Dual Operational Transconductance Amplifiers With Linearizing Diodes and Buffers

DESCRIPTION

The LM13700MX/NOPB-CN 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 LM13700MX/NOPB-CN differ from those of the LM13700MX/NOPB-CN 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 LM13700MX/NOPB-CN in audio applications.

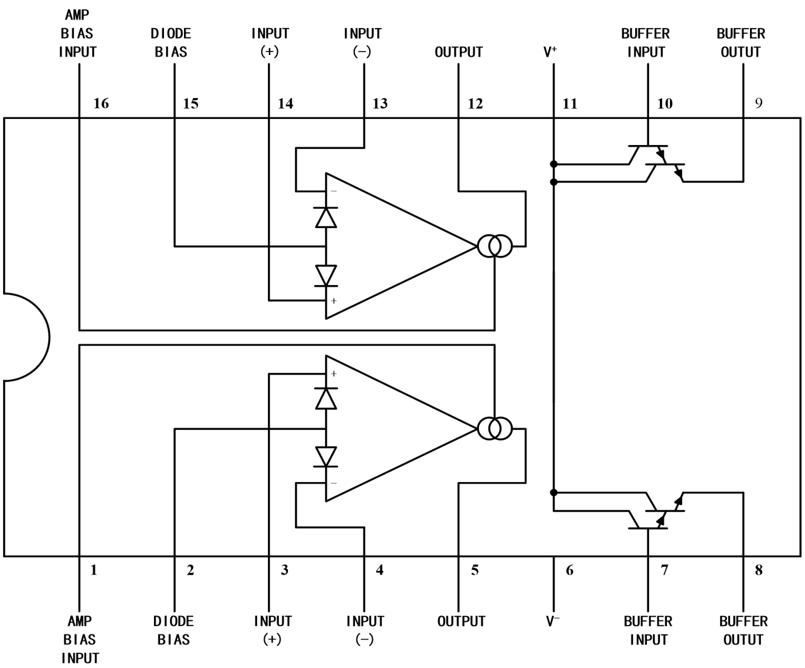
FEATURES

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

APPLICATIONS

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

Pin Configuration



Absolute Maximum Ratings

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

PARAMETER		MIN	MAX	UNIT
Supply Voltage, Vs=(V+) - (V-)	Single-supply		+36	V
	Dual-supply	-18	+18	V
DC Input Voltage		$-V_S$	$+V_S$	V
Differential input voltage		-5	+5	V
Diode bias current (I_D)			2	mA
Amplifier bias current (I_{ABC})			2	mA
Buffer output current(I_{Buffer})(2)			20	mA
Output short circuit duration		Continuous		
Storage temperature(Ts)		-65	+150	℃

Note 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.

Note 2: Buffer output current should be limited so as to not exceed package dissipation.

Recommended Operating Conditions

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

PARAMETER	MIN	TYP	MAX	UNIT
V_S (single-supply configuration)	10		32	V
V+ (dual-supply configuration)	5		16	V
V- (dual-supply configuration)	-16		-5	V
Operating Temperature Range(T_A)	-20		85	℃

ELECTRICAL CHARACTERISTICS

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

PARAMETER	SYMBOL	CONDITIONS	MIN	TYP	MAX	UNIT
Input offset voltage	V_{OS}	Over specified temperature range		0.4	4	mV
		I_{ABC}=5uA		0.3	4	mV
V_{OS} including diodes	V_{OS_D}	Diode bias current (I_D)=500μA		0.5	5	mV
Input offset change	ΔV_{OS}	5uA≤I_{ABC}≤500uA		0.1	3	mV
Input offset current	I_{OS}			0.1	0.6	uA
Input bias current	I_B			0.4	5	uA
		Over specified temperature range		1	8	uA
Forward transconductance	gm	Take 10mV and 25mV to calculate	6700	9600	13000	μS
		Over specified temperature range	5400			μS
gm tracking	gm_t			0.3		dB
Peak output current	Ipk	R_L=0, I_{ABC}=5uA		5		uA
		R_L=0, I_{ABC}=500uA	350	500	650	uA
		R_L=0, Over specified temperature range	300			uA
Supply current	I_{CC}	I_{ABC}=500uA, both channels		2.2		mA
Common-mode range	Vic		±12	±13.5		V
Common-mode rejection ratio	CMRR		80	110		dB
Crosstalk	Crosstalk	Referred to input[1], 20Hz<f<20kHz		100		dB
Differential input current	Id	I_{ABC}=0， input=±4V		0.02	100	nA
Leakage current	I_{LEAK}	I_{ABC}=0(refer to test circuit)		0.2	100	nA
Input resistance	Z_{IN}		10	26		kΩ
Open-loop bandwidth	BW			2		MHz
Slew rate	SR	Unity gain compensated		50		V/μs
Buffer input current	I_{BIN}	See [1]		0.5	2	uA
Peak buffer output voltage	Ipkout-buf	See [1]	10			V
PEAK OUTPUT VOLTAGE						
Positive	V_{OP}	R_L=∞, 5uA≤I_{ABC}≤500uA	12	14.2		V
Negative	V_{ON}	R_L=∞, 5uA≤I_{ABC}≤500uA	-12	-14.4		V
V_{OS} SENSITIVITY						
Positive		ΔVos/ΔV+		20	150	μV/V
Negative		ΔVos/ΔV-		20	150	μV/V

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

TYPICAL CHARACTERISTICS

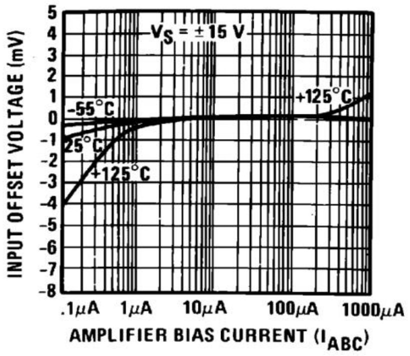


Figure 1. Input Offset Voltage vs I_{ABC}

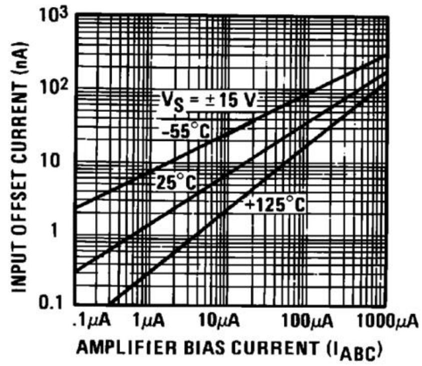


Figure 2. Input Offset Current vs I_{ABC}

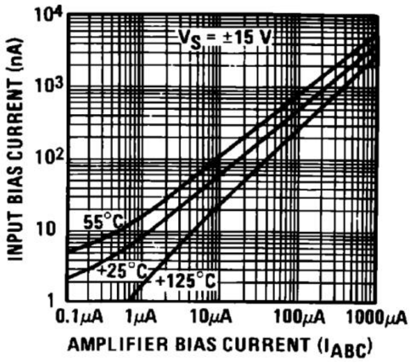


Figure 3. Input BIAS Current vs I_{ABC}

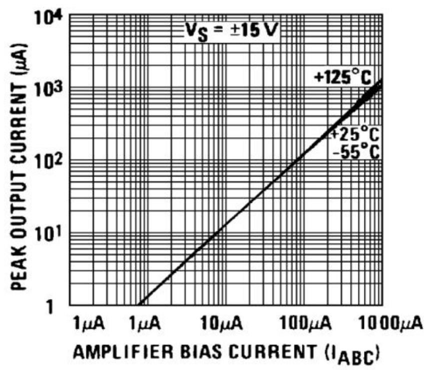


Figure 4. Peak Output Current vs I_{ABC}

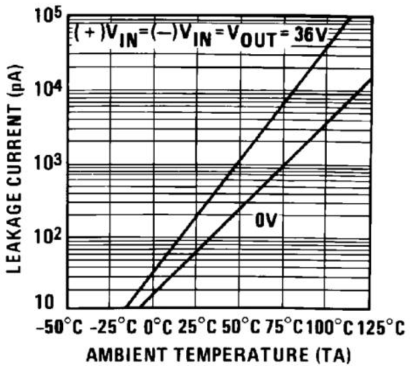


Figure 5. Leak Current vs Temperature

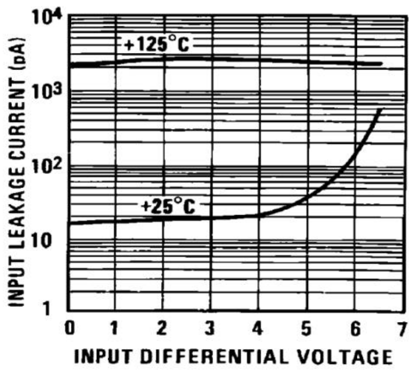


Figure 6. Input Leak Current vs Input Different Voltage

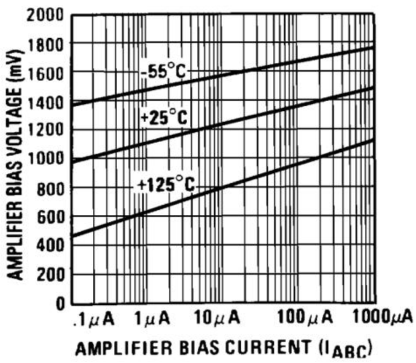


Figure 7. Amplifier Bias Voltage vs I_{ABC}

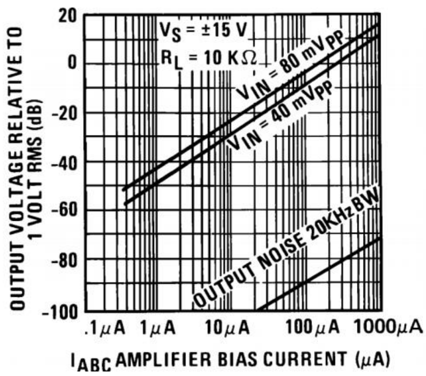


Figure 8. Output Voltage vs I_{ABC}

Detailed Description

Overview

The LM13700MX/NOPB-CN 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.

Functional Block Diagram

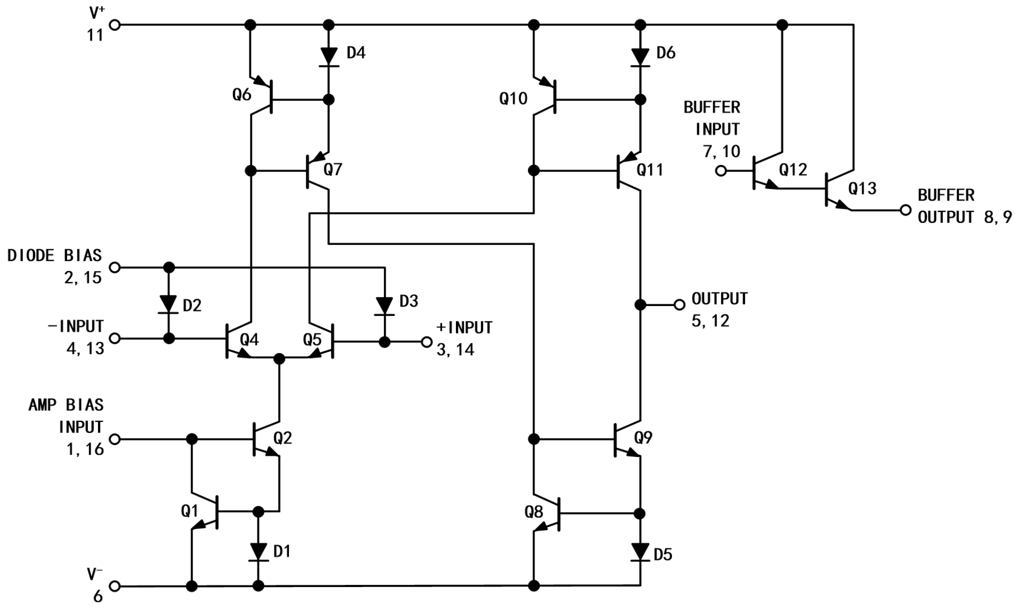


Figure 9. One Operational Transconductance Amplifier

(1) Feature 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:

$$V_{IN} = \frac{kT}{q} \ln \frac{I_5}{I_4} \quad (1)$$

where V_{IN} is the differential input voltage, kT/q is approximately 26 mV at 25℃ 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 D1 form a current mirror which forces the sum of currents I_4 and I_5 to equal I_{ABC}:

$$I_4 + I_5 = I_{ABC} \quad (2)$$

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:

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

$$I_4 \approx I_5 \approx \frac{I_{ABC}}{2} \quad (3)$$

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

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:

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

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

(2) Linearizing Diodes

For differential voltages greater than a few millivolts, Equation 3 becomes less valid and the transconductance becomes increasingly nonlinear. Figure 10 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:

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

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

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

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

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.

(3) 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 LM13700MX/NOPB-CN 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.

(4) Output Buffers

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

Application and Implementation

Application Information

An OTA is a versatile building block analog component that can be considered an ideal transistor. The LM13700MX/NOPB-CN 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 LM13700MX/NOPB-CN well suited for stereo audio applications.

Typical Application

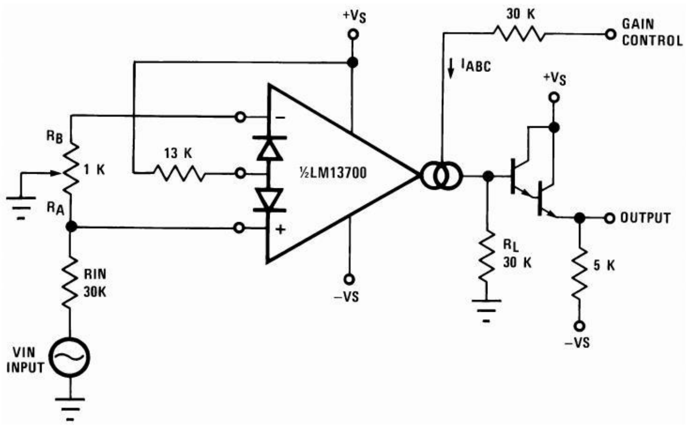


Figure 10 . Voltage Controlled Amplifier

(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 ±15V supplies. The volume control varies between -13 V and 15 V and needs to provide an adjustable gain range of >30dB.

(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 0V, the Diode Bias input pins are 1 diode drop above 0V, which is +0.7V. Tying the bias to the clean V+ supply, results in a voltage drop of 14.3V across R_D. Using the recommended 1mA for I_D is appropriate here, and with V_S=+15 V, the voltage drop is 14.3V, and so using the standard value of 13kΩ is acceptable and will provide the desired gain control.

To obtain the <0.1% THD requirement, the differential input voltage must be <60mV_{PP} when the linearizing diodes are used. The input divider on the input will reduce the 1V_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 -13.6V. To set I_{BIAS} to 1mA when V_C=15V requires a 28.6kΩ; 30kΩ is a standard value and is used for this application. The gain will be linear with the applied voltage.

(3) Application Curve

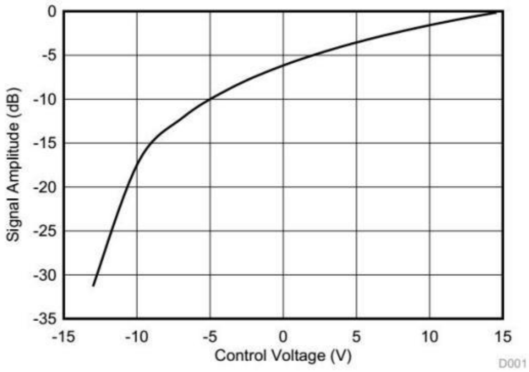


Figure 11 . Signal Amplitude vs Control Voltage

System Examples - Voltage-Controlled Amplifiers

Figure 13 shows how the linearizing diodes is used in a voltage-controlled amplifier. To understand the input biasing, it is best to consider the 13kΩ resistor as a current source and use a Thevenin equivalent circuit as shown in Figure 14. This circuit is similar to Figure 12 and operates the same. The potentiometer in Figure 14 is adjusted to minimize the effects of the control signal at the output.

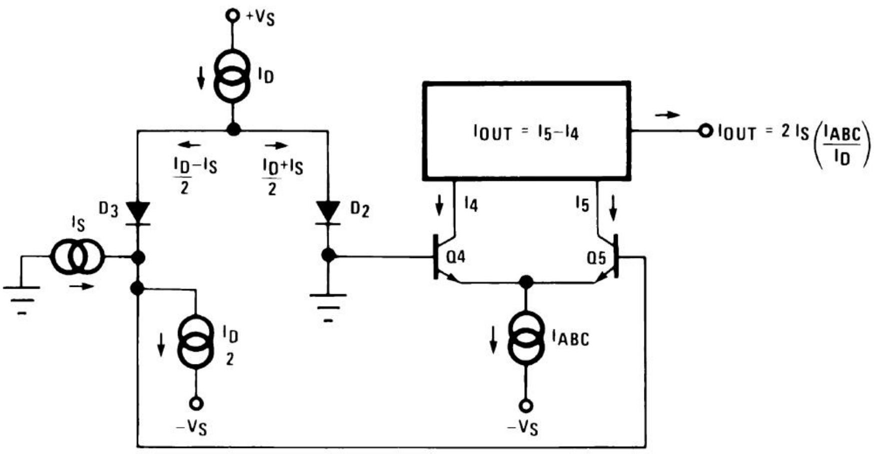


Figure 12 . Linearizing Diodes

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 13) 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 1mA is recommended for I_D unless the specific application demands otherwise.

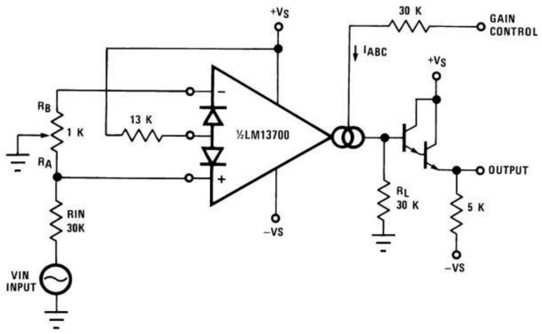


Figure 13. Voltage-Controlled Amplifier

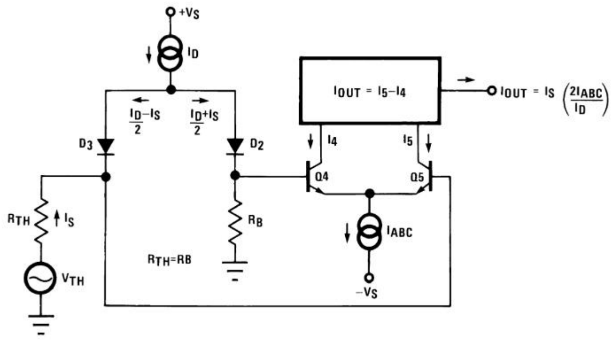


Figure 14. Equivalent VCA Input Circuit

Other Applications

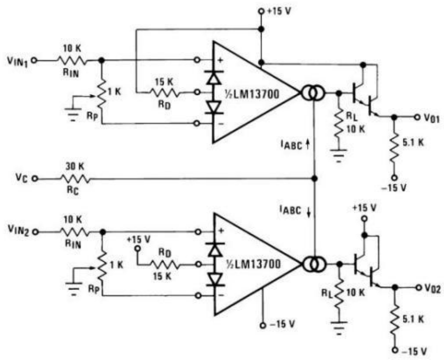


Figure 15. Stereo Volume Control

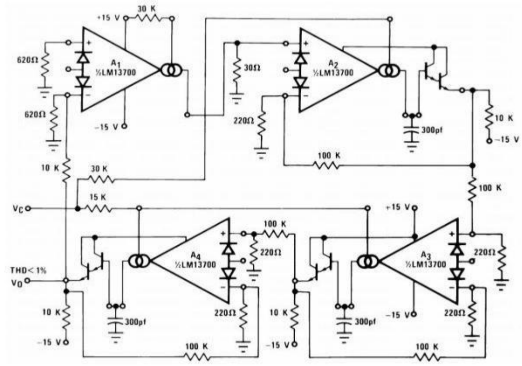


Figure 16. Sinusoidal VCO

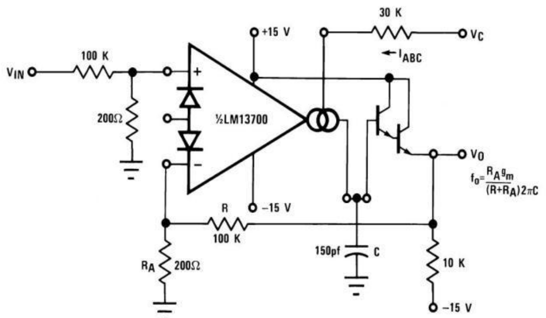


Figure 17. Voltage-Controlled Low-Pass Filter

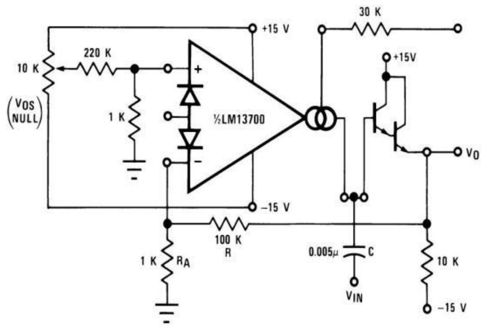


Figure 18. Voltage-Controlled Hi-Pass Filter

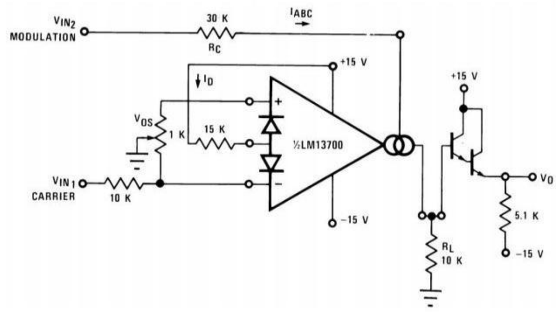


Figure 19. Amplitude Modulator

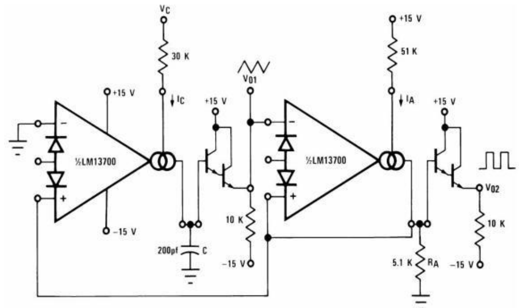


Figure 20. Triangular/Square-Wave VCO

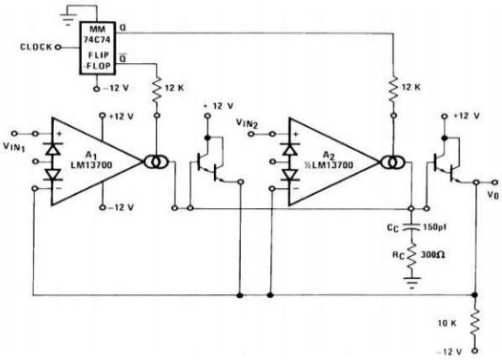


Figure 21. Multiplexer

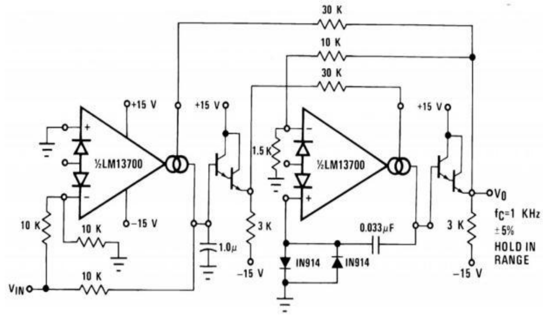


Figure 22. Phase Lock Loop

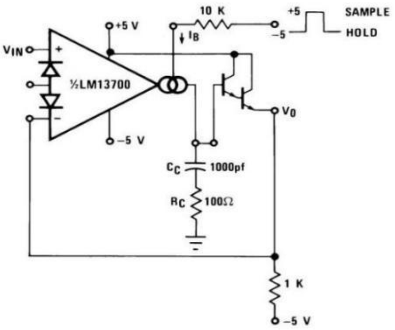


Figure 23. Sample-Hold Circuit

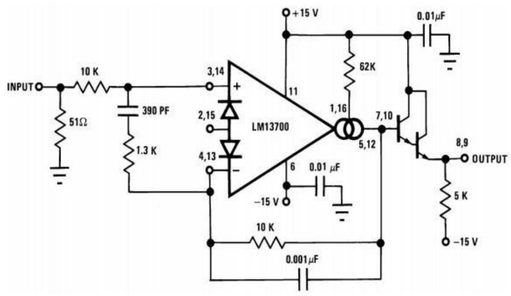


Figure 24. Unity Gain Follower

Test Circuits

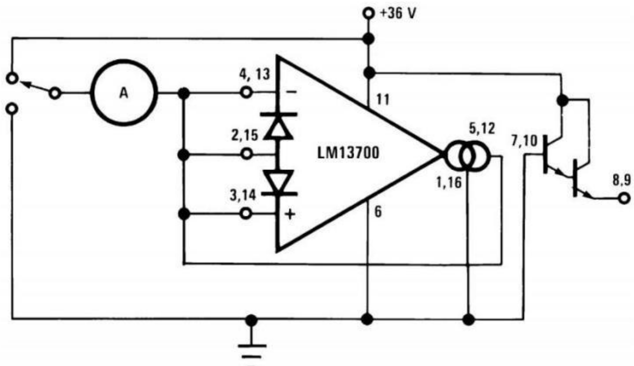


Figure 25. Leakage Current Test Circuit

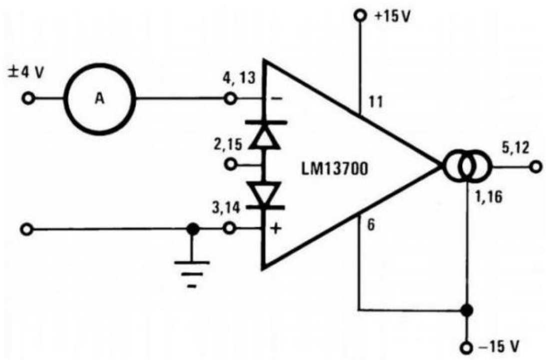
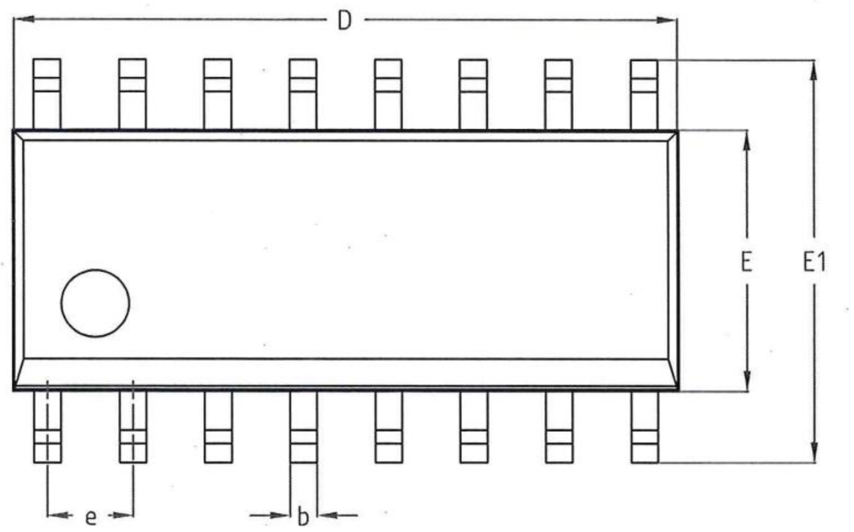


Figure 26. Differential Input Current Test Circuit

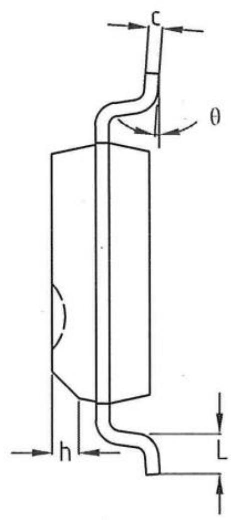
PACKAGE OUTLINE DIMENSIONS

SOP16

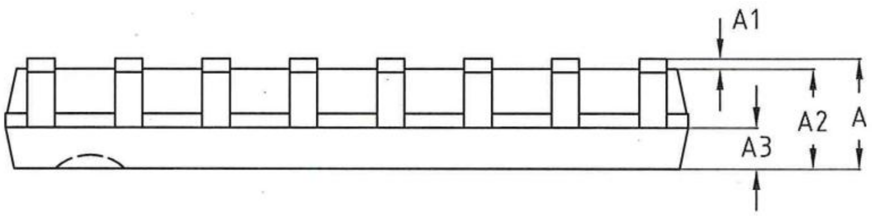
TOP VIEW
正视图



SIDE VIEW
侧视图



SIDE VIEW
侧视图



SYMBOL	MILLIMETER			SYMBOL	MILLIMETER		
	MIN	NOM	MAX		MIN	NOM	MAX
A	-	-	1.75	E	3.80	3.90	4.00
A1	0.10	-	0.25	E1	5.80	6.00	6.20
A2	1.35	1.45	1.55	e	1.27 BSC		
A3	0.60	0.65	0.70	h	0.30	-	0.50
b	0.35	-	0.50	L	0.40	-	0.80
c	0.19	-	0.25	θ	0°	-	8°
D	9.80	9.90	10.00				

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