

# LM13700 Dual Operational Transconductance Amplifiers with Linearizing Diodes and Buffers

Check for Samples: [LM13700](#)

## FEATURES

- $g_m$  Adjustable over 6 Decades
- Excellent  $g_m$  Linearity
- Excellent Matching between Amplifiers
- Linearizing Diodes
- High Impedance Buffers
- High Output Signal-to-Noise Ratio

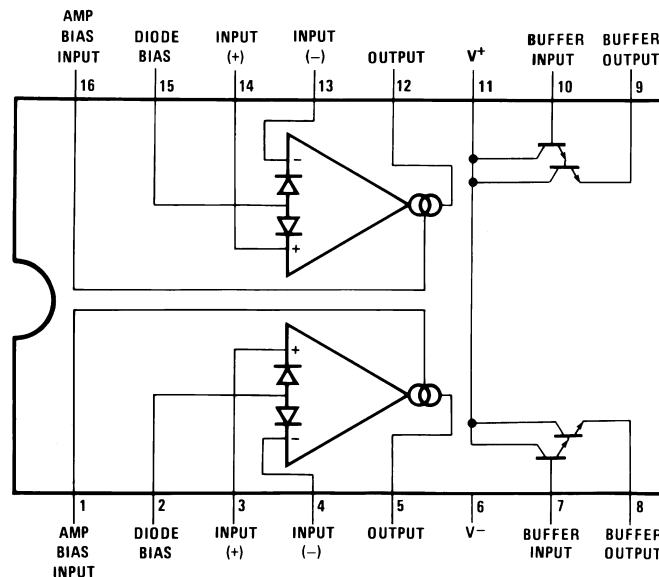
## APPLICATIONS

- Current-Controlled Amplifiers
- Current-Controlled Impedances
- Current-Controlled Filters
- Current-Controlled Oscillators
- Multiplexers
- Timers
- Sample-and-Hold circuits

## DESCRIPTION

The LM13700 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 LM13700 differ from those of the LM13600 in that their input bias currents (and hence their output DC levels) are independent of  $I_{ABC}$ . This may result in performance superior to that of the LM13600 in audio applications.

## Connection Diagram



**Figure 1. PDIP and SOIC Packages-Top View**  
See Package Number D0016A or NFG0016E



Please be aware that an important notice concerning availability, standard warranty, and use in critical applications of Texas Instruments semiconductor products and disclaimers thereto appears at the end of this data sheet.

All trademarks are the property of their respective owners.



These devices have limited built-in ESD protection. The leads should be shorted together or the device placed in conductive foam during storage or handling to prevent electrostatic damage to the MOS gates.

### Absolute Maximum Ratings <sup>(1)</sup>

Supply Voltage	
LM13700	36 V <sub>DC</sub> or ±18V
Power Dissipation <sup>(2)</sup> T <sub>A</sub> = 25°C	
LM13700N	570 mW
Differential Input Voltage	±5V
Diode Bias Current (I <sub>D</sub> )	2 mA
Amplifier Bias Current (I <sub>ABC</sub> )	2 mA
Output Short Circuit Duration	Continuous
Buffer Output Current <sup>(3)</sup>	20 mA
Operating Temperature Range	
LM13700N	0°C to +70°C
DC Input Voltage	+V <sub>S</sub> to -V <sub>S</sub>
Storage Temperature Range	-65°C to +150°C
Soldering Information	
PDIP Package	
Soldering (10 sec.)	260°C
SOIC Package	
Vapor Phase (60 sec.)	215°C
Infrared (15 sec.)	220°C

- (1) "Absolute Maximum Ratings" indicate limits beyond which damage to the device may occur. Operating Ratings indicate conditions for which the device is functional, but do not ensure specific performance limits.
- (2) 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: LM13700N, 90°C/W; LM13700M, 110°C/W.
- (3) Buffer output current should be limited so as to not exceed package dissipation.

**Electrical Characteristics <sup>(1)</sup>**

Parameter	Test Conditions	LM13700			Units
		Min	Typ	Max	
Input Offset Voltage (V <sub>OS</sub> )	Over Specified Temperature Range		0.4	4	mV
	I <sub>ABC</sub> = 5 μA		0.3	4	
V <sub>OS</sub> Including Diodes	Diode Bias Current (I <sub>D</sub> ) = 500 μA		0.5	5	mV
Input Offset Change	5 μA ≤ I <sub>ABC</sub> ≤ 500 μA		0.1	3	mV
Input Offset Current			0.1	0.6	μA
Input Bias Current	Over Specified Temperature Range		0.4	5	μA
			1	8	
Forward Transconductance (g <sub>m</sub> )		6700	9600	13000	μmho
	Over Specified Temperature Range	5400			
g <sub>m</sub> Tracking			0.3		dB
Peak Output Current	R <sub>L</sub> = 0, I <sub>ABC</sub> = 5 μA		5		μA
	R <sub>L</sub> = 0, I <sub>ABC</sub> = 500 μA	350	500	650	
	R <sub>L</sub> = 0, Over Specified Temp Range	300			
Peak Output Voltage					
Positive	R <sub>L</sub> = ∞, 5 μA ≤ I <sub>ABC</sub> ≤ 500 μA	+12	+14.2		V
Negative	R <sub>L</sub> = ∞, 5 μA ≤ I <sub>ABC</sub> ≤ 500 μA	−12	−14.4		V
Supply Current	I <sub>ABC</sub> = 500 μA, Both Channels		2.6		mA
V <sub>OS</sub> Sensitivity					
Positive	ΔV <sub>OS</sub> /ΔV <sup>+</sup>		20	150	μV/V
Negative	ΔV <sub>OS</sub> /ΔV <sup>−</sup>		20	150	μV/V
CMRR		80	110		dB
Common Mode Range		±12	±13.5		V
Crosstalk	Referred to Input <sup>(2)</sup> 20 Hz < f < 20 kHz		100		dB
Differential Input Current	I <sub>ABC</sub> = 0, Input = ±4V		0.02	100	nA
Leakage Current	I <sub>ABC</sub> = 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	<sup>(2)</sup>		0.5	2	μA
Peak Buffer Output Voltage	<sup>(2)</sup>	10			V

- (1) These specifications apply for  $V_S = \pm 15V$ ,  $T_A = 25^\circ C$ , amplifier bias current ( $I_{ABC}$ ) = 500  $\mu A$ , pins 2 and 15 open unless otherwise specified. The inputs to the buffers are grounded and outputs are open.
- (2) These specifications apply for  $V_S = \pm 15V$ ,  $I_{ABC} = 500 \mu A$ ,  $R_{OUT} = 5 \text{ k}\Omega$  connected from the buffer output to  $-V_S$  and the input of the buffer is connected to the transconductance amplifier output.

## Schematic Diagram

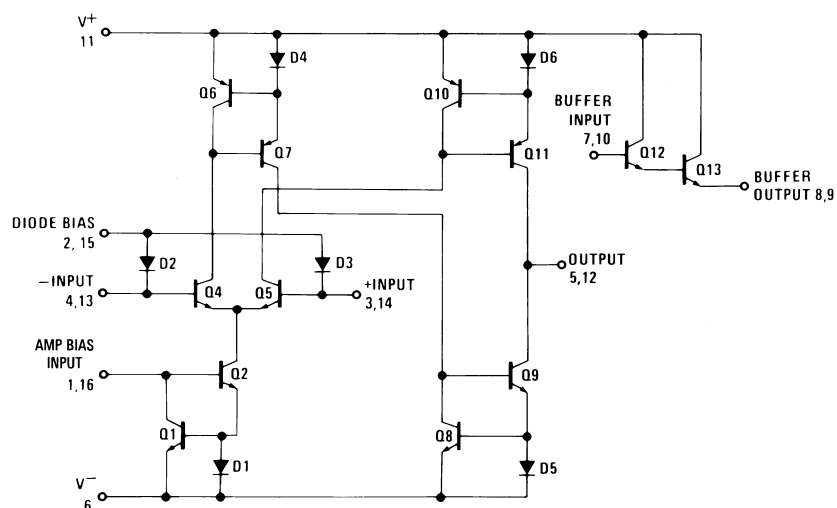


Figure 2. One Operational Transconductance Amplifier

## Typical Application

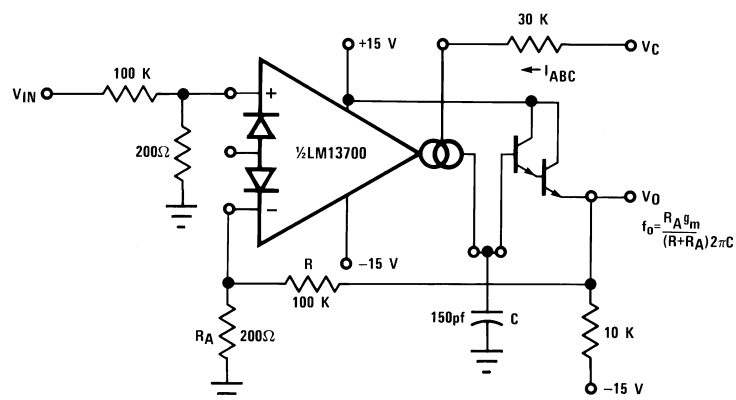
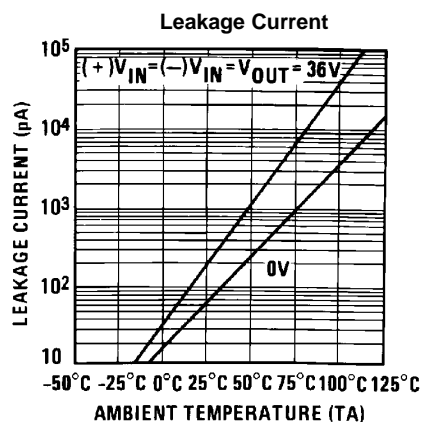
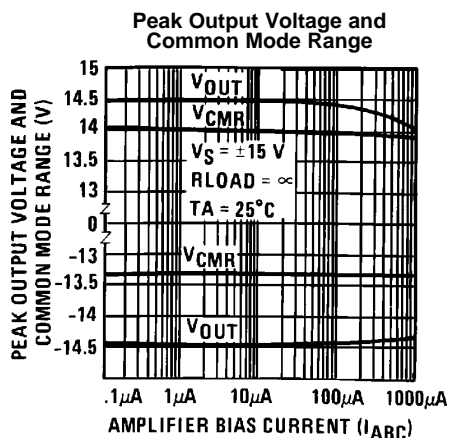
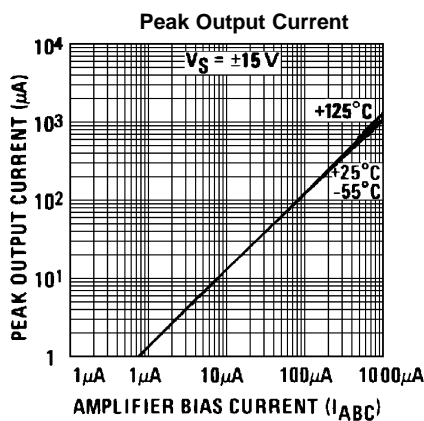
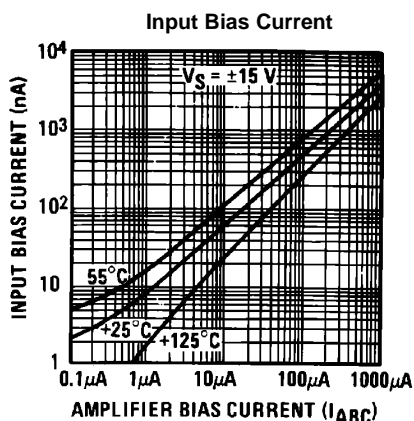
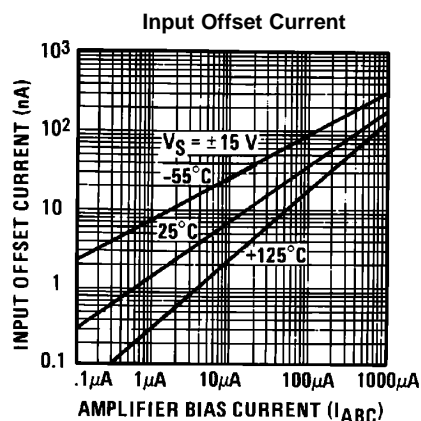
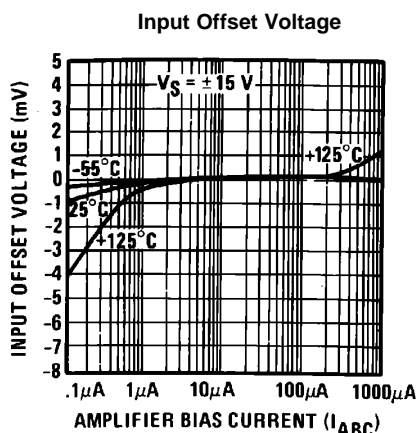


Figure 3. Voltage Controlled Low-Pass Filter

## Typical Performance Characteristics



## Typical Performance Characteristics (continued)

### Input Leakage

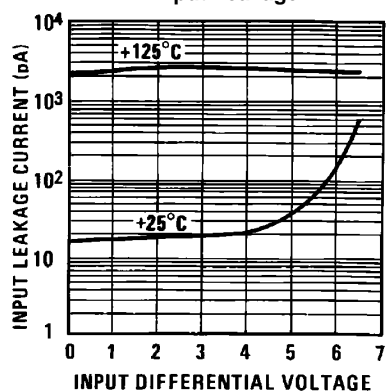


Figure 10.

### Transconductance

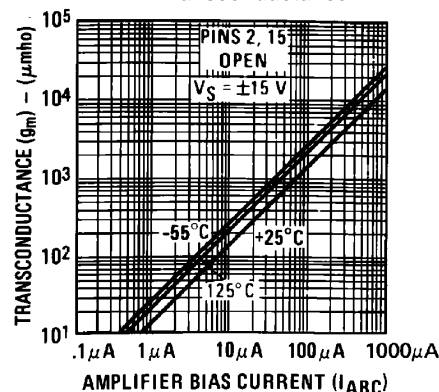


Figure 11.

### Input Resistance

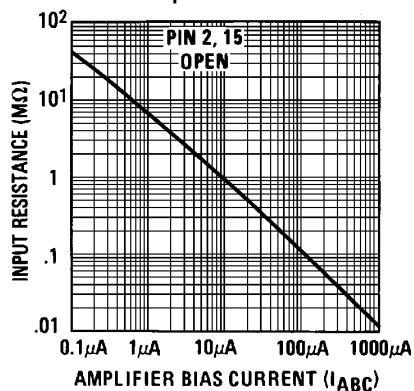


Figure 12.

### Amplifier Bias Voltage vs. Amplifier Bias Current

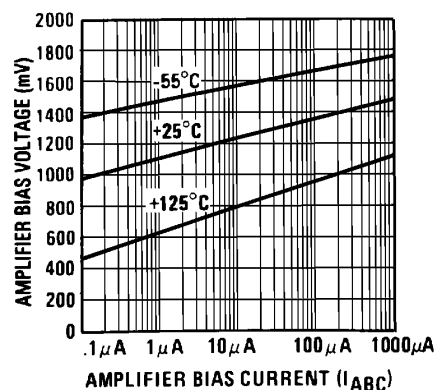


Figure 13.

### Input and Output Capacitance

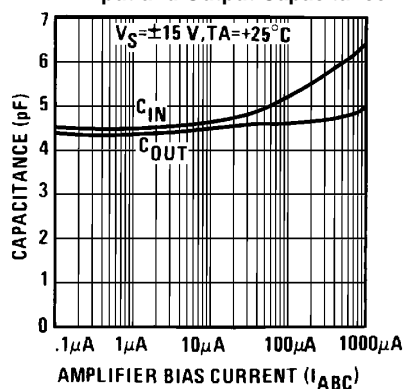


Figure 14.

### Output Resistance

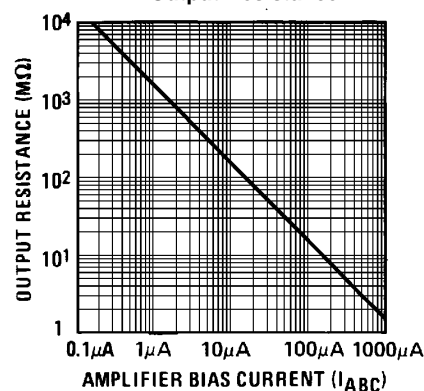


Figure 15.

## Typical Performance Characteristics (continued)

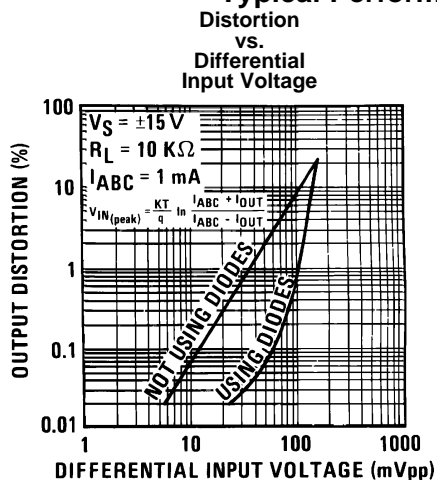


Figure 16.

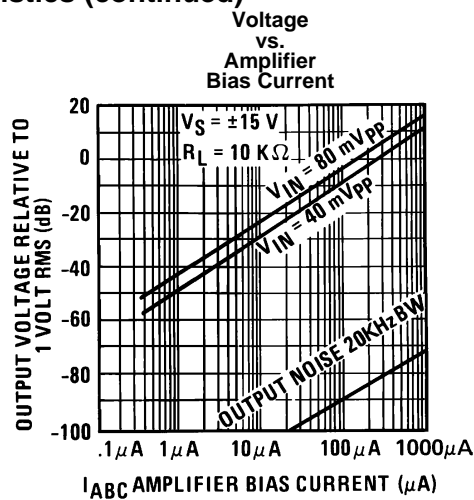


Figure 17.

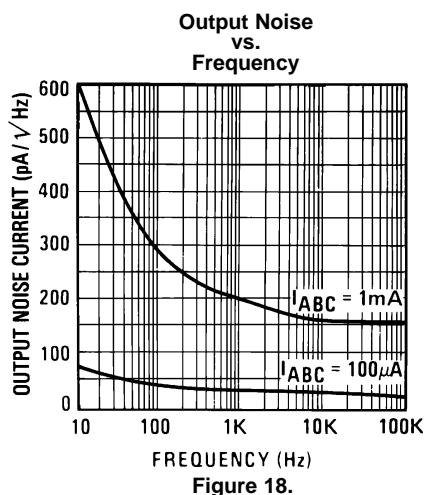


Figure 18.

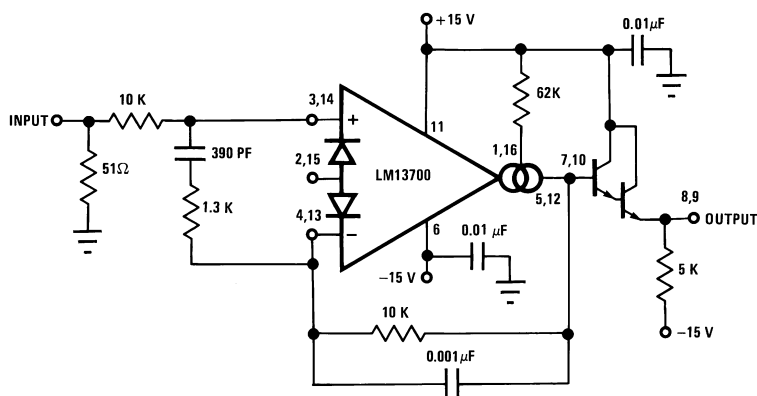


Figure 19. Unity Gain Follower

### Typical Performance Characteristics (continued)

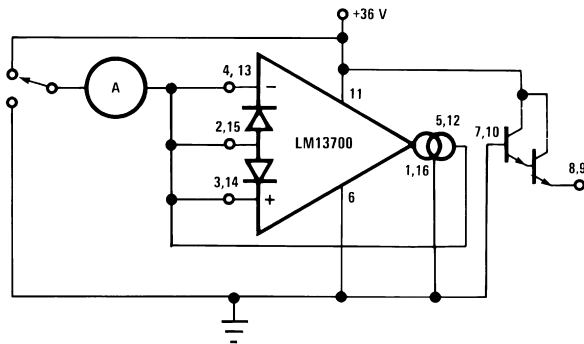


Figure 20. Leakage Current Test Circuit

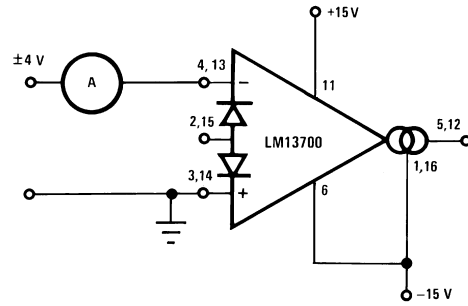


Figure 21. Differential Input Current Test Circuit

### 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:

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

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  $I_{ABC}$ :

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

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  $\ln$  function can be approximated as:

$$\begin{aligned} \frac{kT}{q} \ln \frac{I_5}{I_4} &\approx \frac{kT}{q} \frac{I_5 - I_4}{I_4} \\ I_4 &\approx I_5 \approx \frac{I_{ABC}}{2} \end{aligned} \quad (3)$$

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

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  $I_{ABC}$ .

### Linearizing Diodes

For differential voltages greater than a few millivolts, Equation 3 becomes less valid and the transconductance becomes increasingly nonlinear. Figure 22 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  $I_5$  can be 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.

## APPLICATIONS

### Voltage Controlled Amplifiers

Figure 23 shows how the linearizing diodes can be 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 24. This circuit is similar to Figure 22 and operates the same. The potentiometer in Figure 23 is adjusted to minimize the effects of the control signal at the output.

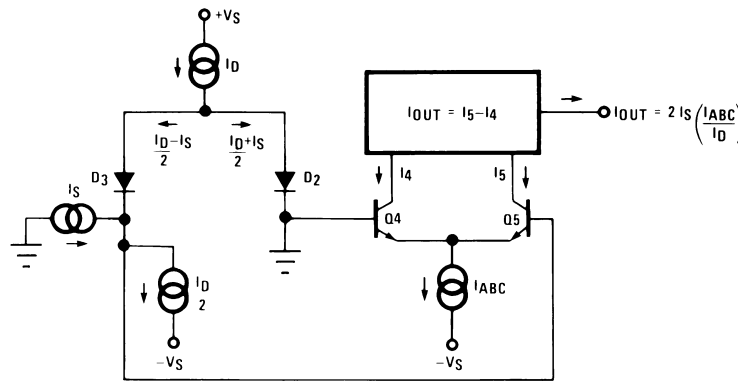


Figure 22. Linearizing Diodes

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 23) until the output distortion is below some 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.

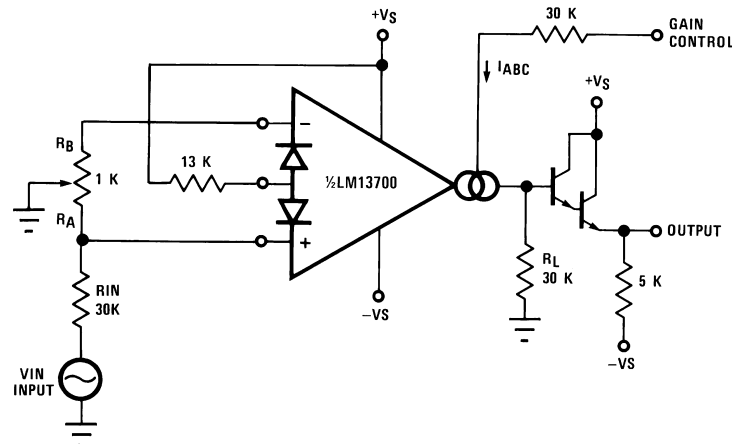


Figure 23. Voltage Controlled Amplifier

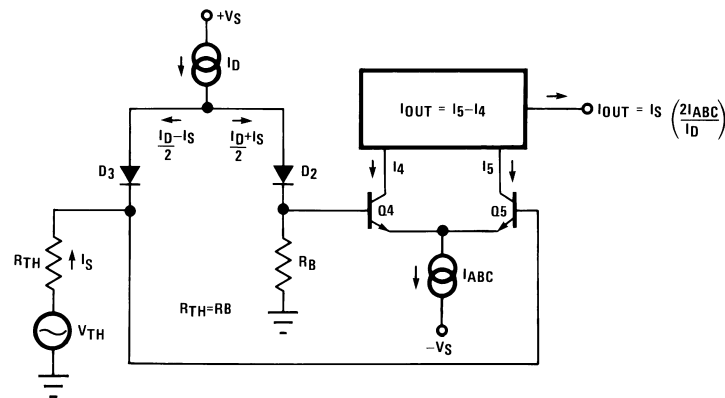


Figure 24. Equivalent VCA Input Circuit

## Stereo Volume Control

The circuit of Figure 25 uses the excellent matching of the two LM13700 amplifiers to provide a Stereo Volume Control with a typical channel-to-channel gain tracking of 0.3 dB.  $R_P$  is provided to minimize the output offset voltage and may be replaced with two 510Ω resistors in AC-coupled applications. For the component values given, amplifier gain is derived for Figure 23 as being:

$$\frac{V_O}{V_{IN}} = 940 \times I_{ABC} \quad (8)$$

If  $V_C$  is derived from a second signal source then the circuit becomes an amplitude modulator or two-quadrant multiplier as shown in Figure 26, where:

$$I_O = \frac{-2I_S}{I_D} (I_{ABC}) = \frac{-2I_S}{I_D} \frac{V_{IN2}}{R_C} - \frac{2I_S}{I_D} \frac{(V^- + 1.4V)}{R_C} \quad (9)$$

The constant term in the above equation may be cancelled by feeding  $I_S \times I_D R_C / 2(V^- + 1.4V)$  into  $I_O$ . The circuit of Figure 27 adds  $R_M$  to provide this current, resulting in a four-quadrant multiplier where  $R_C$  is trimmed such that  $V_O = 0V$  for  $V_{IN2} = 0V$ .  $R_M$  also serves as the load resistor for  $I_O$ .

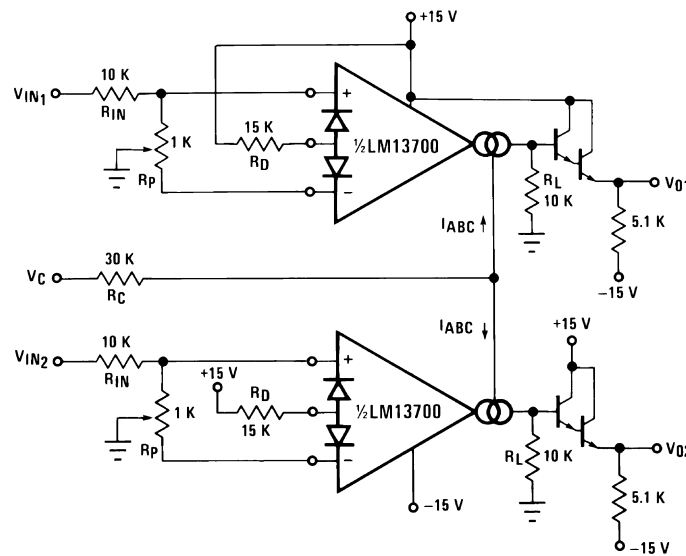


Figure 25. Stereo Volume Control

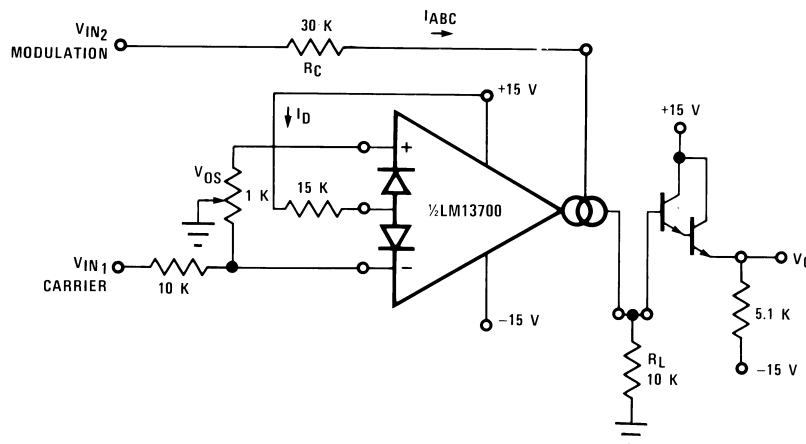


Figure 26. Amplitude Modulator

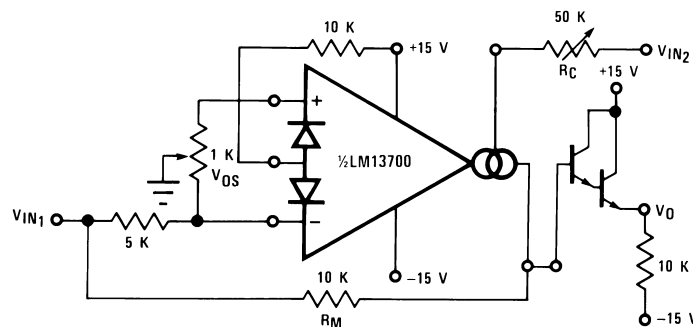


Figure 27. Four-Quadrant Multiplier

Noting that the gain of the LM13700 amplifier of Figure 24 may be controlled by varying the linearizing diode current  $I_D$  as well as by varying  $I_{ABC}$ , Figure 28 shows an AGC Amplifier using this approach. As  $V_O$  reaches a high enough amplitude ( $3V_{BE}$ ) to turn on the Darlington transistors and the linearizing diodes, the increase in  $I_D$  reduces the amplifier gain so as to hold  $V_O$  at that level.

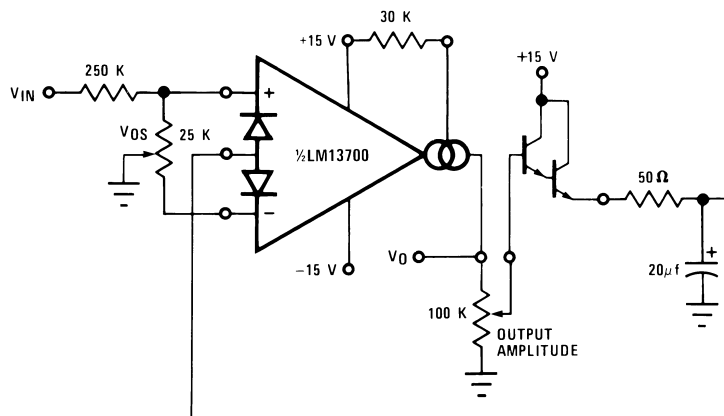
### Voltage Controlled Resistors

An Operational Transconductance Amplifier (OTA) may be used to implement a Voltage Controlled Resistor as shown in Figure 29. A signal voltage applied at  $R_X$  generates a  $V_{IN}$  to the LM13700 which is then multiplied by the  $g_m$  of the amplifier to produce an output current, thus:

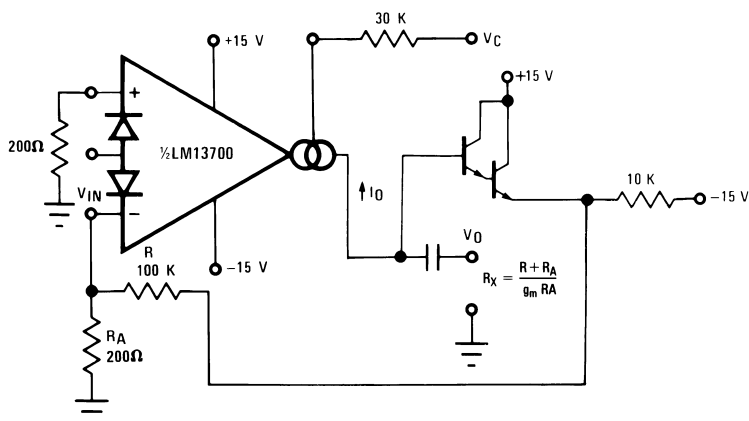
$$R_X = \frac{R + R_A}{g_m R_A} \quad (10)$$

where  $g_m \approx 19.2I_{ABC}$  at 25°C. Note that the attenuation of  $V_O$  by  $R$  and  $R_A$  is necessary to maintain  $V_{IN}$  within the linear range of the LM13700 input.

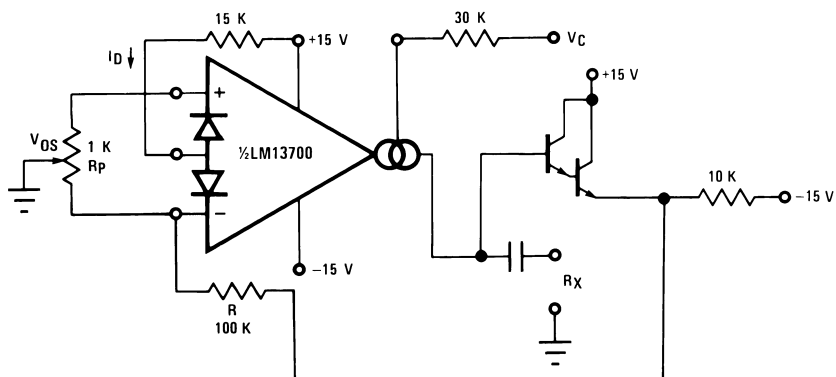
Figure 30 shows a similar VCR where the linearizing diodes are added, essentially improving the noise performance of the resistor. A floating VCR is shown in Figure 31, where each “end” of the “resistor” may be at any voltage within the output voltage range of the LM13700.



**Figure 28. AGC Amplifier**



**Figure 29. Voltage Controlled Resistor, Single-Ended**



**Figure 30. Voltage Controlled Resistor with Linearizing Diodes**

## Voltage Controlled Filters

OTA's are extremely useful for implementing voltage controlled filters, with the LM13700 having the advantage that the required buffers are included on the I.C. The VC Lo-Pass Filter of Figure 32 performs as a unity-gain buffer amplifier at frequencies below cut-off, with the cut-off frequency being the point at which  $X_C/g_m$  equals the closed-loop gain of  $(R/R_A)$ . At frequencies above cut-off the circuit provides a single RC roll-off (6 dB per octave) of the input signal amplitude with a  $-3$  dB point defined by the given equation, where  $g_m$  is again  $19.2 \times I_{ABC}$  at room temperature. Figure 33 shows a VC High-Pass Filter which operates in much the same manner, providing a single RC roll-off below the defined cut-off frequency.

Additional amplifiers may be used to implement higher order filters as demonstrated by the two-pole Butterworth Lo-Pass Filter of Figure 34 and the state variable filter of Figure 35. Due to the excellent  $g_m$  tracking of the two amplifiers, these filters perform well over several decades of frequency.

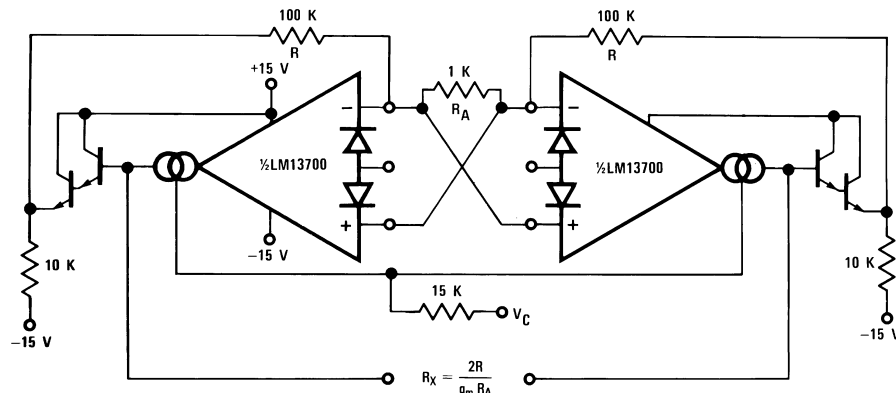


Figure 31. Floating Voltage Controlled Resistor

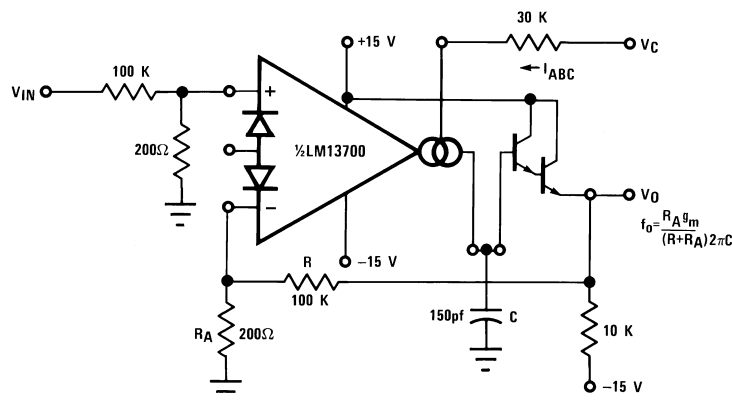
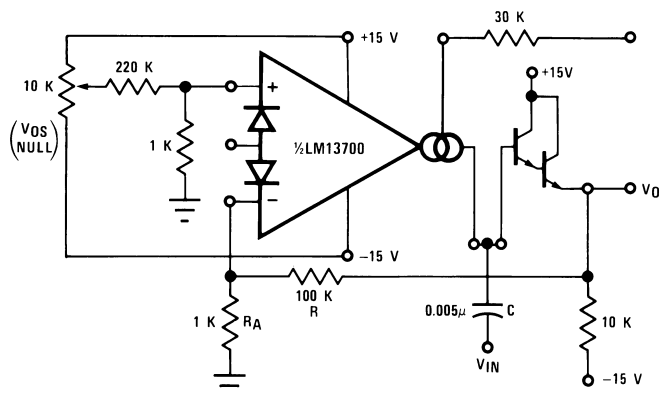
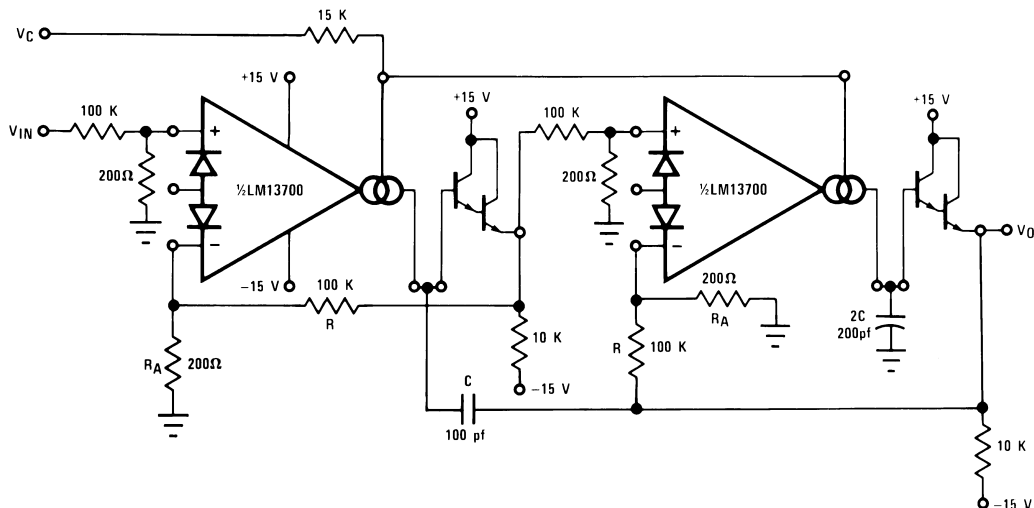


Figure 32. Voltage Controlled Low-Pass Filter



$$f_o = \frac{R_A g_m}{(R + R_A) 2\pi C}$$

**Figure 33. Voltage Controlled Hi-Pass Filter**



$$f_o = \frac{R_A g_m}{(R + R_A) 2\pi C}$$

**Figure 34. Voltage Controlled 2-Pole Butterworth Lo-Pass Filter**

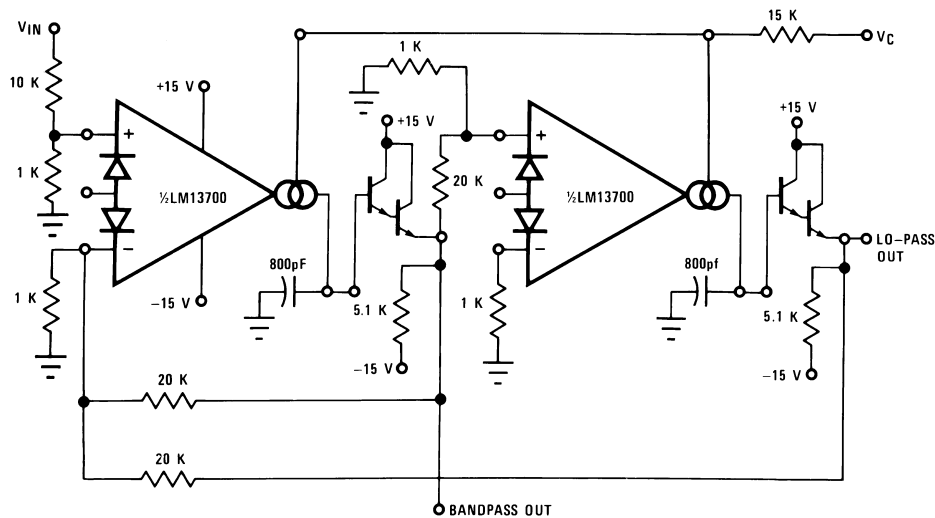


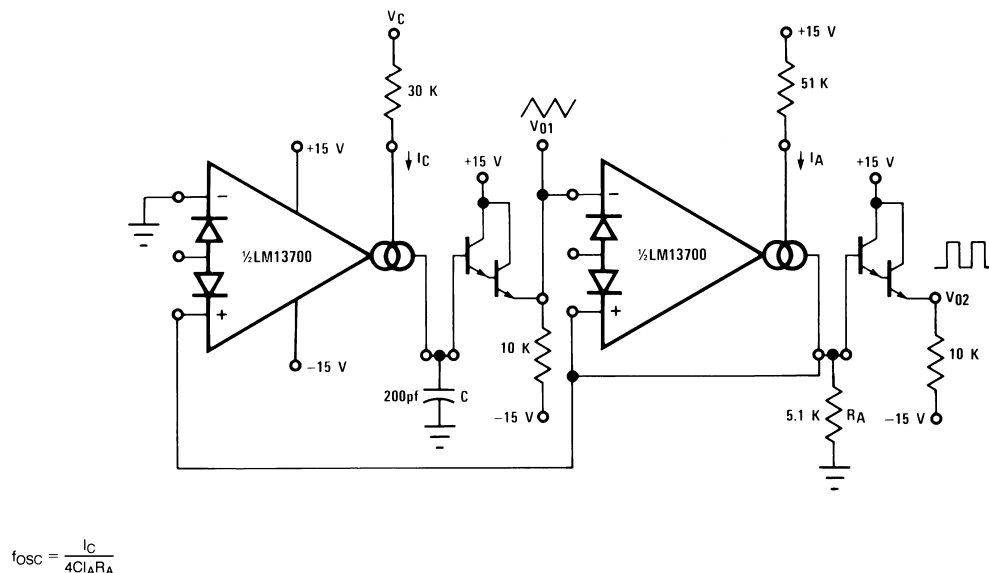
Figure 35. Voltage Controlled State Variable Filter

### Voltage Controlled Oscillators

The classic Triangular/Square Wave VCO of Figure 36 is one of a variety of Voltage Controlled Oscillators which may be built utilizing the LM13700. With the component values shown, this oscillator provides signals from 200 kHz to below 2 Hz as  $I_C$  is varied from 1 mA to 10 nA. The output amplitudes are set by  $I_A \times R_A$ . Note that the peak differential input voltage must be less than 5V to prevent zenering the inputs.

A few modifications to this circuit produce the ramp/pulse VCO of Figure 37. When  $V_{O2}$  is high,  $I_F$  is added to  $I_C$  to increase amplifier A1's bias current and thus to increase the charging rate of capacitor C. When  $V_{O2}$  is low,  $I_F$  goes to zero and the capacitor discharge current is set by  $I_C$ .

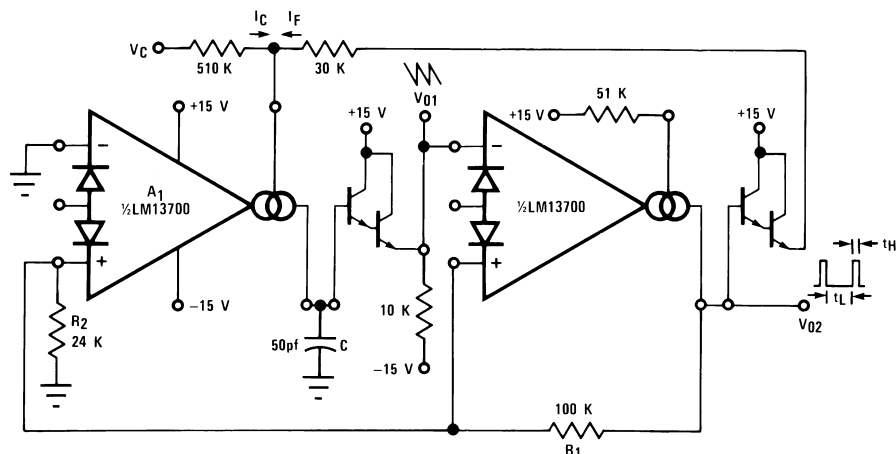
The VC Lo-Pass Filter of Figure 32 may be used to produce a high-quality sinusoidal VCO. The circuit of Figure 37 employs two LM13700 packages, with three of the amplifiers configured as lo-pass filters and the fourth as a limiter/inverter. The circuit oscillates at the frequency at which the loop phase-shift is  $360^\circ$  or  $180^\circ$  for the inverter and  $60^\circ$  per filter stage. This VCO operates from 5 Hz to 50 kHz with less than 1% THD.



$$f_{osc} = \frac{I_C}{4C I_A R_A}$$

Figure 36. Triangular/Square-Wave VCO





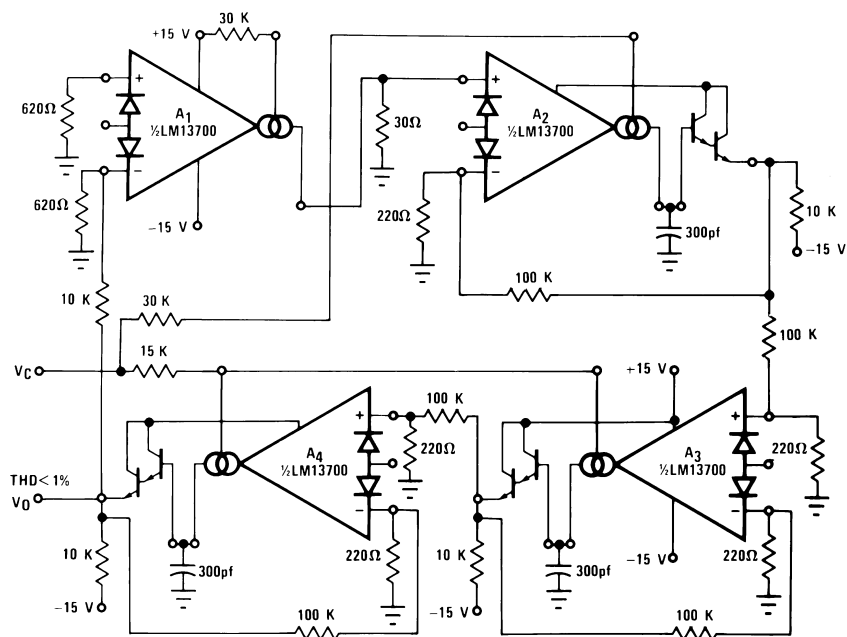
$$V_{PK} = \frac{(V^+ \pm 0.8V) R_2}{R_1 + R_2}$$

$$t_H \approx \frac{2V_{PK}C}{I_F}$$

$$t_L = \frac{2V_{PK}C}{I_C}$$

$$f_0 \approx \frac{I_C}{2V_{PK}C} \text{ for } I_C \ll I_F$$

### Figure 37. Ramp/Pulse VCO



### Figure 38. Sinusoidal VCO

Figure 39 shows how to build a VCO using one amplifier when the other amplifier is needed for another function.

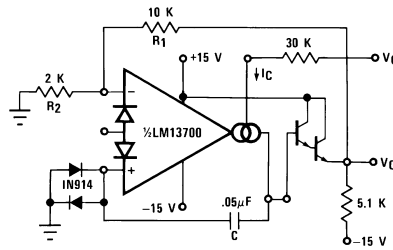


Figure 39. Single Amplifier VCO

## Additional Applications

Figure 40 presents an interesting one-shot which draws no power supply current until it is triggered. A positive-going trigger pulse of at least 2V amplitude turns on the amplifier through  $R_B$  and pulls the non-inverting input high. The amplifier regenerates and latches its output high until capacitor  $C$  charges to the voltage level on the non-inverting input. The output then switches low, turning off the amplifier and discharging the capacitor. The capacitor discharge rate is speeded up by shorting the diode bias pin to the inverting input so that an additional discharge current flows through  $D_1$  when the amplifier output switches low. A special feature of this timer is that the other amplifier, when biased from  $V_O$ , can perform another function and draw zero stand-by power as well.

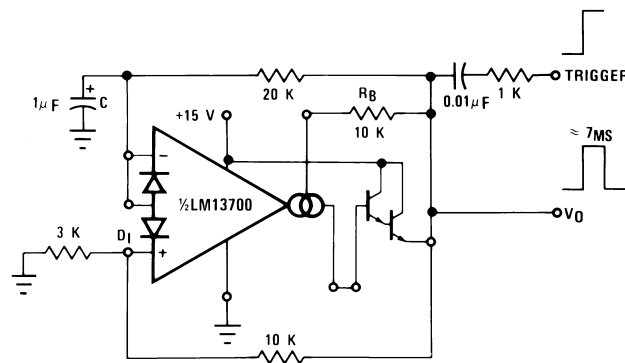
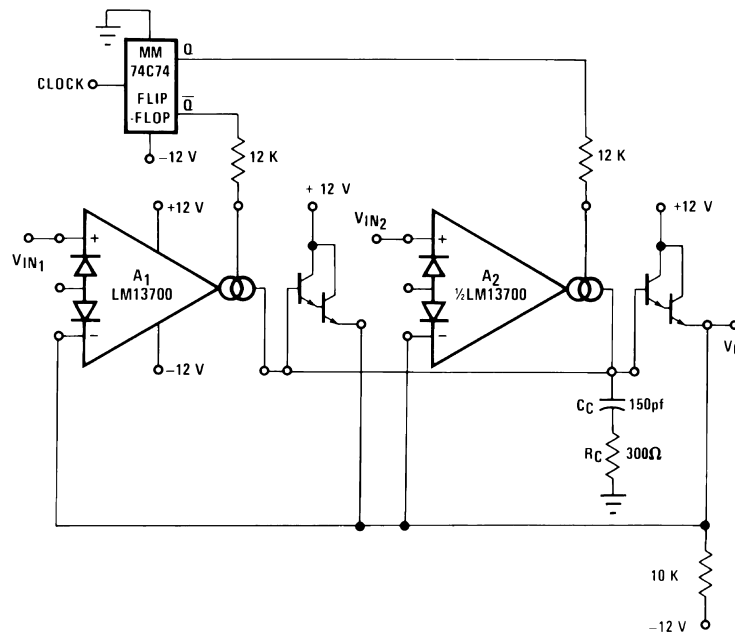


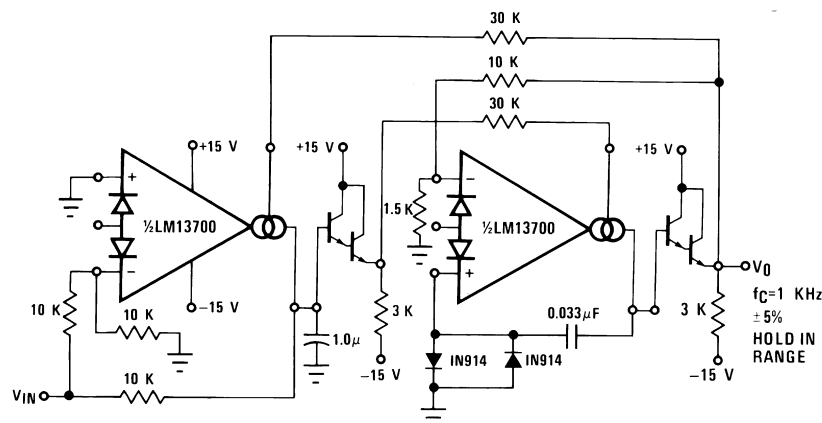
Figure 40. Zero Stand-By Power Timer

The operation of the multiplexer of Figure 41 is very straightforward. When A1 is turned on it holds  $V_O$  equal to  $V_{IN1}$  and when A2 is supplied with bias current then it controls  $V_O$ .  $C_C$  and  $R_C$  serve to stabilize the unity-gain configuration of amplifiers A1 and A2. The maximum clock rate is limited to about 200 kHz by the LM13700 slew rate into 150 pF when the  $(V_{IN1}-V_{IN2})$  differential is at its maximum allowable value of 5V.

The Phase-Locked Loop of Figure 42 uses the four-quadrant multiplier of Figure 27 and the VCO of Figure 39 to produce a PLL with a  $\pm 5\%$  hold-in range and an input sensitivity of about 300 mV.



### Figure 41. Multiplexer



### Figure 42. Phase Lock Loop

The Schmitt Trigger of [Figure 43](#) uses the amplifier output current into R to set the hysteresis of the comparator; thus  $V_H = 2 \times R \times I_B$ . Varying  $I_B$  will produce a Schmitt Trigger with variable hysteresis.

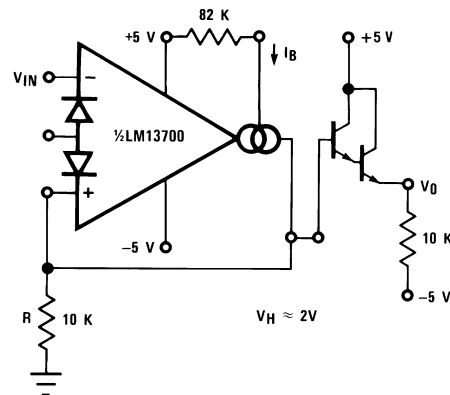


Figure 43. Schmitt Trigger

Figure 44 shows a Tachometer or Frequency-to-Voltage converter. Whenever A1 is toggled by a positive-going input, an amount of charge equal to  $(V_H - V_L) C_t$  is sourced into  $C_t$  and  $R_t$ . This once per cycle charge is then balanced by the current of  $V_O/R_t$ . The maximum  $F_{IN}$  is limited by the amount of time required to charge  $C_t$  from  $V_L$  to  $V_H$  with a current of  $I_B$ , where  $V_L$  and  $V_H$  represent the maximum low and maximum high output voltage swing of the LM13700. D1 is added to provide a discharge path for  $C_t$  when A1 switches low.

The Peak Detector of Figure 45 uses A2 to turn on A1 whenever  $V_{IN}$  becomes more positive than  $V_O$ . A1 then charges storage capacitor C to hold  $V_O$  equal to  $V_{IN}$  PK. Pulling the output of A2 low through D1 serves to turn off A1 so that  $V_O$  remains constant.

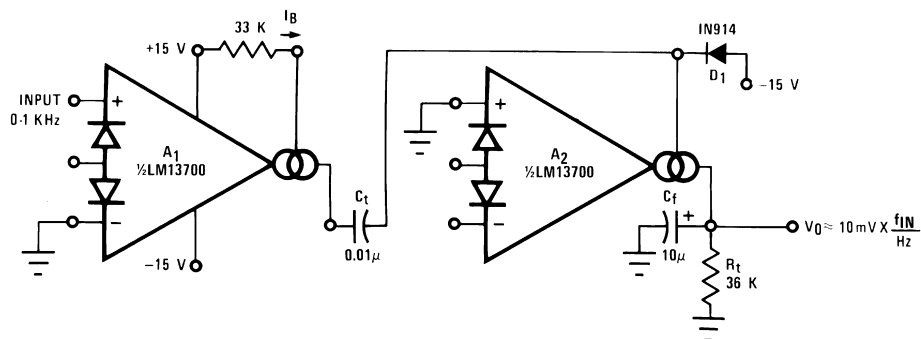


Figure 44. Tachometer

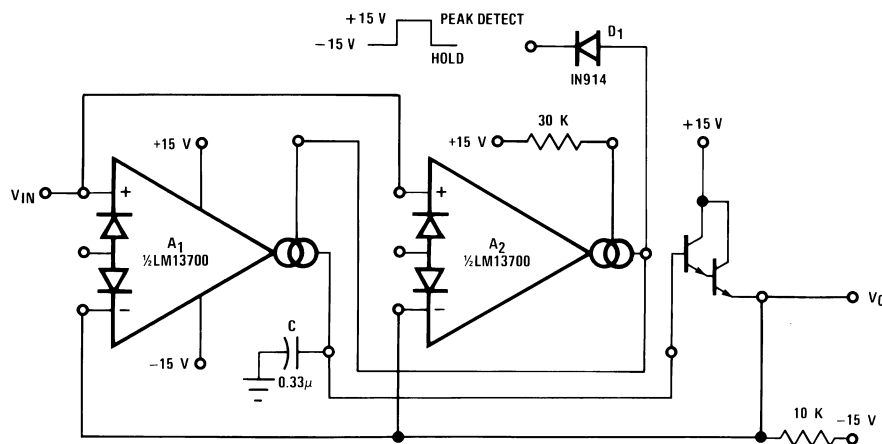


Figure 45. Peak Detector and Hold Circuit

The Ramp-and-Hold of Figure 47 sources  $I_B$  into capacitor C whenever the input to A1 is brought high, giving a ramp-rate of about 1V/ms for the component values shown.

The true-RMS converter of Figure 48 is essentially an automatic gain control amplifier which adjusts its gain such that the AC power at the output of amplifier A1 is constant. The output power of amplifier A1 is monitored by squaring amplifier A2 and the average compared to a reference voltage with amplifier A3. The output of A3 provides bias current to the diodes of A1 to attenuate the input signal. Because the output power of A1 is held constant, the RMS value is constant and the attenuation is directly proportional to the RMS value of the input voltage. The attenuation is also proportional to the diode bias current. Amplifier A4 adjusts the ratio of currents through the diodes to be equal and therefore the voltage at the output of A4 is proportional to the RMS value of the input voltage. The calibration potentiometer is set such that  $V_O$  reads directly in RMS volts.

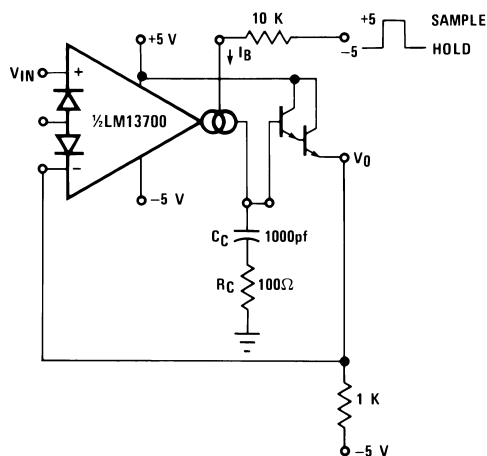


Figure 46. Sample-Hold Circuit

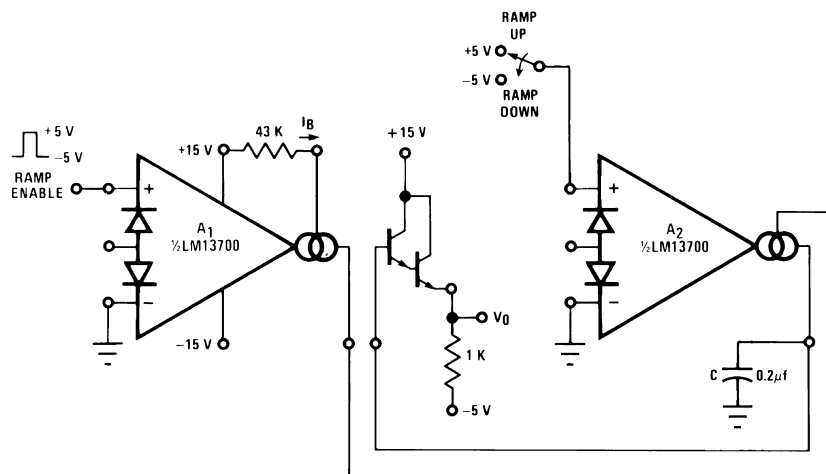


Figure 47. Ramp and Hold

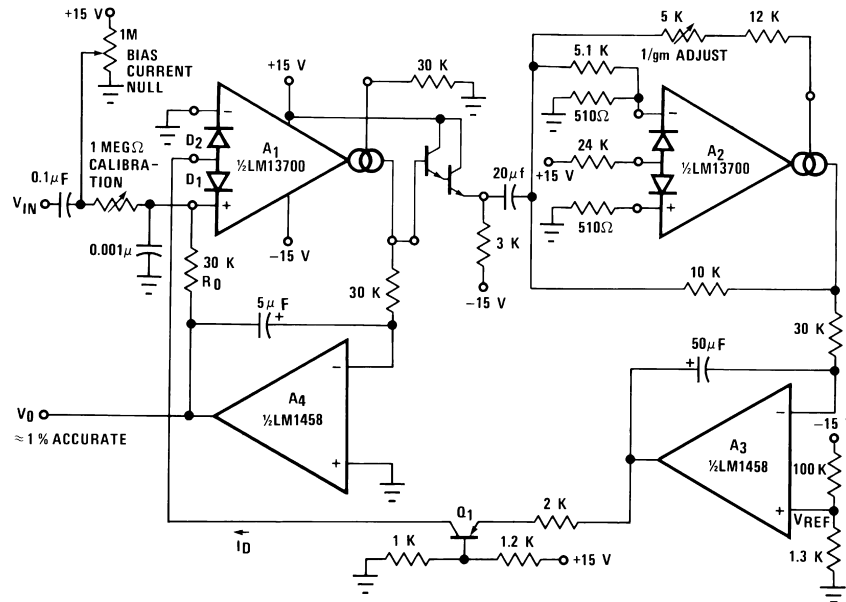


Figure 48. True RMS Converter

The circuit of [Figure 49](#) is a voltage reference of variable Temperature Coefficient. The 100 kΩ potentiometer adjusts the output voltage which has a positive TC above 1.2V, zero TC at about 1.2V, and negative TC below 1.2V. This is accomplished by balancing the TC of the A2 transfer function against the complementary TC of D1.

The wide dynamic range of the LM13700 allows easy control of the output pulse width in the Pulse Width Modulator of [Figure 50](#).

For generating  $I_{ABC}$  over a range of 4 to 6 decades of current, the system of [Figure 51](#) provides a logarithmic current out for a linear voltage in.

Since the closed-loop configuration ensures that the input to A2 is held equal to 0V, the output current of A1 is equal to  $I_3 = -V_C/R_C$ .

The differential voltage between Q1 and Q2 is attenuated by the R1,R2 network so that A1 may be assumed to be operating within its linear range. From [Equation 5](#), the input voltage to A1 is:

$$V_{IN1} = \frac{-2kT I_3}{q I_2} = \frac{-2kT V_C}{q I_2 R_C} \quad (11)$$

The voltage on the base of Q1 is then

$$V_{B1} = \frac{(R_1 + R_2) V_{IN1}}{R_1} \quad (12)$$

The ratio of the Q1 and Q2 collector currents is defined by:

$$V_{B1} = \frac{kT}{q} \ln \frac{I_{C2}}{I_{C1}} \approx \frac{kT}{q} \ln \frac{I_{ABC}}{I_1} \quad (13)$$

Combining and solving for  $I_{ABC}$  yields:

$$I_{ABC} = I_1 \exp \frac{2(R_1 + R_2) V_C}{R_1 I_2 R_C} \quad (14)$$

This logarithmic current can be used to bias the circuit of [Figure 25](#) to provide temperature independent stereo attenuation characteristic.

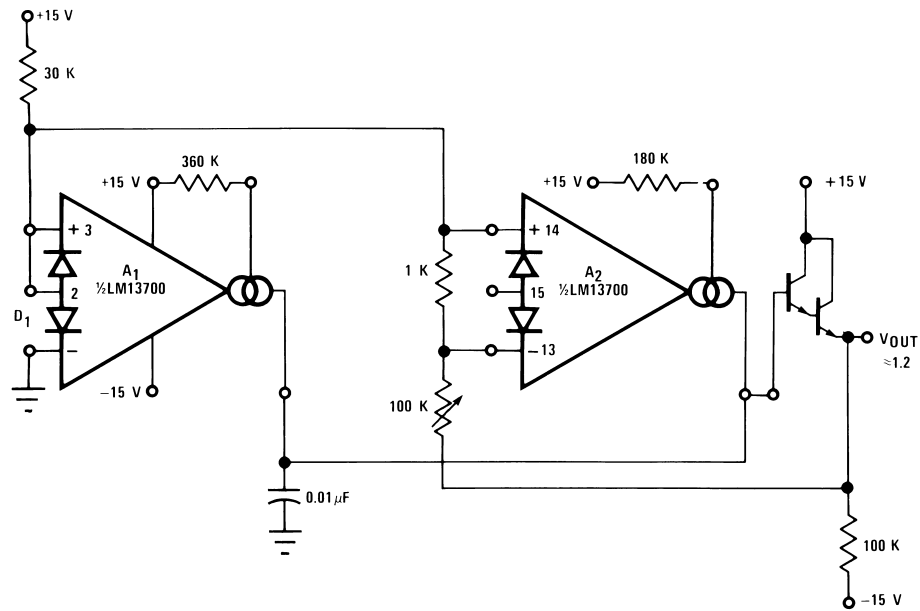


Figure 49. Delta VBE Reference

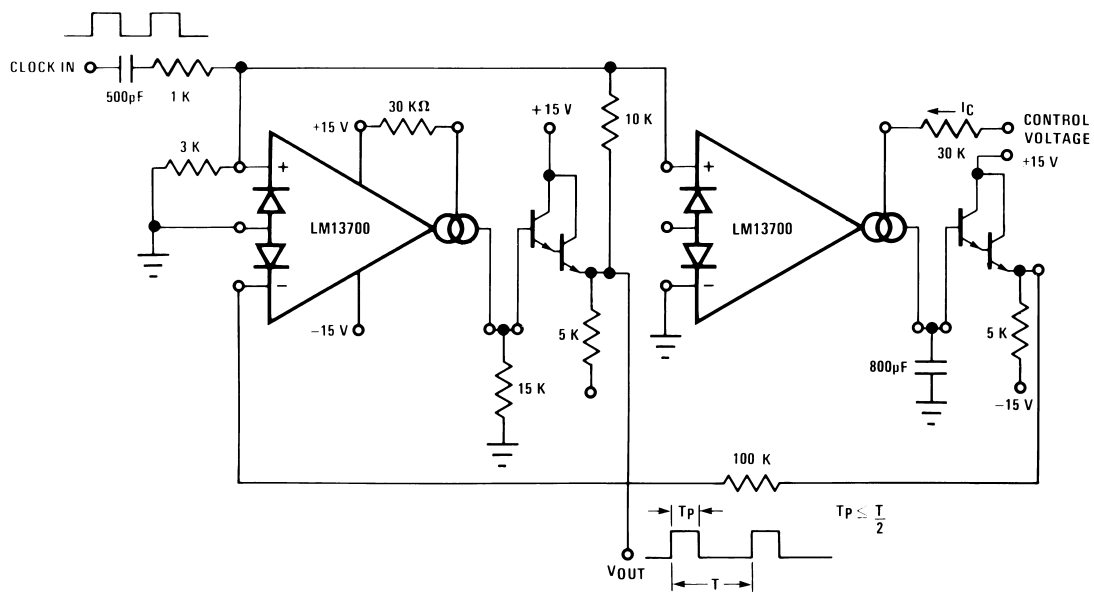


Figure 50. Pulse Width Modulator

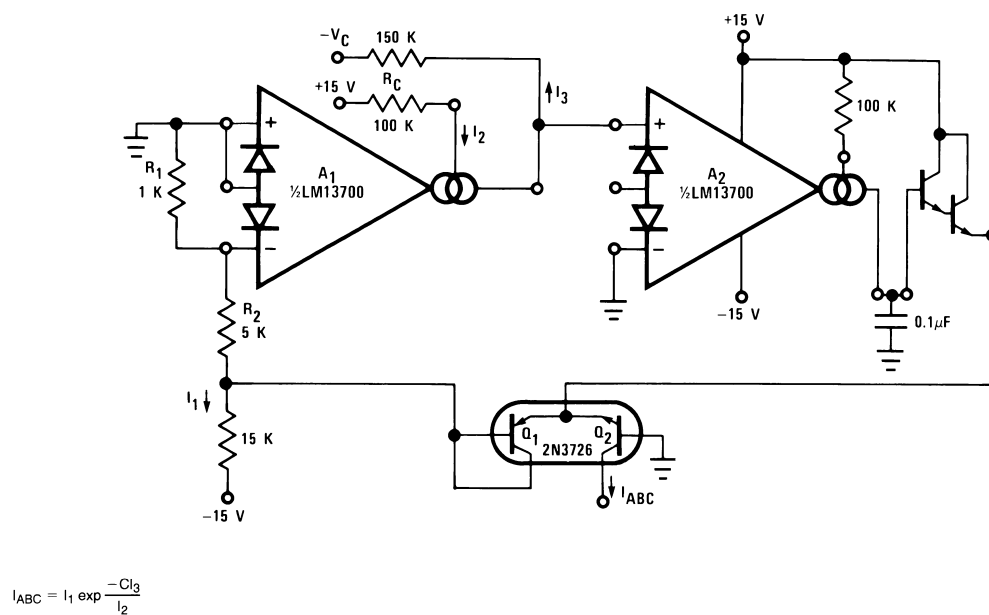


Figure 51. Logarithmic Current Source



## REVISION HISTORY

Changes from Revision D (March 2013) to Revision E	Page
• Changed layout of National Data Sheet to TI format .....	<a href="#">24</a>

## PACKAGING INFORMATION

Orderable Device	Status (1)	Package Type	Package Drawing	Pins	Package Qty	Eco Plan (2)	Lead/Ball Finish (6)	MSL Peak Temp (3)	Op Temp (°C)	Device Marking (4/5)	Samples
LM13700M	NRND	SOIC	D	16	48	TBD	Call TI	Call TI	0 to 70	LM13700M	
LM13700M/NOPB	ACTIVE	SOIC	D	16	48	Green (RoHS & no Sb/Br)	CU SN	Level-1-260C-UNLIM	0 to 70	LM13700M	<a href="#">Samples</a>
LM13700MX	NRND	SOIC	D	16	2500	TBD	Call TI	Call TI	0 to 70	LM13700M	
LM13700MX/NOPB	ACTIVE	SOIC	D	16	2500	Green (RoHS & no Sb/Br)	CU SN   Call TI	Level-1-260C-UNLIM	0 to 70	LM13700M	<a href="#">Samples</a>
LM13700N	NRND	PDIP	NFG	16	25	TBD	Call TI	Call TI	0 to 70	LM13700N	
LM13700N/NOPB	ACTIVE	PDIP	NFG	16	25	Pb-Free (RoHS)	CU SN	Level-1-NA-UNLIM	0 to 70	LM13700N	<a href="#">Samples</a>

(1) The marketing status values are defined as follows:

**ACTIVE:** Product device recommended for new designs.

**LIFEBUY:** TI has announced that the device will be discontinued, and a lifetime-buy period is in effect.

**NRND:** Not recommended for new designs. Device is in production to support existing customers, but TI does not recommend using this part in a new design.

**PREVIEW:** Device has been announced but is not in production. Samples may or may not be available.

**OBSOLETE:** TI has discontinued the production of the device.

(2) Eco Plan - The planned eco-friendly classification: Pb-Free (RoHS), Pb-Free (RoHS Exempt), or Green (RoHS & no Sb/Br) - please check <http://www.ti.com/productcontent> for the latest availability information and additional product content details.

**TBD:** The Pb-Free/Green conversion plan has not been defined.

**Pb-Free (RoHS):** TI's terms "Lead-Free" or "Pb-Free" mean semiconductor products that are compatible with the current RoHS requirements for all 6 substances, including the requirement that lead not exceed 0.1% by weight in homogeneous materials. Where designed to be soldered at high temperatures, TI Pb-Free products are suitable for use in specified lead-free processes.

**Pb-Free (RoHS Exempt):** This component has a RoHS exemption for either 1) lead-based flip-chip solder bumps used between the die and package, or 2) lead-based die adhesive used between the die and leadframe. The component is otherwise considered Pb-Free (RoHS compatible) as defined above.

**Green (RoHS & no Sb/Br):** TI defines "Green" to mean Pb-Free (RoHS compatible), and free of Bromine (Br) and Antimony (Sb) based flame retardants (Br or Sb do not exceed 0.1% by weight in homogeneous material)

(3) MSL, Peak Temp. - The Moisture Sensitivity Level rating according to the JEDEC industry standard classifications, and peak solder temperature.

(4) There may be additional marking, which relates to the logo, the lot trace code information, or the environmental category on the device.

(5) Multiple Device Markings will be inside parentheses. Only one Device Marking contained in parentheses and separated by a "~" will appear on a device. If a line is indented then it is a continuation of the previous line and the two combined represent the entire Device Marking for that device.

<sup>(6)</sup> Lead/Ball Finish - Orderable Devices may have multiple material finish options. Finish options are separated by a vertical ruled line. Lead/Ball Finish values may wrap to two lines if the finish value exceeds the maximum column width.

**Important Information and Disclaimer:** The information provided on this page represents TI's knowledge and belief as of the date that it is provided. TI bases its knowledge and belief on information provided by third parties, and makes no representation or warranty as to the accuracy of such information. Efforts are underway to better integrate information from third parties. TI has taken and continues to take reasonable steps to provide representative and accurate information but may not have conducted destructive testing or chemical analysis on incoming materials and chemicals. TI and TI suppliers consider certain information to be proprietary, and thus CAS numbers and other limited information may not be available for release.

In no event shall TI's liability arising out of such information exceed the total purchase price of the TI part(s) at issue in this document sold by TI to Customer on an annual basis.

**TAPE AND REEL INFORMATION**


\*All dimensions are nominal

Device	Package Type	Package Drawing	Pins	SPQ	Reel Diameter (mm)	Reel Width W1 (mm)	A0 (mm)	B0 (mm)	K0 (mm)	P1 (mm)	W (mm)	Pin1 Quadrant
LM13700MX	SOIC	D	16	2500	330.0	16.4	6.5	10.3	2.3	8.0	16.0	Q1
LM13700MX/NOPB	SOIC	D	16	2500	330.0	16.4	6.5	10.3	2.3	8.0	16.0	Q1

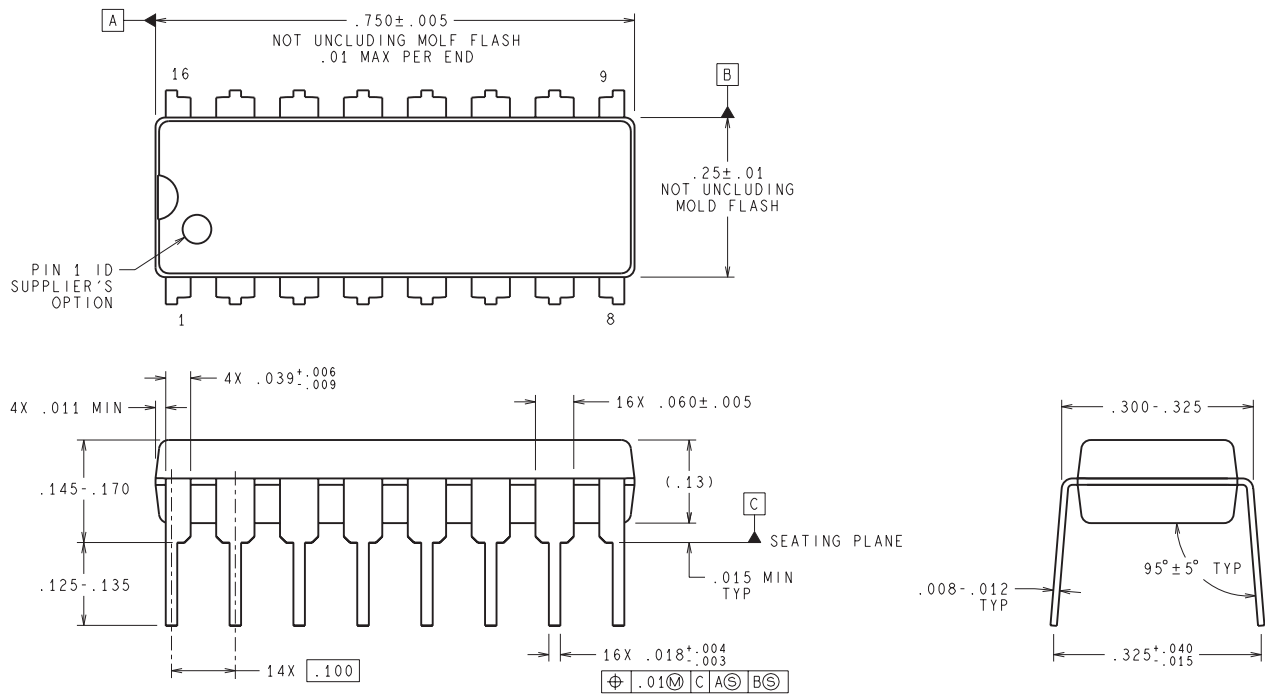
## TAPE AND REEL BOX DIMENSIONS



\*All dimensions are nominal

Device	Package Type	Package Drawing	Pins	SPQ	Length (mm)	Width (mm)	Height (mm)
LM13700MX	SOIC	D	16	2500	367.0	367.0	35.0
LM13700MX/NOPB	SOIC	D	16	2500	367.0	367.0	35.0

## NFG0016E



**DIMENSIONS ARE IN INCHES**  
DIMENSIONS IN ( ) FOR REFERENCE ONLY

N16E (Rev G)

D (R-PDSO-G16)

PLASTIC SMALL OUTLINE



- NOTES:
- A. All linear dimensions are in inches (millimeters).
  - B. This drawing is subject to change without notice.
  - $\triangle C$  Body length does not include mold flash, protrusions, or gate burrs. Mold flash, protrusions, or gate burrs shall not exceed 0.006 (0,15) each side.
  - $\triangle D$  Body width does not include interlead flash. Interlead flash shall not exceed 0.017 (0,43) each side.
  - E. Reference JEDEC MS-012 variation AC.

## IMPORTANT NOTICE

Texas Instruments Incorporated and its subsidiaries (TI) reserve the right to make corrections, enhancements, improvements and other changes to its semiconductor products and services per JESD46, latest issue, and to discontinue any product or service per JESD48, latest issue. Buyers should obtain the latest relevant information before placing orders and should verify that such information is current and complete. All semiconductor products (also referred to herein as "components") are sold subject to TI's terms and conditions of sale supplied at the time of order acknowledgment.

TI warrants performance of its components to the specifications applicable at the time of sale, in accordance with the warranty in TI's terms and conditions of sale of semiconductor products. Testing and other quality control techniques are used to the extent TI deems necessary to support this warranty. Except where mandated by applicable law, testing of all parameters of each component is not necessarily performed.

TI assumes no liability for applications assistance or the design of Buyers' products. Buyers are responsible for their products and applications using TI components. To minimize the risks associated with Buyers' products and applications, Buyers should provide adequate design and operating safeguards.

TI does not warrant or represent that any license, either express or implied, is granted under any patent right, copyright, mask work right, or other intellectual property right relating to any combination, machine, or process in which TI components or services are used. Information published by TI regarding third-party products or services does not constitute a license to use such products or services or a warranty or endorsement thereof. Use of such information may require a license from a third party under the patents or other intellectual property of the third party, or a license from TI under the patents or other intellectual property of TI.

Reproduction of significant portions of TI information in TI data books or data sheets is permissible only if reproduction is without alteration and is accompanied by all associated warranties, conditions, limitations, and notices. TI is not responsible or liable for such altered documentation. Information of third parties may be subject to additional restrictions.

Resale of TI components or services with statements different from or beyond the parameters stated by TI for that component or service voids all express and any implied warranties for the associated TI component or service and is an unfair and deceptive business practice. TI is not responsible or liable for any such statements.

Buyer acknowledges and agrees that it is solely responsible for compliance with all legal, regulatory and safety-related requirements concerning its products, and any use of TI components in its applications, notwithstanding any applications-related information or support that may be provided by TI. Buyer represents and agrees that it has all the necessary expertise to create and implement safeguards which anticipate dangerous consequences of failures, monitor failures and their consequences, lessen the likelihood of failures that might cause harm and take appropriate remedial actions. Buyer will fully indemnify TI and its representatives against any damages arising out of the use of any TI components in safety-critical applications.

In some cases, TI components may be promoted specifically to facilitate safety-related applications. With such components, TI's goal is to help enable customers to design and create their own end-product solutions that meet applicable functional safety standards and requirements. Nonetheless, such components are subject to these terms.

No TI components are authorized for use in FDA Class III (or similar life-critical medical equipment) unless authorized officers of the parties have executed a special agreement specifically governing such use.

Only those TI components which TI has specifically designated as military grade or "enhanced plastic" are designed and intended for use in military/aerospace applications or environments. Buyer acknowledges and agrees that any military or aerospace use of TI components which have **not** been so designated is solely at the Buyer's risk, and that Buyer is solely responsible for compliance with all legal and regulatory requirements in connection with such use.

TI has specifically designated certain components as meeting ISO/TS16949 requirements, mainly for automotive use. In any case of use of non-designated products, TI will not be responsible for any failure to meet ISO/TS16949.

### Products

Audio	<a href="http://www.ti.com/audio">www.ti.com/audio</a>
Amplifiers	<a href="http://amplifier.ti.com">amplifier.ti.com</a>
Data Converters	<a href="http://dataconverter.ti.com">dataconverter.ti.com</a>
DLP® Products	<a href="http://www.dlp.com">www.dlp.com</a>
DSP	<a href="http://dsp.ti.com">dsp.ti.com</a>
Clocks and Timers	<a href="http://www.ti.com/clocks">www.ti.com/clocks</a>
Interface	<a href="http://interface.ti.com">interface.ti.com</a>
Logic	<a href="http://logic.ti.com">logic.ti.com</a>
Power Mgmt	<a href="http://power.ti.com">power.ti.com</a>
Microcontrollers	<a href="http://microcontroller.ti.com">microcontroller.ti.com</a>
RFID	<a href="http://www.ti-rfid.com">www.ti-rfid.com</a>
OMAP Applications Processors	<a href="http://www.ti.com/omap">www.ti.com/omap</a>
Wireless Connectivity	<a href="http://www.ti.com/wirelessconnectivity">www.ti.com/wirelessconnectivity</a>

### Applications

Automotive and Transportation	<a href="http://www.ti.com/automotive">www.ti.com/automotive</a>
Communications and Telecom	<a href="http://www.ti.com/communications">www.ti.com/communications</a>
Computers and Peripherals	<a href="http://www.ti.com/computers">www.ti.com/computers</a>
Consumer Electronics	<a href="http://www.ti.com/consumer-apps">www.ti.com/consumer-apps</a>
Energy and Lighting	<a href="http://www.ti.com/energy">www.ti.com/energy</a>
Industrial	<a href="http://www.ti.com/industrial">www.ti.com/industrial</a>
Medical	<a href="http://www.ti.com/medical">www.ti.com/medical</a>
Security	<a href="http://www.ti.com/security">www.ti.com/security</a>
Space, Avionics and Defense	<a href="http://www.ti.com/space-avionics-defense">www.ti.com/space-avionics-defense</a>
Video and Imaging	<a href="http://www.ti.com/video">www.ti.com/video</a>

### TI E2E Community

[e2e.ti.com](http://e2e.ti.com)