1 Features

- g_m Adjustable Over 6 Decades
- Excellent g_m Linearity
- Excellent Matching Between Amplifiers
- Linearizing Diodes for reduced output distortion
- High Impedance Buffers
- High Output Signal-to-Noise Ratio

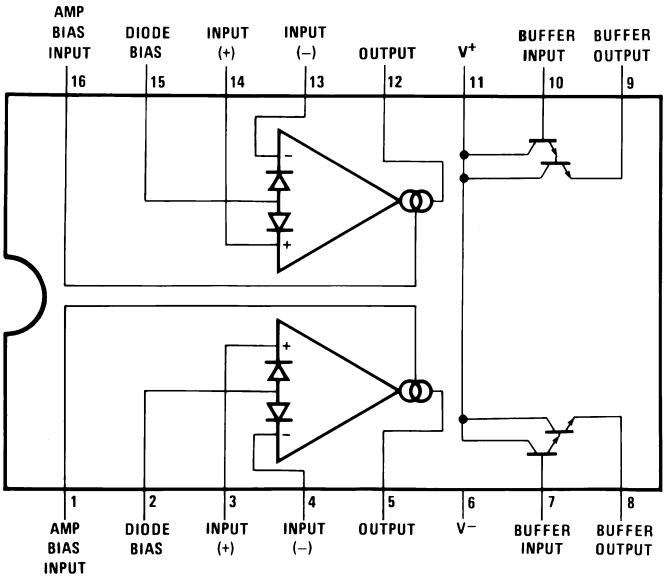
2 Applications

- Current-Controlled Amplifiers
- Stereo Audio Amplifiers
- Current-Controlled Impedances
- Current-Controlled Filters
- Current-Controlled Oscillators
- Multiplexers
- Timers
- Sample-and-Hold Circuits

3 Description

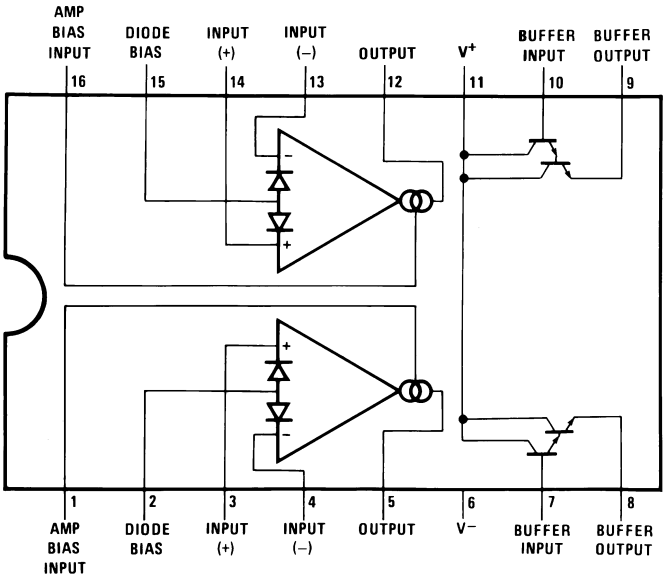
The 13600 series consists of two current-controlled transconductance amplifiers, each with differential inputs and a push-pull output. The two amplifiers share common supplies but otherwise operate independently. Linearizing diodes are provided at the inputs to reduce distortion and allow higher input levels. The result is a 10-dB signal-to-noise improvement referenced to 0.5 percent THD. High impedance buffers are provided which are especially designed to complement the dynamic range of the amplifiers. The output buffers of the 13600 differ from those of the 13600 in that their input bias currents (and thus their output DC levels) are independent of I_{ABC}. This may result in performance superior to that of the 3700 in audio applications.

4 Connection Diagram



5 Pin Configuration and Functions

D or NFG Package
16-Pin SOIC or PDIP
Top View



Pin Functions

PIN		I/O	DESCRIPTION
NAME	NO.		
Amp bias input	1, 16	A	Current bias input
Buffer input	7, 10	A	Buffer amplifier input
Buffer output	8, 9	A	Buffer amplifier output
Diode bias	2, 15	A	Linearizing diode bias input
Input+	3, 14	A	Positive input
Input–	4, 13	A	Negative input
Output	5, 12	A	Unbuffered output
V^+	11	P	Positive power supply
V^-	6	P	Negative power supply

6 Specifications

6.1 Absolute Maximum Ratings

over operating free-air temperature range (unless otherwise noted)(1)

	MIN	MAX	UNIT
Supply voltage		36 V_{DC} or ±18	V
DC input voltage	$+V_S$	$-V_S$	V
Differential input voltage		±5	V
Diode bias current (I_D)		2	mA
Amplifier bias current (I_{ABC})		2	mA
Buffer output current(2)		20	mA
Power dissipation(3) T_A = 25°C – 13600		570	mW
Output short circuit duration	Continuous		
Storage temperature, T_{stg}	−65	150	°C

(1) Stresses beyond those listed under *Absolute Maximum Ratings* may cause permanent damage to the device. These are stress ratings only, which do not imply functional operation of the device at these or any other conditions beyond those indicated under *Recommended Operating Conditions*. Exposure to absolute-maximum-rated conditions for extended periods may affect device reliability.
(2) Buffer output current should be limited so as to not exceed package dissipation.
(3) For operation at ambient temperatures above 25°C, the device must be derated based on a 150°C maximum junction temperature and a thermal resistance, junction to ambient, as follows: 13600, 90°C/W; 13600, 110°C/W.

6.2 Recommended Operating Conditions

over operating free-air temperature range (unless otherwise noted)

		MIN	MAX	UNIT
V+ (single-supply configuration)		9.5	32	V
V+ (dual-supply configuration)		4.75	16	V
V– (dual-supply configuration)		–16	–4.75	V
Operating temperature, T_A	13600	0	70	°C

6.3 Thermal Information

THERMAL METRIC(1)		1700		UNIT
		D (SOIC)	NFG (PDIP)	
		16 PINS	16 PINS	
$R_{\theta JA}$	Junction-to-ambient thermal resistance	83.0	43.8	°C/W
$R_{\theta JC(top)}$	Junction-to-case (top) thermal resistance	44.0	34.9	°C/W
$R_{\theta JB}$	Junction-to-board thermal resistance	40.5	28.3	°C/W
ψ_{JT}	Junction-to-top characterization parameter	11.5	19.1	°C/W
ψ_{JB}	Junction-to-board characterization parameter	40.2	28.2	°C/W

6.4 Electrical Characteristics

These specifications apply for V_S = ±15 V, T_A = 25°C, amplifier bias current (I_{ABC}) = 500 µA, pins 2 and 15 open unless otherwise specified. The inputs to the buffers are grounded and outputs are open.

PARAMETER	TEST CONDITIONS	MIN	TYP	MAX	UNIT
Input offset voltage (V_{OS})	Over specified temperature range		0.4	4	mV
	I_{ABC} = 5 µA		0.3	4	
V_{OS} including diodes	Diode bias current (I_D) = 500 µA		0.5	5	mV
Input offset change	5 µA ≤ I_{ABC} ≤ 500 µA		0.1	3	mV
Input offset current			0.1	0.6	µA
Input bias current			0.4	5	µA
	Over specified temperature range		1	8	
Forward transconductance (g_m)		6700	9600	13000	µS
	Over specified temperature range	5400			
g_m tracking			0.3		dB
Peak output current	R_L = 0, I_{ABC} = 5 µA		5		µA
	R_L = 0, I_{ABC} = 500 µA	350	500	650	
	R_L = 0, Over Specified Temp Range	300			
Supply current	I_{ABC} = 500 µA, both channels		2.6		mA
CMRR		80	110		dB
Common-mode range		±12	±13.5		V
Crosstalk	Referred to input(1) 20 Hz < f < 20 kHz		100		dB
Differential input current	I_{ABC} = 0, input = ±4 V		0.02	100	nA
Leakage current	I_{ABC} = 0 (refer to test circuit)		0.2	100	nA
Input resistance		10	26		kΩ
Open-loop bandwidth			2		MHz
Slew rate	Unity gain compensated		50		V/µs
Buffer input current	See (1)		0.5	2	µA
Peak buffer output voltage	See (1)	10			V
PEAK OUTPUT VOLTAGE					
Positive	R_L = ∞, 5 µA ≤ I_{ABC} ≤ 500 µA	12	14.2		V
Negative	R_L = ∞, 5 µA ≤ I_{ABC} ≤ 500 µA	−12	−14.4		V
V_{OS} SENSITIVITY					
Positive	$\Delta V_{OS}/\Delta V^+$		20	150	µV/V
Negative	$\Delta V_{OS}/\Delta V^-$		20	150	µV/V

(1) These specifications apply for V_S = ±15 V, I_{ABC} = 500 µA, R_{OUT} = 5-kΩ connected from the buffer output to $-V_S$ and the input of the buffer is connected to the transconductance amplifier output.

6.5 Typical Characteristics

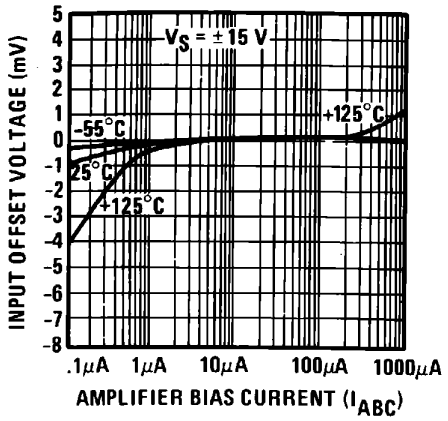


Figure 1. Input Offset Voltage

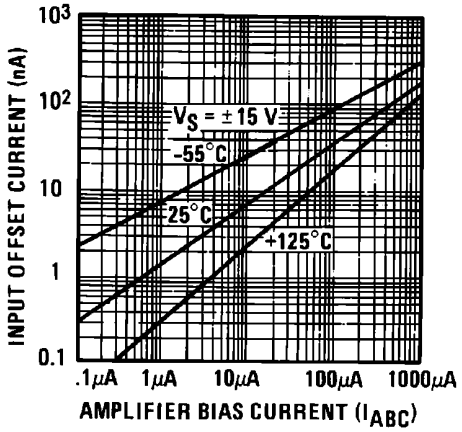


Figure 2. Input Offset Current

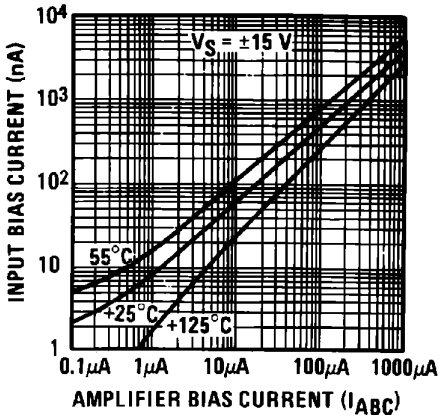


Figure 3. Input Bias Current

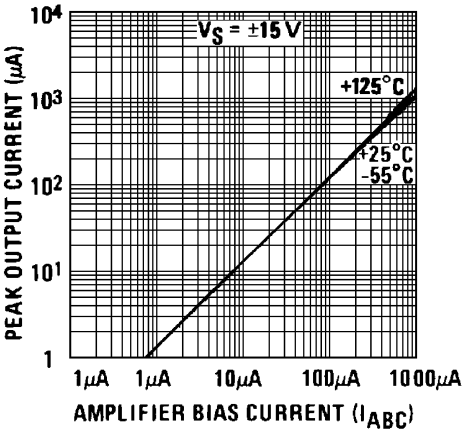


Figure 4. Peak Output Current

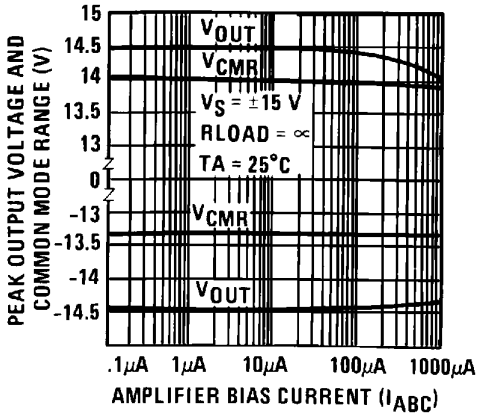


Figure 5. Peak Output Voltage and Common Mode Range

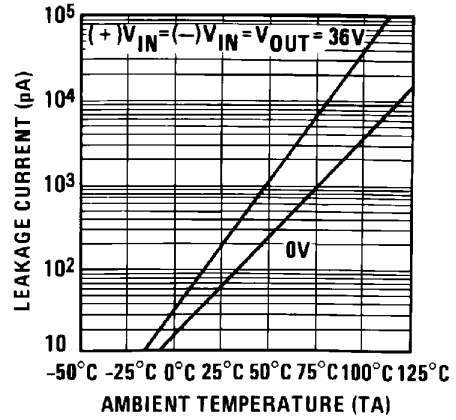


Figure 6. Leakage Current

Typical Characteristics (continued)

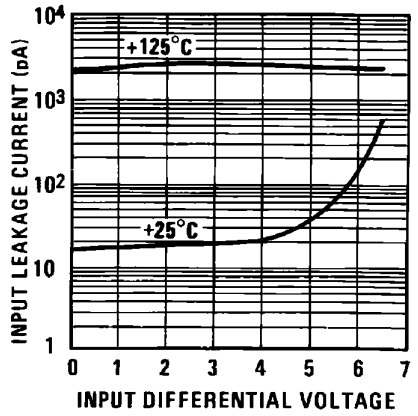


Figure 7. Input Leakage

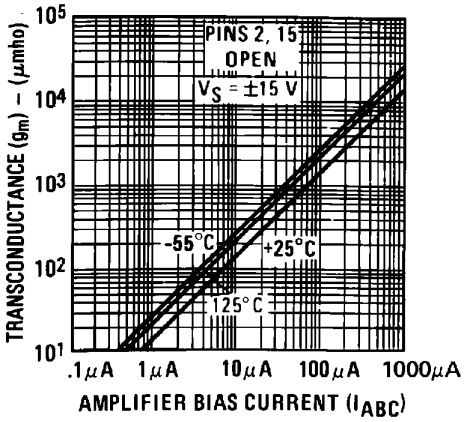


Figure 8. Transconductance

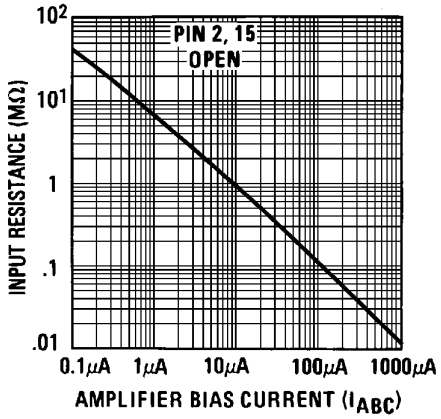


Figure 9. Input Resistance

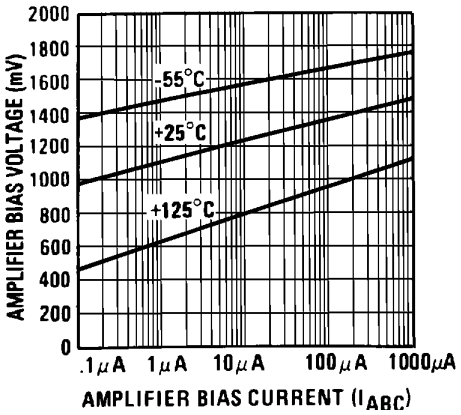


Figure 10. Amplifier Bias Voltage vs. Amplifier Bias Current

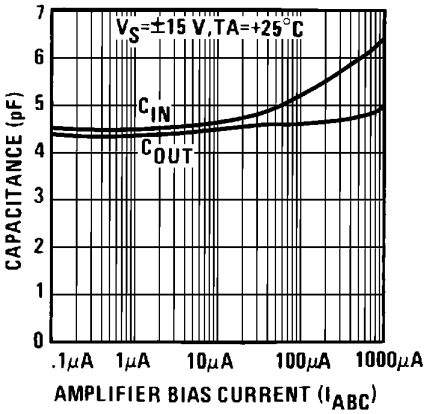


Figure 11. Input and Output Capacitance

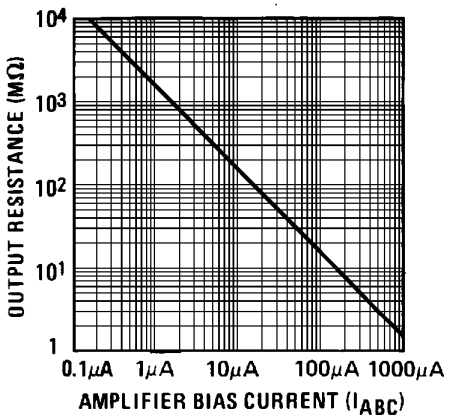


Figure 12. Output Resistance

Typical Characteristics (continued)

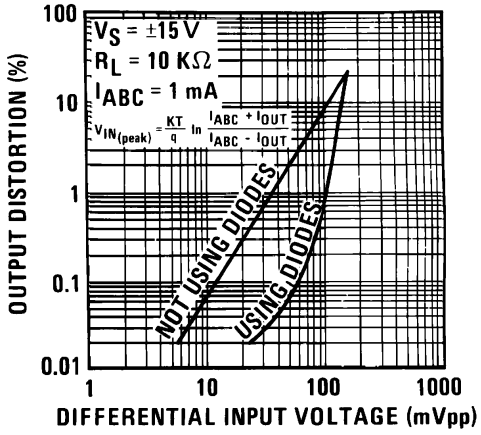


Figure 13. Distortion vs. Differential Input Voltage

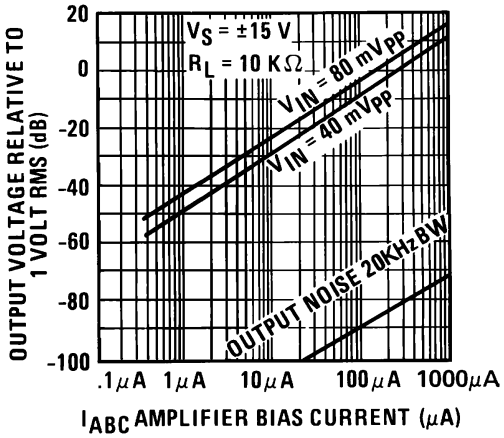


Figure 14. Voltage vs. Amplifier Bias Current

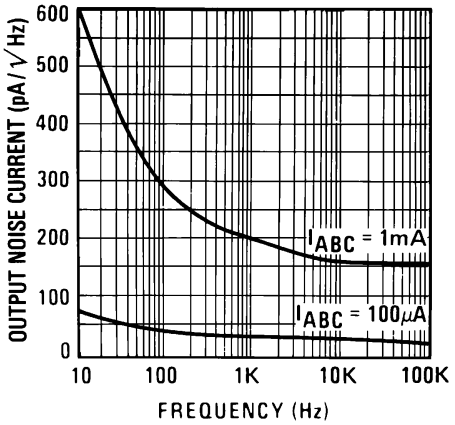


Figure 15. Output Noise vs Frequency

7 Detailed Description

7.1 Overview

The 13600 is a two channel current controlled differential input transconductance amplifier with additional output buffers. The inputs include linearizing diodes to reduce distortion, and the output current is controlled by a dedicated pin. The outputs can sustain a continuous short to ground.

7.2 Functional Block Diagram

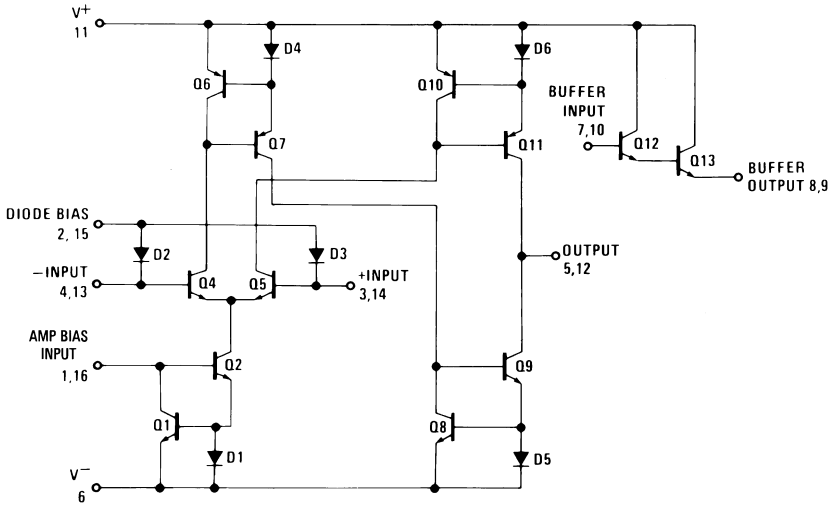


Figure 16. One Operational Transconductance Amplifier

7.3 Feature Description

7.3.1 Circuit Description

The differential transistor pair Q_4 and Q_5 form a transconductance stage in that the ratio of their collector currents is defined by the differential input voltage according to the transfer function:

$$V_{IN} = \frac{kT}{q} \ln \frac{I_5}{I_4} \tag{1}$$

where V_{IN} is the differential input voltage, kT/q is approximately 26 mV at 25°C and I_5 and I_4 are the collector currents of transistors Q_5 and Q_4 respectively. With the exception of Q_{12} and Q_{13}, all transistors and diodes are identical in size. Transistors Q_1 and Q_2 with Diode D_1 form a current mirror which forces the sum of currents I_4 and I_5 to equal I_{ABC}:

$$I_4 + I_5 = I_{ABC} \tag{2}$$

where I_{ABC} is the amplifier bias current applied to the gain pin.

For small differential input voltages the ratio of I_4 and I_5 approaches unity and the Taylor series of the In function is approximated as:

$$\frac{kT}{q} \ln \frac{I_5}{I_4} \approx \frac{kT}{q} \frac{I_5 - I_4}{I_4}$$

$$I_4 \approx I_5 \approx \frac{I_{ABC}}{2} \tag{3}$$

$$V_{IN} \left[\frac{I_{ABC} q}{2kT} \right] = I_5 - I_4 \tag{4}$$

Feature Description (continued)

Collector currents I_4 and I_5 are not very useful by themselves and it is necessary to subtract one current from the other. The remaining transistors and diodes form three current mirrors that produce an output current equal to I_5 minus I_4 thus:

$$V_{IN}\left[\frac{I_{ABC}q}{2kT}\right] = I_{OUT} \tag{5}$$

The term in brackets is then the transconductance of the amplifier and is proportional to I_{ABC}.

7.3.2 Linearizing Diodes

For differential voltages greater than a few millivolts, Equation 3 becomes less valid and the transconductance becomes increasingly nonlinear. Figure 19 demonstrates how the internal diodes can linearize the transfer function of the amplifier. For convenience assume the diodes are biased with current sources and the input signal is in the form of current I_S. Since the sum of I_4 and I_5 is I_{ABC} and the difference is I_{OUT}, currents I_4 and I_5 is written as follows:

$$I_4 = \frac{I_{ABC}}{2} - \frac{I_{OUT}}{2},\ I_5 = \frac{I_{ABC}}{2} + \frac{I_{OUT}}{2} \tag{6}$$

Since the diodes and the input transistors have identical geometries and are subject to similar voltages and temperatures, the following is true:

$$\frac{kT}{q}\ln\frac{\frac{I_D}{2} + I_S}{\frac{I_D}{2} - I_S} = \frac{kT}{q}\ln\frac{\frac{I_{ABC}}{2} + \frac{I_{OUT}}{2}}{\frac{I_{ABC}}{2} - \frac{I_{OUT}}{2}}$$

$$\therefore I_{OUT} = I_S\left(\frac{2I_{ABC}}{I_D}\right) \text{ for } |I_S| < \frac{I_D}{2} \tag{7}$$

Notice that in deriving Equation 7 no approximations have been made and there are no temperature-dependent terms. The limitations are that the signal current not exceed I_D / 2 and that the diodes be biased with currents. In practice, replacing the current sources with resistors will generate insignificant errors.

7.4 Device Functional Modes

Use in single ended or dual supply systems requires minimal changes. The outputs can support a sustained short to ground. Note that use of the 13700 in ±5 V supply systems requires will reduce signal dynamic range; this is due to the PNP transistors having a higher V_{BE} than the NPN transistors.

7.4.1 Output Buffers

Each channel includes a separate output buffer which consists of a Darlington pair transistor that can drive up to 20mA.

8 Application and Implementation

8.1 Application Information

An OTA is a versatile building block analog component that can be considered an ideal transistor. The 13600 can be used in a wide variety of applications, from voltage-controlled amplifiers and filters to VCOs. The 2 well-matched, independent channels make the 13600 well suited for stereo audio applications.

8.2 Typical Application

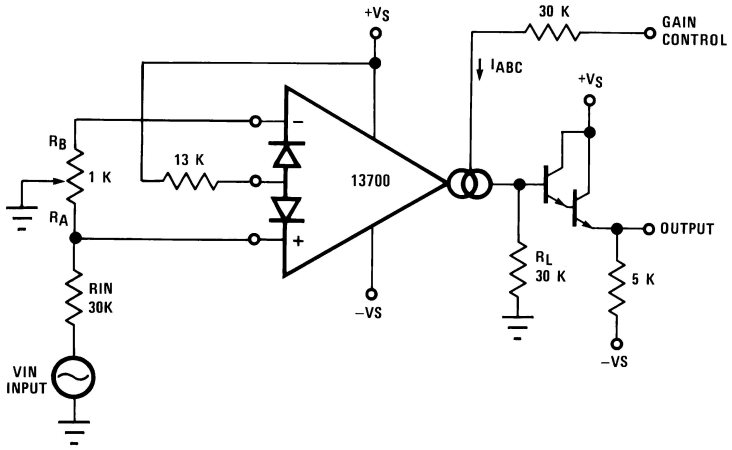


Figure 17. Voltage Controlled Amplifier

8.2.1 Design Requirements

For this example application, the system requirements provide a volume control for a 1 V_P input signal with a THD < 0.1% using ±15 V supplies. The volume control varies between -13 V and 15 V and needs to provide an adjustable gain range of >30dB.

8.2.2 Detailed Design Procedure

Using the linearizing diodes is recommended for most applications, as they greatly reduce the output distortion. It is required that the diode bias current, I_D be greater than twice the input current, I_S. As the input voltage has a DC level of 0 V, the Diode Bias input pins are 1 diode drop above 0 V, which is +0.7 V. Tying the bias to the clean V+ supply, results in a voltage drop of 14.3 V across R_D. Using the recommended 1mA for I_D is appropriate here, and with VS=+15 V, the voltage drop is 14.3 V, and so using the standard value of 13-kΩ is acceptable and will provide the desired gain control.

To obtain the <0.1% THD requirement, the differential input voltage must be <60mVpp when the linearizing diodes are used. The input divider on the input will reduce the 1 V_P input to 33mV_{PP}, which is within the desired spec.

Next, set I_{BIAS}. The Bias Input pins (pins 1 or 16), are 2 diode drops above the negative supply, and therefore V_{BIAS} = 2(V_{BE}) + V- , which for this application is -13.6 V. To set I_{BIAS} to 1ma when V_C = 15 V requires a 28.6-kΩ; 30-kΩ is a standard value and is used for this application. The gain will be linear with the applied voltage.

Typical Application (continued)

8.2.3 Application Curve

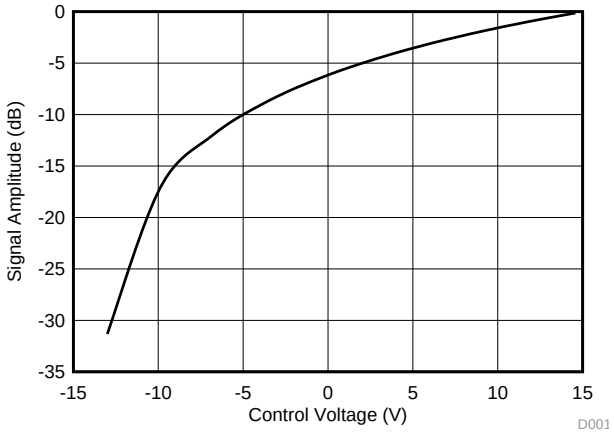


Figure 18. Signal Amplitude vs Control Voltage

8.3 System Examples

8.3.1 Voltage-Controlled Amplifiers

Figure 20 shows how the linearizing diodes is used in a voltage-controlled amplifier. To understand the input biasing, it is best to consider the 13-kΩ resistor as a current source and use a Thevenin equivalent circuit as shown in Figure 21. This circuit is similar to Figure 19 and operates the same. The potentiometer in Figure 20 is adjusted to minimize the effects of the control signal at the output.

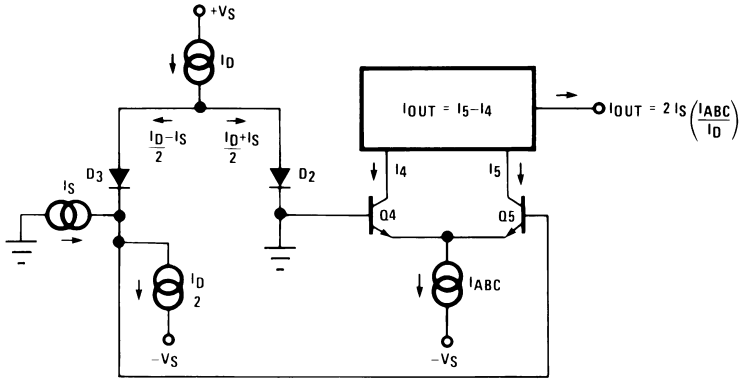
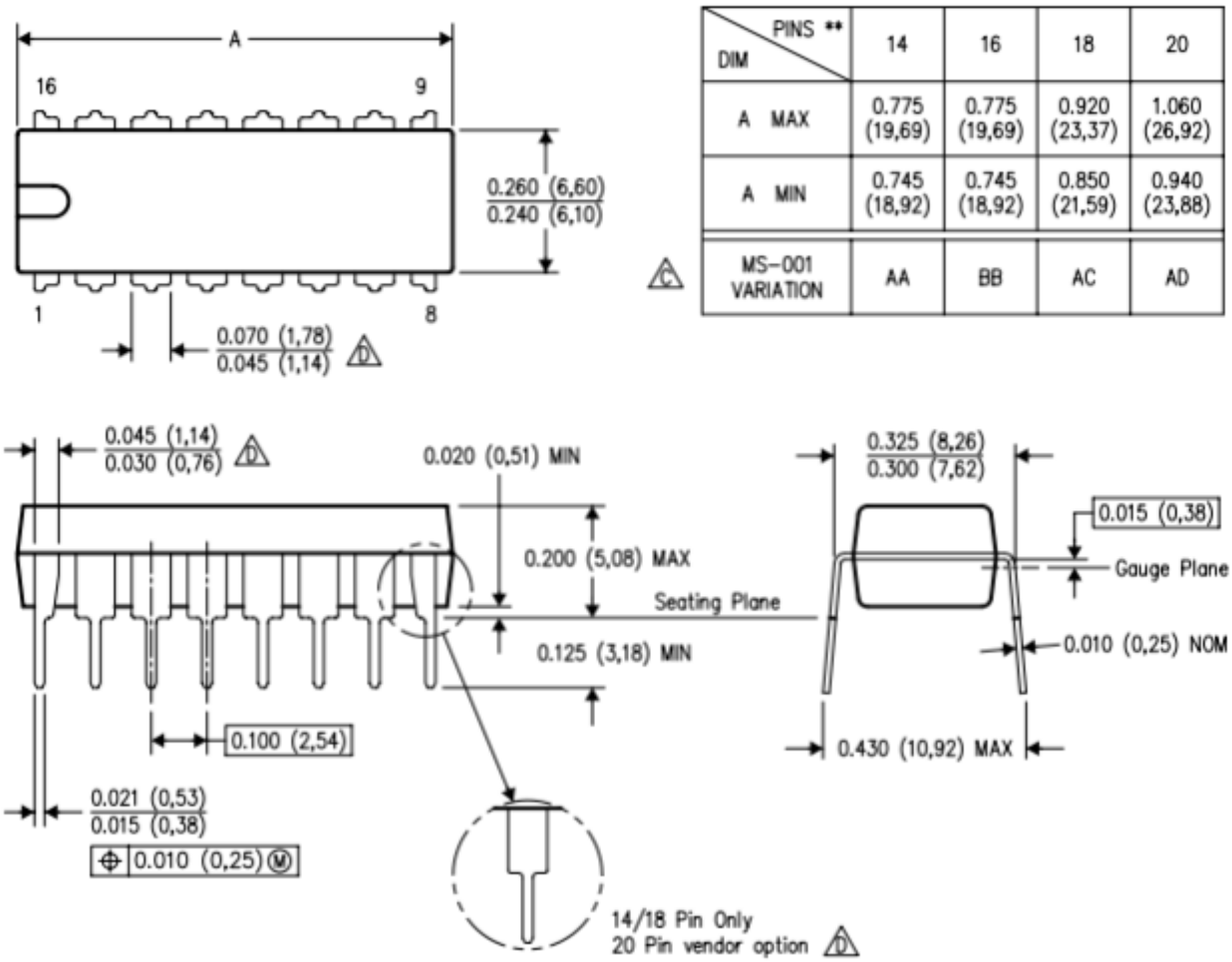


Figure 19. Linearizing Diodes

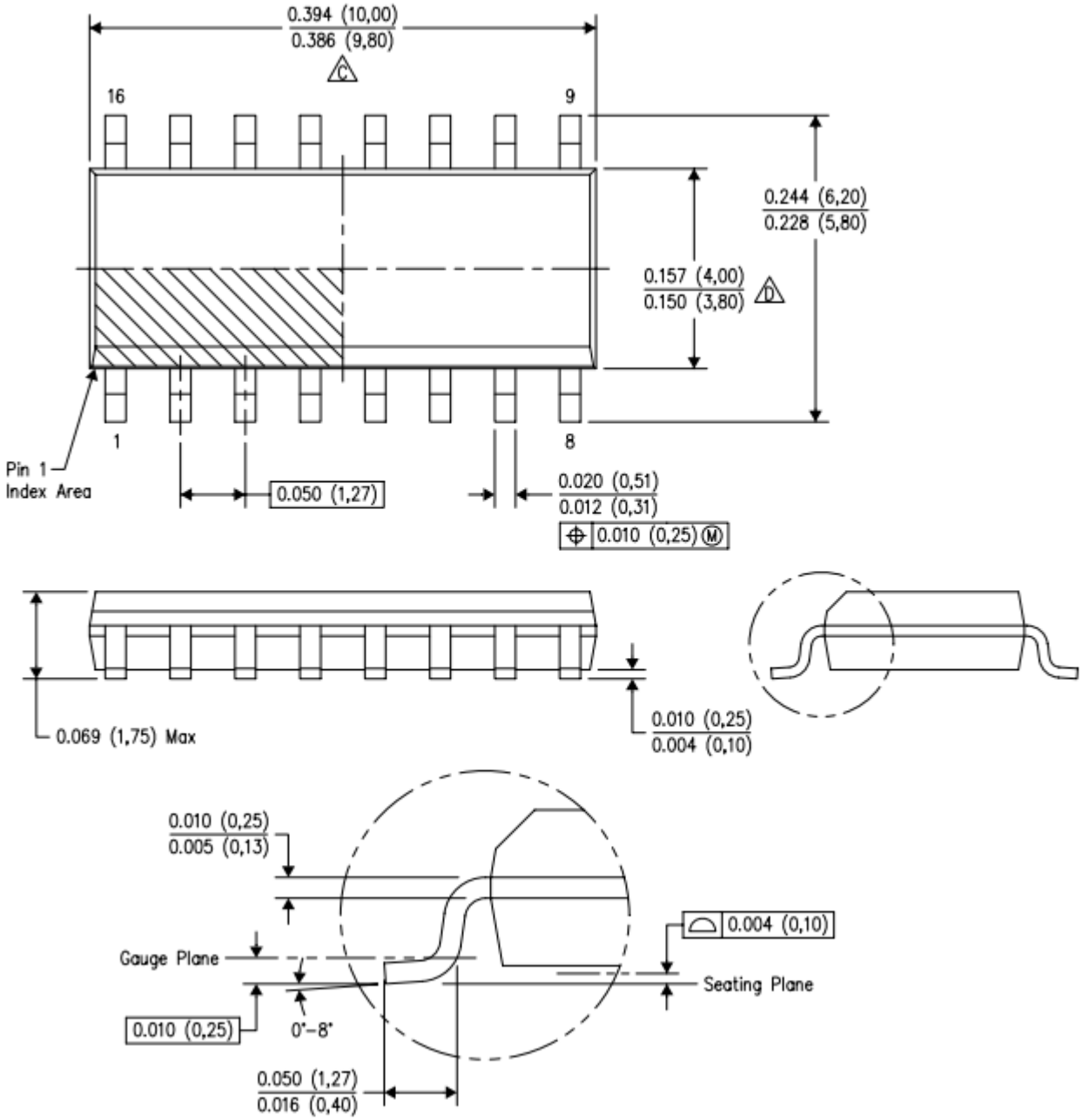
For optimum signal-to-noise performance, I_{ABC} should be as large as possible as shown by the Output Voltage vs Amplifier Bias Current graph. Larger amplitudes of input signal also improve the S/N ratio. The linearizing diodes help here by allowing larger input signals for the same output distortion as shown by the Distortion vs. Differential Input Voltage graph. S/N may be optimized by adjusting the magnitude of the input signal via R_{IN} (Figure 20) until the output distortion is below the desired level. The output voltage swing can then be set at any level by selecting R_L.

Although the noise contribution of the linearizing diodes is negligible relative to the contribution of the amplifier's internal transistors, I_D should be as large as possible. This minimizes the dynamic junction resistance of the diodes (r_e) and maximizes their linearizing action when balanced against R_{IN}. A value of 1 mA is recommended for I_D unless the specific application demands otherwise.

DIP16



DIM \ PINS **	14	16	18	20
A MAX	0.775 (19,69)	0.775 (19,69)	0.920 (23,37)	1.060 (26,92)
A MIN	0.745 (18,92)	0.745 (18,92)	0.850 (21,59)	0.940 (23,88)
MS-001 VARIATION	AA	BB	AC	AD



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