DUAL OPERATIONAL TRANSCONDUCTANCE AMPLIFIER NE5517/5517A

DESCRIPTION

The NE5517 contains two current controlled transconductance amplifiers, each with a differential input and push-pull output. The NE5517 offers significant design and performance advantages over similar devices for all types of programmable gain applications. Circuit performance is enhanced through the use of linearizing diodes at the inputs which enable a 10dB signal to noise improvement referenced to .5 percent THD. The NE5517 is suited for a wide variety of industrial and consumer applications and is recommended as the preferred circuit in the Dolby* HX (Headroom Extension) system.

Constant-Impedance-Buffers on the chip allow general use of the NE5517. These buffers are made of Darlington-Transistor and a biasing-network which changes bias current in dependence of I_{ABC}.

Therefore changes of output offset voltages are almost eliminated. This is an advantage of the NE5517 compared to LM13600. With the LM13600 a burst in the bias current I_{ABC} guides to an audible offset voltage change at the output. With the Constant-Impedance-Buffers of the NE5517 this effect can be avoided and makes this circuit preferable for high quality audio applications.

FEATURES

- **Constant impedance buffers**
- **ΔV_{BE} of buffer is constant with amplifier I_{BIAS} change**
- **Pin compatible with LM13600**
- **Excellent matching between amplifiers**
- **Linearizing diodes**
- **High output signal-to-noise ratio**

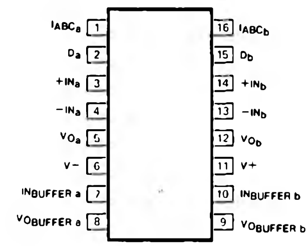
APPLICATIONS

- **Multiplexers**
- **Timers**
- **Electronic music synthesizers**
- **Dolby* HX Systems**
- **Current-controlled amplifiers, filters**
- **Current-controlled oscillators, impedances**

NOTE
*Dolby is a registered trademark of Dolby Laboratories Inc., San Francisco, Calif.

PIN CONFIGURATION

D,N PACKAGE



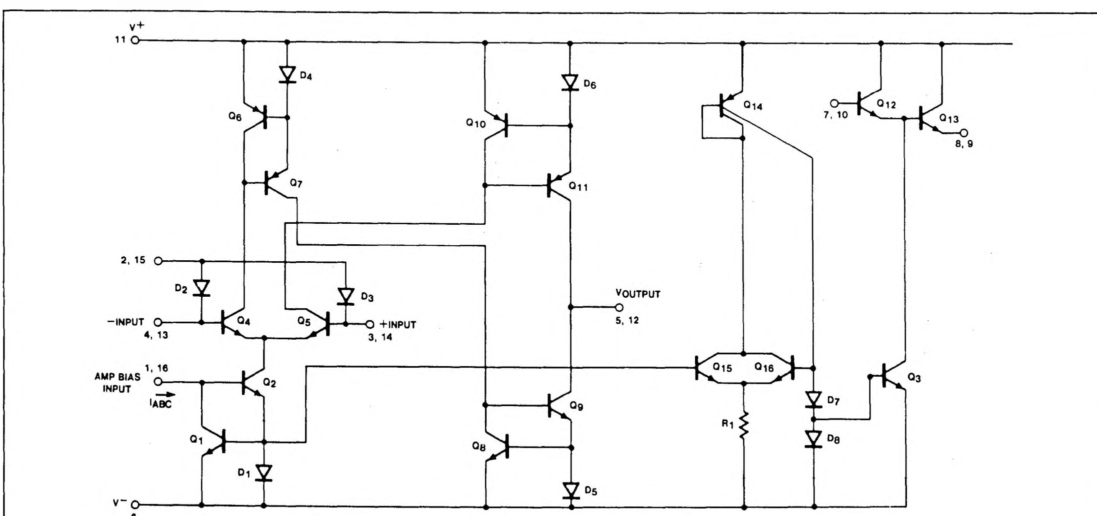
TOP VIEW

ORDER NUMBERS
NE5517N NE5517D NE5517AN

ABSOLUTE MAXIMUM RATINGS

PARAMETER	RATING	UNIT
Supply Voltage[1]		
NE5517	36 V_{DC} or ±18	V
NE5517A	44 V_{DC} or ±22	V
Power Dissipation[2] T_A = 25°C		
NE5517N, NE5517AN	570	mW
Differential Input Voltage	±5	V
Diode Bias Current (I_D)	2	mA
Amplifier Bias Current (I_{ABC})	2	mA
Output Short Circuit Duration	Indefinite	
Buffer Output Current[3]	20	mA
Operating Temperature Range		
NE5517N, NE5517AN	0°C to +70	°C
DC Input Voltage	$+V_S$ to $-V_S$	
Storage Temperature Range	−65°C to +150	°C
Lead Temperature (Soldering, 10 Seconds)	300	°C

CIRCUIT SCHEMATIC

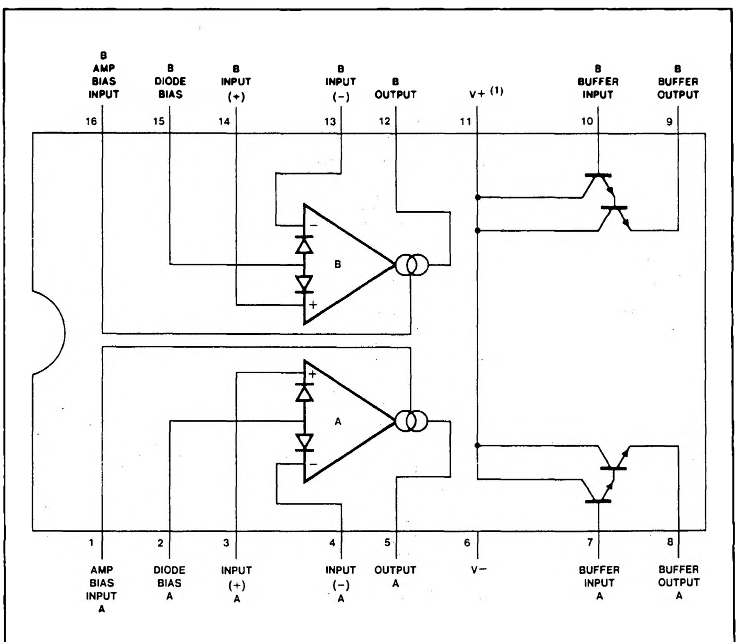


DUAL OPERATIONAL TRANSCONDUCTANCE AMPLIFIER NE5517/5517A

PIN DESIGNATION

PIN NO.	SYMBOL	NAME AND FUNCTION
1	I_{ABCa}	Amplifier bias input A
2	D_a	Diode bias A
3	$+IN_a$	Non-inverting input A
4	$-IN_a$	Inverting input A
5	V_{oa}	Output A
6	V−	negative supply
7	$IN_{Buffer\ (a)}$	Buffer input A
8	$VO_{Buffer\ (a)}$	Buffer output A
9	$VO_{Buffer\ (b)}$	Buffer output B
10	$IN_{Buffer\ (b)}$	Buffer input B
11	V+	Positive supply
12	V_{ob}	Output B
13	$-IN_b$	Inverting input B
14	$+IN_b$	Non-inverting input B
15	D_b	Diode bias B
16	I_{ABCb}	Amplifier bias input B

CONNECTION DIAGRAM



NOTE:
1. V+ of output buffers and amplifiers are internally connected.

DUAL OPERATIONAL TRANSCONDUCTANCE AMPLIFIER NE5517/5517A

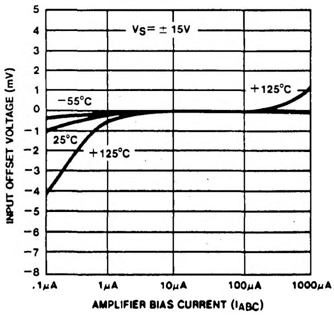
ELECTRICAL CHARACTERISTICS[4]

PARAMETER	TEST CONDITIONS	NE5517 Min	NE5517 Typ	NE5517 Max	NE5517A Min	NE5517A Typ	NE5517A Max	UNIT
Input offset voltage (V_{OS})			0.4	5		0.4	2	mV
	Over temperature range						5	mV
	I_{ABC} 5μA		0.3	5		0.3	2	mV
$\Delta V_{OS}/\Delta T$	Avg. TC of input offset voltage		7			7		μV/°C
V_{OS} including diodes	Diode bias current (I_D) = 500μA		0.5	5		0.5	2	mV
Input offset change	5μA ≤ I_{ABC} ≤ 500μA		0.1			0.1	3	mV
Input offset current			0.1	0.6		0.1	0.6	μA
$\Delta I_{OS}/\Delta T$	Avg. TC of input offset current		0.001			0.001		μA/°C
Input bias current			0.4	5		0.4	5	μA
	Over temperature range		1	8		1	7	μA
$\Delta I_B/\Delta T$	Avg. TC of input current		0.01			0.01		μA/°C
Forward Transconductance (gm)		6700	9600	13000	7700	9600	12000	μmho
	Over temperature range	5400			4000			μmho
gm tracking			0.3			0.3		dB
Peak output current	RL = 0, I_{ABC} = 5μA		5		3	5	7	μA
	RL = 0, I_{ABC} = 500μA	350	500	650	350	500	650	μA
	RL = 0,	300			300			μA
Peak output voltage								
Positive	RL = ∞, 5μA ≤ I_{ABC} ≤ 500μA	+12	+14.2		+12	+14.2		V
Negative	RL = ∞, 5μA ≤ I_{ABC} ≤ 500μA	−12	−14.4		−12	−14.4		V
Supply current	I_{ABC} = 500μA, both channels		2.6	4		2.6	4	mA
V_{OS} sensitivity								
Positive	$\Delta V_{OS}/\Delta V+$		20	150		20	150	μV/V
Negative	$\Delta V_{OS}/\Delta V-$		20	150		20	150	μV/V
CMRR		80	110		80	110		dB
Common mode range		±12	±13.5		±12	±13.5		V
Crosstalk	Referred to input[5] 20Hz < f < 20kHz		100			100		dB
Diff. input current	I_{ABC} = 0, input = ±4V		0.02	100		0.02	10	nA
Leakage current	I_{ABC} = 0 (Refer to test circuit)		0.2	100		0.2	5	nA
Input resistance		10	26		10	26		KΩ
Open loop bandwidth			2			2		MHz
Slew rate	Unity gain compensated		50			50		V/μSec
Buff. input current	5		0.4	5		0.4	5	μA
Peak buffer output voltage	5	10			10			V
ΔV_{BE} of buffer	6 Refer to Buffer V_{BE} test circuit		0.5	5		0.5	5	mV

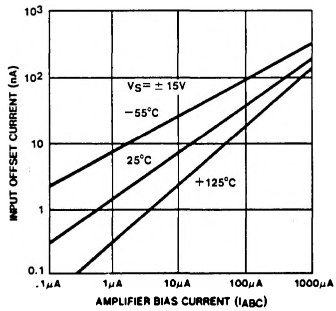
NOTES
1. For selections to a supply voltage above ±22V, contact factory.
2. For operating at high temperatures, the device must be derated based on a 150°C maximum junction temperature and a thermal resistance of 175° C/W which applies for the device soldered in a printed circuit board, operating in still air.
3. Buffer output current should be limited so as to not exceed package dissipation.
4. These specifications apply for V_S = ±15V, T_A = 25°C, amplifier bias current (I_{ABC}) = 500μA, pins 2 and 15 open unless otherwise specified. The inputs to the buffers are grounded and outputs are open.
5. 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.
6. V_S = ±15, R_{OUT} = 5KΩ connected from Buffer output to $-V_S$ and 5μA ≤ I_{ABC} ≤ 500μA.

TYPICAL PERFORMANCE CHARACTERISTICS

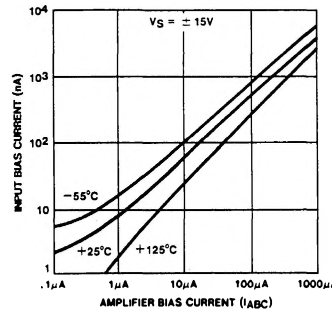
INPUT OFFSET VOLTAGE



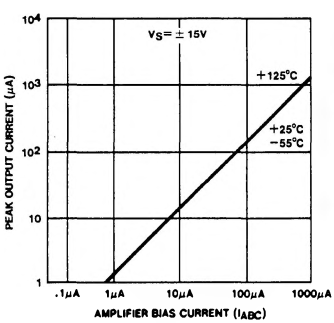
INPUT OFFSET CURRENT



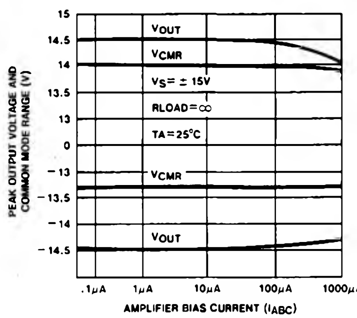
INPUT BIAS CURRENT



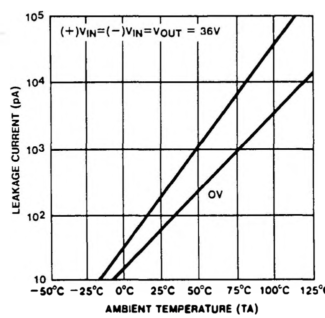
PEAK OUTPUT CURRENT



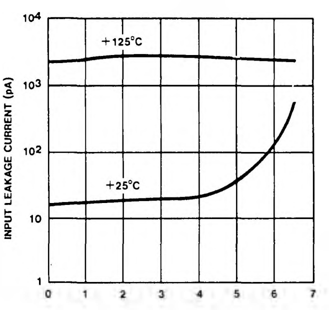
PEAK OUTPUT VOLTAGE AND COMMON MODE RANGE



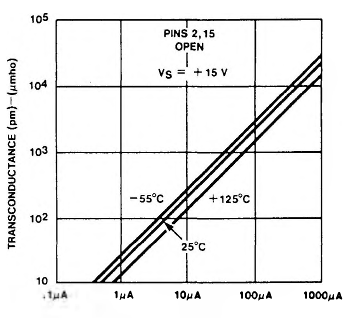
LEAKAGE CURRENT



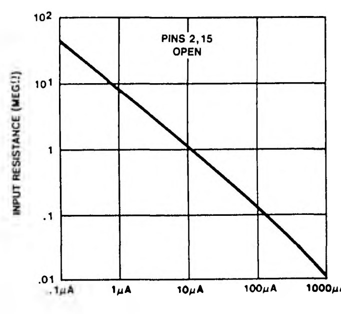
INPUT LEAKAGE



TRANSCONDUCTANCE



INPUT RESISTANCE



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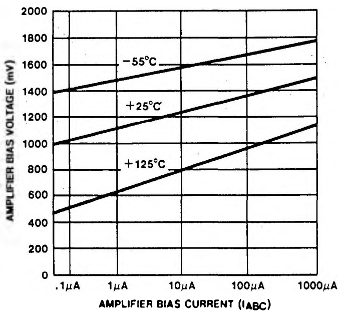
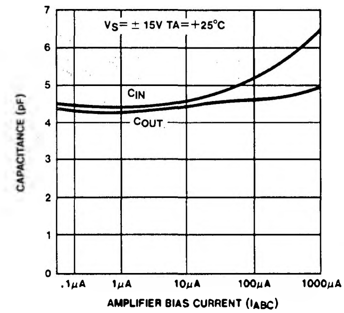
TYPICAL PERFORMANCE CHARACTERISTICS (Cont'd)

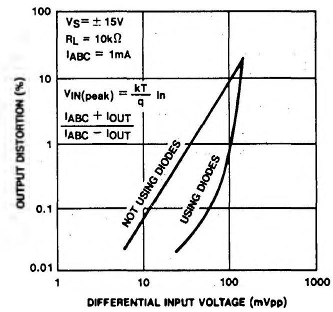
AMPLIFIER BIAS VOLTAGE vs AMPLIFIER BIAS CURRENT



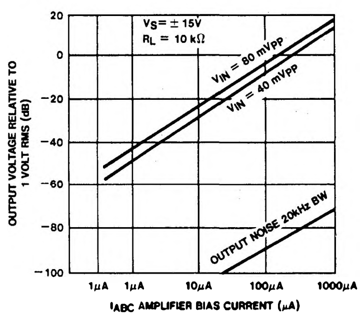
INPUT AND OUTPUT CAPACITANCE



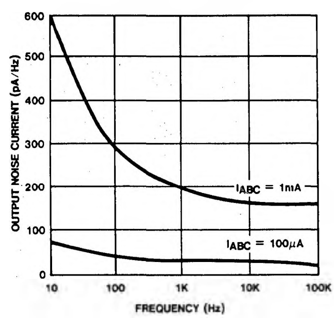
DISTORTION vs DIFFERENTIAL INPUT VOLTAGE



VOLTAGE vs AMPLIFIER BIAS CURRENT



OUTPUT NOISE vs FREQUENCY



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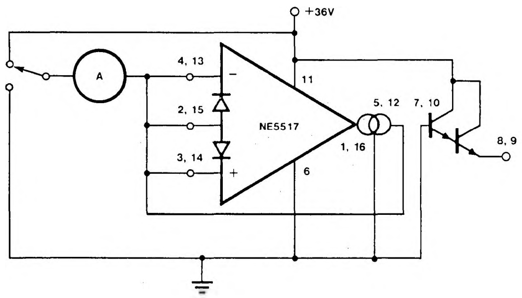
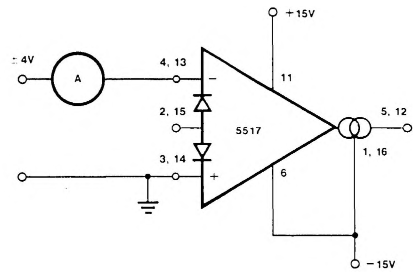
TYPICAL PERFORMANCE CHARACTERISTICS (Cont'd)

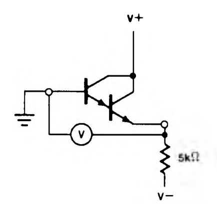
LEAKAGE CURRENT TEST CIRCUIT



DIFFERENTIAL INPUT CURRENT TEST CIRCUIT

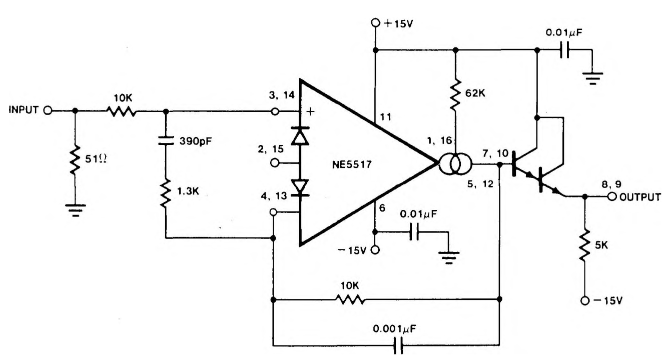


BUFFER V_{BE} TEST CIRCUIT



APPLICATIONS

UNITY GAIN FOLLOWER



CIRCUIT DESCRIPTION

The circuit schematic diagram of one half of the NE5517, a dual operational transconductance amplifier with linearizing diodes and impedance buffers, is shown in Figure 1.

1. Transconductance Amplifier

The transistor pair Q_4 and Q_5 form a transconductance stage. The ratio of their collector currents (I_4 and I_5 respectively) is defined by the differential input voltage, V_{IN}, which is shown in equation 1.

$$V_{IN} = \frac{KT}{q} \ln \frac{I_5}{I_4} \qquad (1)$$

Where V_{IN} is the difference of the two input voltages

$KT \cong 26mV$ at room temperature (300°K)

Transistors Q_1, Q_2 and diode D_1 form a current mirror which focuses the sum of current I_4 and I_5 to be equal to amplifier bias current I_B:

$$I_4 + I_5 = I_B \qquad (2)$$

If V_{IN} is small the ratio of I_5 and I_4 will approach to unity and the Taylor series of ln function can be approximated as:

$$\frac{KT}{q} \ln \frac{I_5}{I_4} \approx \frac{KT}{q} \frac{I_5 - I_4}{I_4} \qquad (3)$$

and $I_4 \approx I_5 \approx {}^1\!/_2 I_B$

$$\frac{KT}{q} \ln \frac{I_5}{I_4} \approx \frac{KT}{q} \frac{I_5 - I_4}{{}^1\!/_2 I_B} = \frac{2KT}{q} \frac{I_5 - I_4}{I_B} = V_{IN}$$

$$I_5 - I_4 = V_{IN} \frac{(I_B q)}{2KT} \qquad (4)$$

The remaining transistors (Q_6 to Q_{11}) and diodes (D_4 to D_6) form three current mirrors that produce an output current equal to I_5 minus I_4. Thus:

$$V_{IN} \left\{ I_B \frac{q}{2KT} \right\} = I_O \qquad (5)$$

The term $\frac{(I_B q)}{2KT}$ is then the transconductance of the amplifier and is proportional to I_B.

2. Linearizing Diodes

For V_{IN} greater than a few millivolts, equation 3 becomes invalid and the transconductance increases nonlinearly. Figure 2 shows how the internal diodes can linearize the transfer function of the operational amplifier. Assume D_2 and D_3 are biased with current sources and the input signal current is I_S. Since

$I_4 + I_5 = I_B$ and $I_5 - I_4 = I_O$, that is:

$I_4 = {}^1\!/_2(I_B - I_O)$, $I_5 = {}^1\!/_2(I_B + I_O)$

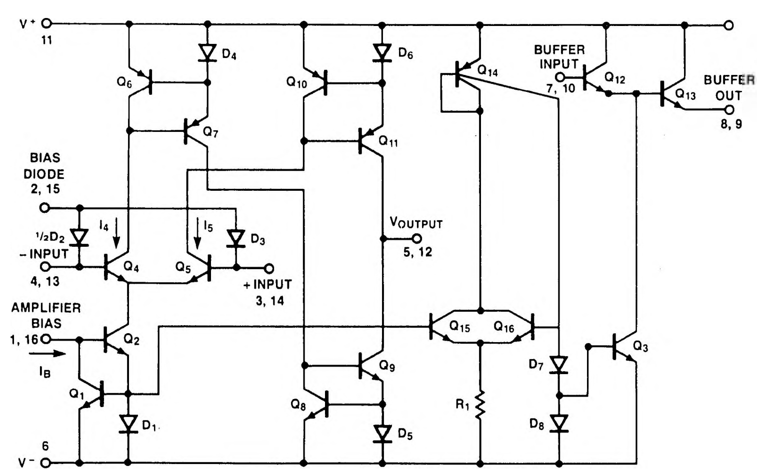


Figure 1. Circuit Diagram of NE5517

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

$$\frac{KT}{q}\ln\frac{\frac{I_D}{2}+I_S}{\frac{I_D}{2}-I_S}=\frac{KT}{q}\ln\frac{\frac{1}{2}(I_B+I_0)}{\frac{1}{2}(I_B-I_0)}$$

$$I_0 = I_S\frac{(2I_B)}{I_D} \text{ for } |I_S| < \frac{I_D}{2} \qquad (6)$$

The only limitation is that the signal current should not exceed 1/2 I_D.

3. Impedance Buffer

The upper limit of transconductance is defined by the maximum value of I_B (2mA). The lowest value of I_B for which the amplifier will function therefore determines the overall dynamic range. At low values of I_B, a buffer with very low input bias current is desired. A Darlington amplifier with constant current source (Q_{14}, Q_{15}, Q_{16}, D_7, D_8, and R_1) suits the need.

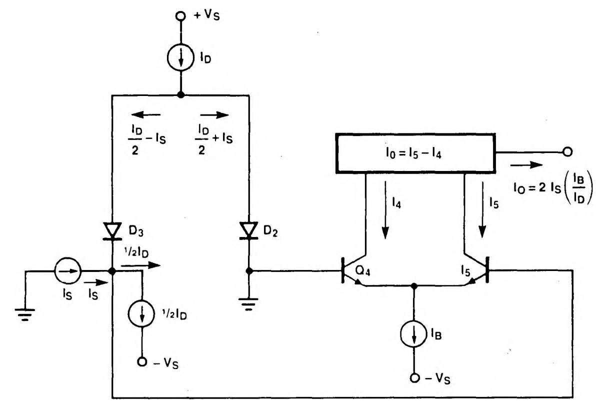

Figure 2. Linearizing Diode

APPLICATIONS

Voltage Controlled Amplifier

The voltage-divider R_2, R_3 divides the input-voltage into small values (mV-range) so the amplifier operates in a linear manner.

It is:

$$I_{OUT} = -V_{IN} \times \frac{R_3}{R_2+R_3} \times gm;$$

$$V_{OUT} = I_{OUT} \times R_L;$$

$$A = \frac{V_{OUT}}{V_{IN}} = \frac{R_3}{R_2+R_3}\, gm\, R_L;$$

$$\boxed{A = \frac{R_3}{R_2+R_3} \times gm \times R_L} \quad (3)\ gm = 19.2\ I_{ABC}$$

(gm in mS for I_{ABC} in mA)

Since gm is directly proportional to I_{ABC}, the amplification is controlled by the voltage V_C in a simple way.

When V_C is taken relative to $-V_{CC}$ the following formula is valid:

$$I_{ABC} = \frac{(V_C - 1.2V)}{R_1};$$

The 1.2V is the voltage across two base-emitter paths in the current mirrors. This circuit is the base for many applications of the NE5517.

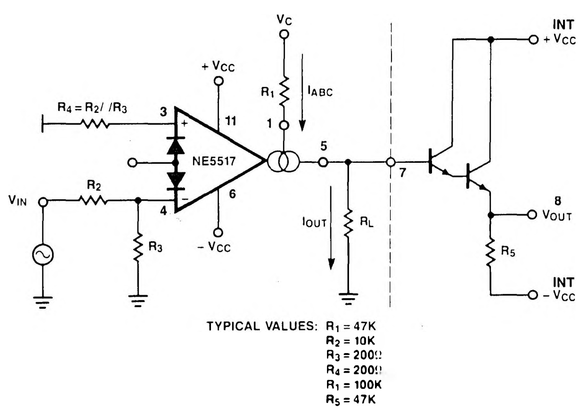

Figure 3.

DUAL OPERATIONAL TRANSCONDUCTANCE AMPLIFIER NE5517/5517A

Stereo Amplifier With Gain Control

Figure 4 shows a stereo amplifier with variable gain via a control input. Excellent tracking of typical 0.3dB is easy to achieve. With the potentiometer R_P, the offset can be adjusted. For AC-coupled amplifiers you can replace the potentiometer with two 510Ω resistors.

Modulators

Because the transconductance of an OTA is directly proportional to I_{ABC}, the amplification of a signal can be controlled easily. The output current is the product from transconductance x input voltage. The circuit works up to approximately 200KHz. Modulation of 99 percent is easy to achieve.

Voltage Controlled Resistors (VCR)

The principle is based on the capability of an OTA to vary a current proportional to a controlled voltage which is according to a resistor. The circuit takes advantage of the possibility to control a resistor via gm.

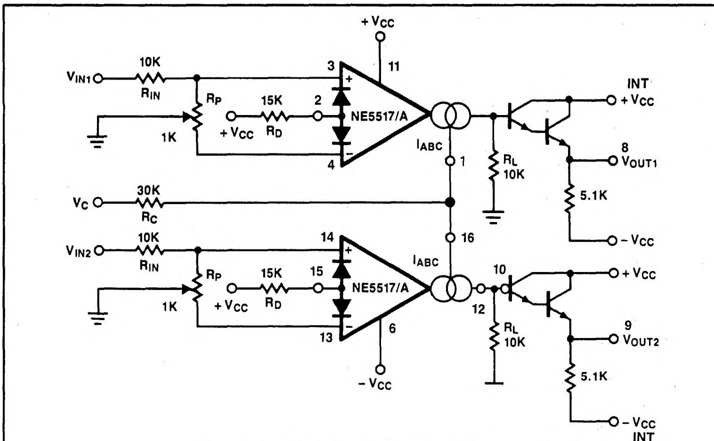

Figure 4. Gain Controlled Stereo Amplifier

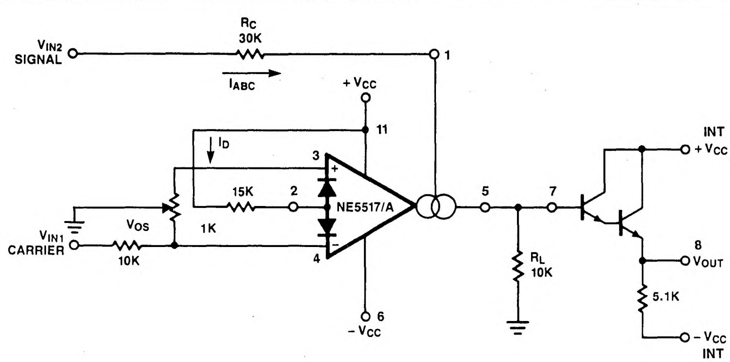

Figure 5. Amplitude modulator

Voltage Controlled Filters

Voltage controlled filters can be realized extremely easily with the help of an OTA.

Figure 8 shows the circuit for a low-pass filter. Below the corner frequency the circuit has an amplification of 0dB. Above the corner frequency the attentuation drops by 6dB/octave.

The high-pass filter is built in a similar manner, except the input is coupled via capacitor.

Voltage Controlled Oscillators

Figure 12 shows a voltage controlled triangle-square-wave-generator. With the indicated values a range from 2Hz to 200kHz is possible by varying I_{ABC} from 1mA to 10μA.

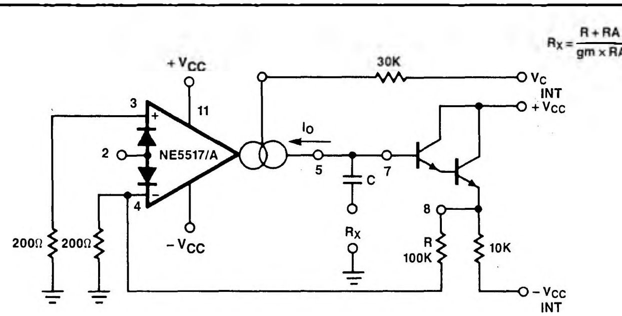

Figure 6. VCR

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The output amplitude is determined by $I_{OUT} \times R_{OUT}$.

Please notice the differential-input-voltage is not allowed to be above 5V.

With a slight modification of this circuit you can get the sawtooth-pulse-generator as shown in Figure 13.

Programmable Amplifier

The intention of the following application is to show how the NE5517 works in connection with a DAC. Almost all applications described above can be made digitally programmable (μP-compatible) in this way.

In the application Figure 14 the NE5118 is used, an eight-bit DAC with current output (see Section), its input-register makes this device fully μP-compatible.

The circuitry of Figure 14 consists of three functional blocks: the NE5118, which generates a control current equivalent to the applied data byte, a current mirror, and the NE5517.

The amplification is given by the following equation:

$$A = \frac{DW\ (10)}{256} \times \frac{I_{DAC}\ max}{2 \times V_T} \times R_L$$

DW (10) = Data word decimal

I_{DAC} max = Maximum DAC output current (here −1mA)

R_L = Load resistance

The equation is only valid for the amplification of the signal directly applied to the OTA. To get the gain overall A must be multiplied with the input-attenuation factor.

APPLICATION HINTS:

To hold the transconductance gm within the linear range, I_{ABC} should be chosen not greater than 1mA. The current mirror ratio should be as accurate as possible over the entire current range. A current mirror with only two transistors is not recommended. A suitable current mirror can be built with a pnp-transistor array which causes excellent matching and thermal coupling among the transistors. The output current range of the DAC normally reaches from 0 . . . −2mA. In this application, however, the current range is set through R_{REF} (10KΩ) to 0 . . . −1mA.

$$I_{DAC}\ max = 2 \times \frac{V_{REF}}{R_{REF}} = 2 \times \frac{5V}{10K} = 1mA$$

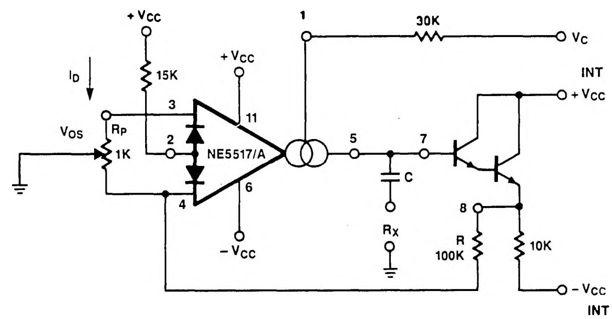


Figure 7. VCR with Linearizing Diodes

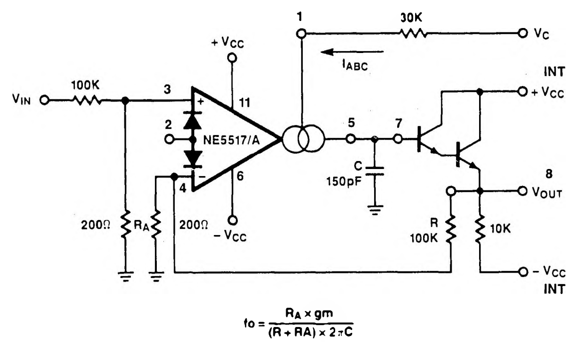


Figure 8. Voltage Controlled Low Pass Filter

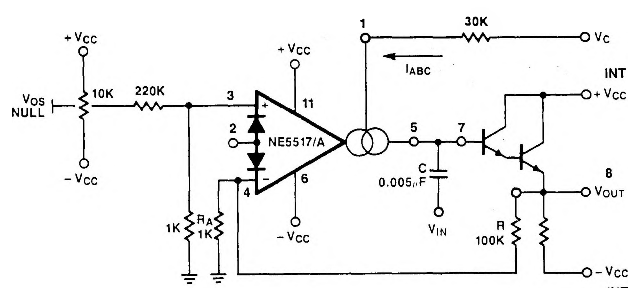


Figure 9. Voltage Controlled High Pass Filter

DUAL OPERATIONAL TRANSCONDUCTANCE AMPLIFIER NE5517/5517A

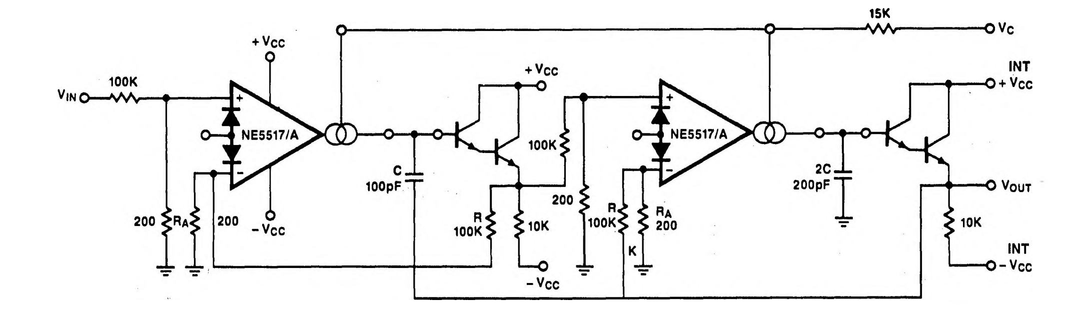


Figure 10. Butterworth Filter — 2nd Order

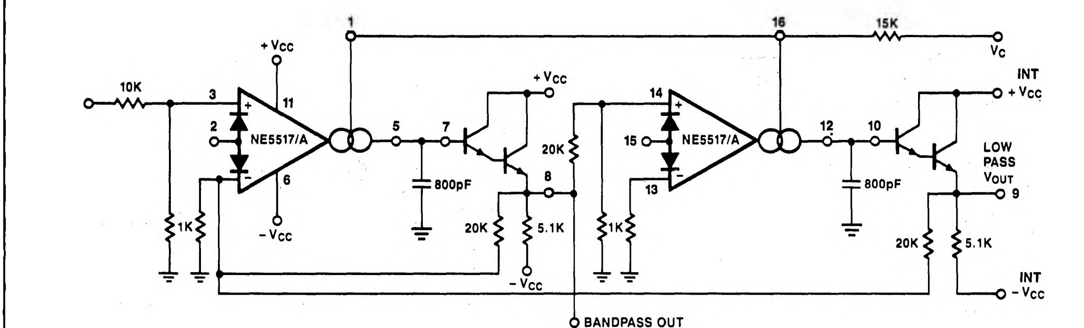


Figure 11. State Variable Filter

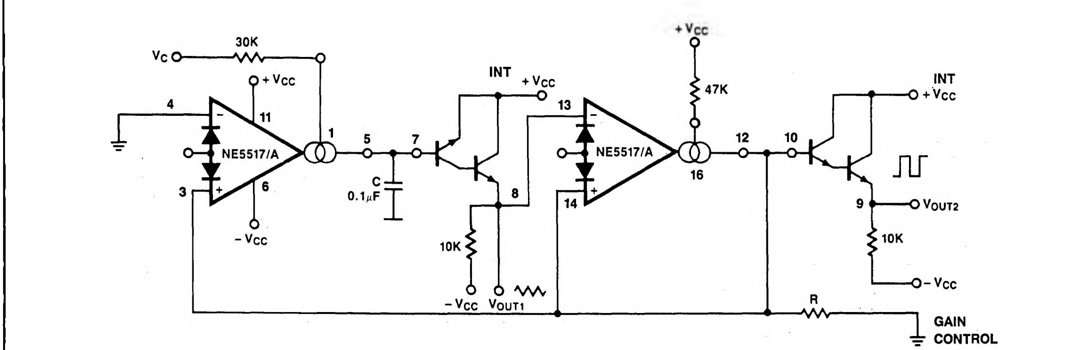
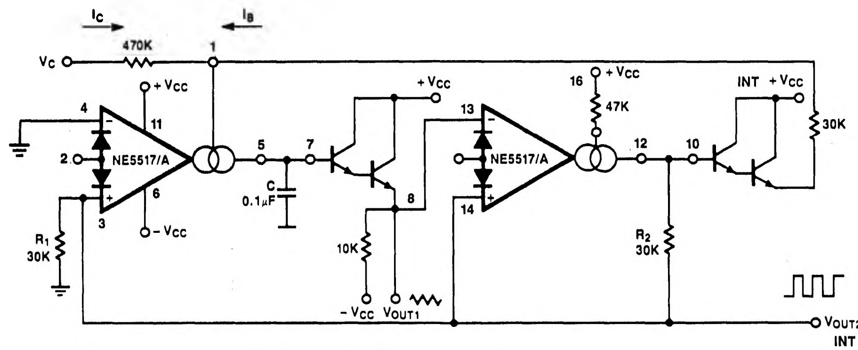


Figure 12. Triangle-Squarewave-Generator (VCO)



$$V_{PK} = \frac{(V_S - 0.8)\,R_1}{R_1 + R_2} \quad T_H = \frac{2V_{PK} \times C}{I_B} \quad T_L = \frac{2V_{PK} \times C}{I_C} \quad f_{osc} \frac{I_C}{2V_{PK} \times C} \quad I_C << I_B$$

Figure 13. Sawtooth-Pulse-VCO

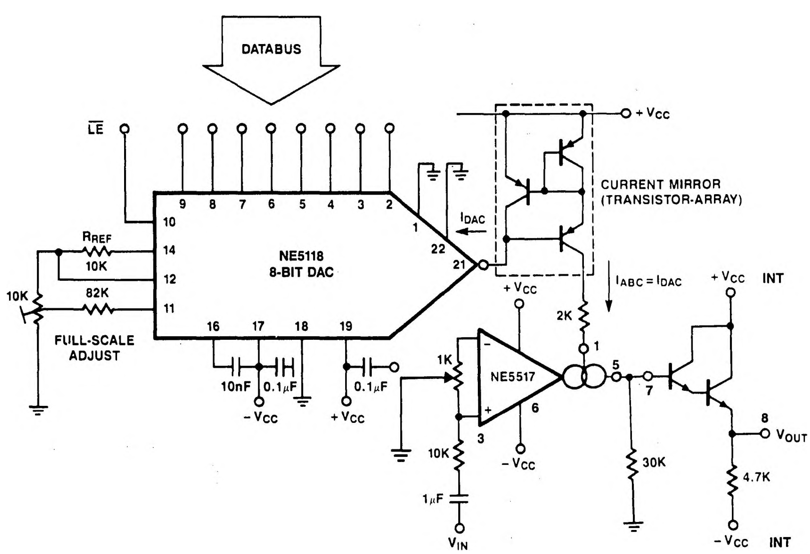


Figure 14. Digital Programmable Amplifier

***For additional information, consult the Applications Section.**