National Semiconductor

DAC1285A, DAC1285 (DAC85, DAC87) 12-Bit Digital-to-Analog Converters

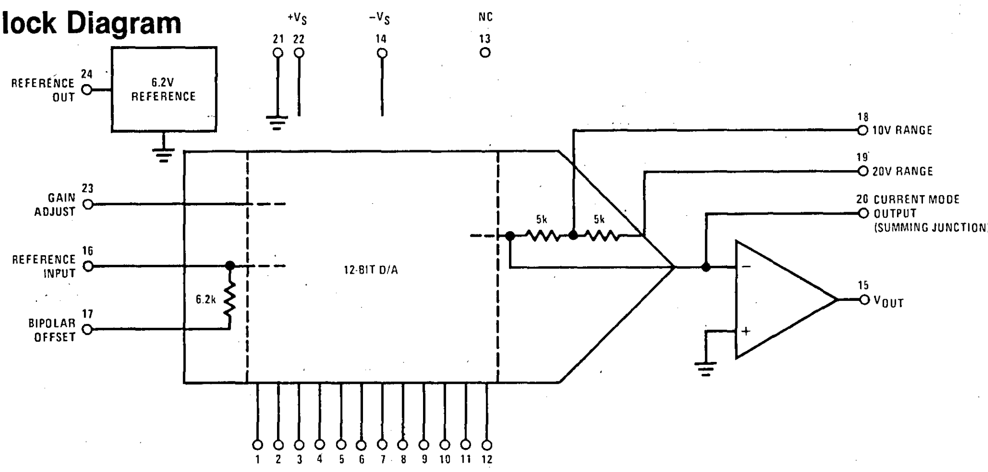
General Description

The DAC1285 series is a family of precision, low cost, fully self-contained digital-to-analog converters. The devices include 12 precision current switches, a 12-bit thin film resistor network, output amplifier, buffered internal reference, and several precision resistors, which allow the user to tailor his system needs to accommodate a variety of bipolar and unipolar output voltage and current ranges. Logic inputs are TTL, DTL and CMOS compatible, and are complementary binary (CBI) format. In all instances, a logic low (≤0.8V) turns a given bit ON, and a logic high (≥2V) turns a given bit OFF. Internally supplied resistor options provide low drift bipolar output voltage ranges of ±2.5V, ±5V, ±10V, and unipolar ranges of 0V to 5V or 0V to 10V. Current mode output is 0 mA to 2 mA.

Features

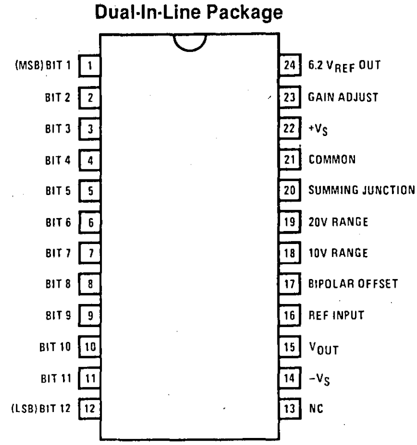
- Completely self-contained with internal reference and output amplifier
- High reliability exact replacement for DAC85-CBI-V, DAC85LD-CBI-V, and DAC87-CBI-V
- ±1/2 LSB linearity max over temperature range
- ±2.5V, ±5V, ±10V, 0V to 5V, 0V to 10V voltage outputs
- 0 mA to 2 mA current output
- Fast settling time: 300 ns current mode; 2.5 μs voltage mode
- Hermetic 24-pin IC package
- Low cost
- TTL CMOS compatible binary input logic over temperature
- Parameters guaranteed over operating temperature range −25°C to +85°C or −55°C to +125°C

Block Diagram



Connection Diagram

Dual-In-Line Package



Order Number
DAC1285ACD, DAC85LD-CB1-V,
DAC1285HCD, DAC85-CB1-V,
DAC1285AD, DAC87-CB1-V
See NS Package D24G

Absolute Maximum Ratings

Supply Voltage (V^+ and V^-)	± 18V
Current Output (Pin 20) Compliance	± 10V
Logic Input Voltage	− 0.7V, 10V
Reference Input Voltage (V_{REF})	0V, 18V
Short-Circuit Duration (Pins 15, 20 and 24)	Continuous
Operating Temperature Range	
DAC1285A	− 55°C to + 125°C
DAC1285AC	− 25°C to + 85°C
DAC1285HC	− 25°C to + 85°C
Storage Temperature Range	− 65°C to + 150°C
Lead Temperature (Soldering, 10 seconds)	300°C

Electrical Characteristics

T_A = − 55°C to + 125°C for DAC1285A and − 25°C to + 85°C for DAC1285AC and DAC1285HC, V_S = ± 11.4V to ± 15.75V for DAC1285A and DAC1285AC and V_S = ± 15V for DAC1285HC unless otherwise noted.

Parameter	Conditions	DAC1285A			DAC1285AC			DAC1285HC			Units
		Min	Typ (Note 1)	Max	Min	Typ (Note 1)	Max	Min	Typ (Note 1)	Max	
CONVERTER CHARACTERISTICS											
Resolution		12			12			12			Bits
Linearity Error	T_A = 25°C		± 1/4	± 1/2		± 1/4	± 1/2		± 1/4	± 1/2	LSB
				± 3/4			± 1/2			± 1/2	
Differential Non-Linearity	T_A = 25°C		± 1/2	± 3/4		± 1/2			± 1/2		
				± 1							
Monotonicity		12			12			12			Bits
Full-Scale (Gain) Error	T_A = 25°C (Note 2)		± 0.1	± 0.2		± 0.1			± 0.1		% FSR (Note 3)
Zero-Scale (Offset) Error	T_A = 25°C (Note 2)		± 0.02	± 0.1		± 0.02			± 0.02		
Full-Scale (Gain) Tempco	With Internal Reference		± 10	± 20		± 10			± 15	± 30	ppm/°C
	Without Internal Reference		± 5	± 10		± 5	± 10		± 5	± 20	
Zero-Scale (Offset) Tempco	Unipolar		± 1	± 3		± 1			± 1		ppm FSR/°C
	Bipolar		± 3	± 10		± 3	± 5		± 3	± 10	
Total Bipolar Tempco (Note 4)	Includes Gain, Offset, and Linearity		± 10	± 30		± 10			± 10		
Total Error (Note 5)	Unipolar		± 0.08	± 0.3		± 0.08			± 0.08		% FSR
	Bipolar		± 0.06	± 0.24		± 0.06			± 0.06		
Output Voltage Range	Using Internally Supplied Resistors (Note 6)	± 2.5V, ± 5V, ± 10V, 0V to 5V, 0V to 10V									V
Output Voltage Swing	R_L ≥ 5 kΩ, Pin 15	± 10			± 10			± 10			
Output Short Circuit Current	Pin 15	± 5	± 25	± 50	± 5	± 25	± 50	± 5	± 25	± 50	mA
Output Impedance	Pin 15, Closed Loop		0.05			0.05			0.05		Ω
Current Mode Output Range	Unipolar, Pin 20		0 to − 2			0 to − 2			0 to − 2		mA
	Bipolar, Pin 20		± 1.0			± 1.0			± 1.0		
Current Mode Compliance				± 2.5			± 2.5			± 2.5	V
Current Mode Output Impedance	Unipolar		2			2			2		kΩ
	Bipolar		1.5			1.5			1.5		
REFERENCE CHARACTERISTICS											
Reference Voltage	I_{REF} ≤ 2 mA, T_A = 25°C	6.07	6.2	6.33	6.07	6.2	6.33		6.2		V
Tempco of Drift			± 5	± 10		± 10	± 20		± 10	± 20	ppm/°C
External Use Current				2.5			2.5			2.5	mA
Output Impedance			0.05	1.0		0.05	1.0		0.05	1.0	Ω

Electrical Characteristics (Continued)

$T_A = -55°C$ to $+125°C$ for DAC1285A and $-25°C$ to $+85°C$ for DAC1285AC and DAC1285HC, $V_S = \pm 11.4V$ to $\pm 15.75V$ for DAC1285A and DAC1285AC and $V_S = \pm 15V$ for DAC1285HC unless otherwise noted.

Parameter	Conditions	DAC1285A, DAC1285AC			DAC1285HC			Units
		Min	Typ (Note 1)	Max	Min	Typ (Note 1)	Max	
DIGITAL AND DC CHARACTERISTICS								
Logic "1" Input Voltage (Bit OFF)		2.0			2.0			V
Logic "0" Input Voltage (Bit ON)				0.8			0.8	V
Logic "1" Input Current	$V_{IN} = 2.5V$		0.05	1		0.05	1	µA
Logic "0" Input Current	$V_{IN} = 0V$			−100			−100	µA
Power Supply Current	I^+, $T_A = 25°C$		10	18		10		mA
	I^-, $T_A = 25°C$		25	30		25		mA
Power Supply Sensitivity			0.001	0.002		0.001		% FSR/%V
AC CHARACTERISTICS								
Voltage Mode Settling Time	1 LSB Change		400			400		ns
	FSR Change 10V		2.5			2.5		µs
	FSR Change 20V		4			4		µs
Voltage Mode Slew Rate	$T_A = 25°C$	10	30			30		V/µs
Current Mode Settling Time	10Ω to 100Ω Load		300			300		ns

Note 1: All typical values are for $T_A = 25°C$.

Note 2: Externally adjustable to zero.

Note 3: FSR means "full-scale range" and is 20V for ± 10V range, 10V for ± 5V, etc.

Note 4: See paragraph 2.0 for definition.

Note 5: With gain and offset errors adjusted to zero at 25°C

Note 6: $\pm V_S$ must have absolute value 2V greater than V_{OUT}. Output voltage ranges −10V to +10V and 0V to +10V are not recommended with V_S less than ± 12V.

1.0 Definition of Terms

1.1 Accuracy

Accuracy of a D/A converter is the difference between the actual analog output that is measured when a given digital code is applied and the analog output that is expected with that code applied to the converter. Accuracy errors can be specified by the three parameters of gain or full-scale error, zero-scale or offset error, and linearity error.

1.2 Linearity Error

Linearity error is the maximum deviation from a *straight line passing through the endpoints of the DAC transfer characteristic.* It is measured after adjusting for zero and full-scale. Linearity error is a parameter intrinsic to the device and cannot be externally adjusted.

1.3 Differential Linearity Error and Monotonicity

Differential linearity error of a D/A converter is the deviation from an ideal 1 LSB voltage change from one adjacent output state to the next. A differential linearity error specification of ± 1/2 LSB means that the output voltage step sizes can range from 1/2 LSB to 3/2 LSB when the input changes from one adjacent input state to the next. 12-bit monotonicity is guaranteed to ensure that the analog output will not decrease with increasing input digital codes.

1.4 Gain Tempco

Gain tempco is a measure of the change in the full-scale range output over temperature expressed in parts per million per °C (ppm/°C).

1.5 Offset Tempco

Offset tempco is a measure of the actual change in output with all "1"s on the input over the specified temperature range. The offset is measured at low and high temperature. The maximum change in offset is referenced to the offset at 25°C and is divided by the temperature range. This offset change is expressed in parts per million of full-scale range per °C (ppm of FSR/°C).

1.6 Settling Time

Settling time for each DAC1285 series part is the total time (including slew time) required for the output to settle within an error band around its final value after a change in input *(Figures 1 and 2).*

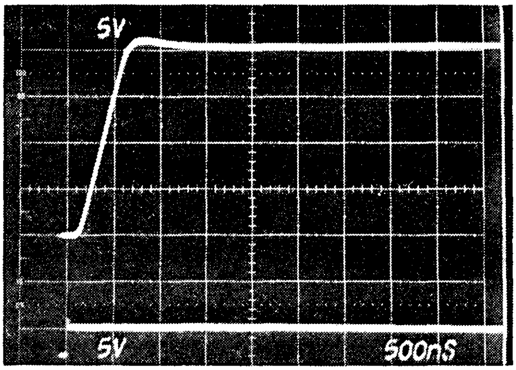


FIGURE 1. Voltage Mode Settling Time-FSR Change

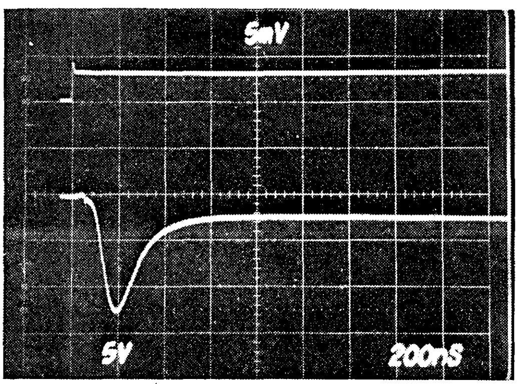


FIGURE 2. Voltage Mode Settling Time-1 LSB Change

Voltage Output. Three settling times are specified to ±0.01% of full-scale range (FSR); two for maximum full-scale range changes of 20V, 10V and one for a 1 LSB change. The 1 LSB change is measured at the major carry (0111...11 to 1000...00), the point at which the worst case settling time occurs.

Current Output. Settling time is specified to ±0.01% of FSR. This is given with a range of resistive loads: 10Ω to 100Ω.

1.7 Compliance

Compliance voltage is the maximum voltage swing allowed on the current output pin (pin 20). Note that the absolute current offset error with any DAC will be increased by an amount given by V_{OUT}/R_{OUT}. In many situations this will be a significant error term if the voltage on the current output pin is allowed to exceed a few millivolts.

1.8 Power Supply Sensitivity

Power supply sensitivity is a measure of the effect of a power supply change on the D/A converter output. It is defined as a percent of FSR per percent of change in either the positive, negative, or logic supplies about the nominal power supply voltages.

1.9 Reference Supply

The DAC1285 series are supplied with an internal 6.2V reference voltage supply. This voltage (pin 24) is accurate to ±2% and must be connected to the Reference Input (pin 16) for specified operation. This reference may also be used externally with external current drain limited to 2.5 mA. All gain adjustments should be made under constant load conditions.

2.0 Analyzing Device Accuracy Over the Temperature Range

For the purposes of temperature drift analysis, the major device components are shown in *Figure 3.* The reference element and buffer amplifier drifts are combined to give the total reference temperature coefficient, which is specified as a maximum. The input reference current to the DAC, I_{REF}, is developed from the internal reference and will show the same drift rate as the reference voltage. The DAC output current, I_{DAC}, which is a function of the digital input code, is designed to track I_{REF}; if there is a slight mismatch in these currents over temperature, it will contribute to the gain TC. The bipolar offset resistor, R_{BP}, and gain setting resistor, R_{GAIN}, also have temperature coefficients which contribute to system drift errors. The input offset voltage drift of the output amplifier, OA, also contributes a small error.

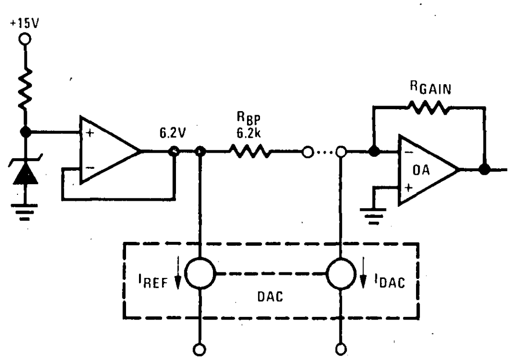


FIGURE 3. Bipolar Configuration

There are three types of drift errors over temperature: offset, gain, and linearity. Offset drift causes a vertical translation of the entire transfer curve; gain drift is a change in the slope of the curve; and linearity drift represents a change in the shape of the curve. The combination of these three drifts results in the complete specification for total error over temperature.

Total error is defined as the deviation from a true straight line transfer characteristic from exactly zero at a digital input which calls for zero output to a point which is defined as full-scale. A specification for total error over temperature assumes that both the zero and full-scale points have been trimmed for zero error at 25°C. Total error is normally expressed as a percentage of the full-scale range. In the bipolar situation, this means the total range from $-V_{FS}$ to $+V_{FS}$.

2.1 Monotonicity and Linearity

The initial linearity error and the differential linearity error guarantee monotonic performance over the operating temperature range. It can therefore be assumed that linearity errors are insignificant in computation of total temperature errors.

2.2 Unipolar Errors

Temperature error analysis in the unipolar mode is straightforward: there is an offset drift and a gain drift. The offset drift, which comes from leakage currents and drift in the output amplifier, causes a linear shift in the transfer curve as shown in *Figure 4*. The gain drift causes a change in the slope of the curve and results from reference drift, DAC drift, and drift in R_{GAIN} relative to the DAC resistors.

2.3 Bipolar Range Errors

The analysis is slightly more complex in the bipolar mode. In this mode R_{BP} is connected to the summing node of the output amplifier (see *Figure 3*) to generate a current which exactly balances the current of the MSB so that the output voltage is zero with only the MSB on.

Note that if the DAC and application resistors track perfectly, the bipolar offset drift will be zero even if the reference drifts. A change in the reference voltage, which causes a shift in the bipolar offset, will also cause an equivalent change in I_{REF} and thus I_{DAC}, so that I_{DAC} will always be exactly balanced by I_{BP} with the MSB turned on. This effect is shown in *Figure 6*. The net effect of the reference drift then is simply to cause a rotation in the transfer around bipolar zero. However, consideration of second order effects (which are often overlooked) reveals the errors in the bipolar mode. The unipolar offset drifts discussed before will have the same effect on the bipolar offset. A mismatch of R_{BP} to the DAC resistors is usually the largest component of bipolar drift. Gain drift in the DAC also contributes to bipolar offset drift, as well as full-scale drift. In the bipolar ranges, full-scale is defined as the total range from $-V_{FS}$ to $+V_{FS}$.

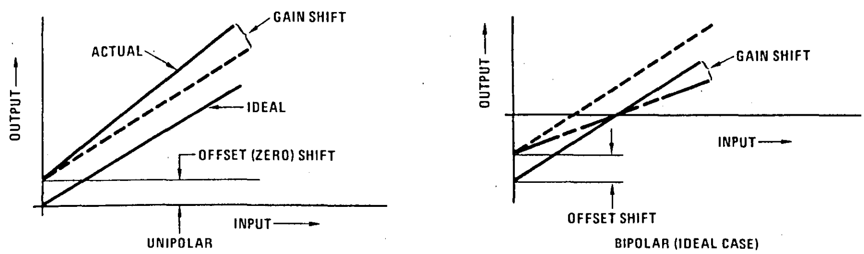
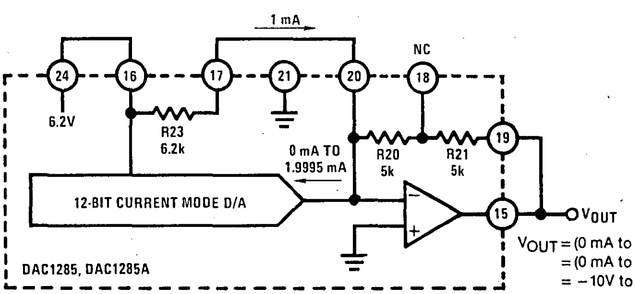
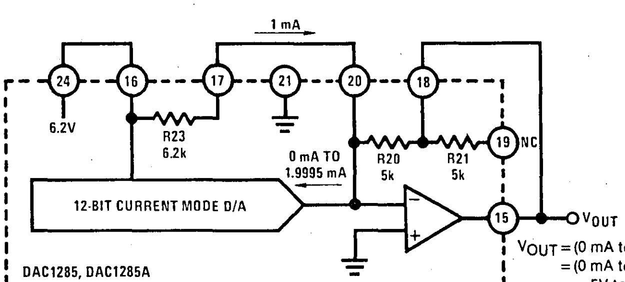


FIGURE 4. Unipolar and Bipolar Drifts



V_{OUT} = (0 mA to 1.9995 mA) (R20 + R21)-(6.2V/R23) (R21 + R22)
= (0 mA to 1.9995 mA) (10k)-(1 mA) (10k)
= −10V to +9.995V
1 LSB = 20V/4096 = 4.88 mV

FIGURE 5. ±10V Bipolar Operation



V_{OUT} = (0 mA to 1.9995 mA) (R20)-(R20/R23) (6.2V)
= (0 mA to 1.9995 mA) (5k)-(5k/6.2k) (6.2V)
= −5V to 4.9975V
1 LSB = 10V/4096 = 2.44 mV

FIGURE 6. ±5V Bipolar Operation

3.0 Applications and Functional Description

3.1 Voltage Mode Operation

These D/As provide internal scaling resistors which permit a wide range of bipolar and unipolar output configurations. Bipolar output formats of ± 2.5V, ± 5V, ± 10V and unipolar formats of 0V to 5V and 0V to 10V are possible using resistor strap options included within the device. Table I and *Figures 5, 6 and 7* summarize the proper pin connections required for these formats.

3.2 Current Mode Operation

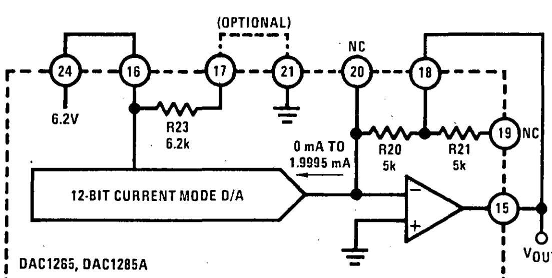
Current mode applications which make use of an external op amp, comparator, or a resistive load are possible with the DAC1285 series using pin 20. When an external op amp is used, the internal scaling resistors should be utilized to minimize full-scale drift. Configurations shown in Table I apply directly. *Figure 8* shows one application using an external fast operational amplifier.

Current mode operation into a resistive load or open circuit must account for the DACs nominal output resistance of 2k at pin 20. With this in mind, the output will swing 0V to − 4V open circuit and about − 1.5V to + 1.5V with the bipolar offset resistor connected. An external load resistor may be used as part of the load, but there will be an error due to temperature coefficients mistracking.

TABLE I. Output Voltage/Current Ranges for DAC1285 Series

Output Range	Digital Input Code	Connect Pin 15 to	Connect Pin 16 to	Connect Pin 17 to	Connect Pin 19 to
± 10V	Complementary Offset Binary	19	24	20	15
± 5V	Complementary Offset Binary	18	24	20	NC
± 2.5V	Complementary Offset Binary	18	24	20	20
10V	Complementary Binary	18	24	21*	NC
5V	Complementary Binary	18	24	21*	20
± 1 mA	Complementary Offset Binary	NC	24	20	NC
− 2 mA	Complementary Binary	NC	24	21*	NC

* Optional, no connection necessary



V_{OUT} = (0 mA to 1.9995 mA) (R20)
= (0 mA to 1.9995 mA) (5k)
= 0V to 9.9976V
1 LSB = 2.44 mV

FIGURE 7. 10V Unipolar Operation

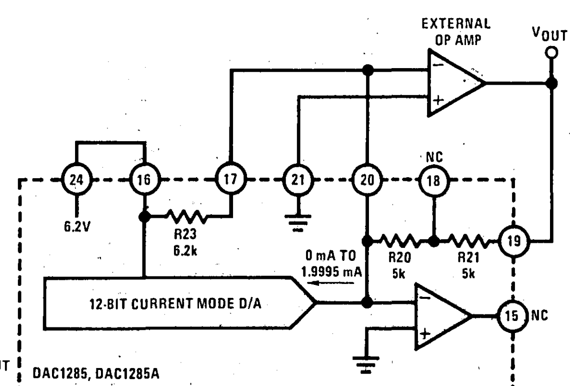


FIGURE 8. ± 10V Bipolar Operation with External Operational Amplifier

3.3 Offset and Full-Scale Adjust

The DAC1285 series may be offset and full-scale adjusted using the circuit shown in *Figure 9*. Offset voltage should be adjusted first. A logic "1" (≥2V) should be applied to all logic inputs. In bipolar mode, the offset is adjusted to equal minus full-scale. In unipolar mode, the offset is adjusted to read 0V at the output. Full-scale is then adjusted by applying a logic "0" (≤0.8V) to all inputs for operation. The range of R1 and R2 shown in *Figure 9* is approximately ±0.2% of full-scale for the values shown.

A 30 second "warm-up" period should be allowed (after power turn-on) before making the above adjustments.

3.4 Logic Input Coding

The logic inputs to the DAC1285 series are complementary; i.e., a given bit is turned ON by an active low input. Table II summarizes input status for unipolar and bipolar codes.

3.5 Reference Supply

The DAC1285 series is supplied with an internal 6.2V reference regulator (pin 24). In order to obtain the specified unadjusted performance, the reference output (pin 24) should be connected to the reference input (pin 16). An external reference voltage may be used with the DAC1285 series if provision is made to calibrate full-scale as shown in *Figure 9*. Since the reference is buffered, it may be used externally at currents up to 2.5 mA.

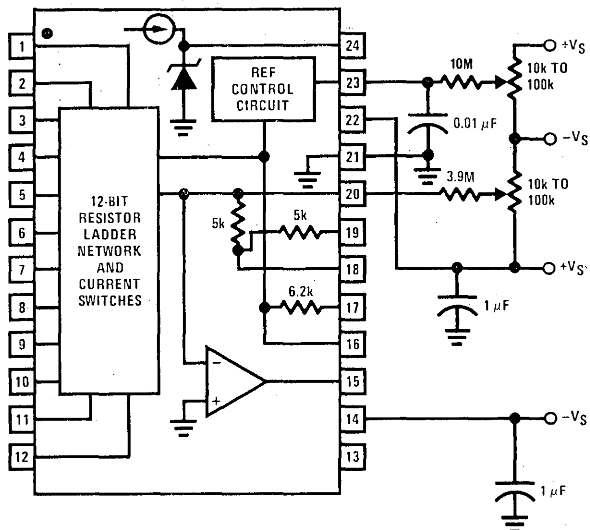


FIGURE 9. External Adjustment and Voltage Supply Connection Diagram

TABLE II

Code Type	Input Code (Note 7) MSB … LSB	Output State	Unipolar Output Ranges: 0V to 10V	0V to 5V	0 mA-2 mA / 0 mA-1.25 mA
Unipolar	0 0 0 0 0 0 0 0 0 0 0 0	Full-Scale	9.9976V	4.9988V	−1.9995 mA
Complementary	1 1 1 1 1 1 1 1 1 1 1 0	1 LSB ON	0.0024V	0.0012V	−0.0005 mA
Binary	1 1 1 1 1 1 1 1 1 1 1 1	Zero-Scale	0.0000V	0.0000V	0.0000 mA

Code Type	Input Code (Note 7) MSB … LSB	Output State	Bipolar Output Voltage Ranges: ±10V	±5V	±2.5V	±1 mA
Bipolar	0 0 0 0 0 0 0 0 0 0 0 0	Full-Scale	9.9951V	4.9976V	2.4988V	−0.9995 mA
Complementary	0 1 1 1 1 1 1 1 1 1 1 1	Half-Scale	0.0000V	0.0000V	0.0000V	0.0000 mA
Binary	1 1 1 1 1 1 1 1 1 1 1 0	1 LSB ON	−9.9951V	−4.9976V	−2.4988V	0.9995 mA
	1 1 1 1 1 1 1 1 1 1 1 1	Zero-Scale	−10.0000V	−5.0000V	−2.5000V	1.0000 mA

Note 7: Logic input sense is such that an active low (V_{IN}≤0.8V) turns a given bit ON and is represented as a logic "0" in the table.

3.6 Logic Input Compatibility

The design of the current mode switches in the DAC1285 series gives the device true TTL compatibility. It is TTL compatible over the entire operating temperature range and is independent of the reference voltage and V_{CC}. Furthermore, since the input breakdown ratings are in excess of 10V, the DAC1285 series may be driven directly from high (or low) voltage CMOS.

3.7 ±12 Volt Supply Operation

These DACs will operate with supply voltages as low as ±11.4V. It is recommended that output voltage ranges −10V to +10V and 0V to 10V not be used if the supply voltages are ever less than the recommended ±12V. The output amplifier may saturate if $|V_{SUPPLY}| - |V_{OUT}$ maximum$| < 2.0V$.

3.8 Power Supply Connections

For optimum performance power supply decoupling capacitors should be added as shown in the connection diagrams *(Figure 9)*. These capacitors (1 μF electrolytic recommended) should be located close to the device. Electrolytic capacitors, if used, should be paralleled with 0.01 μF ceramic capacitors for optimum high frequency performance.

Ordering Information

Part Number	Temperature Range	Package
DAC1285ACD DAC85LD-CBI-V	−25°C to +85°C	D24G
DAC1285HCD DAC85-CBI-V	−25°C to +85°C	D24G
DAC1285AD DAC87-CBI-V	−55°C to +125°C	D24G

*Devices may be ordered by either part number.