noise which is reduced by a factor of $\sqrt{3}$ when the input transistors are parallel connected. Schottky noise, the other major noise-generating mechanism, is minimized by using a relatively high collector current (1mA per device). High current ensures a low dynamic emitter resistance, but does increase the base current and its associated current noise. Higher current noise is relatively unimportant when low-impedance transducers are used.

Figure I
Simplified Schematic



Simplified Schematic for Very-Low-Noise Operational Amplifier

Original date of publication: February 1984.

Circuit Description

The detailed circuit is shown in Figure 2. A total input-stage emitter current of 6mA is provided by Q4. The transistor acts as a true current source to provide the highest possible common-mode rejection. R_1, R_2 and R_3 ensure that this current splits equally among the three input pairs. The constant current in Q4 is set by using the forward voltage of a GaAsP light-emitting diode as a reference. The difference between this voltage and the base-emitter voltage of a silicon transistor is predictable and constant (to within a few percent) over the military temperature range. The voltage difference, approximately 1V, is impressed across the emitter resistor R_{12} which produces a temperature-stable emitter current.

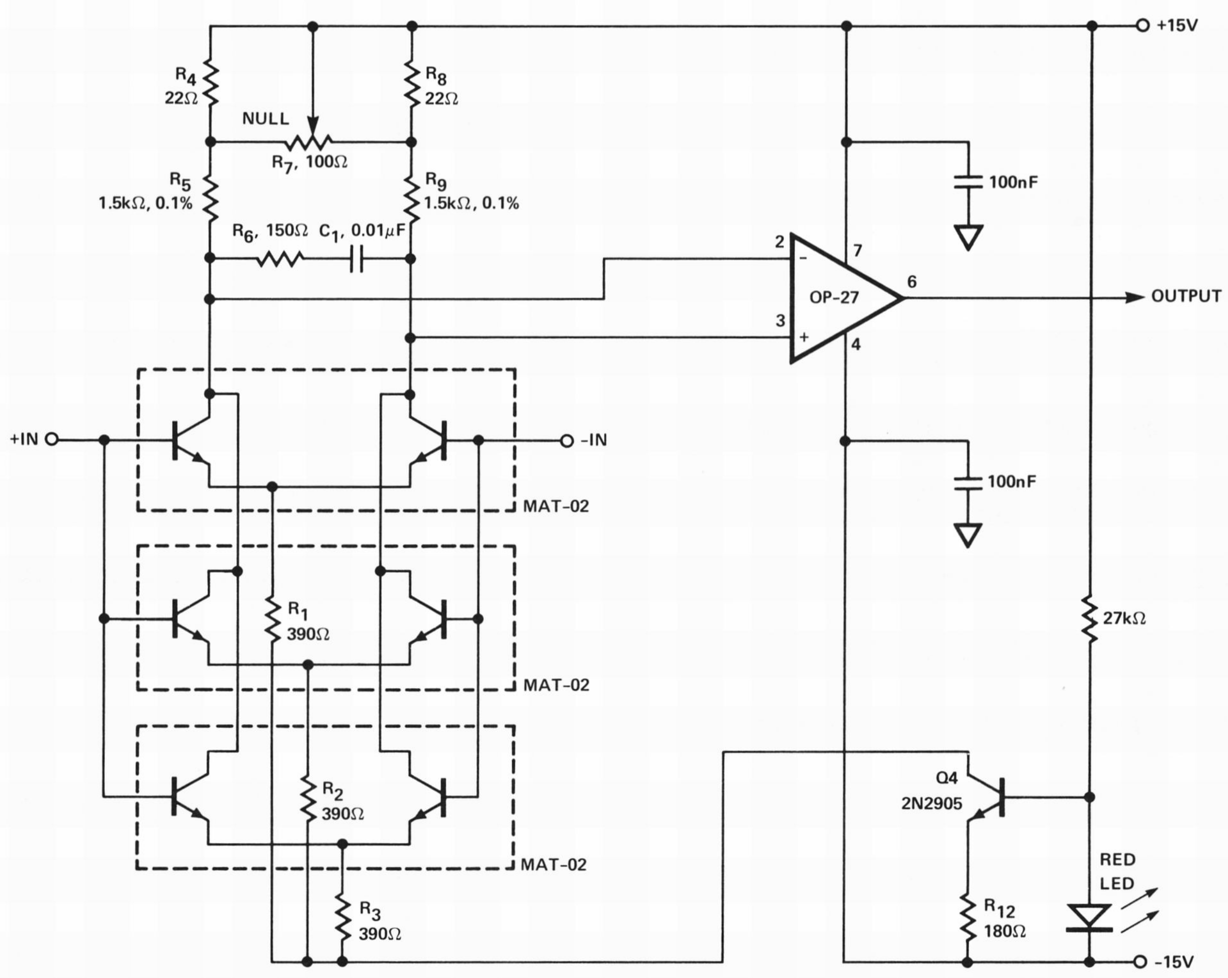
R_6 and C_1 provide phase compensation for the amplifier and are sufficient to ensure stability at gains of ten and above.

R_7 is an input offset trim that provides approximately $\pm300\mu V$ trim range. The very low drift characteristics of the MAT-02 make it possible to obtain drifts of less than $0.1\mu V/°C$ when the offset is nulled close to zero. If this trim is not required, the R_4, R_7, and R_8 network should be omitted and R_5/R_9 connected directly to V+.

Amplifier Performance

The measured performance of the op amp is summarized in Table 1. Figure 3 shows the broadband noise spectrum which is flat at about

Figure 2
Complete Amplifier Schematic



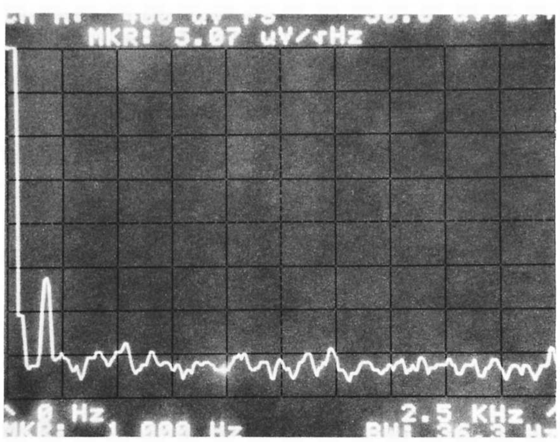
Very-Low-Noise Operational Amplifier

500pV/$\sqrt{\text{Hz}}$. Figure 4 shows the low-frequency spectrum which illustrates the low 1/f noise corner at 1.5Hz. The low-frequency characteristic in the time domain from 0.1Hz to 10Hz is shown in Figure 5; peak-to-peak amplitude is less than 40nV.

Table I
Measured Performance of the Op Amp

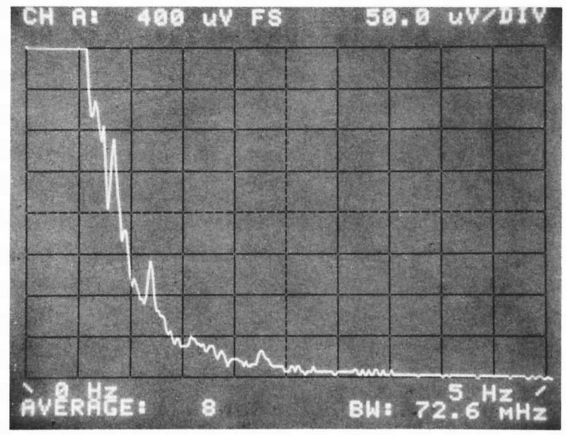
Input Noise Voltage Density at 1kHz		500pV/$\sqrt{\text{Hz}}$
Input Noise Voltage from 0.1Hz to 10Hz		$40nV_{p\text{-}p}$
Input Noise Current at 1kHz		1.5pA/$\sqrt{\text{Hz}}$
Gain-Bandwidth	G = 10 G = 100 G = 1000	3MHz 600kHz 150kHz
Slew Rate		2V/μs
Open-Loop Gain		3×10^7
Common-Mode Rejection		130dB
Input Bias Current		3μA
Supply Current		10mA
Nulled TCV_{OS}		0.1μV/°C Max
T.H.D. at 1kHz	G = 1000	0.002%

Figure 3
Spectrum Analyzer Display — Broadband



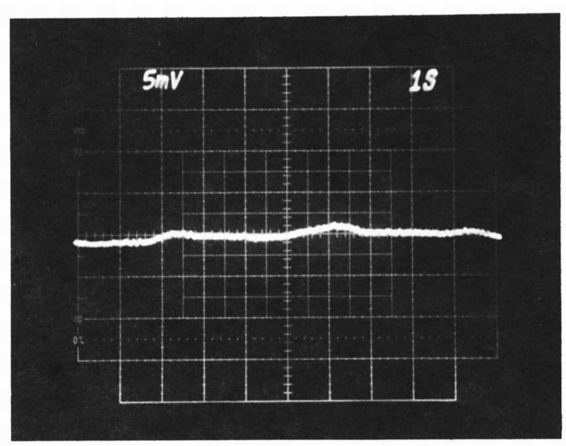
Spectrum analyzer display of broadband noise with a gain of 10,000.
Horizontal axis = 0 to 2.5kHz.
Normalized vertical axis = 830pV/$\sqrt{\text{Hz}}$ R.T.I.
e_n = 507pV/$\sqrt{\text{Hz}}$ at 1kHz.

Figure 4
Spectrum Analyzer Display — Low Frequency



Low frequency noise spectrum at a gain of 10,000 showing a low 1.5Hz noise corner.

Figure 5
Oscilloscope Display



Peak-to-peak noise from 0.1 to 10Hz.
Overall gain is 100,000.

Conclusion:

Using MAT-02 matched transistor pairs operating at a high current level, it is possible to construct a high-performance, low-noise operational amplifier. The circuit uses a minimum of components and achieves performance levels impractical with monolithic amplifiers.

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