



MAT-03

LOW NOISE, MATCHED,
DUAL PNP TRANSISTOR

Precision Analog Devices, Inc.

FEATURES

- Dual Matched PNP Transistor
- Low Offset Voltage 100 μ V Max
- Low Noise 1nV/ $\sqrt{\text{Hz}}$ @ 1kHz Max
- High Gain 100 Min
- High Gain Bandwidth 190MHz Typ
- Tight Gain Matching 3% Max
- Excellent Logarithmic Conformance $r_{BE} \approx 0.3\Omega$ Typ
- Available in Die Form

ORDERING INFORMATION†

$T_A = +25^\circ\text{C}$ $V_{OS} \text{ MAX}$ (μV)	PACKAGE		OPERATING TEMPERATURE RANGE
	TO-78	LCC	
100	MAT03AH*	MAT03ARC/883	MIL
100	MAT03EH	—	XIND
200	MAT03FH	—	XIND

* For devices processed in total compliance to MIL-STD-883, add /883 after part number. Consult factory for 883 data sheet.

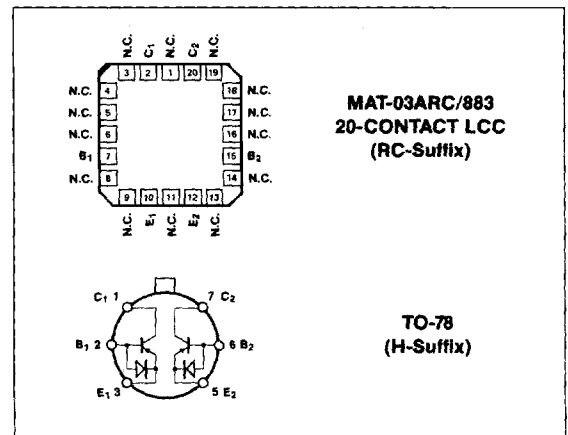
† Burn-in is available on industrial temperature range parts. For ordering information, see PMI's Data Book, Section 2.

GENERAL DESCRIPTION

The MAT-03 dual monolithic PNP transistor offers excellent parametric matching and high frequency performance. Low noise characteristics (1nV/ $\sqrt{\text{Hz}}$ Max @ 1kHz), high bandwidth (190MHz typical), and low offset voltage (100 μ V Max), makes the MAT-03 an excellent choice for demanding preamplifier applications. Tight current gain matching (3% Max mismatch) and high current gain (100 Min), over a wide range of collector current, makes the MAT-03 an excellent choice for current mirrors. A low value of bulk resistance (typically 0.3 Ω) also makes the MAT-03 an ideal component for applications requiring accurate logarithmic conformance.

Each transistor is individually tested to data sheet specifications. Device performance is guaranteed at 25°C and over the extended industrial and military temperature ranges. To insure the long-term stability of the matching parameters, internal protection diodes across the base-emitter junction clamp any reverse base-emitter junction potential. This prevents a base-emitter breakdown condition which can result in degradation of gain and matching performance due to excessive breakdown current.

PIN CONNECTIONS



**ABSOLUTE MAXIMUM RATINGS** (Note 1)

Collector-Base Voltage (V_{CB0})	36V
Collector-Emitter Voltage (V_{CE0})	36V
Collector-Collector Voltage (V_{CC})	36V
Emitter-Emitter Voltage (V_{EE})	36V
Collector Current (I_C)	20mA
Emitter Current (I_E)	20mA
Total Power Dissipation	
Ambient Temperature $\leq 70^\circ\text{C}$ (Note 2)	500mW
Operating Temperature Range	
MAT-03A	-55°C to $+125^\circ\text{C}$
MAT-03E/F	-40°C to $+85^\circ\text{C}$

Operating Junction Temperature	-55°C to $+150^\circ\text{C}$
Storage Temperature	-65°C to $+150^\circ\text{C}$
Lead Temperature (Soldering, 60 sec)	$+300^\circ\text{C}$
Junction Temperature	-65°C to $+150^\circ\text{C}$

NOTES:

1. Absolute maximum ratings apply to both DICE and packaged devices.
2. Rating applies to TO-78 not using a heat sink, and LCC; devices in free air only. For TO-78, derate linearly at 6.3mW/ $^\circ\text{C}$ above 70°C ambient temperature; for LCC, derate at 7.8mW/ $^\circ\text{C}$.

ELECTRICAL CHARACTERISTICS at $T_A = +25^\circ\text{C}$, unless otherwise noted.

PARAMETER	SYMBOL	CONDITIONS	MAT-03A			MAT-03E			MAT-03F			UNITS
			MIN	TYP	MAX	MIN	TYP	MAX	MIN	TYP	MAX	
Current Gain (Note 1)	h_{FE}	$V_{CB} = 0\text{V}, -36\text{V}$										
		$I_C = 1\text{mA}$	100	165	—	100	165	—	80	165	—	
		$I_C = 100\mu\text{A}$	90	150	—	90	150	—	70	150	—	
		$I_C = 10\mu\text{A}$	80	120	—	80	120	—	60	120	—	
Current Gain Matching (Note 2)	Δh_{FE}	$I_C = 100\mu\text{A}, V_{CB} = 0\text{V}$	—	0.5	3	—	0.5	3	—	0.5	6	%
Offset Voltage (Note 3)	V_{OS}	$V_{CB} = 0\text{V}, I_C = 100\mu\text{A}$	—	40	100	—	40	100	—	40	200	μV
Offset Voltage Change vs Collector Voltage	$\Delta V_{OS}/\Delta V_{CB}$	$I_C = 100\mu\text{A}$ $V_{CB1} = 0\text{V}$ $V_{CB2} = -36\text{V}$	—	11	150	—	11	150	—	11	200	μV
Offset Voltage Change vs Collector Current	$\Delta V_{OS}/\Delta I_C$	$V_{CB} = 0\text{V}$ $I_{C1} = 10\mu\text{A}, I_{C2} = 1\text{mA}$	—	12	50	—	12	50	—	12	75	μV
Bulk Resistance	r_{BE}	$V_{CB} = 0\text{V}$, $10\mu\text{A} \leq I_C \leq 1\text{mA}$	—	0.3	0.75	—	0.3	0.75	—	0.3	0.75	Ω
Offset Current	I_{OS}	$I_C = 100\mu\text{A}, V_{CB} = 0\text{V}$	—	6	35	—	6	35	—	6	45	nA
Collector-Base Leakage Current	I_{CB0}	$V_{CB} = -36\text{V} = V_{MAX}$	—	50	200	—	50	200	—	50	400	pA
Noise Voltage Density (Note 4)	e_N	$I_C = 1\text{mA}, V_{CB} = 0$										
		$f_o = 10\text{Hz}$	—	0.8	2	—	0.8	—	—	0.8	—	
		$f_o = 100\text{Hz}$	—	0.7	1	—	0.7	—	—	0.7	—	
		$f_o = 1\text{kHz}$	—	0.7	1	—	0.7	—	—	0.7	—	
		$f_o = 10\text{kHz}$	—	0.7	1	—	0.7	—	—	0.7	—	$\text{nV}/\sqrt{\text{Hz}}$
Collector Saturation Voltage	$V_{CE(SAT)}$	$I_C = 1\text{mA}, I_B = 100\mu\text{A}$	—	0.025	0.1	—	0.025	0.1	—	0.025	0.1	V

NOTES:

1. Current gain is measured at collector-base voltages (V_{CB}) swept from 0 to V_{MAX} at indicated collector current. Typical values are measured at $V_{CB} = 0\text{V}$.
2. Current gain matching (Δh_{FE}) is defined as:

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

3. Offset voltage is defined as:
 $V_{OS} = V_{BE1} - V_{BE2}$,
where V_{OS} is the differential voltage for

$$I_{C1} = I_{C2}; V_{OS} = V_{BE1} - V_{BE2} = \frac{KT}{q} \ln \left(\frac{I_{C1}}{I_{C2}} \right)$$

4. Sample tested. Noise tested and specified as equivalent input voltage for each transistor.

MATCHED TRANSISTORS

**ELECTRICAL CHARACTERISTICS** at $-55^{\circ}\text{C} \leq T_A \leq +125^{\circ}\text{C}$, unless otherwise noted.

PARAMETER	SYMBOL	CONDITIONS	MAT-03A			UNITS
			MIN	TYP	MAX	
Current Gain	h_{FE}	$V_{CB} = 0\text{V}, -36\text{V}$				
		$I_C = 1\text{mA}$	70	110	—	
		$I_C = 100\mu\text{A}$	60	100	—	
		$I_C = 10\mu\text{A}$	50	85	—	
Offset Voltage	V_{OS}	$I_C = 100\mu\text{A}, V_{CB} = 0\text{V}$	—	40	150	μV
Offset Voltage Drift (Note 1)	TCV_{OS}	$I_C = 100\mu\text{A}, V_{CB} = 0\text{V}$	—	0.3	0.5	$\mu\text{V}/^{\circ}\text{C}$
Offset Current	I_{OS}	$I_C = 100\mu\text{A}, V_{CB} = 0\text{V}$	—	15	85	nA
Breakdown Voltage	BV_{CEO}		36	54	—	V

NOTE:

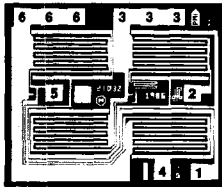
- Guaranteed by V_{OS} test ($TCV_{OS} = V_{OS}/T$ for $V_{OS} \ll V_{BE}$)
where $T = 298^{\circ}\text{K}$ for $T_A = 25^{\circ}\text{C}$.

ELECTRICAL CHARACTERISTICS at $-40^{\circ}\text{C} \leq T_A \leq +85^{\circ}\text{C}$, unless otherwise noted.

PARAMETER	SYMBOL	CONDITIONS	MAT-03E			MAT-03F			UNITS
			MIN	TYP	MAX	MIN	TYP	MAX	
Current Gain	h_{FE}	$V_{CB} = 0\text{V}, -36\text{V}$							
		$I_C = 1\text{mA}$	70	120	—	60	120	—	
		$I_C = 100\mu\text{A}$	60	105	—	50	105	—	
		$I_C = 10\mu\text{A}$	50	90	—	40	90	—	
Offset Voltage	V_{OS}	$I_C = 100\mu\text{A}, V_{CB} = 0\text{V}$	—	30	135	—	30	265	μV
Offset Voltage Drift (Note 1)	TCV_{OS}	$I_C = 100\mu\text{A}, V_{CB} = 0\text{V}$	—	0.3	0.5	—	0.3	1.0	$\mu\text{V}/^{\circ}\text{C}$
Offset Current	I_{OS}	$I_C = 100\mu\text{A}, V_{CB} = 0\text{V}$	—	10	85	—	10	200	nA
Breakdown Voltage	BV_{CEO}		36	—	—	36	—	—	V

NOTE:

- Guaranteed by V_{OS} test ($TCV_{OS} = V_{OS}/T$ for $V_{OS} \ll V_{BE}$)
where $T = 298^{\circ}\text{K}$ for $T_A = 25^{\circ}\text{C}$.

DICE CHARACTERISTICS


DIE SIZE 0.070 × 0.060 inch, 4,200 sq. mils
(1.78 × 1.52 mm, 2.70 sq. mm)

1. COLLECTOR 1
2. BASE 1
3. EMITTER 1
4. COLLECTOR 2
5. BASE 2
6. EMITTER 2

Substrate can be connected
to V- or floated.

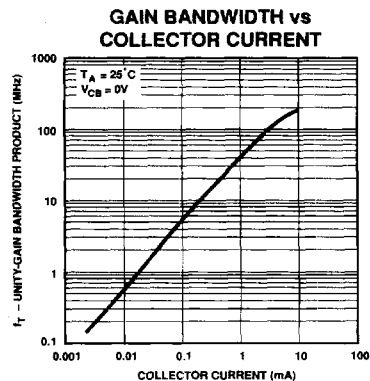
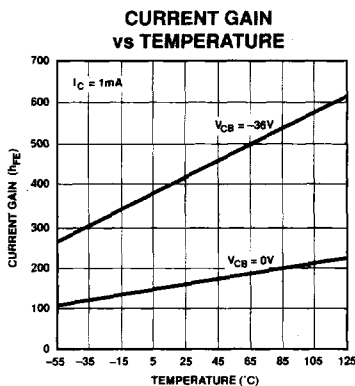
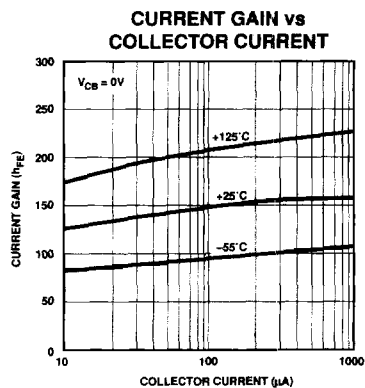
For additional DICE ordering information,
refer to PMI's Data Book, Section 2.

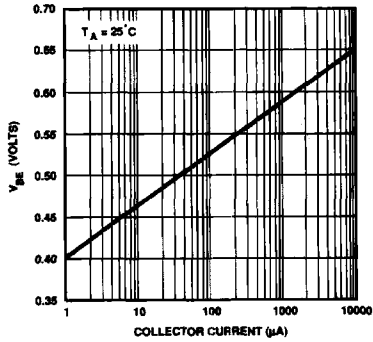
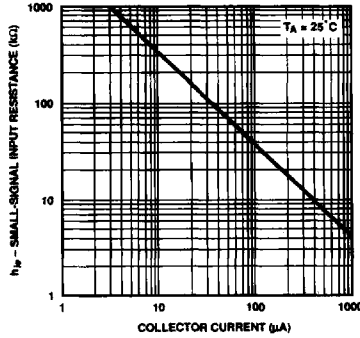
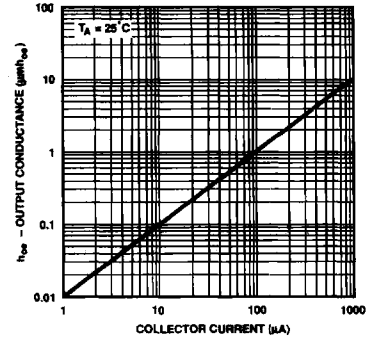
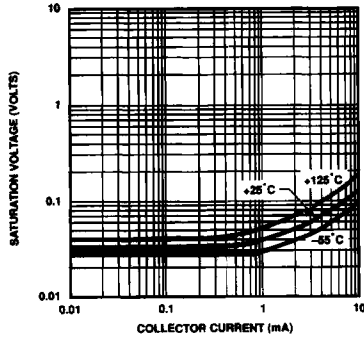
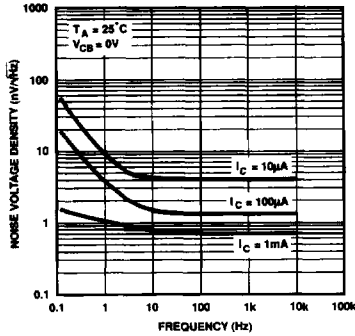
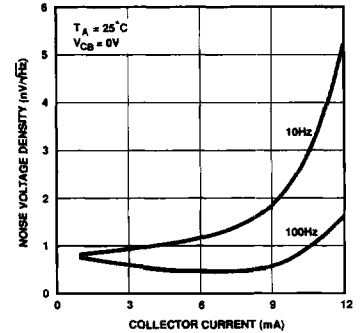
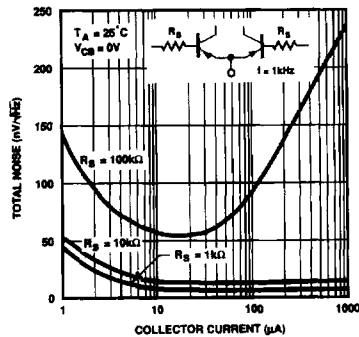
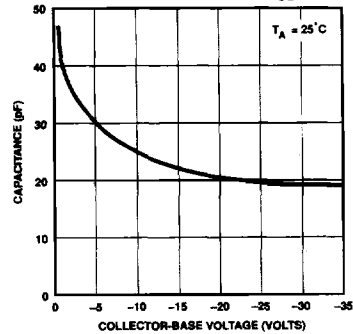
WAFER TEST LIMITS at 25°C, unless otherwise noted.

PARAMETER	SYMBOL	CONDITIONS	MAT-03N LIMITS	UNITS
Breakdown Voltage	BV_{CEO}		36	V MIN
Offset Voltage	V_{OS}	$I_C = 100\mu A$, $V_{CB} = 0V$ $10\mu A \leq I_C \leq 1mA$	200	μV MAX
Current Gain	h_{FE}	$I_C = 1mA$, $V_{CB} = 0V, -36V$ $I_C = 10\mu A$, $V_{CB} = 0V, -36V$	80 60	MIN
Current Gain Match	Δh_{FE}	$I_C = 100\mu A$, $V_{CB} = 0V$	6	% MAX
Offset Voltage Change vs. V_{CB}	$\Delta V_{OS}/\Delta V_{CB}$	$V_{CB1} = 0V$, $I_C = 100\mu A$ $V_{CB2} = -36V$	200	μV MAX
Offset Voltage Change vs. Collector Current	$\Delta V_{OS}/\Delta I_C$	$V_{CB} = 0$ $I_{C1} = 10\mu A$, $I_{C2} = 1mA$	75	μV MAX
Bulk Resistance	r_{BE}	$10\mu A \leq I_C \leq 1mA$	0.75	Ω MAX
Collector Saturation Voltage	$V_{CE(SAT)}$	$I_C = 1mA$ $I_B = 100\mu A$	0.1	V MAX

NOTE:

Electrical tests are performed at wafer probe to the limits shown. Due to variations in assembly methods and normal yield loss, yield after packaging is not guaranteed for standard product dice. Consult factory to negotiate specifications based on dice lot qualification through sample lot assembly and testing.

TYPICAL PERFORMANCE CHARACTERISTICS


TYPICAL PERFORMANCE CHARACTERISTICS *Continued*
BASE-EMITTER VOLTAGE vs COLLECTOR CURRENT

SMALL-SIGNAL INPUT RESISTANCE (h_{ie}) vs COLLECTOR CURRENT

SMALL-SIGNAL OUTPUT CONDUCTANCE (h_{oe}) vs COLLECTOR CURRENT

SATURATION VOLTAGE vs COLLECTOR CURRENT

NOISE VOLTAGE DENSITY vs FREQUENCY

NOISE VOLTAGE DENSITY vs COLLECTOR CURRENT

TOTAL NOISE vs COLLECTOR CURRENT

COLLECTOR-BASE CAPACITANCE vs V_{CB}


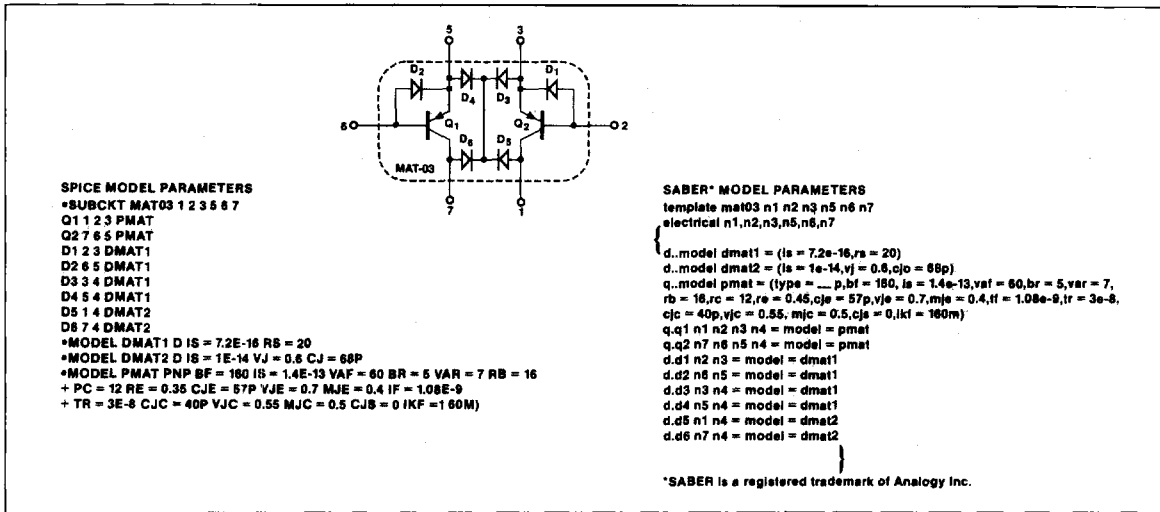


FIGURE 1: SPICE or SABER Model

APPLICATIONS INFORMATION

MAT-03 MODELS

The MAT-03 model (Figure 1) includes parasitic diodes D_3 through D_6 . D_1 and D_2 are internal protection diodes which prevent zenering of the base-emitter junctions.

The analysis programs, SPICE and SABER, are primarily used in evaluating the functional performance of systems. The models are provided only as an aid in utilizing these simulation programs.

MAT-03 NOISE MEASUREMENT

All resistive components (Johnson noise, $e_n^2 = 4kTBR$, or $e_n = 0.13\sqrt{R}$ nV/ $\sqrt{\text{Hz}}$, where R is in $k\Omega$) and semiconductor junctions (Shot noise, caused by current flowing through a junction, produces voltage noise in series impedances such as transistor-collector load resistors, $I_n = 0.566\sqrt{I}$ pA/ $\sqrt{\text{Hz}}$ where I is in μA) contribute to the system input noise.

Figure 2 illustrates a technique for measuring the equivalent input noise voltage of the MAT-03. 1mA of stage current is used

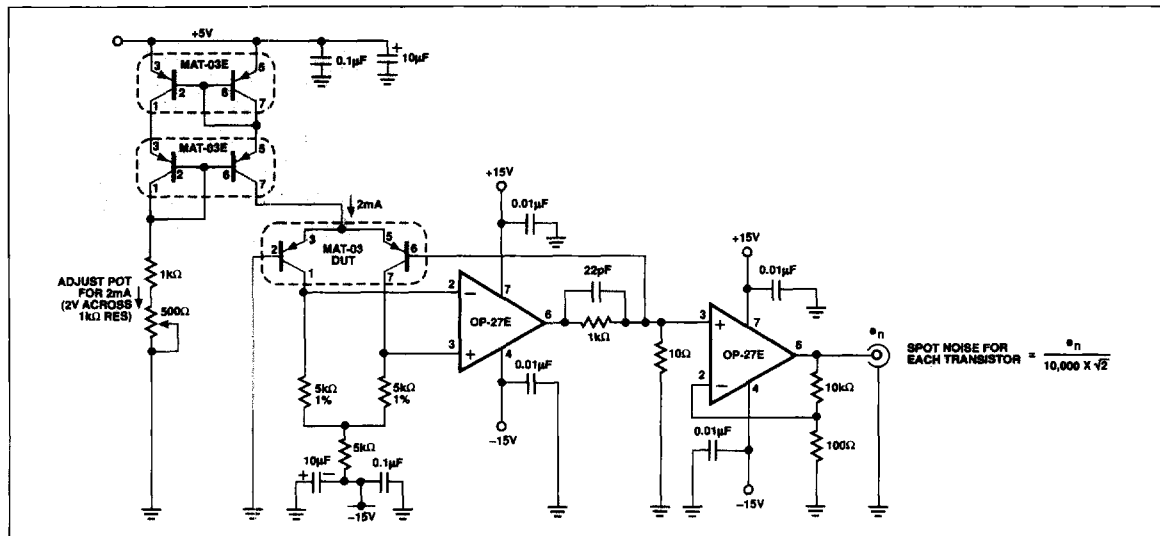


FIGURE 2: MAT-03 Voltage Noise Measurement Circuit

to bias each side of the differential pair. The $5k\Omega$ collector resistors noise contribution is insignificant compared to the voltage noise of the MAT-03. Since noise in the signal path is referred back to the input, this voltage noise is attenuated by the gain of the circuit. Consequently, the noise contribution of the collector load resistors is only $0.048nV/\sqrt{Hz}$. This is considerably less than the typical $0.8nV/\sqrt{Hz}$ input noise voltage of the MAT-03 transistor.

The noise contribution of the OP-27 gain stages is also negligible due to the gain in the signal path. The op amp stages amplify the input referred noise of the transistors to increase the signal strength to allow the noise spectral density ($e_{in} \times 10000$) to be measured with a spectrum analyzer. And, since we assume equal noise contributions from each transistor in the MAT-03, the output is divided by $\sqrt{2}$ to determine a single transistor's input noise.

Air currents cause small temperature changes that can appear as low frequency noise. To eliminate this noise source, the

measurement circuit must be thermally isolated. Effects of extraneous noise sources must also be eliminated by totally shielding the circuit.

SUPER LOW NOISE AMPLIFIER

The circuit in Figure 3a is a super low noise amplifier with equivalent input voltage noise of $0.32nV/\sqrt{Hz}$. By paralleling three MAT-03 matched pairs, a further reduction of amplifier noise is attained by a reduction of the base spreading resistance by a factor of 3, and consequently the noise by $\sqrt{3}$. Additionally, the shot noise contribution is reduced by maintaining a high collector current (2mA/device) which reduces the dynamic emitter resistance and decreases voltage noise. The voltage noise is inversely proportional to the square root of the stage current, and current noise increases proportionally to the square root of the stage current. Accordingly, this amplifier capitalizes on voltage noise reduction techniques at the expense of increasing the current noise. However, high current noise is not usually important when dealing with low impedance sources.

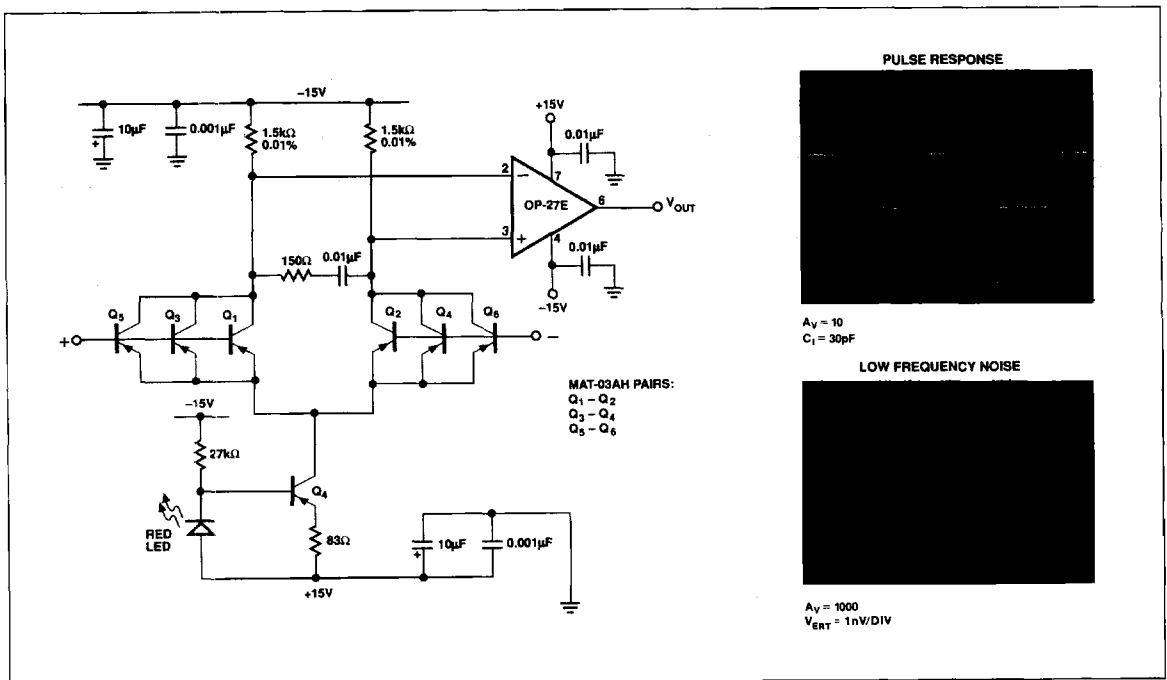


FIGURE 3a: Super Low Noise Amplifier

This amplifier exhibits excellent full power AC performance, 0.08% THD into a 600Ω load, making it suitable for exacting audio applications (see Figure 3b).

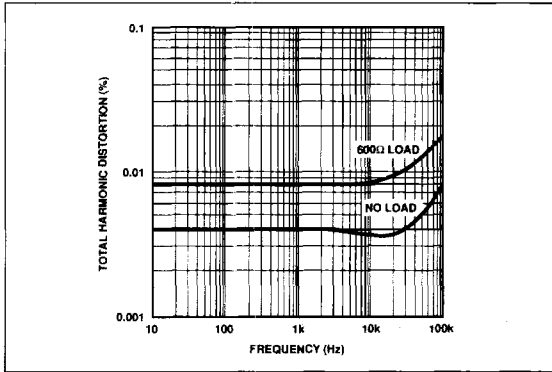


FIGURE 3b: Super Low Noise Amplifier – Total Harmonic Distortion

LOW NOISE MICROPHONE PREAMPLIFIER

Figure 4 shows a microphone preamplifier that consists of a MAT-03 and a low noise op amp. The input stage operates at a relatively high quiescent current of 2mA per side, which reduces the MAT-03 transistor's voltage noise. The 1/f corner is less than 1Hz. Total harmonic distortion is under 0.005% for a 10V_{p-p} signal from 20Hz to 20kHz. The preamp gain is 100, but can be modified by varying R₅ or R₆ (V_{OUT}/V_{IN} = R₅/R₆ + 1).

A total input stage emitter current of 4mA is provided by Q₂. The constant current in Q₂ is set by using the forward voltage of a

GaAsP LED as a reference. The difference between this voltage and the V_{BE} of a silicon transistor is predictable and constant (to a few percent) over a wide temperature range. The voltage difference, approximately 1V, is dropped across the 250Ω resistor which produces a temperature stabilized emitter current.

CURRENT SOURCES

A fundamental requirement for accurate current mirrors and active load stages is matched transistor components. Due to the excellent V_{BE} matching (the voltage difference between V_{BE}'s required to equalize collector current) and gain matching, the MAT-03 can be used to implement a variety of standard current mirrors that can source current into a load such as an amplifier stage. The advantages of current loads in amplifiers versus resistors is an increase of voltage gain due to higher impedances, larger signal range, and in many applications a wider signal bandwidth.

Figure 5 illustrates a cascode current mirror consisting of two MAT-03 transistor pairs.

The cascode current source has a common base transistor in series with the output which causes an increase in output impedance of the current source since V_{CE} stays relatively constant. High frequency characteristics are improved due to a reduction of Miller capacitance. The small-signal output impedance can be determined by consulting "h_{OF} vs Collector Current" typical graph. Typical output impedance levels approach the performance of a perfect current source.

Considering a typical collector current of 100μA, we have:

$$r_{OQ3} = \frac{1}{1.0\mu\text{MHOS}} = 1\text{M}\Omega.$$

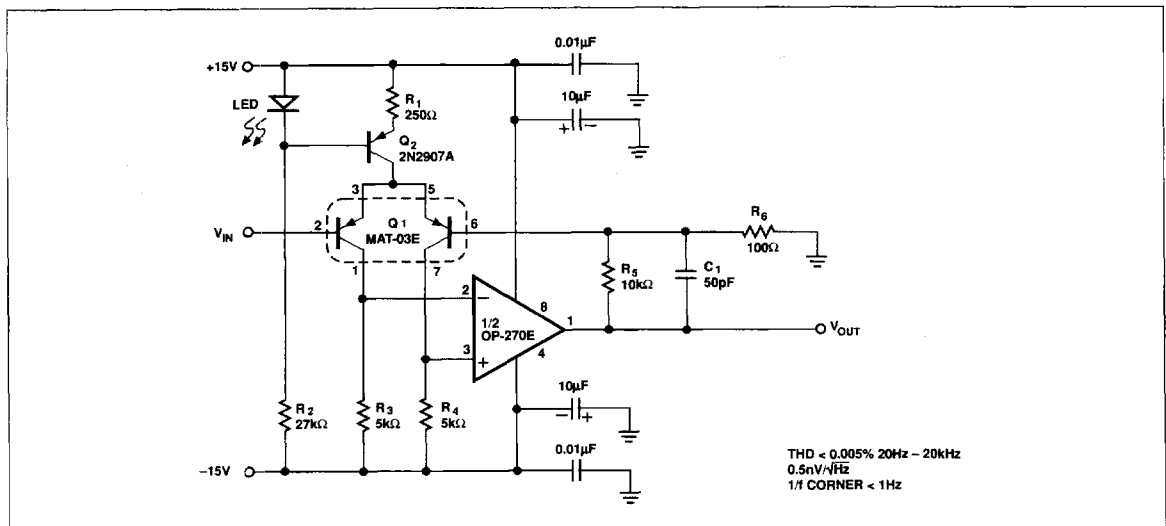


FIGURE 4: Low Noise Microphone Preamplifier



MATCHED TRANSISTORS

Q_2 and Q_3 are in series and operate at the same current level, so the total output impedance is:

$$R_O = h_{FE} r_{OQ_3} \approx (160)(1M\Omega) = 160M\Omega.$$

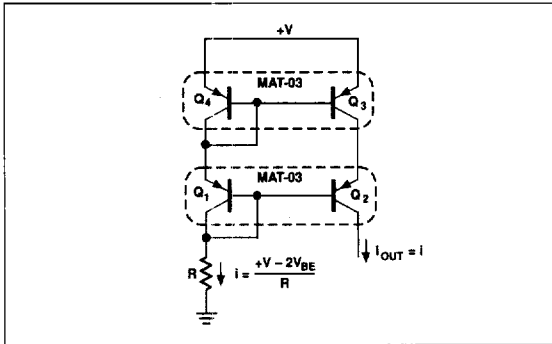


FIGURE 5: Cascode Current Source

CURRENT MATCHING

The objective of current source or mirror design is generation of currents that are either matched or must maintain a constant ratio. However, mismatch of base-emitter voltages cause output current errors. Consider the example of Figure 6a. If the resistors and transistors are equal and the collector voltages are the same, the collector currents will match precisely. Investigating the current-matching errors resulting from a non-zero V_{OS} , we define ΔI_C as the current error between the two transistors.

Graph 6b describes the relationship of current matching errors versus offset voltage for a specified average current I_C . Note that since the relative error between the currents is exponentially proportional to the offset voltage, tight matching is required to design high accuracy current sources. For example, if the offset voltage is 5mV at 100 μ A collector current, the current matching error would be 20%. Additionally, temperature effects such as offset drift (3 μ V/ $^{\circ}$ C per mV of V_{OS}) will degrade performance if Q_1 and Q_2 are not well matched.

DIGITALLY PROGRAMMABLE BIPOLAR CURRENT PUMP

The circuit of Figure 7 is a digitally programmable current pump. The current pump incorporates a DAC-08, and a fast Wilson current source using the MAT-03. Examining Figure 7, the DAC-08 is set for 2mA full-scale range so that bipolar current operation of ± 2 mA is achieved. The Wilson current mirror maintains linearity within the LSB range of the 8-bit DAC-08 (± 2 mA/256 = 15.6 μ A resolution) as seen in Figure 8. A negative feedback path established by Q_2 regulates the collector current so that it matches the reference current programmed by the DAC-08.

Collector-emitter voltages across both Q_1 and Q_3 are matched by D_1 , with Q_3 's collector-emitter voltage remaining constant, independent of the voltage across the current source output.

Since Q_2 buffers Q_3 , both transistors in the MAT-03, Q_1 and Q_3 , maintain the same collector current. D_2 and D_3 form a Baker clamp which prevents Q_2 from turning off, thereby improving the switching speed of the current mirror. The feedback serves to

increase the output impedance and improves accuracy by reducing the base-width modulation which occurs with varying collector-emitter voltages. Accuracy and linearity performance of the current pump is summarized in Figure 8.

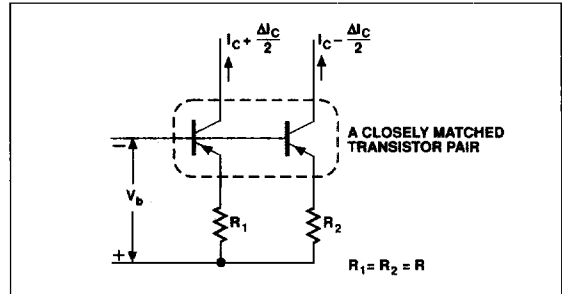


FIGURE 6a: Current Matching Circuit

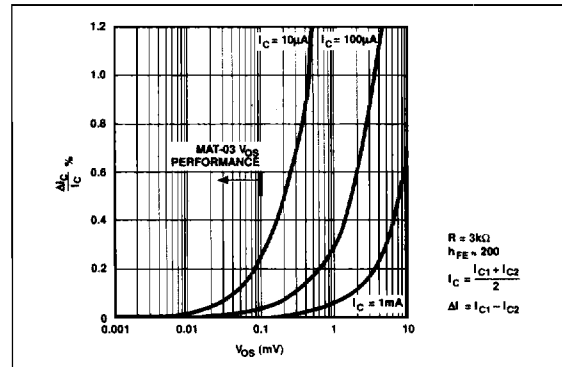


FIGURE 6b: Current Matching Accuracy % vs Offset Voltage

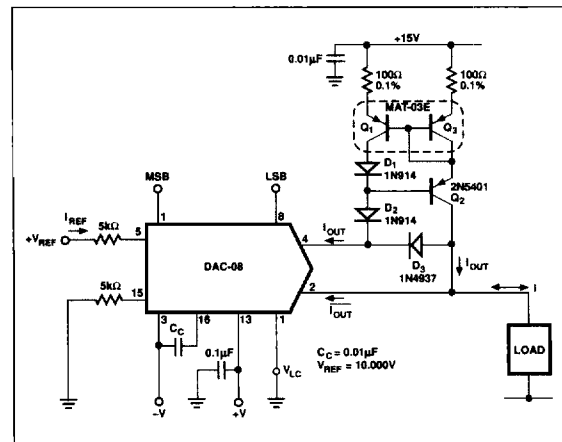


FIGURE 7: Digitally Programmable Bipolar Current Pump

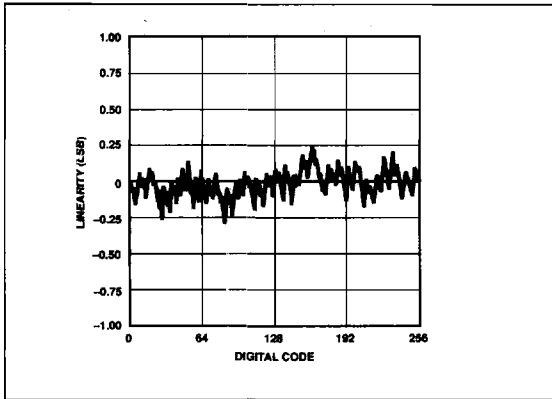


FIGURE 8: Digitally Programmable Current Pump – INL Error vs Digital Code

The full scale output of the DAC-08, I_{OUT} , is a linear function of I_{REF} :

$$I_{FR} = \frac{255}{256} \times I_{REF}, \text{ and } I_{OUT} + \overline{I_{OUT}} = I_{REF} \left(\frac{255}{256} \right).$$

The current mirror output is $I_{OUT} - \overline{I_{OUT}} = I$, so that if $I_{REF} = 2\text{mA}$:

$$I = 2 I_{OUT} - 1.992\text{mA}$$

$$= 2 \left(\frac{\text{Input Code}}{256} \right) (2\text{mA}) - 1.992\text{mA}.$$

DIGITAL CURRENT PUMP CODING

	<u>DIGITAL INPUT</u>		<u>OUTPUT CURRENT</u>
	<u>B1 . . . B8</u>		
FULL RANGE	1111 1111		$I = 1.992\text{mA}$
HALF-RANGE	1000 0000		$I = 0.008\text{mA}$
ZERO-SCALE	0000 0000		$I = -1.992\text{mA}$

