

### FEATURES

- **Low Distortion** – DC to 40kHz,  $A_v = +10$  ..... **0.01% Typ**
- **High Slew Rate** ..... **40V/μs Min**
- **Gain-Bandwidth Product** ..... **10MHz Typ**
- **High Gain** ..... **200,000 Typ**
- **Common-Mode Rejection** ..... **80dB Min**

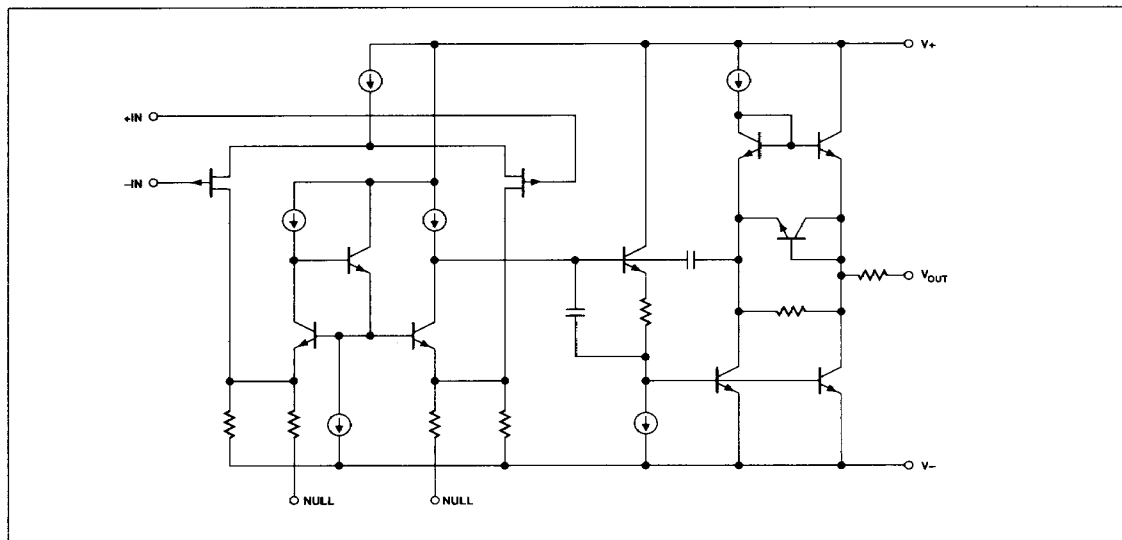
### APPLICATIONS

- **Power Amplifier Driver**
- **Active Filter Circuits**
- **Parametric Equalizers**
- **Graphic Equalizers**
- **Mixing Consoles**
- **Voltage Summers**
- **Active Crossover Networks**

### GENERAL DESCRIPTION

The SSM-2131 is a fast JFET input operational amplifier intended for use in audio applications. The SSM-2131 offers a symmetric 50V/μs slew rate for low distortion and is internally compensated for unity gain operation. Power supply current is less than 6.5mA. Unity-gain stability, a wide full-power bandwidth of 800kHz, and excellent ability to handle transient overloads make the SSM-2131 an ideal amplifier for use in high performance audio amplifier circuits.

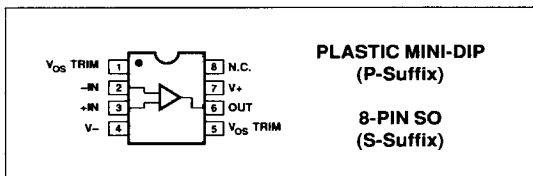
### SIMPLIFIED SCHEMATIC



The SSM-2131's common-mode rejection of 80dB minimum over a  $\pm 11$  range is exceptional for a high-speed amplifier. High CMR, combined with a minimum 500V/mV gain into a 10kΩ load ensures excellent linearity in both noninverting and inverting gain configurations. This means that distortion will be very low over a wide range of circuit configurations. The low offset provided by the JFET input stage often eliminates the need for AC coupling or for external offset trimming.

The SSM-2131 conforms to the standard 741 pinout with nulling to V-. The SSM-2131 upgrades the performance of circuits using the TL071 by direct replacement.

### PIN CONNECTIONS



## ORDERING INFORMATION

PACKAGE		OPERATING TEMPERATURE RANGE
PLASTIC 8-PIN	SO 8-PIN	
SSM2131P	SSM2131S	XIND*

\*XIND = -40°C to +85°C

## ABSOLUTE MAXIMUM RATINGS

Supply Voltage .....	±20V
Input Voltage (Note 1) .....	±20V
Differential Input Voltage (Note 1) .....	40V

Output Short-Circuit Duration .....	Indefinite
Storage Temperature Range .....	-65°C to +175°C
Operating Temperature Range .....	-40°C to +85°C
Junction Temperature .....	-65°C to +175°C
Lead Temperature Range (Soldering, 60 sec) .....	+300°C

PACKAGE TYPE	$\theta_{JA}$ (Note 2)	$\theta_{JC}$	UNITS
8-Pin Plastic DIP (P)	103	43	°C/W
8-Pin SO (S)	158	43	°C/W

## NOTES:

- For supply voltages less than ±20V, the absolute maximum input voltage is equal to the supply voltage.
- $\theta_{JA}$  is specified for worst case mounting conditions, i.e.,  $\theta_{JA}$  is specified for device in socket for P-DIP packages;  $\theta_{JA}$  is specified for device soldered to printed circuit board for SO package.

ELECTRICAL CHARACTERISTICS at  $V_S = \pm 15V$ ,  $T_A = 25^\circ C$ , unless otherwise noted.

PARAMETER	SYMBOL	CONDITIONS	SSM-2131			UNITS
			MIN	TYP	MAX	
Slew Rate	SR		40	50	—	V/ $\mu$ s
Gain-Bandwidth Product	GBW	$f_o = 10\text{kHz}$	—	10	—	MHz
Full-Power Bandwidth	BW <sub>p</sub>	(Note 2)	600	800	—	kHz
Total Harmonic Distortion	THD	DC to 40kHz, $R_L = 10\text{k}\Omega$ , $A_v = +10$	—	0.01	—	%
Voltage Noise Density	$e_n$	$f_o = 10\text{Hz}$	—	38	—	nV/ $\sqrt{\text{Hz}}$
		$f_o = 1\text{kHz}$	—	13	—	
Current Noise Density	$i_n$	$f_o = 1\text{kHz}$	—	0.007	—	pA/ $\sqrt{\text{Hz}}$
Large-Signal Voltage Gain	$A_{VO}$	$R_L = 10\text{k}\Omega$ , $V_O = \pm 10V$	500	900	—	V/mV
		$R_L = 2\text{k}\Omega$ , $T_j = 25^\circ C$	200	260	—	
		$R_L = 1\text{k}\Omega$ , $T_j = 25^\circ C$	100	170	—	
Output Voltage Swing	$V_O$	$R_L = 1\text{k}\Omega$	±11.5	+12.5 -11.9	—	V
Offset Voltage	$V_{OS}$		—	1.5	6.0	mV
Input Bias Current	$I_B$	$V_{CM} = 0V$ , $T_j = 25^\circ C$	—	130	250	pA
Input Offset Current	$I_{OS}$	$V_{CM} = 0V$ , $T_j = 25^\circ C$	—	6	50	pA
Input Voltage Range	IVR	(Note 1)	±11.0	+12.5 -12.0	—	V
Common-Mode Rejection	CMR	$V_{CM} = \pm 11V$	80	92	—	dB
Power-Supply Rejection Ratio	PSRR	$V_S = \pm 10V$ to $\pm 20V$	—	12	50	$\mu V/V$
Supply Current	$I_{SV}$	No Load $V_O = 0V$	—	5.1	6.5	mA
Short-Circuit Current Limit	$I_{SC}$	Output Shorted to Ground	±20	+33 -28	±60	mA
Settling Time	$t_s$	10V Step 0.01% (Note 3)	—	0.9	1.2	$\mu$ s
Overload Recovery Time	$t_{OR}$		—	700	—	ns

**ELECTRICAL CHARACTERISTICS** at  $V_S = \pm 15V$ ,  $T_A = 25^\circ C$ , unless otherwise noted. *Continued*

PARAMETER	SYMBOL	CONDITIONS	SSM-2131			UNITS
			MIN	TYP	MAX	
Phase Margin	$\phi_O$	0dB Gain	—	47	—	degrees
Gain Margin	$A_{180}$	180° Open-Loop Phase Shift	—	9	—	dB
Capacitive Load Drive Capability	$C_L$	Unity-Gain Stable (Note 4)	100	300	—	pF
Supply Voltage Range	$V_S$		$\pm 8$	$\pm 15$	$\pm 20$	V

**NOTES:**

1. Guaranteed by CMR test.
2. Guaranteed by slew-rate test and formula  $BW_p = SR/(2\pi 10V_{PEAK})$ .
3. Settling time is guaranteed but not tested.
4. Guaranteed but not tested.

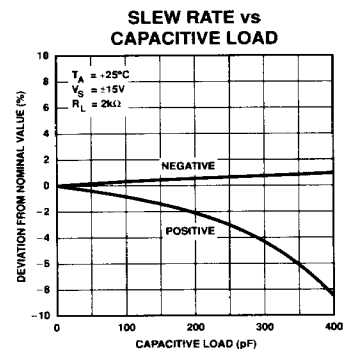
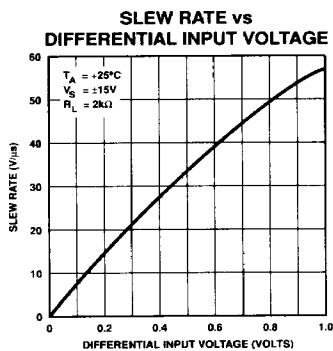
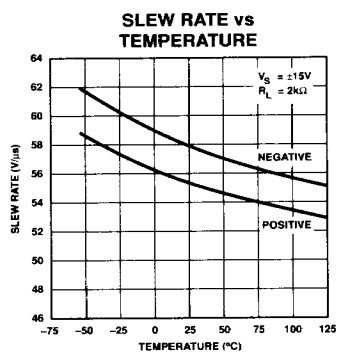
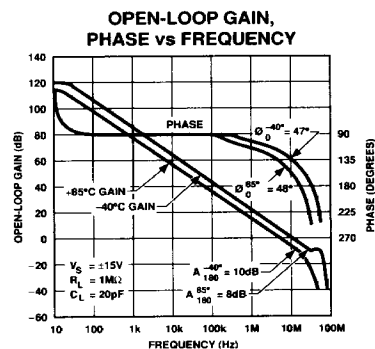
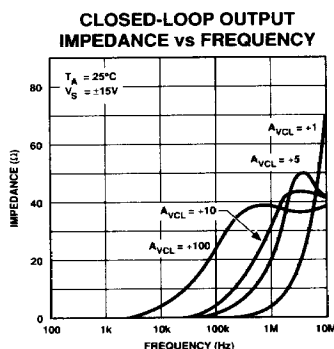
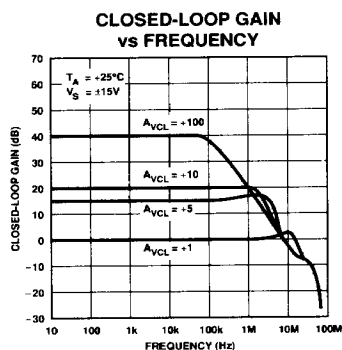
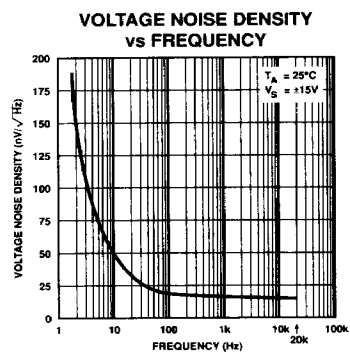
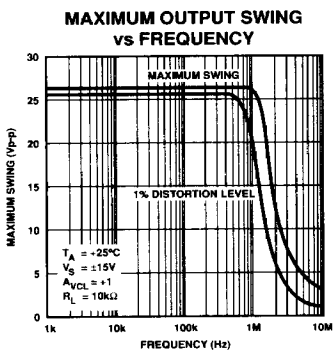
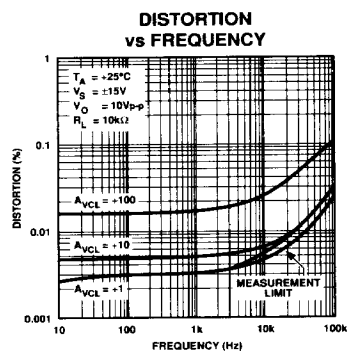
**ELECTRICAL CHARACTERISTICS** at  $V_S = \pm 15V$ ,  $-40^\circ C \leq T_A \leq 85^\circ C$ , unless otherwise noted.

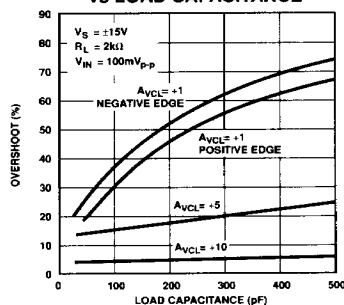
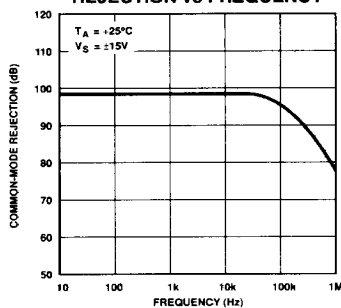
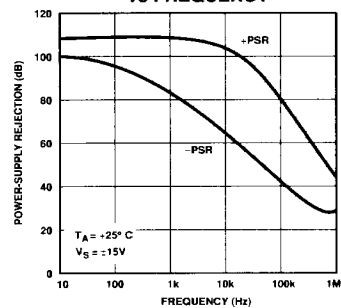
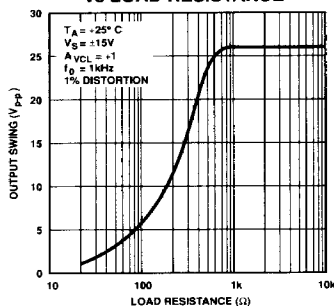
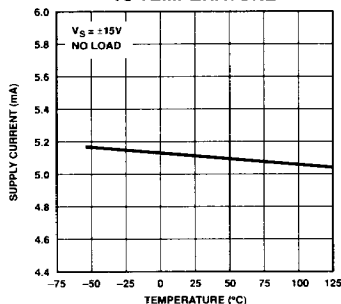
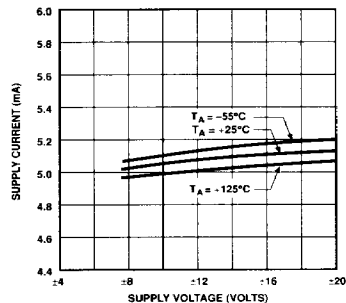
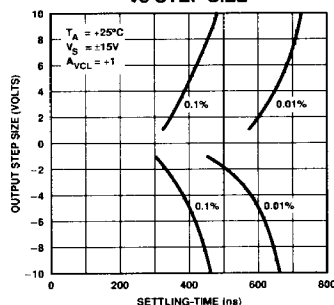
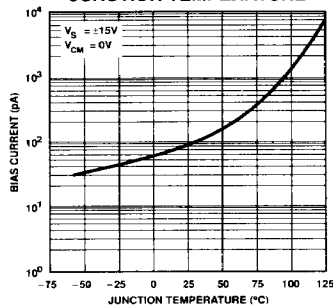
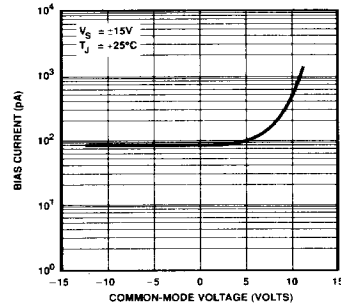
PARAMETER	SYMBOL	CONDITIONS	SSM-2131			UNITS
			MIN	TYP	MAX	
Slew Rate	SR	$R_L = 2k\Omega$	40	50	—	V/ $\mu s$
Large-Signal Voltage Gain	$A_{VO}$	$R_L = 10k\Omega$ (Note 1) $R_L = 2k\Omega$ $V_O = \pm 10V$	200 100	500 160	—	V/mV
Output Voltage Swing	$V_O$	$R_L = 2k\Omega$	$\pm 11.0$	+12.3 -11.8	—	V
Offset Voltage	$V_{OS}$		—	2.0	7.0	mV
Offset Voltage Temperature Coefficient	$TCV_{OS}$		—	8	—	$\mu V/^\circ C$
Input Bias Current	$I_B$	(Note 1)	—	0.6	2.0	nA
Input Offset Current	$I_{OS}$	(Note 1)	—	0.06	0.4	nA
Input Voltage Range	IVR	(Note 2)	$\pm 11.0$	+12.5 -12.0	—	V
Common-Mode Rejection	CMR	$V_{CM} = \pm 11V$	80	94	—	dB
Power-Supply Rejection Ratio	PSRR	$V_S = \pm 10V$ to $\pm 20V$	—	6	50	$\mu V/V$
Supply Current	$I_{SY}$	No Load $V_O = 0V$	—	5.1	6.5	mA
Short-Circuit Current Limit	$I_{SC}$	Output Shorted to Ground	$\pm 8$	—	$\pm 60$	mA

**NOTES:**

1.  $T_A = 85^\circ C$ .
2. Guaranteed by CMR test.

## TYPICAL PERFORMANCE CHARACTERISTICS



TYPICAL PERFORMANCE CHARACTERISTICS *Continued*SMALL-SIGNAL OVERSHOOT  
vs LOAD CAPACITANCECOMMON-MODE  
REJECTION vs FREQUENCYPOWER-SUPPLY REJECTION  
vs FREQUENCYOUTPUT SWING  
vs LOAD RESISTANCESUPPLY CURRENT  
vs TEMPERATURESUPPLY CURRENT vs  
SUPPLY VOLTAGESETTLING-TIME  
vs STEP SIZEBIAS CURRENT vs  
JUNCTION TEMPERATUREBIAS CURRENT vs  
COMMON-MODE VOLTAGE

## APPLICATIONS INFORMATION

The SSM-2131 combines speed with a high level of input precision usually found only with slower devices. Well-behaved AC performance in the form of clean transient response, symmetrical slew rates and a high degree of forgiveness to supply decoupling are the hallmarks of this amplifier. AC gain and phase response are quite independent of temperature or supply voltage. Figure 1 shows the SSM-2131's small-signal response. Even with 75pF loads, there is minimal ringing in the output waveform. Large-signal response is shown in Figure 2. This figure clearly shows the SSM-2131's exceptionally close matching between positive and negative slew rates. Slew rate symmetry decreases the DC offset a system encounters when processing high-frequency signals, and thus reduces the DC current necessary for load driving.

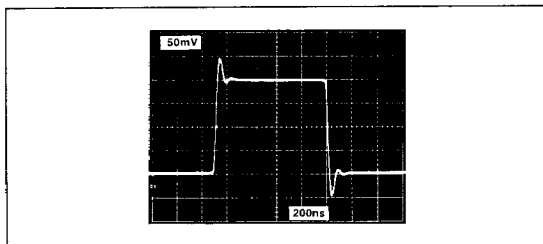


FIGURE 1: Small-Signal Transient Response,  $Z_L = 2k\Omega // 75pF$

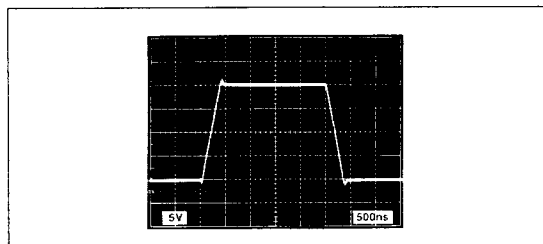


FIGURE 2: Large-Signal Transient Response,  $Z_L = 2k\Omega // 75pF$

As with most JFET-input amplifiers, the output of the SSM-2131 may undergo phase inversion if either input exceeds the specified input voltage range. Phase inversion will not damage the amplifier, nor will it cause an internal latch-up.

Supply decoupling should be used to overcome inductance and resistance associated with supply lines to the amplifier.

For most applications, a 0.1μF to 0.01μF capacitor should be placed between each supply pin and ground.

## OFFSET VOLTAGE ADJUSTMENT

Offset voltage is adjusted with a 10kΩ to 100kΩ potentiometer as shown in Figure 3. The potentiometer should be connected between pins 1 and 5 with its wiper connected to the V- supply.

Alternately,  $V_{OS}$  may be nulled by attaching the potentiometer wiper through a 1MΩ resistor to the positive supply rail.

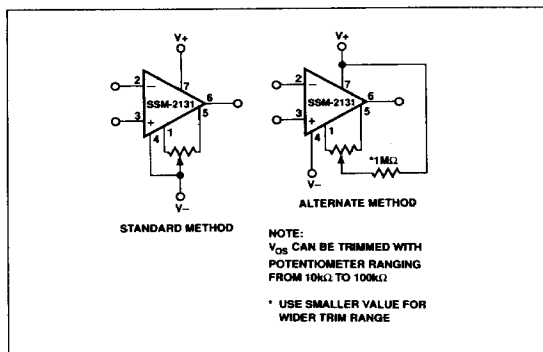


FIGURE 3: Input Offset Voltage Nulling

## VOLTAGE SUMMING

Because of its extremely low input bias current and large unity-gain bandwidth, the SSM-2131 is ideal for use as a voltage summer or adder.

The following figures show both an inverting and noninverting voltage adder.

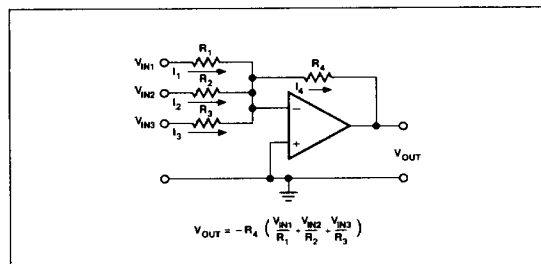


FIGURE 4: Inverting Adder

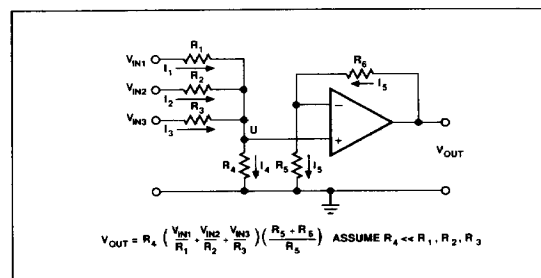


FIGURE 5: Noninverting Adder



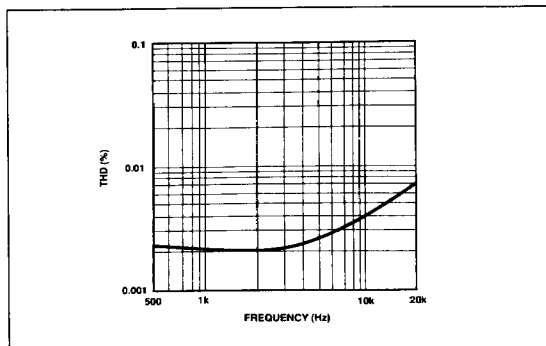


FIGURE 7: THD vs. Frequency (at 50W into 8Ω).

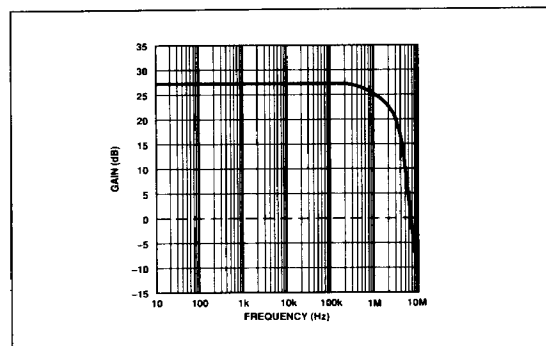


FIGURE 8: Frequency Response

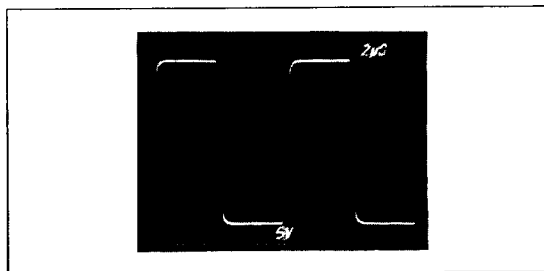


FIGURE 9: 100kHz Square Wave into 8Ω.

One problem that is commonly encountered with current feedback amplifiers is that the mismatch between the two current mirrors A and B forces a small bias current to appear at the input buffer's output terminal. This bias current (usually in the range of 1-100μA) is multiplied by the feedback resistor of 750Ω and generates an output offset that could be tens of millivolts in magnitude. Matched transistors could be used in the current mirrors, but these do not completely eliminate the output offset problem.

An inexpensive solution is to use a low power precision DC op amp, such as the OP-97, to control the amplifier's DC characteristics, thus overriding the DC offset due to mismatch in the current feedback loop. The OP-97 acts as a current output DC-servo amplifier that injects a compensating current into the emitters of the low voltage regulator transistors (that power the SSM-2131) to correct for current mirror mismatch. Since the OP-97 is set for an overall input-to-output gain of 24.0 as well, the DC output offset is equal to the OP-97's  $V_{OS} \times 24.0$ , which is roughly 1 millivolt. Thus, any offset trimming can be completely eliminated. Together, the SSM-2131 and OP-97 provide a level of performance that exceeds most of the requirements for audio power amplifiers. The driver circuit can handle several pairs of power MOSFETs in the output stage if required. This topology can be used in circuits that must deliver several hundreds of watts to a load by using higher voltage transistors in the driver stage. Operation with rail voltages in excess of  $\pm 100V$  is possible. If more gain is desired, the SSM-2131 input buffer can have its gain increased from the nominal value of 1.5 used in this example to as much as 10 before its bandwidth drops below that of the current feedback section.

#### DRIVING A HIGH-SPEED ADC

The SSM-2131's open-loop output resistance is approximately 50Ω. When feedback is applied around the amplifier, output resistance decreases in proportion to closed-loop gain divided by open-loop gain ( $A_{VCL}/A_{VOL}$ ). Output impedance increases as open-loop gain rolls-off with frequency. High-speed analog-to-digital converters require low source impedances at high frequency. Output impedance at 1MHz is typically 5Ω for an SSM-2131 operating at unity-gain. If lower output impedances are required, an output buffer may be placed at the output of the SSM-2131.



## HIGH-CURRENT OUTPUT BUFFER

The circuit in Figure 10 shows a high-current output stage for the SSM-2131 capable of driving a  $75\Omega$  load with low distortion. Output current is limited by  $R_1$  and  $R_2$ . For good tracking between the output transistors  $Q_1$ ,  $Q_2$ , and this biasing diodes  $D_1$  and  $D_2$ , thermal contact must be maintained between the transistor and its associated diode. If good thermal contact is not maintained,  $R_1$  and  $R_2$  must be increased to 5-6 $\Omega$  in order to prevent thermal runaway. Using  $5\Omega$  resistors, the circuit easily drives a  $75\Omega$  load (Figure 11). Output resistance is decreased and heavier loads may be driven by decreasing  $R_1$  and  $R_2$ .

Base current and biasing for  $Q_1$  and  $Q_2$  are provided by two current sources, the SSM-2131 and the JFET. The  $2k\Omega$  potentiometer in the JFET current source should be trimmed for optimum transient performance. The case of the SSM-2210 should be connected to  $V_{-}$ , and decoupled to ground with a  $0.1\mu F$  capacitor. Compensation for the SSM-2131's input capacitance is provided by  $C_C$ . The circuit may be operated at any gain, in the usual op amp configurations.

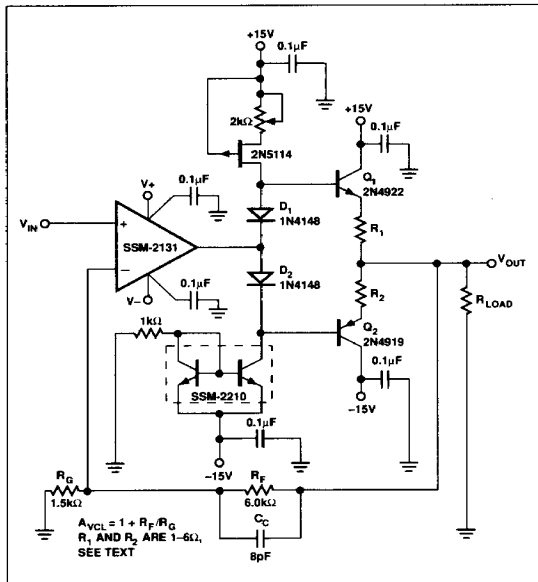


FIGURE 10: High-Current Output Buffer

## DRIVING CAPACITIVE LOADS

Best performance will always be achieved by minimizing input and load capacitances around any high-speed amplifier. However, the SSM-2131 is guaranteed capable of driving a  $100pF$  capacitive load over its full operating temperature range while

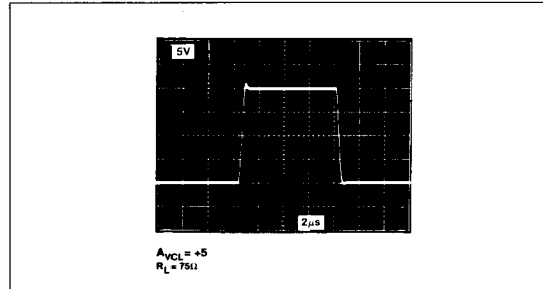


FIGURE 11: Output Buffer Large-Signal Response

operating at any gain including unity. Typically, an SSM-2131 will drive more than  $250pF$  at any temperature. Supply decoupling does affect capacitive load driving ability. Extra care should be given to ensure good decoupling when driving capacitive loads; between  $1\mu F$  and  $10\mu F$  should be placed on each supply rail.

Large capacitive loads may be driven utilizing the circuit shown in Figure 12.  $R_1$  and  $C_1$  introduce a small amount of feedforward compensation around the amplifier to counteract the phase lag induced by the output impedance and load capacitance. At DC and low frequencies,  $R_1$  is contained within the feedback loop. At higher frequencies, feedforward compensation becomes increasingly dominant, and  $R_1$ 's effect on output impedance will become more noticeable.

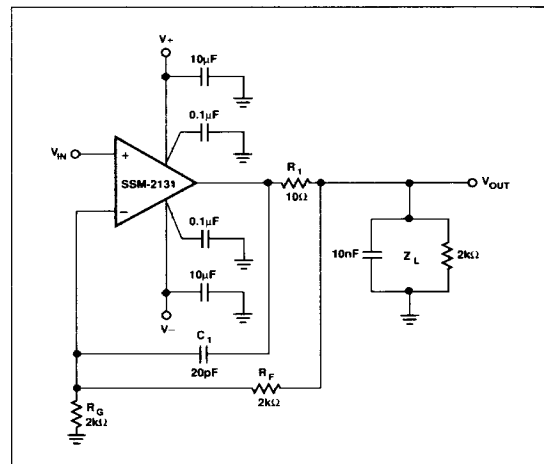


FIGURE 12: Compensation for Large Capacitive Loads

## SSM-2131

When driving very large capacitances, slew rate will be limited by the short-circuit current limit. Although the unloaded slew rate is insensitive to variations in temperature, the output current limit has a negative temperature coefficient, and is asymmetrical with regards to sourcing and sinking current. Therefore, slew rate into excessive capacitances will decrease with increasing temperature, and will lose symmetry.

### DAC OUTPUT AMPLIFIER

The SSM-2131 is an excellent choice for a DAC output amplifier, since its high speed and fast settling-time allow quick transitions between codes, even for full-scale changes in output level. The DAC output capacitance appears at the operational amplifier inputs, and must be compensated to ensure optimal settling speed. Compensation is achieved with capacitor C in Figure 13. C must be adjusted to account for the DAC's output capacitance, the op amp's input capacitance, and any stray capacitance at the inputs. With a bipolar DAC, an additional shunt resistor may be used to optimize response. This technique is described in PMI's application AN-24.

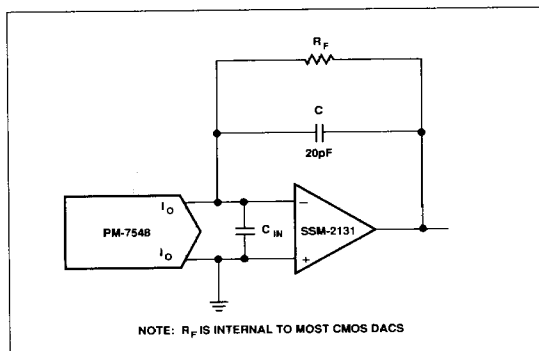


FIGURE 13: DAC Output Amplifier Circuit

Highest speed is achieved using bipolar DACs such as PMI's DAC-08, DAC-10 or DAC-312. The output capacitances of these converters are up to an order of magnitude lower than their CMOS counterparts, resulting in substantially faster settling-times. The high output impedance of bipolar DACs allows the output amplifier to operate in a true current-to-voltage mode, with a noise gain of unity, thereby retaining the amplifier's full bandwidth. Offset voltage has minimal effect on linearity with bipolar converters.

CMOS digital-to-analog converters have higher output capacitances and lower output resistances than bipolar DACs. This results in slower settling-times, higher sensitivity to offset voltages and a reduction in the output amplifier's bandwidth. These trade-offs must be balanced against the CMOS DAC's advantages in terms of interfacing capability, power dissipation, accuracy levels and cost. Using the internal feedback resistor which is present on most CMOS converters, the gain applied to offset voltage varies between 4/3 and 2, depending upon output code. Contributions to linearity error will be as much as  $2/3 V_{OS}$ . In a 10-volt 12-bit system, this may add up to an additional  $1/5LSB$  DNL with

the SSM-2131. Amplifier bandwidth is reduced by the same gain factor applied to offset voltage, however the SSM-2131's 10MHz gain-bandwidth product results in no reduction of the CMOS converter's multiplying bandwidth.

Individual DAC data sheets should be consulted for more complete descriptions of the converters and their circuit applications.

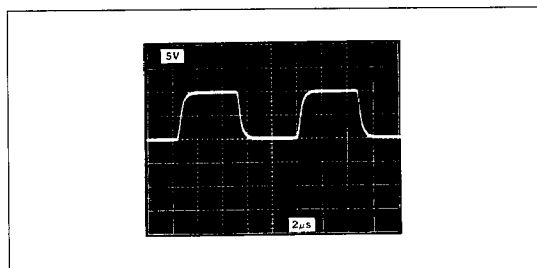


FIGURE 14: DAC Output Amplifier Response (PM-7545 DAC)

### COMPUTER SIMULATIONS

The following pages show the SPICE macro-model for the SSM-2131 high-speed audio operational amplifier. This model was tested with, and is compatible with PSpice\* and HSPICE\*\*. The schematic and net-list are included here so that the model can easily be used. This model can accommodate multiple frequency poles and multiple zeroes, which is an advanced concept that results in more accurate AC and transient responses necessary for simulating the behavior of today's high-speed op amps. For example, 8 poles and 2 zeroes are required to sufficiently simulate the SSM-2131, which this advanced model can easily accommodate.

Throughout the SSM-2131 macro-model, RC networks produce the multiple poles and zeroes which simulate the SSM-2131's AC behavior. Each stage contains a pole or a pole-zero pair. The stages are separated from each other by voltage-controlled current sources so that the poles and zero locations do not interact. The only nonlinear elements in the entire model are two p-channel JFETs which comprise the input stage. Limiting the model to almost entirely linear circuit elements significantly reduces simulation time and simplifies model development.

\*PSpice is a registered trademark of MicroSim Corporation.

\*\*HSPICE is a trademark of Meta-Software, Inc.

## SSM-2131 MACRO-MODEL © PMI 1989

\* subckt SSM-2131 1 2 32 99 50

\* INPUT STAGE &amp; POLE AT 15.9 MHz

```

r1 1 3 5E11
r2 2 3 5E11
r3 5 50 707.36
r4 6 50 707.36
cin 1 2 5E-12
c2 5 6 7.08E-12
i1 99 4 1E-3
ios 1 2 4E-12
eos 7 1 poly(1) 20 26 1E-3 1
j1 5 2 4 jx
j2 6 7 4 jx

```

\* SECOND STAGE &amp; POLE AT 45 Hz

```

r5 9 99 176.84E6
r6 9 50 176.84E6
c3 9 99 20E-12
c4 9 50 20E-12
g1 99 9 poly(1) 5 6 3.96E-3 1.4137E-3
g2 9 50 poly(1) 6 5 3.96E-3 1.4137E-3
v2 99 8 2.5
v3 10 50 3.1
d1 9 8 dx
d2 10 9 dx

```

\* POLE-ZERO PAIR AT 1.80 MHz/2.20 MHz

```

r7 11 99 1E6
r8 11 50 1E6
r9 11 12 4.5E6
r10 11 13 4.5E6
c5 12 99 16.1E-15
c6 13 50 16.1E-15
g3 99 11 9 26 1E-6
g4 11 50 26 9 1E-6

```

\* POLE-ZERO PAIR AT 1.80 MHz/2.20 MHz

```

r11 14 99 1E6
r12 14 50 1E6
r13 14 15 4.5E6
r14 14 16 4.5E6
c7 15 99 16.1E-15
c8 16 50 16.1E-15
g5 99 14 11 26 1E-6
g6 14 50 26 11 1E-6

```

\* POLE AT 53 MHz

```

r15 17 99 1E6
r16 17 50 1E6
c9 17 99 3E-15
c10 17 50 3E-15
g7 99 17 14 26 1E-6
g8 17 50 26 14 1E-6

```

\* POLE AT 53 MHz

```

r17 18 99 1E6
r18 18 50 1E6
c11 18 99 3E-15
c12 18 50 3E-15
g9 99 18 17 26 1E-6
g10 18 50 26 17 1E-6

```

\* POLE AT 53 MHz

```

r19 19 99 1E6
r20 19 50 1E6
c13 19 99 3E-15
c14 19 50 3E-15
g11 99 19 18 26 1E-6
g12 19 50 26 18 1E-6

```

\* COMMON-MODE GAIN NETWORK WITH ZERO AT 100 kHz

```

r21 20 21 1E6
r22 20 23 1E6
i1 21 99 1.5915
i2 23 50 1.5915
g13 99 20 3 26 1E-11
g14 20 50 26 3 1E-11

```

\* POLE AT 79.6 MHz

```

r24 25 99 1E6
r25 25 50 1E6
c15 25 99 2E-15
c16 25 50 2E-15
g15 99 25 19 26 1E-6
g16 25 50 26 19 1E-6

```

\* OUTPUT STAGE

```

r26 26 99 111.1E3
r27 26 50 111.1E3
r28 27 99 90
r29 27 50 90
i3 27 32 2.5E-7
g17 30 50 25 27 11.1111E-3
g18 31 50 27 25 11.1111E-3
g19 27 99 99 25 11.1111E-3
g20 50 27 25 50 11.1111E-3
v6 28 27 0.7
v7 27 29 0.7
d5 25 28 dx
d6 29 25 dx
d7 99 30 dx
d8 99 31 dx
d9 50 30 dy
d10 50 31 dy

```

\* MODELS USED

```

*model jx PJF(BETA=999.3E-6 VTO=-2.000 IS=4E-11)
*model dx D(IS=1E-15)
*model dy D(IS=1E-15 BV=50)
*ends SSM-2131

```

