Single Supply Operation of the DAC0800 and DAC0802

National Semiconductor
Application Note 1525
Nick Gray
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1.0 Executive Summary

The ADC0800 and the ADC0802 are versatile 4 quadrant multiplying DACs (Digital-to-Analog Converters) with a current reference and complementary current outputs. The data sheet indicates a need for bipolar (positive and negative) power supply voltages, but a consideration of relative potentials allows these DACs to be used with positive only supplies, to include a single positive supply. This application note develops the positive only bias voltages needed to successfully operate the ADC0800 and the DAC0802 with a single supply voltage. The principles here also apply to the DAC0808, which is a two quadrant multiplying DAC with a single output.

The DAC0800 is functionally equivalent to the industry standard DAC-08 and the DAC0802 is equivalent to the industry standard DAC-08A. The DAC0808 is functionally equivalent to the industry standard MC1408.

Product Applicability:

DAC0800

DAC0802

DAC0808

2.0 Overview

The DAC0800, the DAC0802 and the DAC0808 seem to suffer from the apparent need for bipolar supplies. But, by setting the negative supply to ground and shifting all other voltages up by 5 Volts, these DACs will behave normally without a negative supply. The requirement is that all of the voltages associated with the DAC are correct relative to each other, and that the proper current levels are maintained.

This application note does not discuss the operation or specifications of the DACs to which this document applies. See the product data sheet for information relating to the operation of the product in question.

Reference to the DAC0800 herein also includes the DAC0802, which is just a more accurate version of the DAC0800. The principles here apply equally well to the DAC0808, except that pin 2 of the DAC0808 is normally ground rather than an output.

3.0 General Biasing Requirements

As long as the relative voltages are correct, the DAC0800 will behave normally. With this in mind, the potentials around the DAC0800 can be modified as indicated in *Table 1*.

The positive supply voltage, V+ at pin 13, must be at least 10V and no more than 30V more positive than V- at pin 3 for proper operation.

There will be no change to the capacitor connection to pin 16, but it should be noted that this capacitor should be connected directly to pin 3, then this connection should be connected to the negative supply voltage or grounded.

Pin 1, the Logic Control pin, controls the logic threshold of the digital inputs. The logic threshold of the digital input is about 1.35V above this pin 1 potential at room temperature and varies linearly between about 1.7V at -55˚C and about 0.95V at 125˚C. The assumption throughout this application note is 5 Volt TTL logic levels.

TABLE 1. DAC0800 Voltages and Currents

Pin	Function	Normal V or I (or Range)	New V or I (or Range)
1	Logic Control	0V	+5V
2	$\overline{I_O}$	−10V to +18V	(V−) + 5V to +28V
3	V-	−15V to −5V	0V
4	I_O	−10V to +18V	(V−) +5 to +28
5	B1 (MSB)	0V to 0.8V (logic low)	5.0V to 5.8V (logic low)
6	B2		
7	B3		
8	B4		
9	B5	2.4V to V+ (logic high)	7.4V to V+ (logic high)
10	B6		
11	B7		
12	B8 (LSB)		
13	V+	+5V to +15V	0V to +20V
14	REF+	200 µA to 4 mA	200 µA to 4 mA
15	REF-	0V thru R	+5V thru R
16	COMP	cap	cap

The general circuit for the DAC0800 is as shown in *Figure 1*.

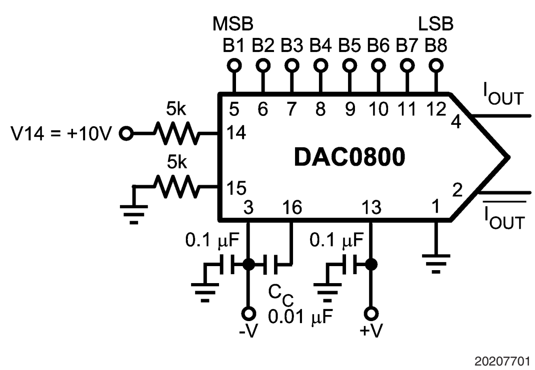

FIGURE 1. General Circuit for the DAC0800

The requirements for reference pins 14 and 15 are that they be at least 5 Volts above the negative supply pin 3, that the resistance in series with these two pins be of equal value and that the value of these two resistors be (V14 - V15) / I_{REF}, where V14 and V15 are the potentials to which the resistors at pins 14 and 15 are returned and I_{REF} is the

3.0 General Biasing Requirements
(Continued)

reference current required and is equal to the value of the maximum output currents at pins 4 and 2. The total of these two output currents is always equal to

$$I_{OUT} + \overline{I_{OUT}} = (2^n - 1)\ I_{REF} / 2^n$$

For 8 bits this becomes

$$I_{OUT} + \overline{I_{OUT}} = 255\ I_{REF} / 256$$

I_{OUT} increases with an increase in the digital code and/or the reference current and $\overline{I_{OUT}}$ decreases with an increase in the digital code and/or the reference current.

We see from *Figure 1* that

$$I_{REF} = (V14 - V15) / 5k$$

$$I_{REF} = (10V - 0V) / 5k = 2\ mA$$

4.0 Unipolar Supply Modification

Again, if we consider the relative circuit potentials and maintain proper current levels, we can make whatever circuit changes we need.

4.1 REFERENCE CONSIDERATIONS

The modified circuit is as shown in *Figure 2*. Here we find that

$$I_{REF} = (V14 - V15) / 2.49k$$

$$I_{REF} = (10V - 5V) / 2.49k = 2.008\ mA$$

and we have about the same reference current as for the general case.

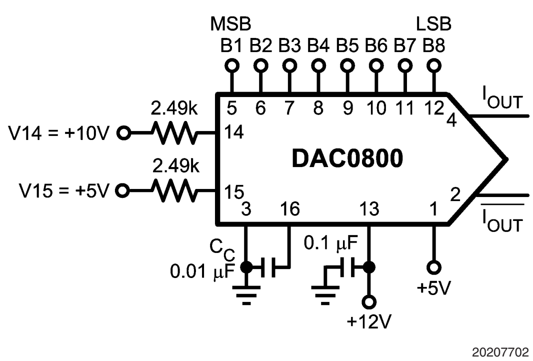

FIGURE 2. Positive only supply circuit for the DAC0800

4.2 OUTPUT BIASING

Another requirement of the DAC0800 is that output pins 2 and 4 must always be at least 5 V more positive than the potential at pin 3. Since pin 3 is grounded, these output pins must never go below +5V. The +28V maximum output voltage indicated in *Table 1* comes from the maximum voltage with respect to pin 3 that the output transistors can withstand without excessive leakage or breakdown.

4.3 INPUT LEVEL THRESHOLD

The logic inputs need to be level shifted up by 5V. This can be done with two resistors at each logic input pin, as shown in *Figure 3*.

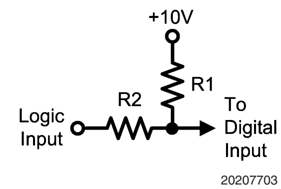

FIGURE 3. Simple digital input level shifting circuit

For driving with 5V TTL devices, R1 and R2 of *Figure 3* are 2.65k and 3.3k, respectively. For driving with 3.3V TTL devices, R1 and R2 are 3.48k and 4.75k, respectively. These resistance values would change for bias voltages other than the +10V shown in *Figure 3*. If the bias voltage is +12V, R1 and R2 of are 5.83k and 4.75k, respectively, for 5V TTL devices and 5.62k and 4.75k, respectively, for driving with 3.3V TTL devices.

Tolerance requirements of both the resistors and of the bias voltage is 1%, so it is best to use a reference source for the bias voltage.

4.4 OUTPUT CONSIDERATIONS

The DAC0800 has a current output. The data sheet indicates how to connect an amplifier to the outputs to derive a voltage output. Keep in mind that the DAC0800 outputs must never transition to a potential that is lower than 5V above its pin 3 voltage.

This means that an op-amp at the output must have its non-inverting input returned to a voltage that is it least +5 Volts, leading to a minimum op-amp output of +5V. In some cases this may be acceptable, but in most cases it is much more desirable to have a minimum output voltage of zero volts.

This minimum zero volts output can be obtained by adding a Zener diode in series with the output to subtract the bias potential from the output, but a Zener diode generally has a large tolerance and a large temperature coefficient. Using an LM4040-5.0 in place of a Zener will provide the same subtraction function, but with a lot better tolerance and lower temperature drift. An example circuit, where the DAC0800 output bias is 5V, is shown in *Figure 4*.

4.0 Unipolar Supply Modification

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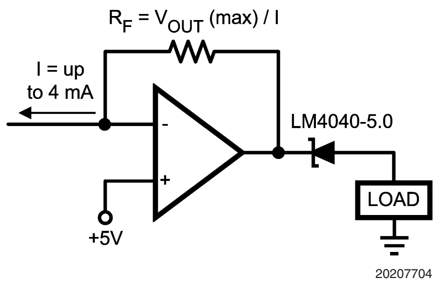

FIGURE 4. Current-to-voltage converter with offset correction.

There are two things to note about the circuit of *Figure 4*. The supply voltage should be more positive than the maximum amplifier output, even if a rail-to-rail output amplifier is used. Otherwise there could be linearity problems at and near full scale.

Second, the maximum current through the LM4040-5.0 is 15 mA, which limits the load current to that value.

The third thing is that the LM4040-5.0 should have a minimum current of 100 µA at all times if it is to reliably subtract 5V from the amplifier output. When the amplifier output is 5V, there is insufficient current through the LM4040-5.0, resulting in an inaccurate load voltage at low load currents. That is, the load voltage can not be reduced to zero at low load currents. The minimum voltage will be a function of the load impedance and the individual LM4040-5.0. For this reason, this circuit may not be practical for applications where the load current can be reduced to a value below 100 microamps.

4.5 COMPLETE CIRCUIT EXAMPLE

Figure 5 gives a complete positive supply circuit solution to provide an output range or 0 to 5V. The Op-amp is a rail-to-rail output type to minimize its output error at very low output voltages. The positive supply voltage for the op-amp should be greater than its maximum output voltage.

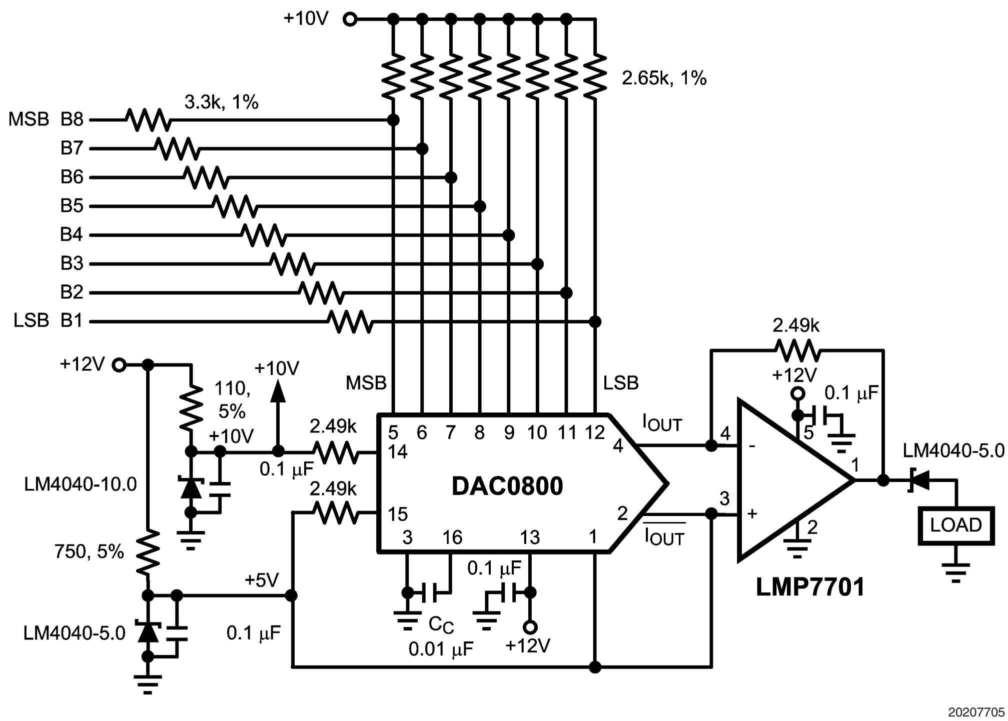

FIGURE 5. A complete single supply DAC0800 design with 0V to 5V output.

5.0 Summary

The DAC0800 is a versatile DAC that has found many uses. The perceived drawback has been its need for a negative supply. However, because the important thing for any electrical component is the relative potentials and correct currents, it is possible to come up with a method to eliminate the need for a negative supply.

Notes

National Semiconductor
Americas Customer
Support Center
Email: new.feedback@nsc.com
Tel: 1-800-272-9959

www.national.com

National Semiconductor
Europe Customer Support Center
Fax: +49 (0) 180-530 85 86
Email: europe.support@nsc.com
Deutsch Tel: +49 (0) 69 9508 6208
English Tel: +44 (0) 870 24 0 2171
Français Tel: +33 (0) 1 41 91 8790

National Semiconductor
Asia Pacific Customer
Support Center
Email: ap.support@nsc.com

National Semiconductor
Japan Customer Support Center
Fax: 81-3-5639-7507
Email: jpn.feedback@nsc.com
Tel: 81-3-5639-7560