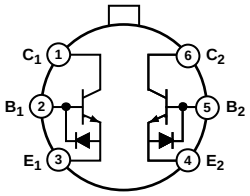
Audio, Dual-Matched NPN Transistor

MAT12

FEATURES

Very low voltage noise: 1 nV/√Hz maximum @ 100 Hz
Excellent current gain match: 0.5% typical
Low offset voltage (V_{OS}): 200 µV maximum
Outstanding offset voltage drift: 0.03 µV/°C typical
High gain bandwidth product: 200 MHz

PIN CONFIGURATION



NOTE
1. SUBSTRATE IS CONNECTED TO CASE ON TO-78 PACKAGE.
2. SUBSTRATE IS NORMALLY CONNECTED TO THE MOST NEGATIVE CIRCUIT POTENTIAL, BUT CAN BE FLOATED.

09044-001

Figure 1. 6-Lead TO-78

GENERAL DESCRIPTION

The MAT12 is a dual, NPN-matched transistor pair that is specifically designed to meet the requirements of ultralow noise audio systems.

With its extremely low input base spreading resistance (rbb' is typically 28 Ω) and high current gain (h_{FE} typically exceeds 600 at I_C = 1 mA), the MAT12 can achieve outstanding signal-to-noise ratios. The high current gain results in superior performance compared to systems incorporating commercially available monolithic amplifiers.

Excellent matching of the current gain (Δh_{FE}) to about 0.5% and low V_{OS} of less than 10 µV typical make the MAT12 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.

The MAT12 is also an ideal choice for accurate and reliable current biasing and mirroring circuits. Furthermore, because the accuracy of a current mirror degrades exponentially with mismatches of V_{BE} between transistor pairs, the low V_{OS} of the MAT12 does not need offset trimming in most circuit applications.

The MAT12 is a good replacement for the MAT02, and its performance and characteristics are guaranteed over the extended temperature range of −40°C to +85°C.

Rev. 0

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REVISION HISTORY

7/10—Revision 0: Initial Version

SPECIFICATIONS

ELECTRICAL CHARACTERISTICS

V_{CB} = 15 V, I_O = 10 µA, T_A = 25°C, unless otherwise specified.

Table 1.

Parameter	Symbol	Test Conditions/Comments	Min	Typ	Max	Unit
DC AND AC CHARACTERISTICS						
Current Gain[1]	h_{FE}	I_C = 1 mA	300	605		
		−40°C ≤ T_A ≤ +85°C	300			
		I_C = 10 µA	200	550		
		−40°C ≤ T_A ≤ +85°C	200			
Current Gain Match[2]	Δh_{FE}	10 µA ≤ I_C ≤ 1 mA		0.5	5	%
Noise Voltage Density[3]	e_N	I_C = 1 mA, V_{CB} = 0 V				
		f_O = 10 Hz		1.6	2	nV/√Hz
		f_O = 100 Hz		0.9	1	nV/√Hz
		f_O = 1 kHz		0.85	1	nV/√Hz
		f_O = 10 kHz		0.85	1	nV/√Hz
Low Frequency Noise (0.1 Hz to 10 Hz)	e_N p-p	I_C = 1 mA		0.4		µV p-p
Offset Voltage	V_{OS}	V_{CB} = 0 V, I_C = 1 mA		10	200	µV
		−40°C ≤ T_A ≤ +85°C			220	µV
Offset Voltage Change vs. V_{CB}	$\Delta V_{OS}/\Delta V_{CB}$	0 V ≤ V_{CB} ≤ V_{MAX}[4], 1 µA ≤ I_C ≤ 1 mA[5]		10	50	µV
Offset Voltage Change vs. I_C	$\Delta V_{OS}/\Delta I_C$	1 µA ≤ I_C ≤ 1 mA[5], V_{CB} = 0 V		5	70	µV
Offset Voltage Drift	$\Delta V_{OS}/\Delta T$	−40°C ≤ T_A ≤ +85°C		0.08	1	µV/°C
		−40°C ≤ T_A ≤ +85°C, V_{OS} trimmed to 0 V		0.03	0.3	µV/°C
Breakdown Voltage, Collector to Emitter	BV_{CEO}		40			V
Gain Bandwidth Product	f_T	I_C = 100 mA, V_{CE} = 10 V		200		MHz
Collector-to-Base Leakage Current	I_{CBO}	V_{CB} = V_{MAX}		25	500	pA
		−40°C ≤ T_A ≤ +85°C		3		nA
Collector-to-Collector Leakage Current[6, 7]	I_{CC}	V_{CC} = V_{MAX}		35	500	pA
		−40°C ≤ T_A ≤ +85°C		4		nA
Collector-to-Emitter Leakage Current[6, 7]	I_{CES}	V_{CE} = V_{MAX}, V_{BE} = 0 V		35	500	pA
		−40°C ≤ T_A ≤ +85°C		4		nA
Input Bias Current	I_B	I_C = 10 µA			50	nA
		−40°C ≤ T_A ≤ +85°C			50	nA
Input Offset Current	I_{OS}	I_C = 10 µA			6.2	nA
		−40°C ≤ T_A ≤ +85°C			13	nA
Input Offset Current Drift[6]	$\Delta I_{OS}/\Delta T$	I_C = 10 µA, −40°C ≤ T_A ≤ +85°C		40	150	pA/°C
Collector Saturation Voltage	$V_{CE\ (SAT)}$	I_C = 1 mA, I_B = 100 µA		0.05	0.2	V
Output Capacitance	C_{OB}	V_{CB} = 15 V, I_E = 0 µA		23		pF
Bulk Resistance[6]	R_{BE}	10 µA ≤ I_C ≤ 10 mA		0.3	1.6	Ω
Collector-to-Collector Capacitance	C_{CC}	V_{CC} = 0 V		35		pF

[1] Current gain is guaranteed with collector-to-base voltage (V_{CB}) swept from 0 V to V_{MAX} at the indicated collector currents.
[2] Current gain match (Δh_{FE}) is defined as follows: $\Delta h_{FE} = (100(\Delta I_B)(h_{FE\ min})/I_C)$.
[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 0 V to 40 V.
[5] Measured at I_C = 10 µA and guaranteed by design over the specified range of I_C.
[6] Guaranteed by design.
[7] I_{CC} and I_{CES} are verified by the measurement of I_{CBO}.

ABSOLUTE MAXIMUM RATINGS

Table 2.

Parameter	Rating
Breakdown Voltage of Collector-to-Base Voltage (BV_{CBO})	40 V
Breakdown Voltage of Collector-to-Emitter Voltage (BV_{CEO})	40 V
Breakdown Voltage of Collector-to-Collector Voltage (BV_{CC})	40 V
Breakdown Voltage of Emitter-to-Emitter Voltage (BV_{EE})	40 V
Collector Current (I_C)	20 mA
Emitter Current (I_E)	20 mA
Storage Temperature Range	−65°C to +150°C
Operating Temperature Range	−40°C to +85°C
Junction Temperature Range	−65°C to +150°C
Lead Temperature (Soldering, 60 sec)	300°C

Stresses above those listed under Absolute Maximum Ratings may cause permanent damage to the device. This is a stress rating only; functional operation of the device at these or any other conditions above those indicated in the operational section of this specification is not implied. Exposure to absolute maximum rating conditions for extended periods may affect device reliability.

THERMAL RESISTANCE

θ_{JA} is specified for the worst-case conditions, that is, a device soldered in a circuit board for surface-mount packages.

Table 3. Thermal Resistance

Package Type	θ_{JA}	θ_{JC}	Unit
6-Lead TO-78	150	45	°C/W

ESD CAUTION

ESD (electrostatic discharge) sensitive device. Charged devices and circuit boards can discharge without detection. Although this product features patented or proprietary protection circuitry, damage may occur on devices subjected to high energy ESD. Therefore, proper ESD precautions should be taken to avoid performance degradation or loss of functionality.

TYPICAL PERFORMANCE CHARACTERISTICS

T_A = 25°C, V_{CE} = 5 V, unless otherwise specified.

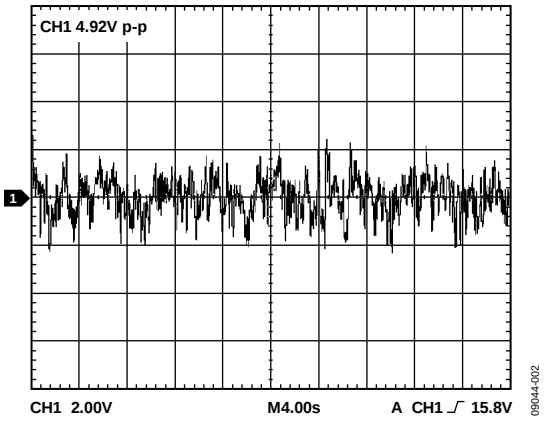

Figure 2. Low Frequency Noise (0.1 Hz to 10 Hz), I_C = 1 mA, Gain = 10,000,000

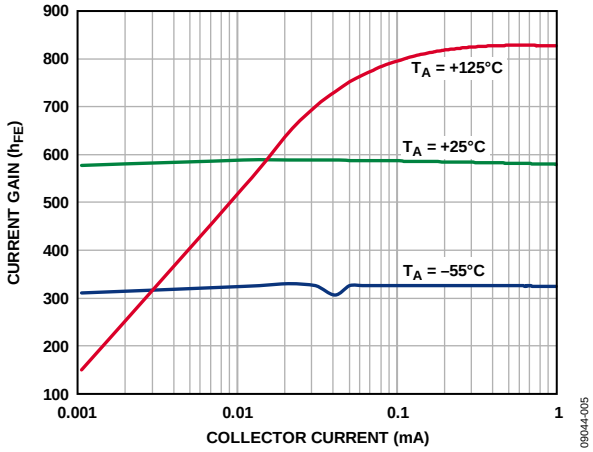

Figure 5. Current Gain vs. Collector Current (V_{CB} = 0 V)

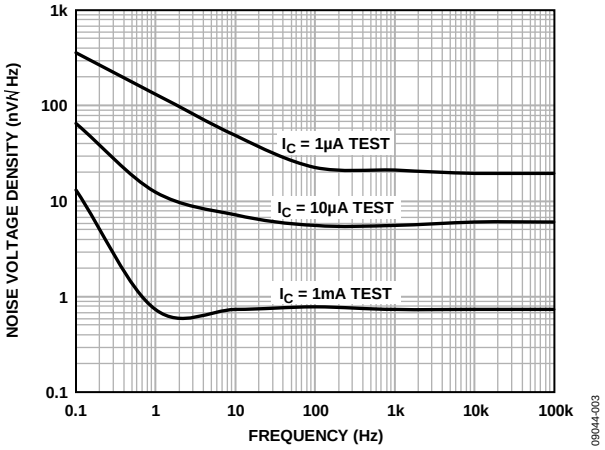

Figure 3. Noise Voltage Density vs. Frequency

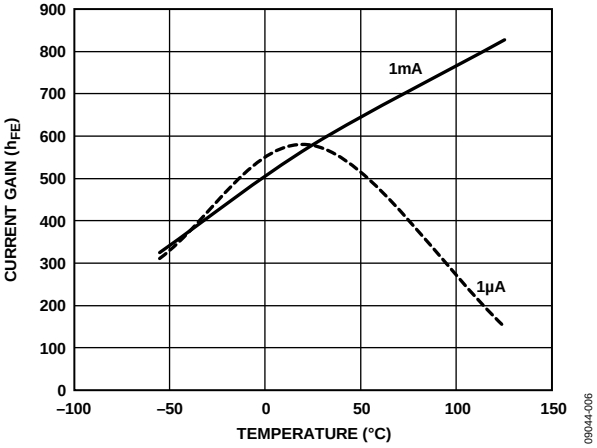

Figure 6. Current Gain vs. Temperature (Excludes I_{CBO})

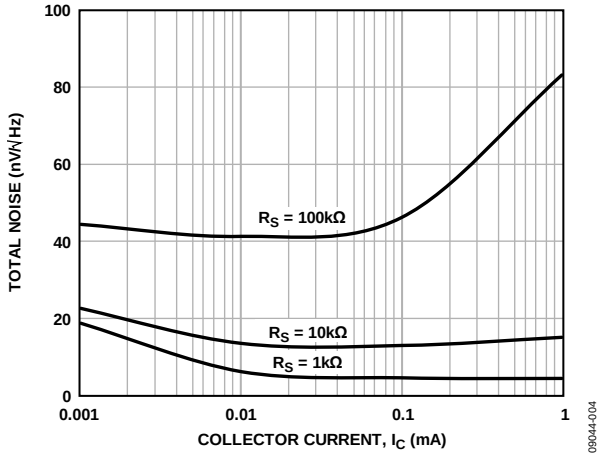

Figure 4. Total Noise vs. Collector Current, f = 1 kHz

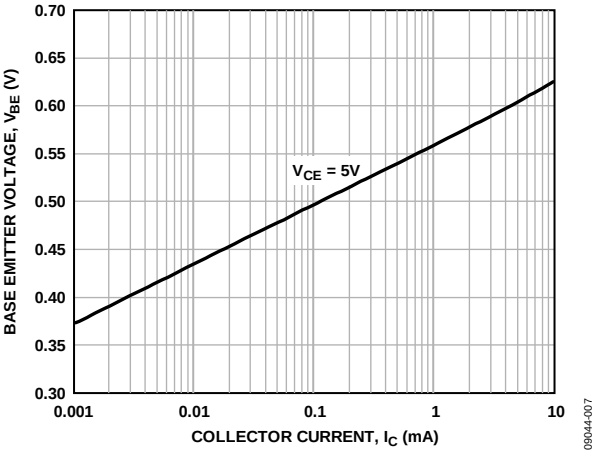

Figure 7. Base Emitter Voltage vs. Collector Current

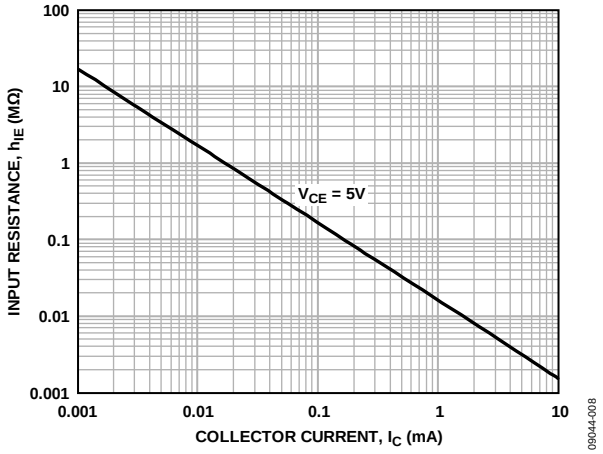

Figure 8. Small Signal Input Resistance vs. Collector Current

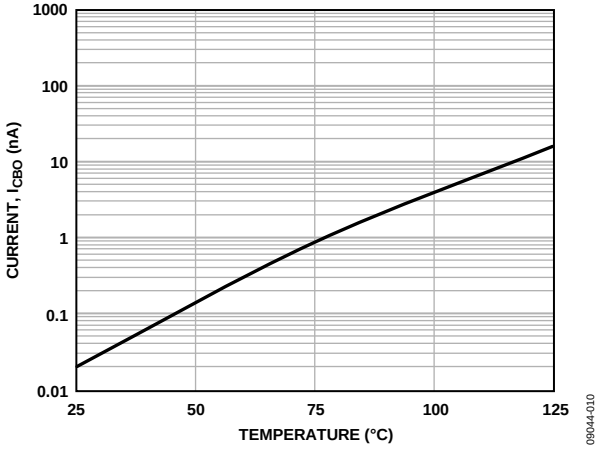

Figure 11. Collector-to-Base Leakage Current vs. Temperature

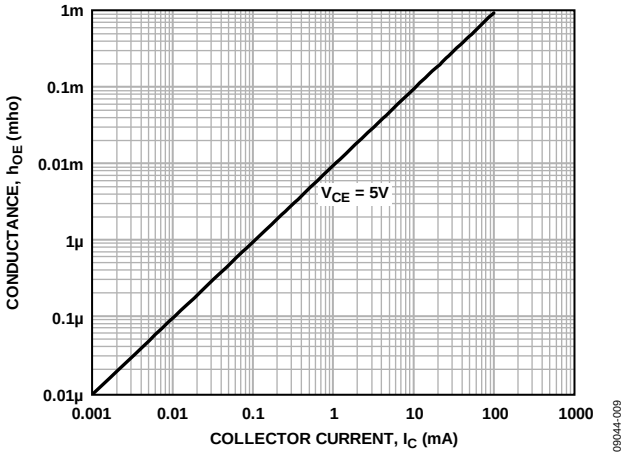

Figure 9. Small Signal Output Conductance vs. Collector Current

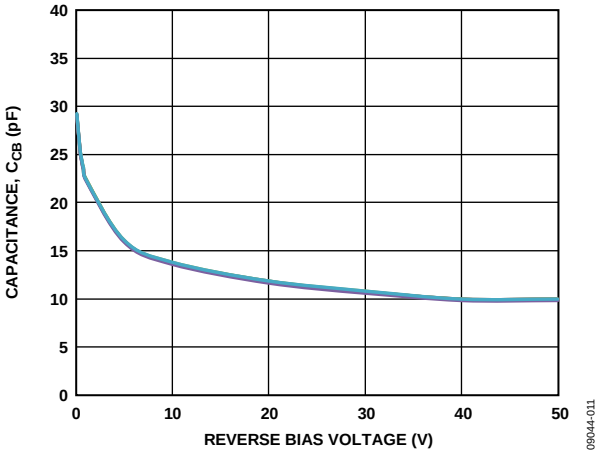

Figure 12. Collector-to-Base Capacitance vs. Reverse Bias Voltage

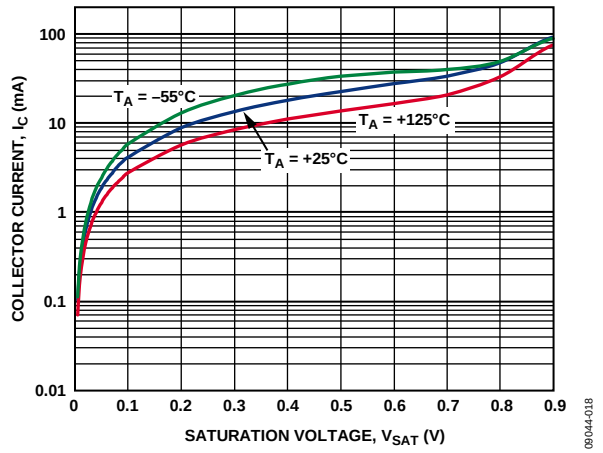

Figure 10. Collector Current vs. Saturation Voltage

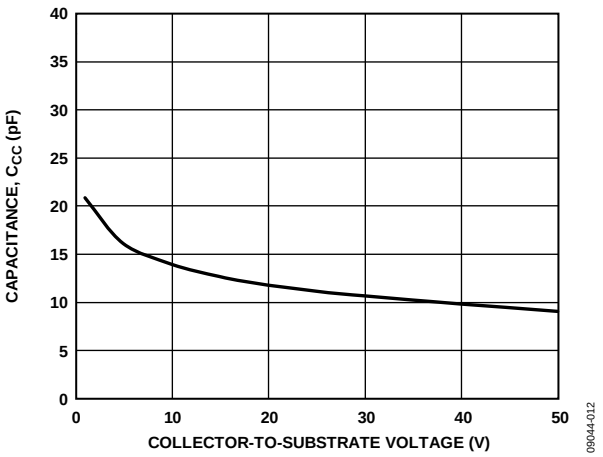

Figure 13. Collector-to-Collector Capacitance vs. Collector-to-Substrate Voltage

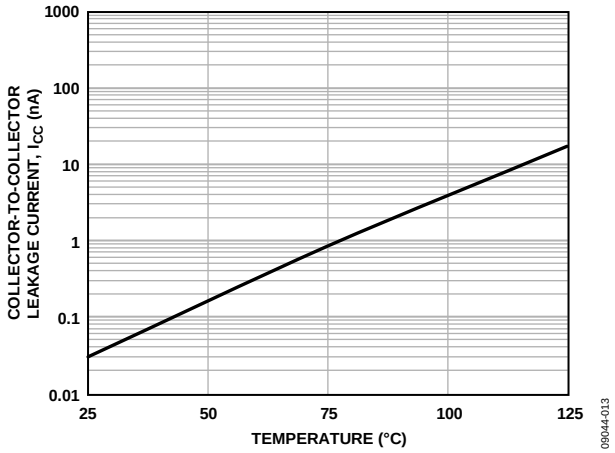

Figure 14. Collector-to-Collector Leakage Current vs. Temperature

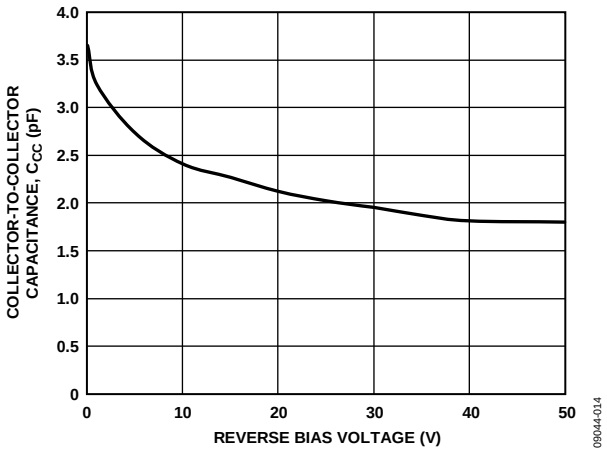

Figure 15. Collector-to-Collector Capacitance vs. Reverse Bias Voltage

APPLICATIONS INFORMATION

FAST LOGARITHMIC AMPLIFIER

The circuit of Figure 16 is a modification of a standard logarithmic amplifier configuration. Running the MAT12 at 2.5 mA per side (full scale) allows for a fast response with a wide dynamic range. The circuit has a seven decade current range and a five decade voltage range, and it is capable of 2.5 µs settling time to 1% with a 1 V to 10 V 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 selected for R_2. The output is inverted with respect to the input and is nominally −1 V/decade using the component values indicated.

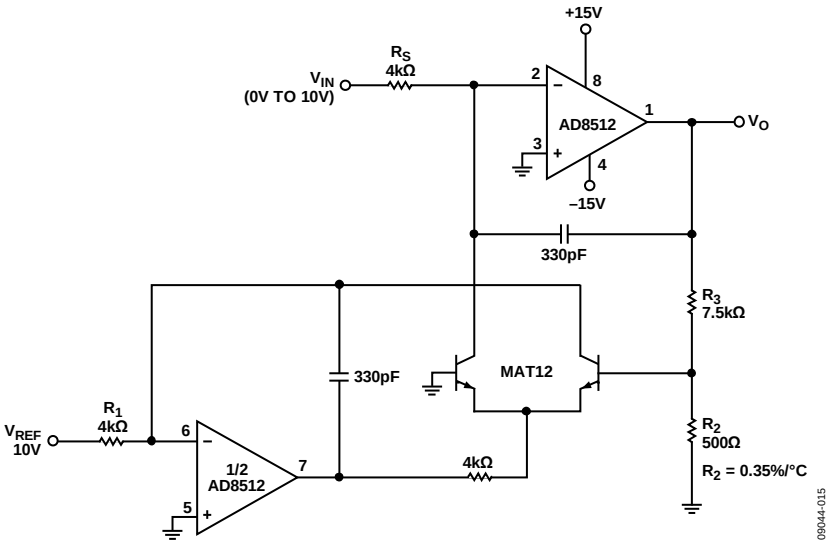

Figure 16. Fast Logarithmic Amplifier

LOG CONFORMANCE TESTING

The log conformance of the MAT12 is tested using the circuit shown in Figure 18. The circuit employs a dual transdiode logarithmic converter operating at a fixed ratio of collector currents that are swept over a 10:1 range. The output of each transdiode converter is the V_{BE} of the transistor plus an error term, which is the product of the collector current and r_{BE}, the bulk emitter resistance. The difference of the V_{BE} is amplified at a gain of ×100 by the AMP02 instrumentation amplifier. The differential emitter base voltage (ΔV_{BE}) consists of a temperature-dependent dc level plus an ac error voltage, which is the deviation from true log conformity as the collector currents vary.

The output of the transdiode logarithmic converter comes from the following idealized intrinsic transistor equation (for silicon)

$$V_{BE} = \frac{kT}{q} \ln \frac{I_C}{I_S} \quad (1)$$

where:
k is Boltzmann's constant (1.38062×10^{-23} J/K).
q is the unit electron charge (1.60219×10^{-19}°C).
T is the absolute temperature, K (= °C + 273.2).
I_S is the extrapolated current for $V_{BE} \rightarrow 0$ (V_{BE} tending to zero).
I_C is the collector current.

An error term must be added to Equation 1 to allow for the bulk resistance (r_{BE}) of the transistor. Error due to the op amp input current is limited by use of the AD8512 dual op amp. The resulting AMP02 input is:

$$\Delta V_{BE} = \frac{kT}{q} = \ln \frac{I_{C1}}{I_{C2}} + I_{C1} r_{BE1} - I_{C2} r_{BE2} \quad (2)$$

A ramp function that sweeps from 1 V to 10 V is converted by the op amps to a collector current ramp through each transistor.

Because I_{C1} is made equal to 10 I_{C2}, and assuming T_A = 25°C, Equation 2 becomes

$$\Delta V_{BE} = 59 \text{ mV} + 0.9\, I_{C1}\, r_{BE} \; (\Delta r_{BE} \sim 0)$$

As viewed on an oscilloscope, the change in ΔV_{BE} for a 10:1 change in I_C is shown in Figure 17.

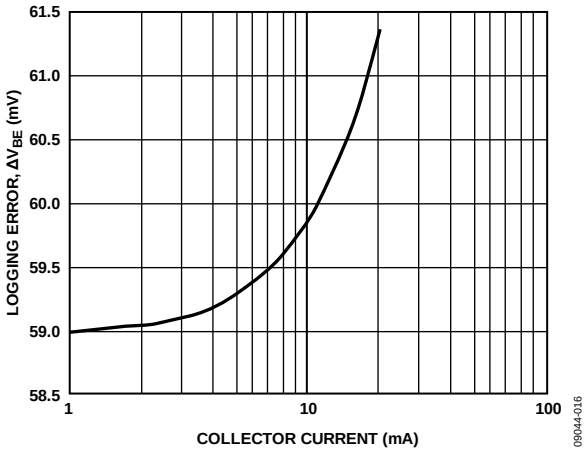

Figure 17. Emitter Base, Log Conformity

With the oscilloscope ac-coupled, the temperature dependent term becomes a dc offset and the trace represents the deviation from true log conformity. The bulk resistance can be calculated from the voltage deviation, ΔV_O, and the change in collector current (9 mA):

$$r_{BE} = \frac{\Delta V_O}{9 \text{ mA}} \times \frac{1}{100} \quad (3)$$

This procedure solves for r_{BE} for Side A. Switching R_1 and R_2 provides the r_{BE} for Side B. Differential r_{BE} is found by making $R_1 = R_2$.

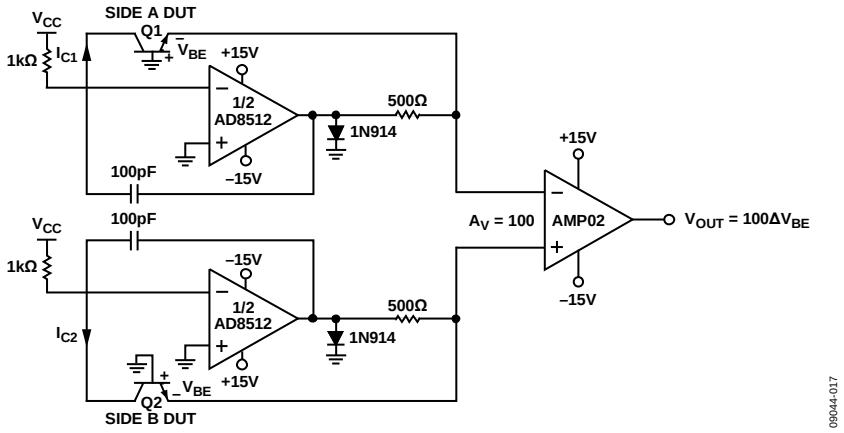

Figure 18. Log Conformance Circuit

OUTLINE DIMENSIONS

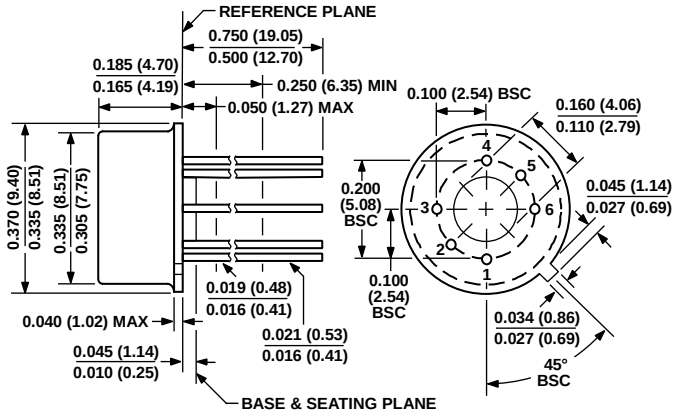

Figure 19. 6-Pin Metal Header Package [TO-78]
(H-06)
Dimensions shown in inches and (millimeters)

ORDERING GUIDE

Model[1]	Temperature Range	Package Description	Package Option
MAT12AHZ	−40°C to +85°C	6-Pin Metal Header Package [TO-78]	H-06

[1] Z = RoHS Compliant Part.

NOTES

NOTES

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