



*Audio Silicon
Specialists™*

T.43-25

SSM-2210

AUDIO DUAL MATCHED
NPN TRANSISTOR

Precision Monolithics Inc.

FEATURES

- Very Low Voltage Noise @ 100Hz, $1\text{nV}/\sqrt{\text{Hz}}$ MAX
- Excellent Current Gain Match 0.5% TYP
- Tight V_{BE} Match (V_{OS}) 200 μV MAX
- Outstanding Offset Voltage Drift 0.03 $\mu\text{V}/^\circ\text{C}$ TYP
- High Gain-Bandwidth Product 200MHz TYP
- Low Cost
- Direct Replacement For LM394BN/CN

The SSM-2210 is also an ideal choice for accurate and reliable current biasing and mirroring circuits. Furthermore, since a current mirror's accuracy degrades exponentially with mismatches of V_{BE} 's between transistor pairs, the low V_{OS} of the SSM-2210 will preclude offset trimming in most circuit applications.

The SSM-2210 is offered in an 8-pin epoxy DIP and 8-pin SO, its performance and characteristics are guaranteed over the extended industrial temperature range of -40°C to $+85^\circ\text{C}$.

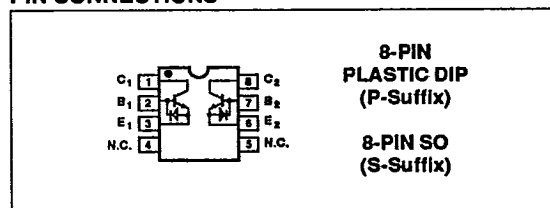
ORDERING INFORMATION

PACKAGE		OPERATING TEMPERATURE RANGE
PLASTIC 8-PIN	SO 8-PIN	
SSM2210P	SSM2210S†	XIND*

* XIND = -40°C to $+85^\circ\text{C}$

† For availability on SO package, contact your local sales office.

PIN CONNECTIONS



GENERAL DESCRIPTION

The SSM-2210 is a dual NPN matched transistor pair specifically designed to meet the requirements of ultra-low noise audio systems.

With its extremely low input base spreading resistance ($r_{bb'}$ is typically 28Ω), and high current gain (h_{FE} typically exceeds 600 @ $I_C = 1\text{mA}$), systems implementing the SSM-2210 can achieve outstanding signal-to-noise ratios. This will result in superior performance compared to systems incorporating commercially available monolithic amplifiers.

The equivalent input voltage noise of the SSM-2210 is typically only $0.8\text{nV}/\sqrt{\text{Hz}}$ over the entire audio bandwidth of 20Hz to 20KHz.

Excellent matching of the current gain (Δh_{FE}) to about 0.5% and low V_{OS} of less than $50\mu\text{V}$ (typical) make it ideal for symmetrically balanced designs which reduce high order amplifier harmonic distortion.

Stability of the matching parameters is guaranteed by protection diodes across the base-emitter junction. These diodes prevent degradation of Beta and matching characteristics due to reverse biasing of the base-emitter junction.

ABSOLUTE MAXIMUM RATINGS

Collector Current (I_C)	20mA
Emitter Current (I_E)	20mA
Collector-Collector Voltage (BV_{CC})	40V
Collector-Base Voltage (BV_{CBO})	40V
Collector-Emitter Voltage (BV_{CEO})	40V
Emitter-Emitter Voltage (BV_{EE})	40V
Operating Temperature Range	-40°C to $+85^\circ\text{C}$
Storage Temperature	-65°C to $+125^\circ\text{C}$
Junction Temperature	-65°C to $+150^\circ\text{C}$
Lead Temperature (Soldering, 60 sec)	$+300^\circ\text{C}$

PACKAGE TYPE	θ_{JA} (NOTE 1)	θ_{JC}	UNITS
8-Pin Plastic DIP (P)	110	50	$^\circ\text{C}/\text{W}$
8-Pin SO (S)	160	44	$^\circ\text{C}/\text{W}$

NOTE:

1. θ_{JA} is specified for worst case mounting conditions, i.e., θ_{JA} is specified for device in socket for P-DIP packages; θ_{JA} is specified for device soldered to printed circuit board for SO packages.

ELECTRICAL CHARACTERISTICS at $V_{CB} = 15V$, $I_C = 10\mu A$, $T_A = 25^\circ C$, unless otherwise noted.

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PARAMETER	SYMBOL	CONDITIONS	SSM-2210			UNITS
			MIN	TYP	MAX	
Current Gain	h_{FE}	$I_C = 1mA$ (Note 1) $I_C = 10\mu A$	300 200	605 550	—	—
Current Gain Match	Δh_{FE}	$10\mu A \leq I_C \leq 1mA$ (Note 2)	—	0.5	5	%
Noise Voltage Density	e_n	$I_C = 1mA$, $V_{CB} = 0$ (Note 3) $f_o = 10Hz$ $f_o = 100Hz$ $f_o = 1kHz$ $f_o = 10kHz$	— — — —	1.8 0.9 0.85 0.85	2 1 1 1	nV/√Hz
Offset Voltage	V_{OS}	$V_{CB} = 0$ $I_C = 1mA$	—	10	200	μV
Offset Voltage Change vs V_{CB}	$\Delta V_{OS}/\Delta V_{CB}$	$0 \leq V_{CB} \leq V_{MAX}$ (Note 4) $1\mu A \leq I_C \leq 1mA$ (Note 5)	—	10	50	μV
Offset Voltage Change vs Collector Current	$\Delta V_{OS}/\Delta I_C$	$V_{CB} = 0V$ $1\mu A \leq I_C \leq 1mA$ (Note 5)	—	5	70	μV
Breakdown Voltage	BV_{CEO}		40	—	—	V
Gain-Bandwidth Product	f_T	$I_C = 10mA$, $V_{CE} = 10V$	—	200	—	MHz
Collector-Base Leakage Current	I_{CBO}	$V_{CB} = V_{MAX}$	—	25	500	pA
Collector-Collector Leakage Current	I_{CC}	$V_{CC} = V_{MAX}$ (Notes 6, 7)	—	35	500	pA
Collector-Emitter Leakage Current	I_{CES}	$V_{CE} = V_{MAX}$ (Notes 6, 7) $V_{BE} = 0$	—	35	500	pA
Input Bias Current	I_B	$I_C = 10\mu A$	—	—	50	nA
Input Offset Current	I_{OS}	$I_C = 10\mu A$	—	—	6.2	nA
Collector Saturation Voltage	$V_{CE(SAT)}$	$I_C = 1mA$ $I_B = 100\mu A$	—	0.05	0.2	V
Output Capacitance	C_{OB}	$V_{CB} = 15V$, $I_E = 0$	—	23	—	pF
Bulk Resistance	r_{BE}	$10\mu A \leq I_C \leq 10mA$ (Note 6)	—	0.3	1.8	Ω
Collector-Collector Capacitance	C_{CC}	$V_{CC} = 0$	—	35	—	pF

NOTES:

1. Current gain is guaranteed with Collector-Base Voltage (V_{CB}) swept from 0 to V_{MAX} at the indicated collector currents.2. Current Gain Match (Δh_{FE}) is defined as:

$$\Delta h_{FE} = \frac{100(\Delta I_B)(h_{FEmin})}{I_C}$$

3.. Noise Voltage Density is guaranteed, but not 100% tested.

4. This is the maximum change in V_{OS} as V_{CB} is swept from 0V to 40V.5. Measured at $I_C = 10\mu A$ and guaranteed by design over the specified range of I_C .

6. Guaranteed by design.

7. I_{CC} and I_{CES} are verified by measurement of I_{CBO} .

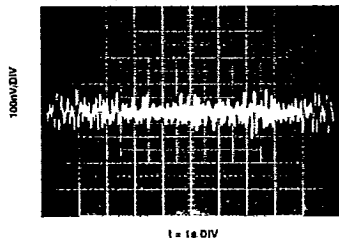
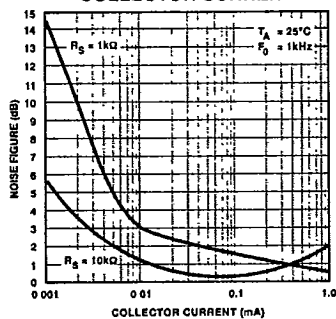
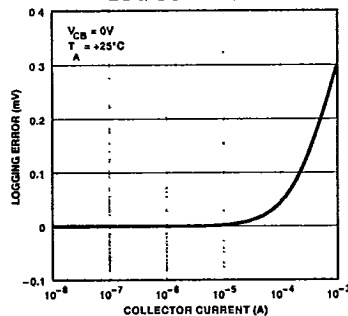
ELECTRICAL CHARACTERISTICS at $V_{CB} = 15V$, $-40^{\circ}C \leq T_A \leq +85^{\circ}C$, unless otherwise noted.*T-43-25*

PARAMETER	SYMBOL	CONDITIONS	SSM-2210			UNITS
			MIN	TYP	MAX	
Current Gain	h_{FE}	$I_C = 1mA$ (Note 1) $I_C = 10\mu A$	300 200	—	—	
Offset Voltage	V_{OS}	$V_{CB} = 0$ $I_C = 1mA$	—	—	220	μV
Average Offset Voltage Drift	TCV_{OS}	$10\mu A \leq I_C \leq 1mA$, $0 \leq V_{CB} \leq V_{MAX}$ (Note 2) V_{OS} Trimmed to Zero (Note 3)	—	0.08 0.03	1 0.3	$\mu V/^{\circ}C$
Input Bias Current	I_B	$I_C = 10\mu A$	—	—	50	nA
Input Offset Current	I_{OS}	$I_C = 10\mu A$	—	—	13	nA
Input Offset Current Drift	TCI_{OS}	$I_C = 10\mu A$ (Note 4)	—	40	150	$pA/^{\circ}C$
Collector-Base Leakage Current	I_{CBO}	$V_{CB} = V_{MAX}$	—	3	—	nA
Collector-Emitter Leakage Current	I_{CES}	$V_{CE} = V_{MAX}$, $V_{BE} = 0$	—	4	—	nA
Collector-Collector Leakage Current	I_{CC}	$V_{CC} = V_{MAX}$	—	4	—	nA

NOTES:

- Current gain is guaranteed with Collector-Base Voltage (V_{CB}) swept from 0 to V_{MAX} at the indicated collector current.
- Guaranteed by V_{OS} test ($TCV_{OS} = \frac{V_{OS}}{T} \times V_{BE}$), $T = 298K$ for $T_A = 25^{\circ}C$.
- The initial zero offset voltage is established by adjusting the ratio of I_{C1} to I_{C2} at $T_A = 25^{\circ}C$. This ratio must be held to 0.003% over the entire temperature range. Measurements are taken at the temperature extremes and $25^{\circ}C$.
- Guaranteed by design.

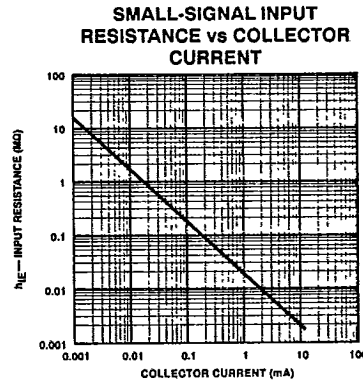
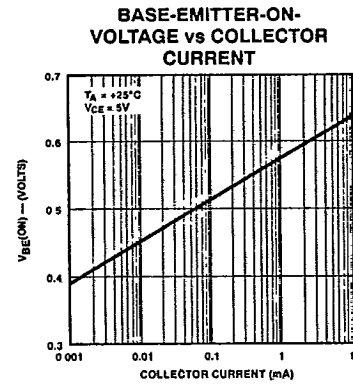
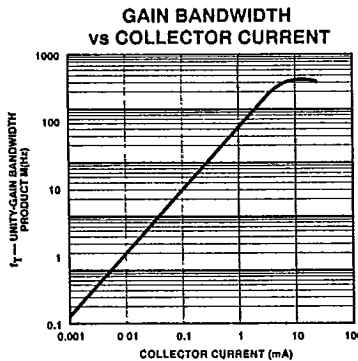
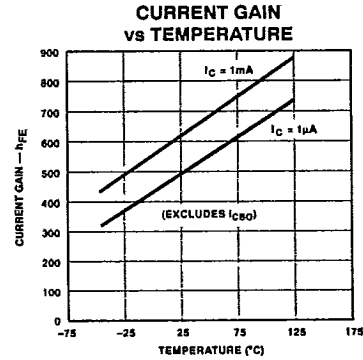
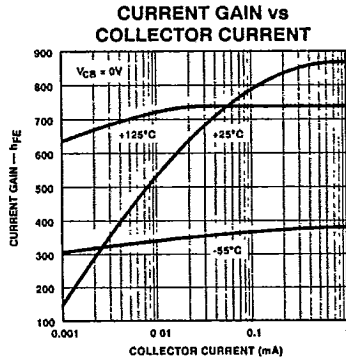
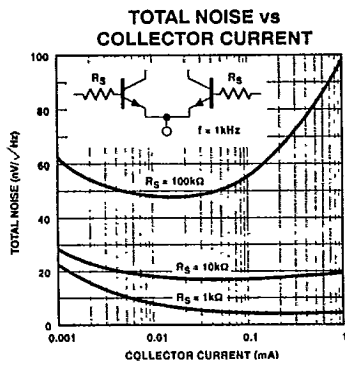
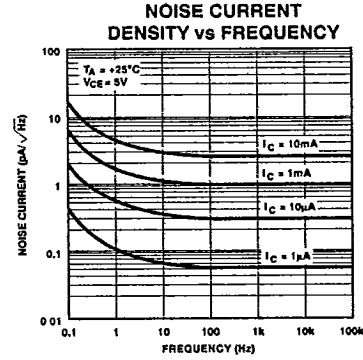
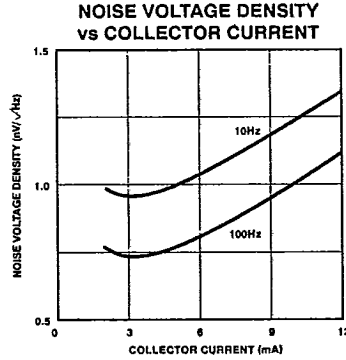
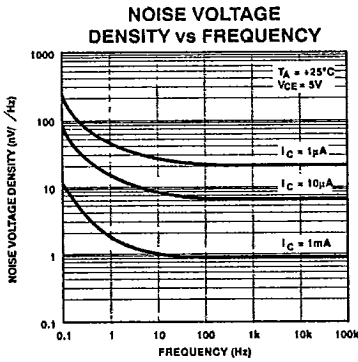
TYPICAL PERFORMANCE CHARACTERISTICS

LOW FREQUENCY NOISE
(0.1 Hz TO 10 Hz)NOISE FIGURE vs
COLLECTOR CURRENTEMITTER-BASE
LOG CONFORMITY



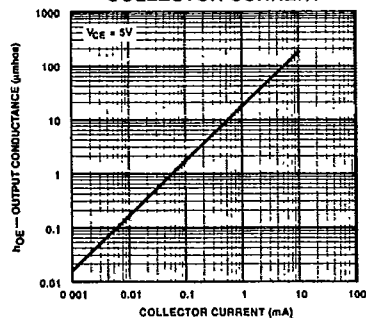
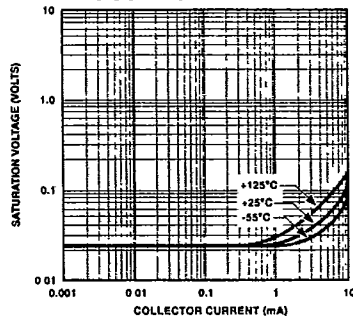
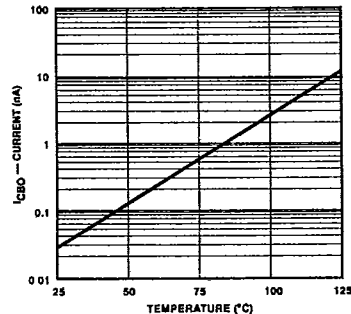
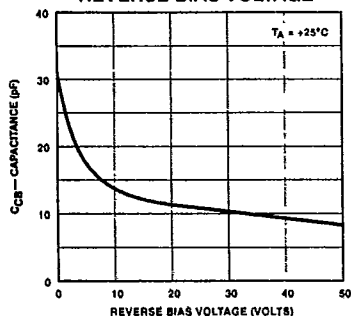
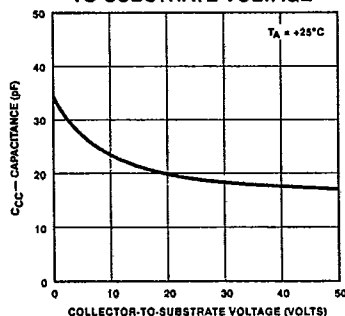
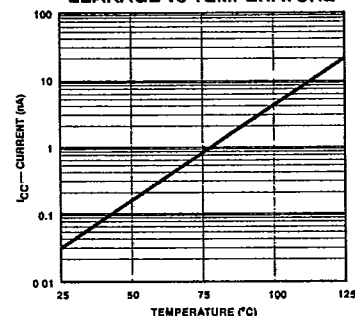
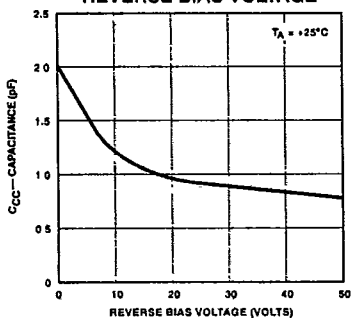
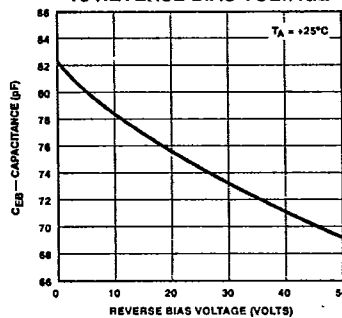
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TYPICAL PERFORMANCE CHARACTERISTICS





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TYPICAL PERFORMANCE CHARACTERISTICS *Continued*SMALL-SIGNAL OUTPUT
CONDUCTANCE vs
COLLECTOR CURRENTSATURATION VOLTAGE
vs COLLECTOR CURRENTCOLLECTOR-TO-BASE
LEAKAGE vs TEMPERATURECOLLECTOR-BASE
CAPACITANCE vs
REVERSE BIAS VOLTAGECOLLECTOR-TO-COLLECTOR
CAPACITANCE vs COLLECTOR-
TO-SUBSTRATE VOLTAGECOLLECTOR-TO-COLLECTOR
LEAKAGE vs TEMPERATURECOLLECTOR-TO-COLLECTOR
CAPACITANCE vs
REVERSE BIAS VOLTAGEEMITTER-BASE CAPACITANCE
vs REVERSE BIAS VOLTAGE



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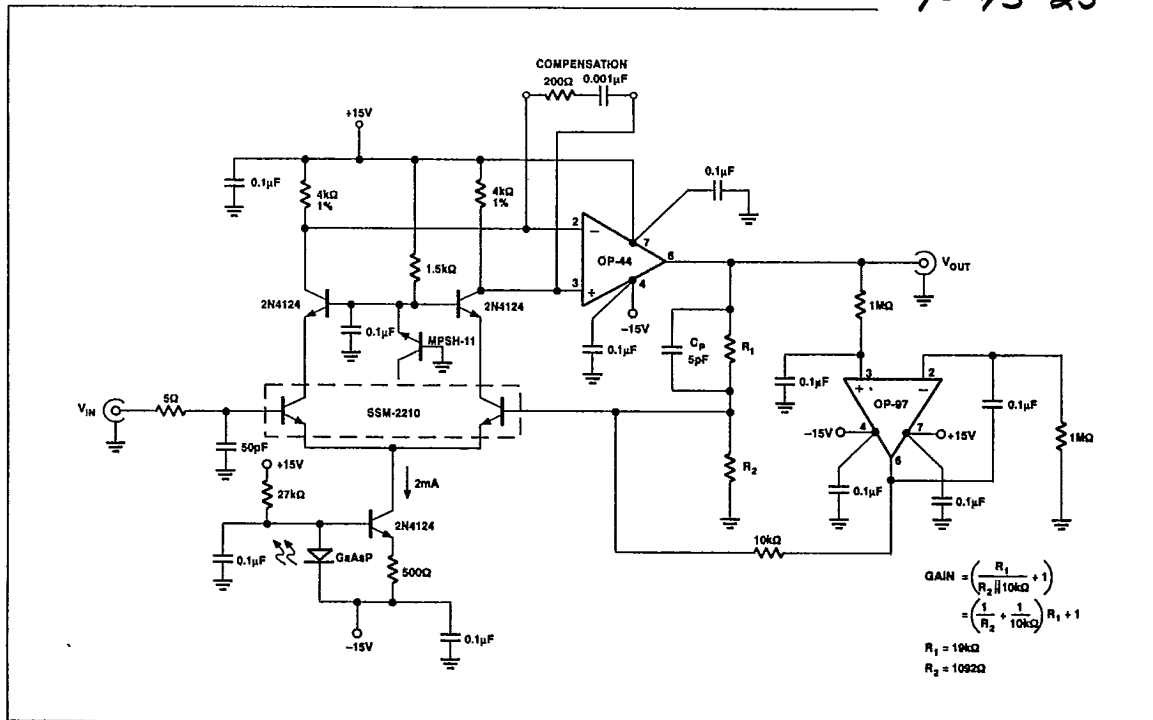


FIGURE 1: A Low-Noise Wideband Amplifier

A VERY LOW-NOISE, WIDEBAND AMPLIFIER

Figure 1 illustrates a low-noise, wide-band amplifier consisting of a high slew rate JFET amplifier, the OP-44, and a cascoded differential preamplifier using the SSM-2210 transistor pair. The SSM-2210 achieves extremely low input voltage noise performance ($e_n \sim 0.7\text{nV}/\sqrt{\text{Hz}}$) via a large geometry transistor design which minimizes the base-spreading resistance. This, however, results in relatively higher collector-to-base capacitance (C_{OB}) than ordinary small-signal transistors. For high gain stages, the Miller effect of C_{OB} will limit the voltage gain bandwidth; resorting to a cascode configuration reduces the Miller feedback capacitance, improving stability, bandwidth, and reducing distortion due to base-width modulation. Additionally, cascoding

does not increase the noise figure of the overall amplifier system and reduces the high order harmonic distortion.

The circuit in Figure 1 balances the impedance symmetrically in the differential preamp. This serves to reject common-mode noise injected from the power supplies.

Although the SSM-2210's transistors are closely matched, an offset voltage error can still be created by imbalanced source impedances. Accordingly, a precision low-power amplifier (OP-97), configured as a noninverting integrator is implemented which servo-out the offset voltage to less than $100\mu\text{V}$ referred to the input of the amplifier.

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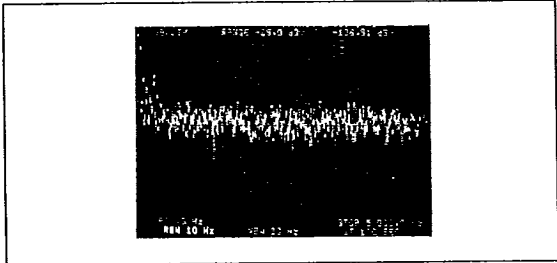


FIGURE 2: Spectrum Analyzer Display of Wideband Amplifier Noise Spectral Density. $e_n \approx 1.7\text{nV}/\sqrt{\text{Hz}}$

Figure 2 illustrates the composite amplifier's low voltage noise density of only $1.7\text{nV}/\sqrt{\text{Hz}}$ @ 1kHz . Figure 3 and Figure 4 show the excellent pulse response and an extremely low distortion of only 0.0015% over the audio bandwidth, respectively.

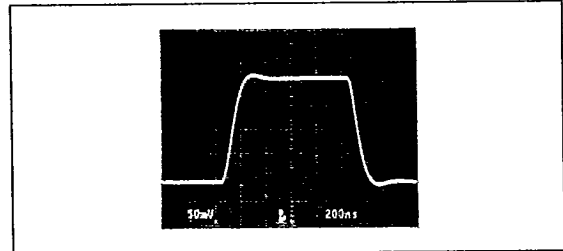


FIGURE 3: Small-Signal Pulse Response

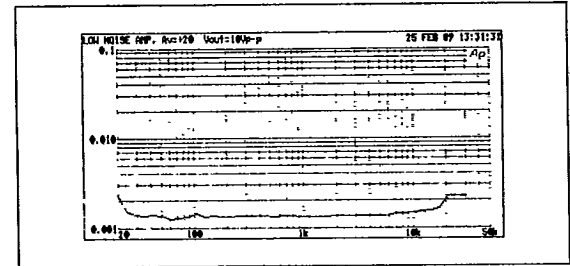


FIGURE 4: Total Harmonic Distortion vs Frequency

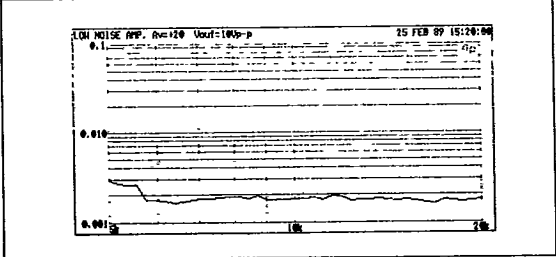


FIGURE 5: D.I.M. vs Frequency

A special test was performed to check for dynamic or transient intermodulation distortion. A square wave of 3.15kHz is mixed with a sine wave probe tone, and the resulting intermodulation distortion was found to be less than 0.002% (Figure 5). This is an impressively low value considering the amplifier's gain of 26dB . Interestingly, the GBW product of the composite amplifier was 63MHz which is much larger than that of the OP-44 by itself. This is made possible by the SSM-2210's cascoded preamplifier having a wide bandwidth and large signal gain.

The measured performance of this amplifier is summarized in Table 1.

TABLE 1: Measured Performance of the Low-Noise Wideband Amplifier

Slew-Rate	40V/ μs
Gain-Bandwidth	63.6 MHz
Input Noise Voltage Density @ 1kHz	1.7nV/ $\sqrt{\text{Hz}}$
Output Voltage Swing	$\pm 13\text{V}$
Input Offset Voltage	10 μV



500pV/ $\sqrt{\text{Hz}}$ AMPLIFIER

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 is an operational amplifier with only 500pV/ $\sqrt{\text{Hz}}$ of broadband noise. The front end uses SSM-2210 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 6 uses an OP-27 op amp (already a low-noise design) preceded by an amplifier consisting of three parallel-connected SSM-2210 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.

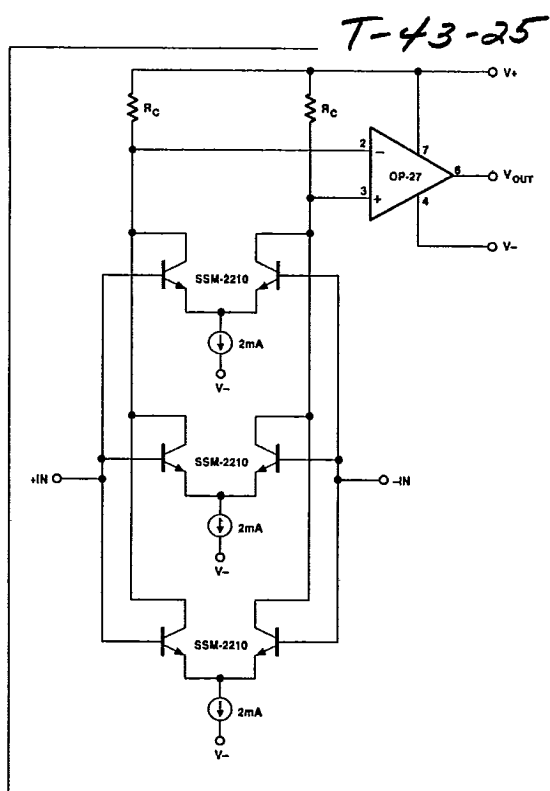


FIGURE 6: Simplified Schematic



CIRCUIT DESCRIPTION

The detailed circuit is shown in Figure 7. A total input-stage emitter current of 6mA is provided by Q_4 . 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 Q_4 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.

R₇ is an input offset trim that provides approximately $\pm 300\mu\text{V}$ trim range. The very low drift characteristics of the SSM-2210 make it possible to obtain drifts of less than $0.1\mu\text{V}/^\circ\text{C}$ when the offset is nulled close to zero. If this trim is not required, the R₄, R₇, and R₉ network should be omitted and R₅/R₈ connected directly to V₊.

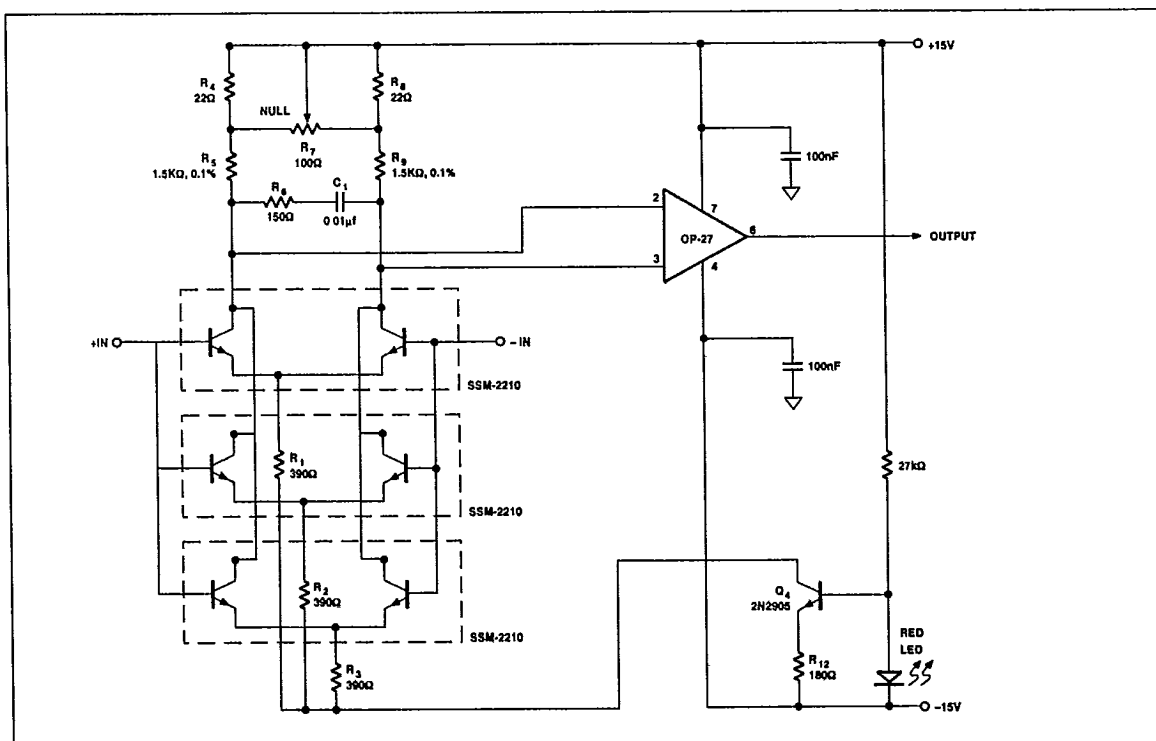


FIGURE 7: Complete Amplifier Schematic



AMPLIFIER PERFORMANCE

The measured performance of the op amp is summarized in Table 2. Figure 8 shows the broadband noise spectrum which is flat at about 500pV/√Hz. Figure 9 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 10; peak-to-peak amplitude is less than 40nV.

TABLE 2: Measured Performance of the Op Amp

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

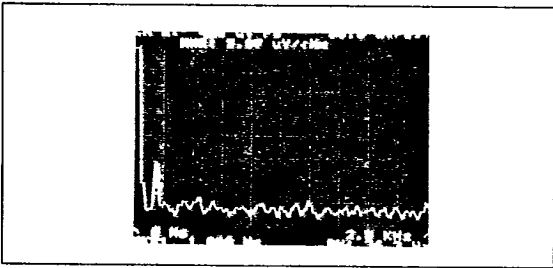


FIGURE 8: Spectrum Analyzer Display – Broadband

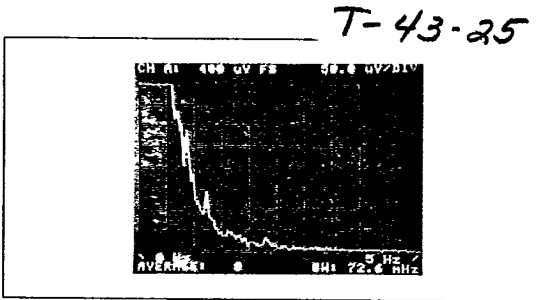


FIGURE 9: Spectrum Analyzer Display – Low Frequency

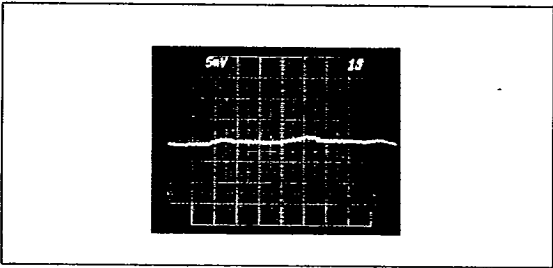


FIGURE 10: Oscilloscope Display

CONCLUSION

Using SSM-2210 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 exceeding monolithic amplifiers.



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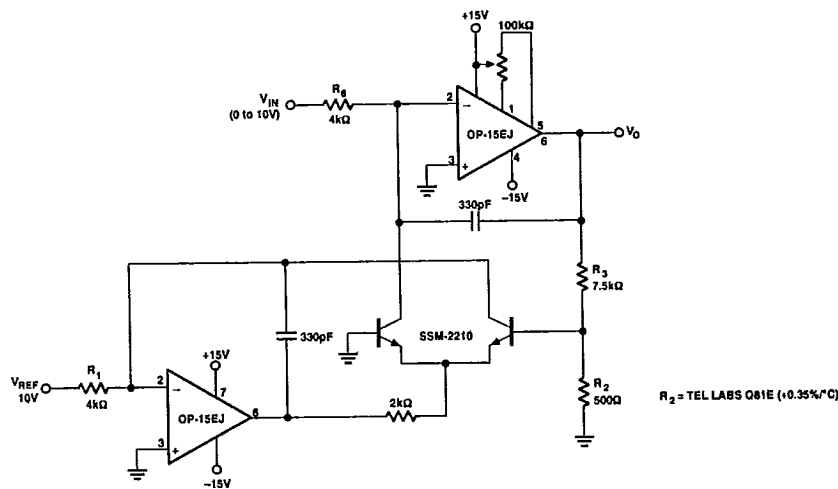


FIGURE 11: Fast Logarithmic Amplifier

FAST LOGARITHMIC AMPLIFIER

The circuit of Figure 11 is a modification of a standard logarithmic amplifier configuration. Running the SSM-2210 at 2.5mA per side (full-scale) allows a fast response with wide dynamic range. The circuit has a 7 decade current range, a 5 decade voltage range, and is capable of 2.5μs settling time to 1% with a 1 to 10V step.

The output follows the equation:

$$V_O = \frac{R_3 + R_2}{R_2} \frac{kT}{q} \ln \frac{V_{REF}}{V_{IN}}$$

To compensate for the temperature dependence of the kT/q term, a resistor with a positive 0.35%/°C temperature coefficient is chosen for R_2 .

The output is inverted with respect to the input, and is nominally -1V/decade using the component values indicated.