

# MAT03—SPECIFICATIONS

## ELECTRICAL CHARACTERISTICS (@ $T_A = 25^\circ\text{C}$ , unless otherwise noted.)

Parameter	Symbol	Conditions	MAT03E			MAT03F			Unit
			Min	Typ	Max	Min	Typ	Max	
Current Gain <sup>1</sup>	$h_{FE}$	$V_{CB} = 0\text{ V}, -36\text{ V}$ $I_C = 1\text{ mA}$ $I_C = 100\text{ }\mu\text{A}$ $I_C = 10\text{ }\mu\text{A}$	100 90 80	165 150 120		80 70 60	165 150 120		
Current Gain Matching <sup>2</sup>	$Dh_{FE}$	$I_C = 100\text{ }\mu\text{A}, V_{CB} = 0\text{ V}$		0.5	3		0.5	6	%
Offset Voltage <sup>3</sup>	$V_{OS}$	$V_{CB} = 0\text{ V}, I_C = 100\text{ }\mu\text{A}$		40	100		40	200	$\mu\text{V}$
Offset Voltage Change vs. Collector Voltage	$\Delta V_{OS}/\Delta V_{CB}$	$I_C = 100\text{ }\mu\text{A}$ $V_{CB1} = 0\text{ V}$ $V_{CB2} = -36\text{ V}$		11	150		11	200	$\mu\text{V}$
Offset Voltage Change vs. Collector Current	$\Delta V_{OS}/\Delta I_C$	$V_{CB} = 0\text{ V}$ $I_{C1} = 10\text{ }\mu\text{A}, I_{C2} = 1\text{ mA}$		12	50		12	75	$\mu\text{V}$
Bulk Resistance	$r_{BE}$	$V_{CB} = 0\text{ V}$ $10\text{ }\mu\text{A} \leq I_C \leq 1\text{ mA}$		0.3	0.75		0.3	0.75	$\Omega$
Offset Current Collector-Base Leakage Current	$I_{OS}$	$I_C = 100\text{ }\mu\text{A}, V_{CB} = 0\text{ V}$		6	35		6	45	nA
Noise Voltage Density <sup>4</sup>	$I_{CB0}$ $e_N$	$V_{CB} = -36\text{ V} = V_{MAX}$ $I_C = 1\text{ mA}, V_{CB} = 0$ $f_o = 10\text{ Hz}$ $f_o = 100\text{ Hz}$ $f_o = 1\text{ kHz}$ $f_o = 10\text{ kHz}$		50	200		50	400	pA $\text{nV}/\sqrt{\text{Hz}}$ $\text{nV}/\sqrt{\text{Hz}}$ $\text{nV}/\sqrt{\text{Hz}}$ $\text{nV}/\sqrt{\text{Hz}}$
Collector Saturation Voltage	$V_{CE(SAT)}$	$I_C = 1\text{ mA}, I_B = 100\text{ }\mu\text{A}$		0.025	0.1		0.025	0.1	V

## ELECTRICAL CHARACTERISTICS (@ $-40^\circ\text{C} \leq T_A \leq 85^\circ\text{C}$ , unless otherwise noted.)

Parameter	Symbol	Conditions	MAT03E			MAT03F			Unit
			Min	Typ	Max	Min	Typ	Max	
Current Gain	$h_{FE}$	$V_{CB} = 0\text{ V}, -36\text{ V}$ $I_C = 1\text{ mA}$ $I_C = 100\text{ }\mu\text{A}$ $I_C = 10\text{ }\mu\text{A}$	70 60 50	120 105 90		60 50 40	120 105 90		
Offset Voltage	$V_{OS}$	$I_C = 100\text{ }\mu\text{A}, V_{CB} = 0\text{ V}$		30	135		30	265	$\mu\text{V}$
Offset Voltage Drift <sup>5</sup>	$TCV_{OS}$	$I_C = 100\text{ }\mu\text{A}, V_{CB} = 0\text{ V}$		0.3	0.5		0.3	1.0	$\mu\text{V}/^\circ\text{C}$
Offset Current	$I_{OS}$	$I_C = 100\text{ }\mu\text{A}, V_{CB} = 0\text{ V}$		10	85		10	200	nA
Breakdown Voltage	$BV_{CEO}$		36			36			V

### NOTES

<sup>1</sup>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  $V_{CB} = 0\text{ V}$ .

<sup>2</sup>Current gain matching ( $\Delta h_{FE}$ ) is defined as:  $\Delta h_{FE} = \frac{100(\Delta I_B) h_{FE}(\text{min})}{I_C}$ .

<sup>3</sup>Offset voltage is defined as:  $V_{OS} = V_{BE1} - V_{BE2}$ , where  $V_{OS}$  is the differential voltage for  $I_{C1} = I_{C2}$ :  $V_{OS} = V_{BE1} - V_{BE2} = \frac{KT}{q} \ln\left(\frac{I_{C1}}{I_{C2}}\right)$ .

<sup>4</sup>Sample tested. Noise tested and specified as equivalent input voltage for each transistor.

<sup>5</sup>Guaranteed by  $V_{OS}$  test ( $TCV_{OS} = V_{OS}/T$  for  $V_{OS} \ll V_{BE}$ ) where  $T = 298\text{ K}$  for  $T_A = 25^\circ\text{C}$ .

Specifications subject to change without notice.

**ORDERING GUIDE**

Model	V <sub>OS</sub> max (T <sub>A</sub> = +25°C)	Temperature Range	Package Option
MAT03EH	100 μV	-40°C to +85°C	TO-78
MAT03FH	200 μV	-40°C to +85°C	TO-78

**ABSOLUTE MAXIMUM RATINGS<sup>1</sup>**

Collector-Base Voltage (BV <sub>CBO</sub> )	36 V
Collector-Emitter Voltage (BV <sub>CEO</sub> )	36 V
Collector-Collector Voltage (BV <sub>CC</sub> )	36 V
Emitter-Emitter Voltage (BV <sub>EE</sub> )	36 V
Collector Current (I <sub>C</sub> )	20 mA
Emitter Current (I <sub>E</sub> )	20 mA
Total Power Dissipation	
Ambient Temperature ≤ 70°C <sup>2</sup>	500 mW
Operating Temperature Range	
MAT03E/F	-40°C to +85°C
Operating Junction Temperature	-55°C to +150°C
Storage Temperature	-65°C to +150°C
Lead Temperature (Soldering, 60 sec)	300°C
Junction Temperature	-65°C to +150°C

**NOTES**

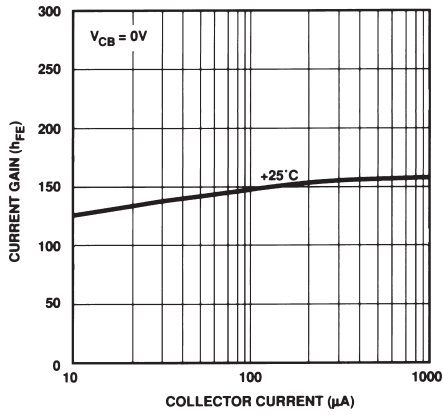
<sup>1</sup>Absolute maximum ratings apply to both DICE and packaged devices.  
<sup>2</sup>Rating applies to TO-78 not using a heat sink and LCC; devices in free air only. For TO-78, derate linearly at 6.3 mW/°C above 70°C ambient temperature; for LCC, derate at 7.8 mW/°C.

**CAUTION**

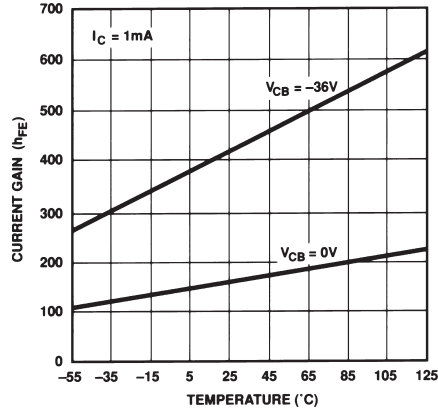
ESD (electrostatic discharge) sensitive device. Electrostatic charges as high as 4000 V readily accumulate on the human body and test equipment and can discharge without detection. Although the MAT03 features propriety ESD protection circuitry, permanent damage may occur on devices subjected to high-energy electrostatic discharges. Therefore, proper ESD precautions are recommended to avoid performance degradation or loss of functionality.



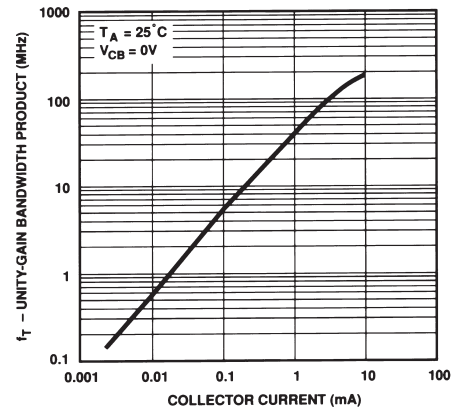
# MAT03—Typical Performance Characteristics



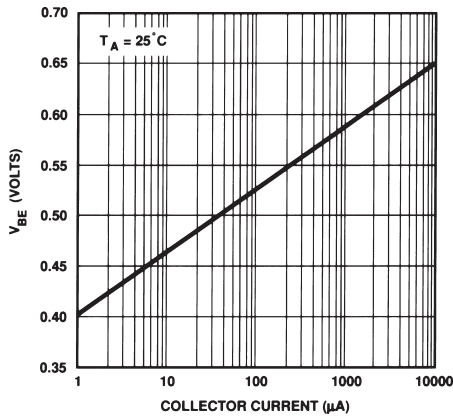
TPC 1. Current Gain vs. Collector Current



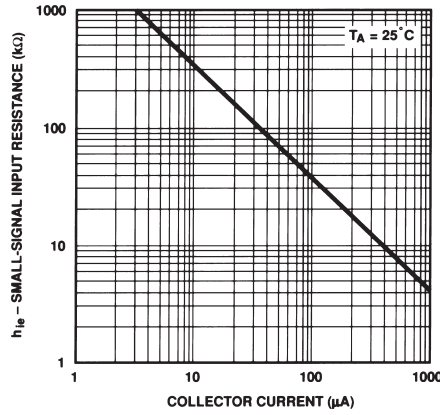
TPC 2. Current Gain vs. Temperature



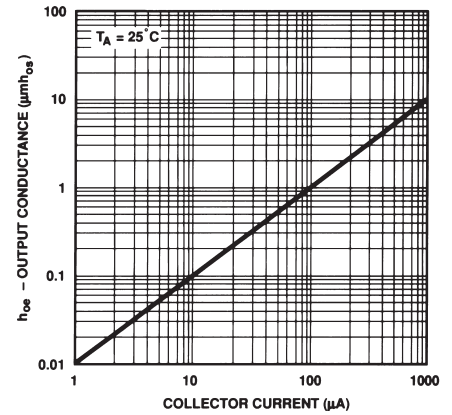
TPC 3. Gain Bandwidth vs. Collector Current



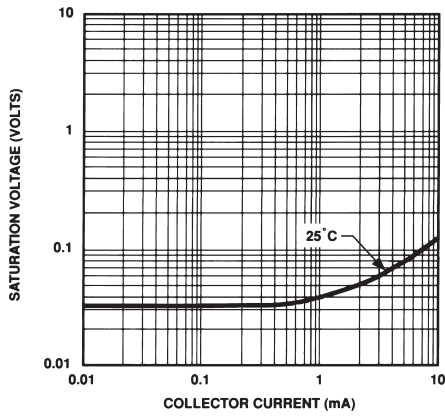
TPC 4. Base-Emitter Voltage vs. Collector Current



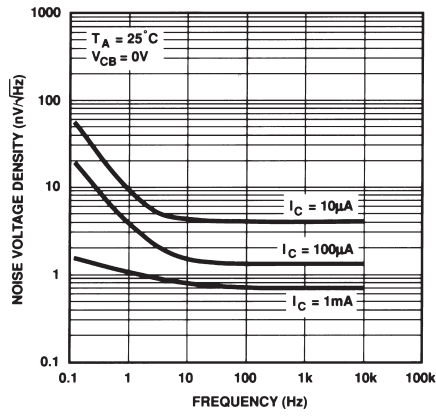
TPC 5. Small-Signal Input Resistance ( $h_{ie}$ ) vs. Collector Current



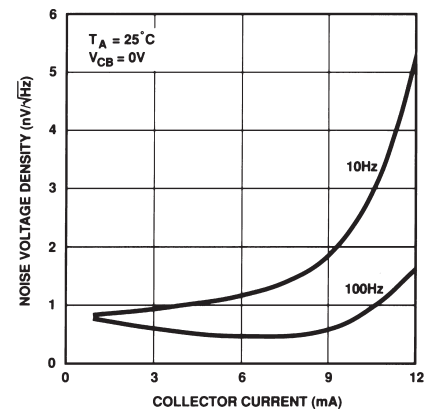
TPC 6. Small Signal Output Conductance ( $h_{oe}$ ) vs. Collector Current



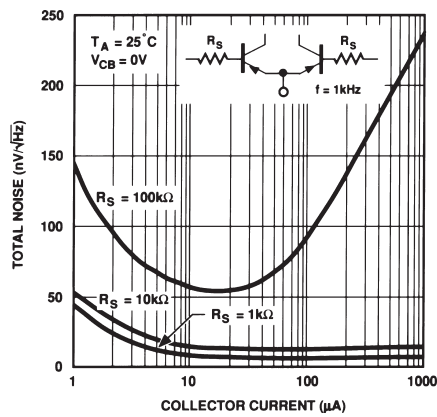
TPC 7. Saturation Voltage vs. Collector Current



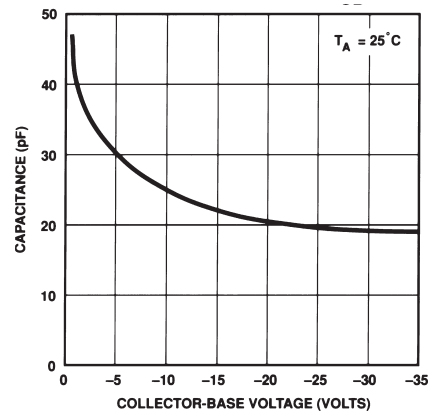
TPC 8. Noise Voltage Density vs. Frequency



TPC 9. Noise Voltage Density vs. Collector Current

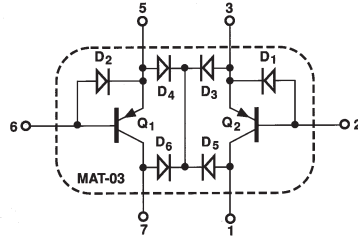


TPC 10. Total Noise vs. Collector Current



TPC 11. Collector-Base Capacitance vs.  $V_{CB}$

# MAT03



### SPICE MODEL PARAMETERS

```

•SUBCKT MAT03 1 2 3 5 6 7
Q1 1 2 3 PMAT
Q2 7 6 5 PMAT
D1 2 3 DMAT1
D2 6 5 DMAT1
D3 3 4 DMAT1
D4 5 4 DMAT1
D5 1 4 DMAT2
D6 7 4 DMAT2
•MODEL DDMAT1 D IS = 7.2E-16 RS = 20
•MODEL DDMAT2 D IS = 1E-14 VJ = 0.6 CJ = 68P
•MODEL PMAT PNP BF = 160 IS = 1.4E-13 VAF = 60 BR = 5 VAR = 7 RB = 16
+ PC = 12 RE = 0.35 CJE = 57P VJE = 0.7 MJE = 0.4 IF = 1.08E-9
+ TR = 3E-8 CJC = 40P VJC = 0.55 MJC = 0.5 CJS = 0 IKF = 160M
    
```

### SABER\* MODEL PARAMETERS

```

template mat03 n1 n2 n3 n5 n6 n7
electrical n1,n2,n3,n5,n6,n7
d..model dmat1 = (is = 7.2e-16,rs = 20)
d..model dmat2 = (is = 1e-14,vj = 0.6,cjo = 68p)
q..model pmat = (type = __p,bf = 160, is = 1.4e-13,vaf = 60,br = 5,var = 7,
rb = 16,rc = 12,re = 0.45,cje = 57p,vje = 0.7,mje = 0.4,tf = 1.08e-9,tr = 3e-8,
cjc = 40p,vjc = 0.55, mjc = 0.5,cjs = 0,ikf = 160m)
q.q1 n1 n2 n3 n4 = model = pmat
q.q2 n7 n6 n5 n4 = model = pmat
d.d1 n2 n3 = model = dmat1
d.d2 n6 n5 = model = dmat1
d.d3 n3 n4 = model = dmat1
d.d4 n5 n4 = model = dmat1
d.d5 n1 n4 = model = dmat2
d.d6 n7 n4 = model = dmat2
    
```

\*SABER is a registered trademark of Analogly Inc.

Figure 1. SPICE or SABER Model

## APPLICATIONS INFORMATION

### MAT03 MODELS

The MAT03 model (Figure 1) includes parasitic diodes D<sub>3</sub> through D<sub>6</sub>. D<sub>1</sub> and D<sub>2</sub> are internal protection diodes that 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 using these simulation programs.

### MAT03 NOISE MEASUREMENT

All resistive components (Johnson noise,  $e_n^2 = 4kTBR$ , or  $e_n = 0.13\sqrt{R}$  nV/ $\sqrt{Hz}$ , 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/ $\sqrt{Hz}$  where I is in  $\mu$ A) contribute to the system input noise.

Figure 2 illustrates a technique for measuring the equivalent input noise voltage of the MAT03. 1 mA of stage current is used

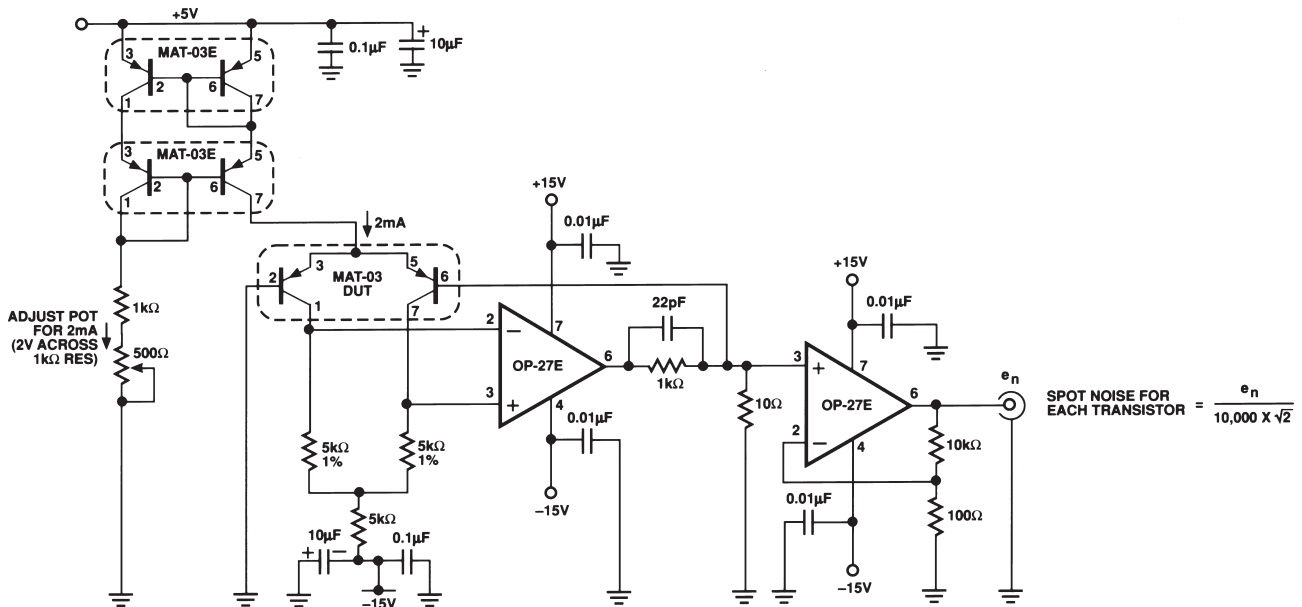


Figure 2. MAT03 Voltage Noise Measurement Circuit

$$\text{SPOT NOISE FOR EACH TRANSISTOR} = \frac{e_n}{10,000 \times \sqrt{2}}$$

to bias each side of the differential pair. The 5 kΩ collector resistors noise contribution is insignificant compared to the voltage noise of the MAT03. 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 0.048 nV/√Hz. This is considerably less than the typical 0.8 nV/√Hz input noise voltage of the MAT03 transistor.

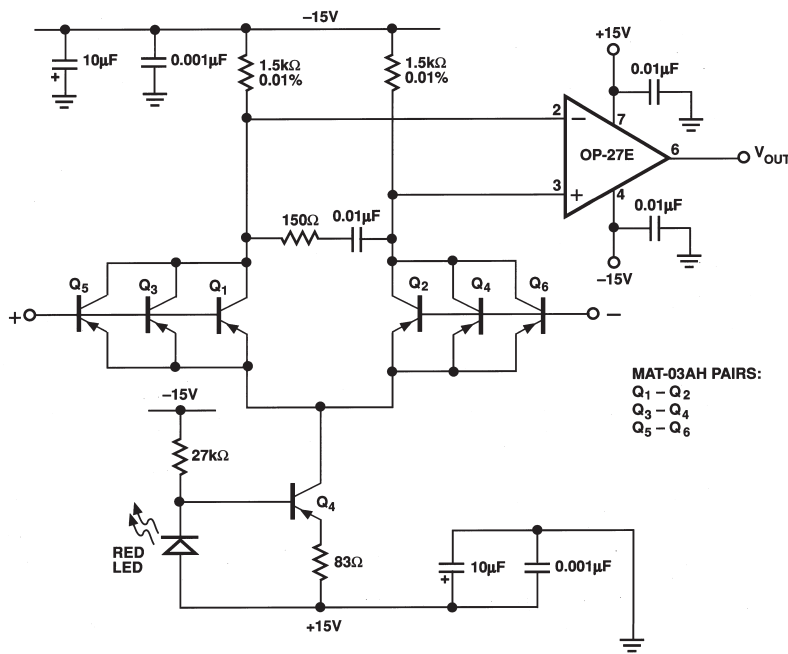
The noise contribution of the OP27 gain stages is also negligible due to the gain in the signal path. The op amp stages amplify the input referred noise of the transistors to increase the signal strength to allow the noise spectral density ( $e_{in} \times 10000$ ) to be measured with a spectrum analyzer. Since we assume equal noise contributions from each transistor in the MAT03, 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 mea-

surement 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 0.32 nV/√Hz. By paralleling three MAT03 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 (2 mA/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.



MAT-03AH PAIRS:  
Q1 - Q2  
Q3 - Q4  
Q5 - Q6

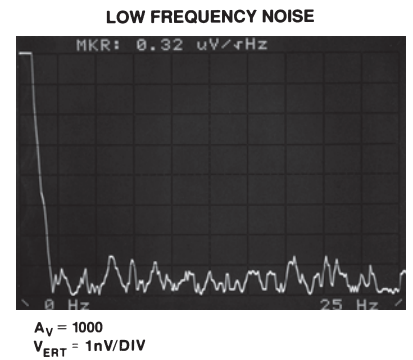
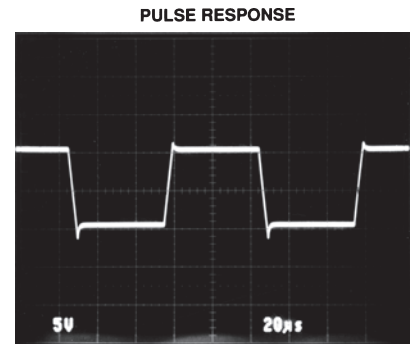


Figure 3a. Super Low Noise Amplifier

# MAT03

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

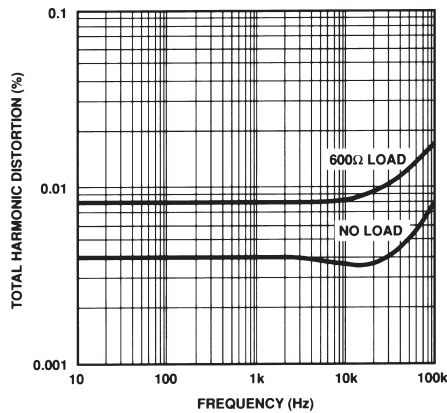


Figure 3b. Super Low Noise Amplifier—Total Harmonic Distortion

## LOW NOISE MICROPHONE PREAMPLIFIER

Figure 4 shows a microphone preamplifier that consists of a MAT03 and a low noise op amp. The input stage operates at a relatively high quiescent current of 2 mA per side, which reduces the MAT03 transistor’s voltage noise. The 1/f corner is less than 1 Hz. Total harmonic distortion is under 0.005% for a 10 V p-p signal from 20 Hz to 20 kHz. The preamp gain is 100, but can be modified by varying R<sub>5</sub> or R<sub>6</sub> ( $V_{OUT}/V_{IN} = R_5/R_6 + 1$ ).

A total input stage emitter current of 4 mA is provided by Q<sub>2</sub>. The constant current in Q<sub>2</sub> is set by using the forward voltage of a GaAsP LED as a reference. The difference between this voltage

and the V<sub>BE</sub> of a silicon transistor is predictable and constant (to a few percent) over a wide temperature range. The voltage difference, approximately 1 V, is dropped across the 250 Ω 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<sub>BE</sub> matching (the voltage difference between V<sub>BES</sub> required to equalize collector current) and gain matching, the MAT03 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 MAT03 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<sub>CE</sub> 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<sub>OF</sub> vs. Collector Current” typical graph. Typical output impedance levels approach the performance of a perfect current source.

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

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

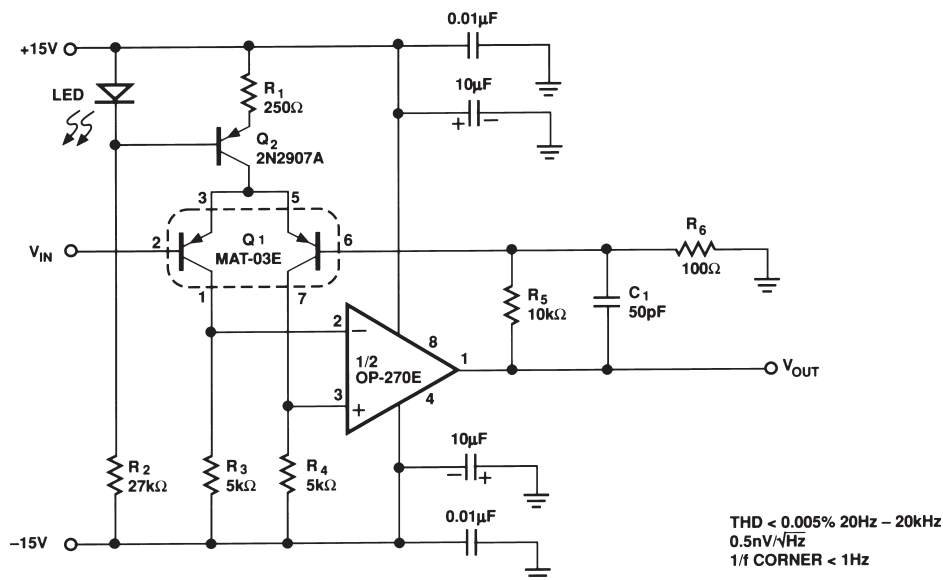


Figure 4. Low Noise Microphone Preamplifier

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

$$R_O = h_{FE} r_{oQ3} @ (160)(1 M\Omega) = 160 M\Omega.$$

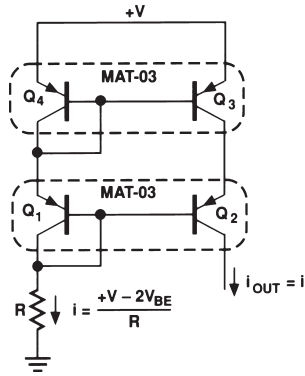


Figure 5. Cascode Current Source

**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 5. 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 nonzero  $V_{OS}$ , we define  $\Delta I_C$  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 5 mV at 100  $\mu$ A collector current, the current matching error would be 20%. Additionally, temperature effects such as offset drift (3  $\mu$ 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 DAC08, and a fast Wilson current source using the MAT03. Examining Figure 7, the DAC08 is set for 2 mA full-scale range so that bipolar current operation of  $\pm 2$  mA is achieved. The Wilson current mirror maintains linearity within the LSB range of the 8-bit DAC08 ( $\pm 2$  mA/256 = 15.6  $\mu$ 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 DAC08.

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 MAT03,  $Q_1$  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.

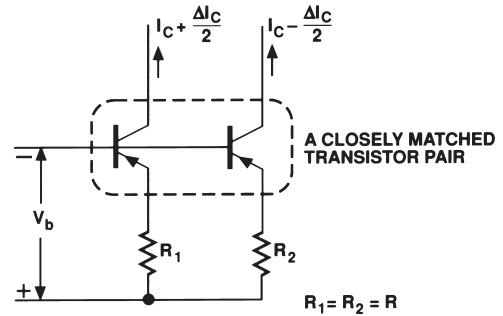


Figure 6a. Current Matching Circuit

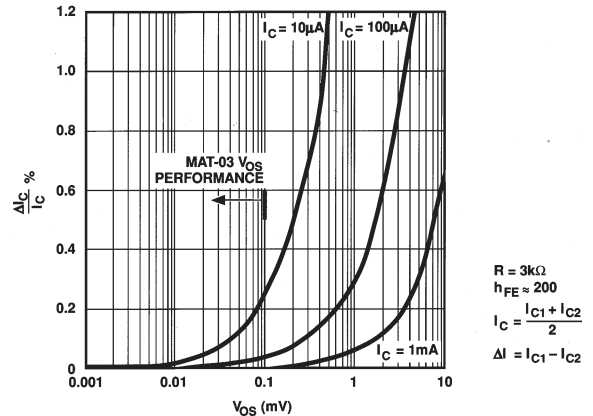


Figure 6b. Current Matching Accuracy % vs. Offset Voltage

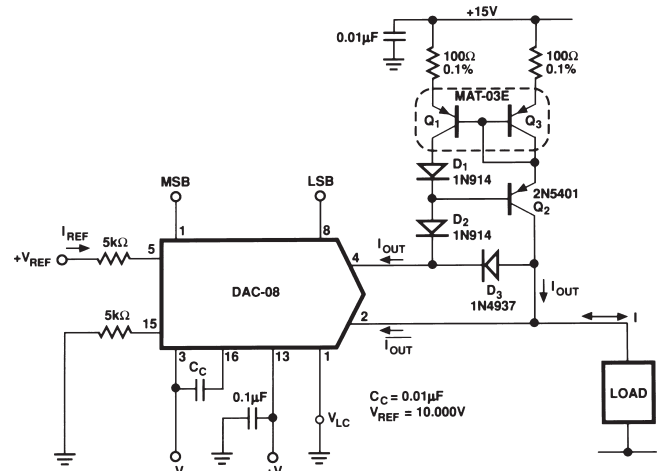


Figure 7. Digitally Programmable Bipolar Current Pump



# MAT03

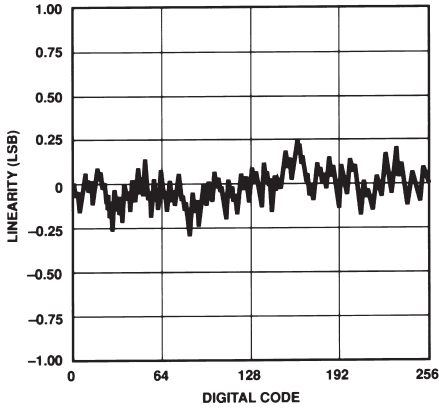


Figure 8. Digitally Programmable Current Pump—INL Error as Digital Code

The full-scale output of the DAC08,  $I_{OUT}$ , is a linear function of  $I_{REF}$

$$I_{FR} = \frac{256}{256} \times I_{REF}, \text{ and } I_{OUT} + \overline{I_{OUT}} = I_{REF} \frac{256}{256}$$

The current mirror output is  $I_{OUT} - \overline{I_{OUT}} = 1$ , so that if

$$I_{REF} = 2 \text{ mA:}$$

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

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

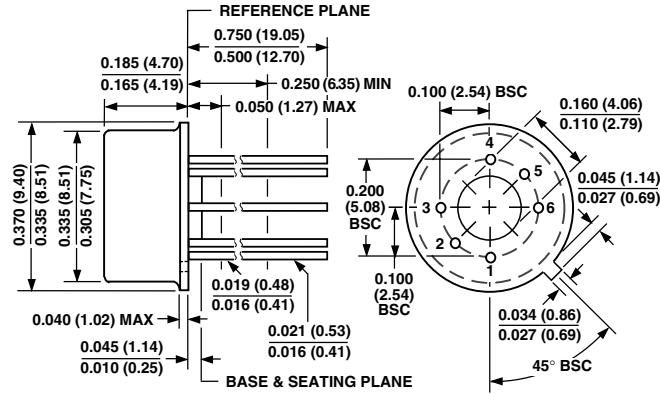
## DIGITAL CURRENT PUMP CODING

	Digital Input B1 . . . B8	Output Current
FULL RANGE	1111 1111	I = 1.992 mA
HALF RANGE	1000 0000	I = 0.008 mA
ZERO SCALE	0000 0000	I = -1.992 mA

**OUTLINE DIMENSIONS**

Dimensions shown in inches and (mm).

**TO-78 Metal Can**



## Revision History

Location	Page
<b>Data Sheet changed from REV. B to REV. C.</b>	
Edits to ELECTRICAL CHARACTERISTICS .....	2
Deleted WAFER TEST LIMITS .....	3
Deleted DICE CHARACTERISTICS .....	3
Edits to ORDERING GUIDE .....	3
Edits to ABSOLUTE MAXIMUM RATINGS .....	3



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