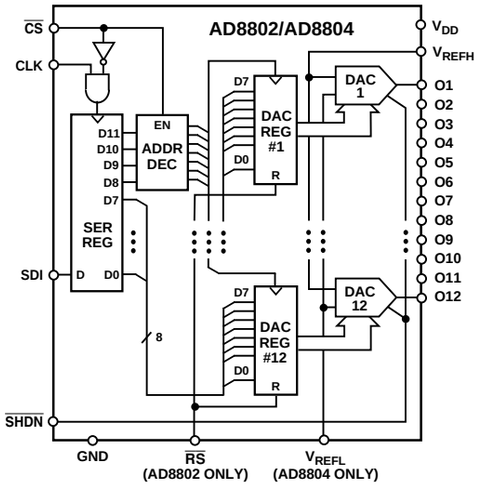
12 Channel, 8-Bit TrimDACs with Power Shutdown

AD8802/AD8804

FEATURES
Low Cost
Replaces 12 Potentiometers
Individually Programmable Outputs
3-Wire SPI Compatible Serial Input
Power Shutdown <55 μWatts Including I_{DD} & I_{REF}
Midscale Preset, AD8802
Separate V_{REFL} Range Setting, AD8804
+3 V to +5 V Single Supply Operation

APPLICATIONS
Automatic Adjustment
Trimmer Replacement
Video and Audio Equipment Gain and Offset Adjustment
Portable and Battery Operated Equipment

FUNCTIONAL BLOCK DIAGRAM



GENERAL DESCRIPTION

The 12-channel AD8802/AD8804 provides independent digitally-controllable voltage outputs in a compact 20-lead package. This potentiometer divider TrimDAC® allows replacement of the mechanical trimmer function in new designs. The AD8802/AD8804 is ideal for dc voltage adjustment applications.

Easily programmed by serial interfaced microcontroller ports, the AD8802 with its midscale preset is ideal for potentiometer replacement where adjustments start at a nominal value. Applications such as gain control of video amplifiers, voltage controlled frequencies and bandwidths in video equipment, geometric correction and automatic adjustment in CRT computer graphic displays are a few of the many applications ideally suited for these parts. The AD8804 provides independent control of both the top and bottom end of the potentiometer divider allowing a separate zero-scale voltage setting determined by the V_{REFL} pin. This is helpful for maximizing the resolution of devices with a limited allowable voltage control range.

Internally the AD8802/AD8804 contains 12 voltage-output digital-to-analog converters, sharing a common reference-voltage input.

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Each DAC has its own DAC latch that holds its output state. These DAC latches are updated from an internal serial-to-parallel shift register that is loaded from a standard 3-wire serial input digital interface. The serial-data-input word is decoded where the first 4 bits determine the address of the DAC latches to be loaded with the last 8 bits of data. The AD8802/AD8804 consumes only 10 μA from 5 V power supplies. In addition, in shutdown mode reference input current consumption is also reduced to 10 μA while saving the DAC latch settings for use after return to normal operation.

The AD8802/AD8804 is available in the 20-pin plastic DIP, the SOIC-20 surface mount package, and the 1 mm thin TSSOP-20 package.

REV. 0

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AD8802/AD8804—SPECIFICATIONS (V_{DD} = +3 V ± 10% or +5 V ± 10%, V_{REFH} = +V_{DD}, V_{REFL} = 0 V, –40°C ≤ T_A ≤ +85°C unless otherwise noted)

Parameter	Symbol	Conditions	Min	Typ[1]	Max	Units
STATIC ACCURACY						
Specifications apply to all DACs						
Resolution	N		8			Bits
Differential Nonlinearity Error	DNL	Guaranteed Monotonic	–1	±1/4	+1	LSB
Integral Nonlinearity Error	INL		–1.5	±1/2	+1.5	LSB
Full-Scale Error	G_{FSE}		–1	1/2	+1	LSB
Zero Code Error	V_{ZSE}		–1	1/4	+1	LSB
DAC Output Resistance	R_{OUT}		3	5	8	kΩ
Output Resistance Match	$\Delta R/R_O$			1.5		%
REFERENCE INPUT						
Voltage Range[2]	V_{REFH}		0		V_{DD}	V
	V_{REFL}	Pin Available on AD8804 Only	0		V_{DD}	V
REFH Input Resistance	R_{REFH}	Digital Inputs = 55_H, V_{REFH} = V_{DD}		1.2		kΩ
REFL Input Resistance[3]	R_{REFL}	Digital Inputs = 55_H, V_{REFL} = V_{DD}		1.2		kΩ
Reference Input Capacitance[3]	C_{REF0}	Digital Inputs all Zeros		32		pF
	C_{REF1}	Digital Inputs all Ones		32		pF
DIGITAL INPUTS						
Logic High	V_{IH}	V_{DD} = +5 V	2.4			V
Logic Low	V_{IL}	V_{DD} = +5 V			0.8	V
Logic High	V_{IH}	V_{DD} = +3 V	2.1			V
Logic Low	V_{IL}	V_{DD} = +3 V			0.6	V
Input Current	I_{IL}	V_{IN} = 0 V or + 5 V			±1	µA
Input Capacitance[3]	C_{IL}			5		pF
POWER SUPPLIES[4]						
Power Supply Range	V_{DD} Range		2.7		5.5	V
Supply Current (CMOS)	I_{DD}	V_{IH} = V_{DD} or V_{IL} = 0 V		0.01	10	µA
Supply Current (TTL)	I_{DD}	V_{IH} = 2.4 V or V_{IL} = 0.8 V, V_{DD} = +5.5 V		1	4	mA
Shutdown Current	I_{REFH}	$\overline{SHDN}$ = 0		0.2	10	µA
Power Dissipation	P_{DISS}	V_{IH} = V_{DD} or V_{IL} = 0 V, V_{DD} = +5.5 V			55	µW
Power Supply Sensitivity	PSRR	V_{DD} = +5 V ± 10%		0.001	0.002	%/%
DYNAMIC PERFORMANCE[3]						
V_{OUT} Settling Time	t_S	±1/2 LSB Error Band		0.6		µs
Crosstalk	CT	Between Adjacent Outputs[5]		50		dB
SWITCHING CHARACTERISTICS[3, 6]						
Input Clock Pulse Width	t_{CH}, t_{CL}	Clock Level High or Low	15			ns
Data Setup Time	t_{DS}		5			ns
Data Hold Time	t_{DH}		5			ns
$\overline{CS}$ Setup Time	t_{CSS}		10			ns
$\overline{CS}$ High Pulse Width	t_{CSW}		10			ns
Reset Pulse Width	t_{RS}		90			ns
CLK Rise to $\overline{CS}$ Rise Hold Time	t_{CSH}		20			ns
$\overline{CS}$ Rise to Clock Rise Setup	t_{CS1}		10			ns

NOTES
[1]Typicals represent average readings at +25°C.
[2]V_{REFH} can be any value between GND and V_{DD}, for the AD8804 V_{REFL} can be any value between GND and V_{DD}.
[3]Guaranteed by design and not subject to production test.
[4]Digital Input voltages V_{IN} = 0 V or V_{DD} for CMOS condition. DAC outputs unloaded. P_{DISS} is calculated from ($I_{DD} \times V_{DD}$).
[5]Measured at a V_{OUT} pin where an adjacent V_{OUT} pin is making a full-scale voltage change (f = 100 kHz).
[6]See timing diagram for location of measured values. All input control voltages are specified with t_R = t_F = 2 ns (10% to 90% of V_{DD}) and timed from a voltage level of 1.6 V.

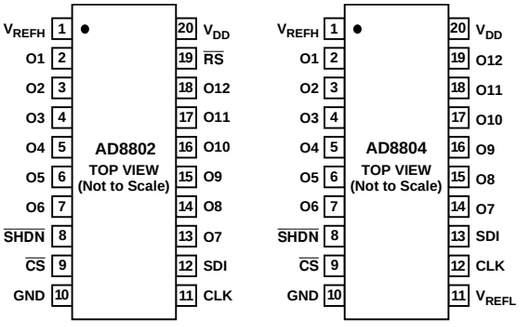
Specifications subject to change without notice.

ABSOLUTE MAXIMUM RATINGS

(T_A = +25°C, unless otherwise noted)

V_{DD} to GND ..... –0.3, + 8 V
V_{REFX} to GND ..... 0 V, V_{DD}
Outputs (Ox) to GND ..... 0 V, V_{DD}
Digital Input Voltage to GND ..... 0 V, +8 V
Operating Temperature Range ..... –40°C to +85°C
Maximum Junction Temperature (T_J MAX) ..... +150°C
Storage Temperature ..... –65°C to +150°C
Lead Temperature (Soldering, 10 sec) ..... +300°C
Package Power Dissipation ..... (T_J MAX – T_A)/θ_{JA}
Thermal Resistance θ_{JA},
SOIC (SOL-20) ..... 60°C/W
P-DIP (N-20) ..... 57°C/W
TSSOP-20 (RU-20) ..... 155°C/W

PIN CONFIGURATIONS



AD8802 PIN DESCRIPTIONS

Pin	Name	Description
1	V_{REF}	Common DAC Reference Input
2	O1	DAC Output #1, addr = 0000_2
3	O2	DAC Output #2, addr = 0001_2
4	O3	DAC Output #3, addr = 0010_2
5	O4	DAC Output #4, addr = 0011_2
6	O5	DAC Output #5, addr = 0100_2
7	O6	DAC Output #6, addr = 0101_2
8	$\overline{SHDN}$	Reference input current goes to zero. DAC latch settings maintained
9	$\overline{CS}$	Chip Select Input, Active Low. When $\overline{CS}$ returns high, data in the serial input register is decoded based on the address bits and loaded into the target DAC register
10	GND	Ground
11	CLK	Serial Clock Input, Positive Edge Triggered
12	SDI	Serial Data Input
13	O7	DAC Output #7, addr = 0110_2
14	O8	DAC Output #8, addr = 0111_2
15	O9	DAC Output #9, addr = 1000_2
16	O10	DAC Output #10, addr = 1001_2
17	O11	DAC Output #11, addr = 1010_2
18	O12	DAC Output #12, addr = 1011_2
19	$\overline{RS}$	Asynchronous Preset to Midscale Output Setting. Loads all DAC Registers with 80_H
20	V_{DD}	Positive Power Supply, Specified for Operation at Both +3 V and +5 V

AD8804 PIN DESCRIPTIONS

Pin	Name	Description
1	V_{REFH}	Common High-Side DAC Reference Input
2	O1	DAC Output #1, addr = 0000_2
3	O2	DAC Output #2, addr = 0001_2
4	O3	DAC Output #3, addr = 0010_2
5	O4	DAC Output #4, addr = 0011_2
6	O5	DAC Output #5, addr = 0100_2
7	O6	DAC Output #6, addr = 0101_2
8	$\overline{SHDN}$	Reference input current goes to zero DAC latch settings maintained
9	$\overline{CS}$	Chip Select Input, Active Low. When $\overline{CS}$ returns high, data in the serial input register is decoded based on the address bits and loaded input the target DAC register
10	GND	Ground
11	V_{REFL}	Common Low-Side DAC Reference Input
12	CLK	Serial Clock Input, Positive Edge Triggered
13	SDI	Serial Data Input
14	O7	DAC Output #7, addr = 0110_2
15	O8	DAC Output #8, addr = 0111_2
16	O9	DAC Output #9, addr = 1000_2
17	O10	DAC Output #10, addr = 1001_2
18	O11	DAC Output #11, addr = 1010_2
19	O12	DAC Output #12, addr = 1011_2
20	V_{DD}	Positive power supply, specified for operation at both +3 V and +5 V

ORDERING GUIDE

Model	FTN	Temperature Range	Package Description	Package Option
AD8802AN	$\overline{RS}$	–40°C/+85°C	PDIP-20	N-20
AD8802AR	$\overline{RS}$	–40°C/+85°C	SOL-20	R-20
AD8802ARU	$\overline{RS}$	–40°C/+85°C	TSSOP-20	RU-20
AD8804AN	REFL	–40°C/+85°C	PDIP-20	N-20
AD8804AR	REFL	–40°C/+85°C	SOL-20	R-20
AD8804ARU	REFL	–40°C/+85°C	TSSOP-20	RU-20

CAUTION

ESD (electrostatic discharge) sensitive device. Electrostatic charges as high as 4000 V readily accumulate on the human body and test equipment and can discharge without detection. Although these devices feature proprietary ESD protection circuitry, permanent damage may occur on devices subjected to high energy electrostatic discharges. Therefore, proper ESD precautions are recommended to avoid performance degradation or loss of functionality.

AD8802/AD8804–Typical Performance Characteristics

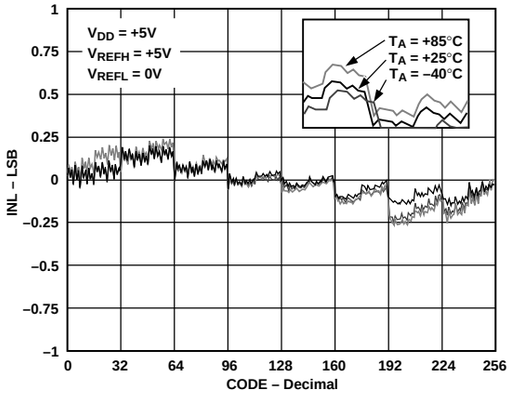


Figure 1. INL vs. Code

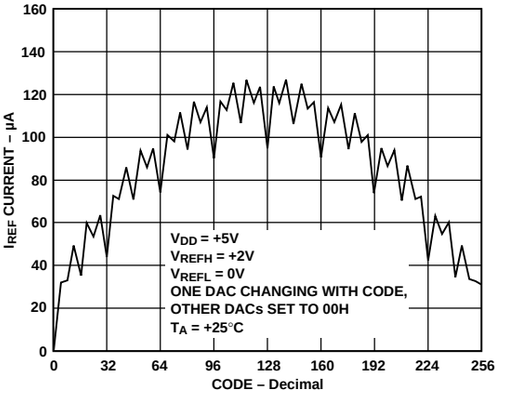


Figure 4. Input Reference Current vs. Code

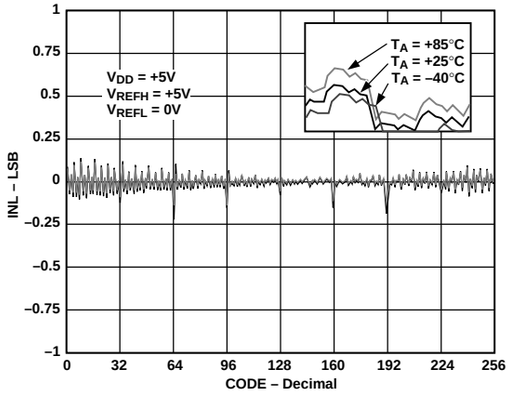


Figure 2. Differential Nonlinearity Error vs. Code

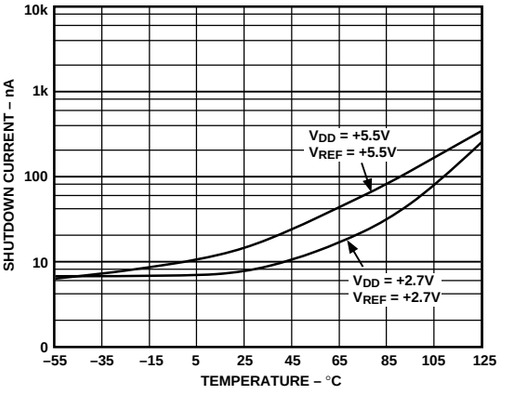


Figure 5. Shutdown Current vs. Temperature

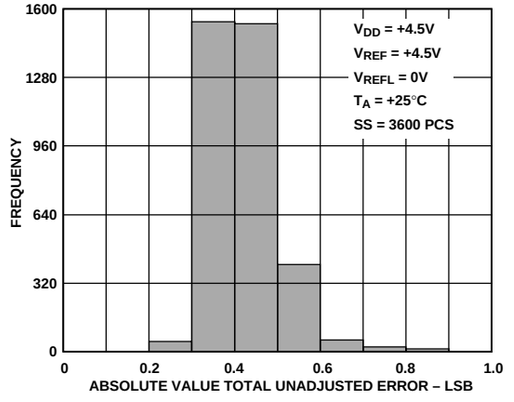


Figure 3. Total Unadjusted Error Histogram

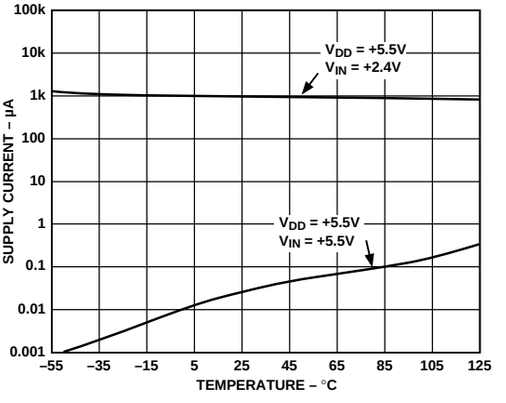


Figure 6. Supply Current vs. Temperature

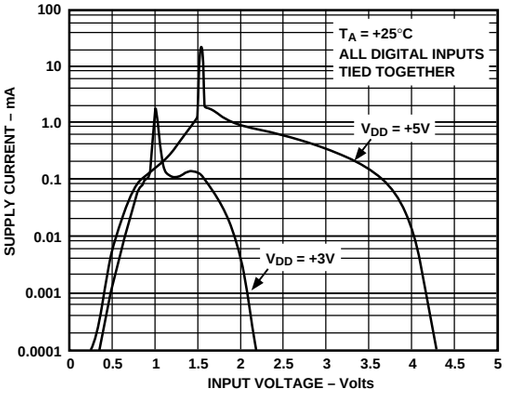


Figure 7. Supply Current vs. Logic Input Voltage

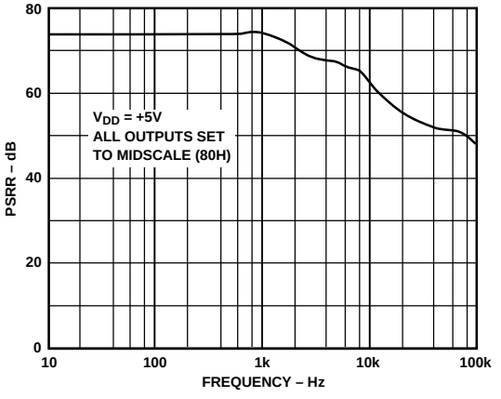


Figure 8. Power Supply Rejection vs. Frequency

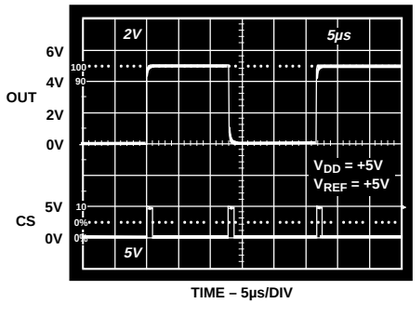


Figure 9. Large-Signal Settling Time

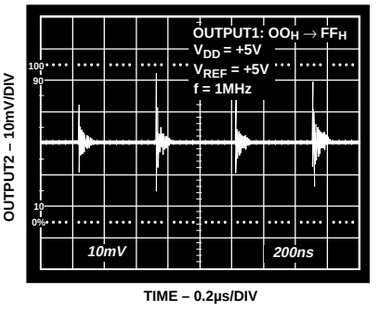


Figure 10. Adjacent Channel Clock Feedthrough

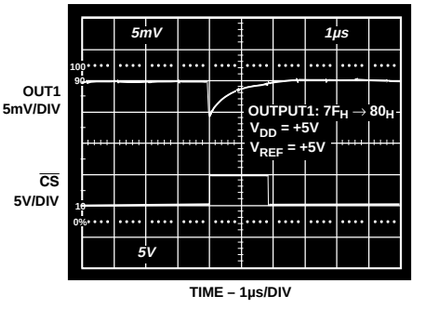


Figure 11. Midscale Transition

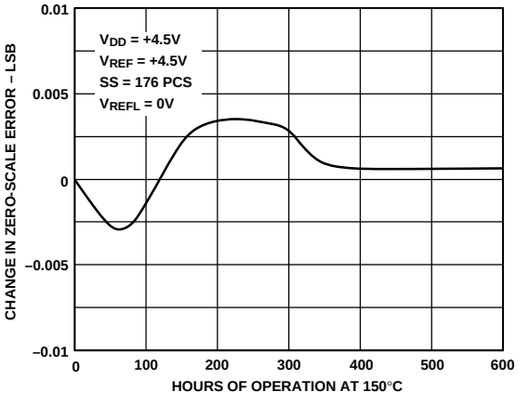


Figure 12. Zero-Scale Error Accelerated by Burn-In

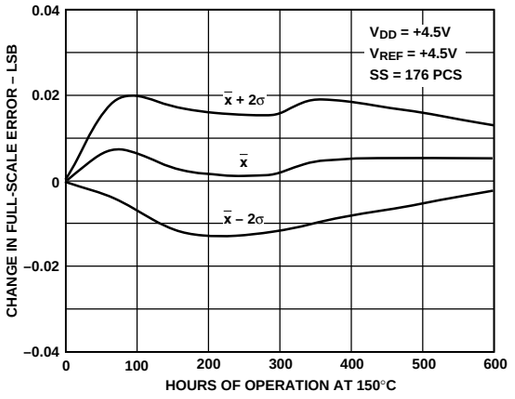


Figure 13. Full-Scale Error Accelerated by Burn-In

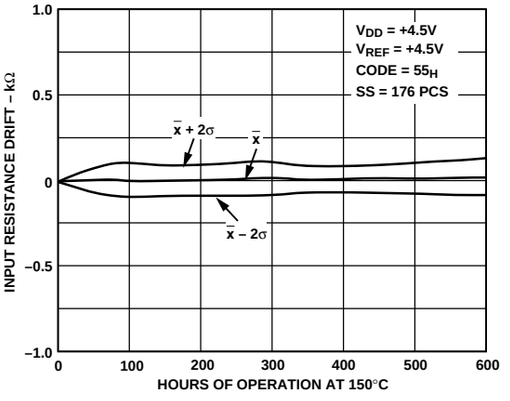


Figure 14. REF Input Resistance Accelerated by Burn-In

OPERATION

The AD8802/AD8804 provides twelve channels of programmable voltage output adjustment capability. Changing the programmed output voltage of each DAC is accomplished by clocking in a 12-bit serial data word into the SDI (Serial Data Input) pin. The format of this data word is four address bits, MSB first, followed by 8 data bits, MSB first. Table I provides the serial register data word format. The AD8802/AD8804 has the following address assignments for the ADDR decode which determines the location of the DAC register receiving the serial register data in Bits B7 through B0:

$$DAC\# = A3 \times 8 + A2 \times 4 + A1 \times 2 + A0 + 1$$

DAC outputs can be changed one at a time in random sequence. The fast serial-data loading of 33 MHz makes it possible to load all 12 DACs in as little time as 4.6 µs (13 × 12 × 30 ns). The exact timing requirements are shown in Figure 15.

Table I. Serial-Data Word Format

ADDR				DATA							
B11	**B10**	**B9**	**B8**	**B7**	**B6**	**B5**	**B4**	**B3**	**B2**	**B1**	**B0**
A3	A2	A1	A0	D7	D6	D5	D4	D3	D2	D1	D0
MSB			LSB	MSB							LSB
2^{11}	2^{10}	2^9	2^8	2^7	2^6	2^5	2^4	2^3	2^2	2^1	2^0

The AD8802 offers a midscale preset activated by the $\overline{RS}$ pin simplifying initial setting conditions at first power-up. The AD8804 has both a V_{REFH} and a V_{REFL} pin to establish independent positive full-scale and zero-scale settings to optimize resolution. Both parts offer a power shutdown $\overline{SHDN}$ which places the DAC structure in a zero power consumption state resulting in only leakage currents being consumed from the power supply and V_{REF} inputs. In shutdown mode the DACX register settings are maintained. When returning to operational mode from power shutdown the DAC outputs return to their previous voltage settings.

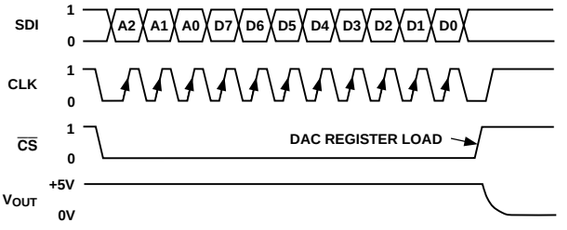


Figure 15a. Timing Diagram

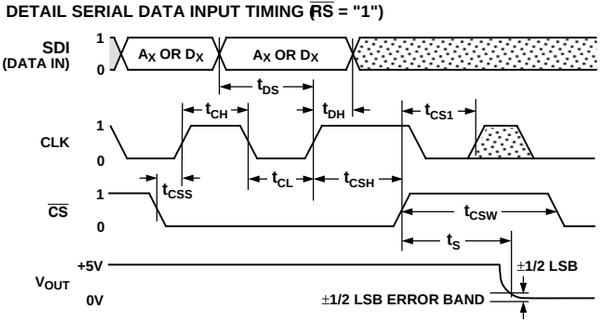


Figure 15b. Detail Timing Diagram

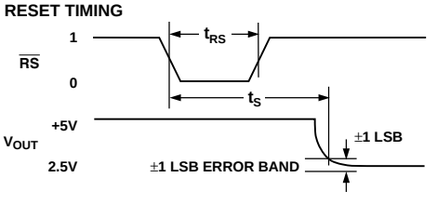


Figure 15c. Reset Timing Diagram

PROGRAMMING THE OUTPUT VOLTAGE

The output voltage range is determined by the external reference connected to V_{REFH} and V_{REFL} pins. See Figure 16 for a simplified diagram of the equivalent DAC circuit. In the case of the AD8802 its V_{REFL} is internally connected to GND and therefore cannot be offset. V_{REFH} can be tied to V_{DD} and V_{REFL} can be tied to GND establishing a basic rail-to-rail voltage output programming range. Other output ranges are established by the use of different external voltage references. The general transfer equation which determines the programmed output voltage is:

$$VO\ (Dx) = (Dx)/256 \times (V_{REFH} - V_{REFL}) + V_{REFL} \qquad \text{Eq. 1}$$

where *Dx* is the data contained in the 8-bit DACx register.

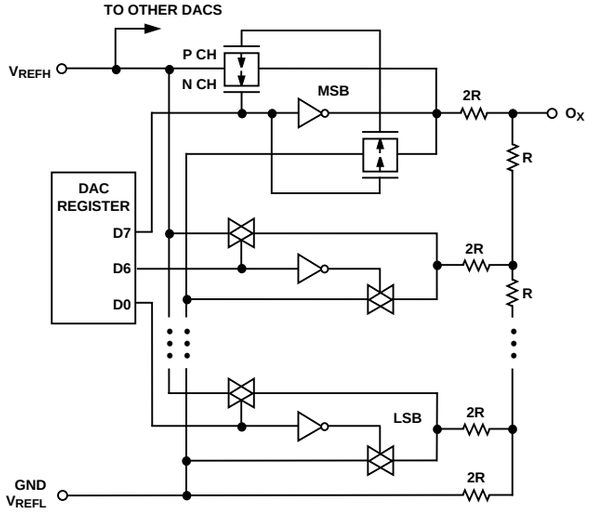


Figure 16. AD8802/AD8804 Equivalent TrimDAC Circuit

For example, when V_{REFH} = +5 V and V_{REFL} = 0 V, the following output voltages will be generated for the following codes:

D	VOx	Output State (V_{REFH} = +5 V, V_{REFL} = 0 V)
255	4.98 V	Full Scale
128	2.50 V	Half Scale (Midscale Reset Value)
1	0.02 V	1 LSB
0	0.00 V	Zero Scale

REFERENCE INPUTS (V_{REFH}, V_{REFL})

The reference input pins set the output voltage range of all twelve DACs. In the case of the AD8802 only the V_{REFH} pin is available to establish a user designed full-scale output voltage. The external reference voltage can be any value between 0 and V_{DD} but must not exceed the V_{DD} supply voltage. The AD8804 has access to the V_{REFL} which establishes the zero-scale output voltage, any voltage can be applied between 0 V and V_{DD}. V_{REFL} can be smaller or larger in voltage than V_{REFH} since the DAC design uses fully bidirectional switches as shown in Figure 16. The input resistance to the DAC has a code dependent variation which has a nominal worst case measured at 55_H, which is approximately 1.2 kΩ. When V_{REFH} is greater than V_{REFL}, the REFL reference must be able to sink current out of the DAC ladder, while the REFH reference is sourcing current into the DAC ladder. The DAC design minimizes reference glitch current maintaining minimum interference between DAC channels during code changes.

DAC OUTPUTS (O1–O12)

The twelve DAC outputs present a constant output resistance of approximately 5 kΩ independent of code setting. The distribution of R_{OUT} from DAC-to-DAC typically matches within ±1%. However device-to-device matching is process lot dependent having a ±20% variation. The change in R_{OUT} with temperature has a 500 ppm/°C temperature coefficient. During power shutdown all twelve outputs are open-circuited.

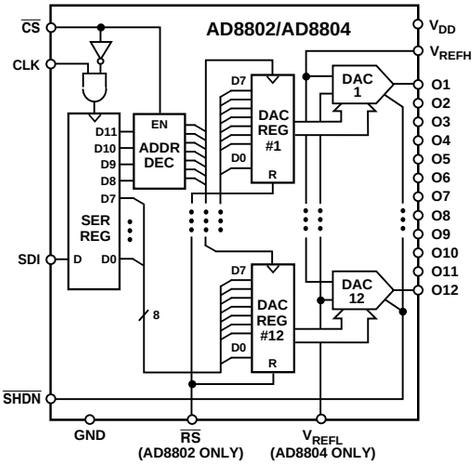


Figure 17. Block Diagram

DIGITAL INTERFACING

The AD8802/AD8804 contains a standard three-wire serial input control interface. The three inputs are clock (CLK), $\overline{CS}$ and serial data input (SDI). The positive-edge sensitive CLK input requires clean transitions to avoid clocking incorrect data into the serial input register. Standard logic families work well. If mechanical switches are used for product evaluation, they should be debounced by a flip-flop or other suitable means. Figure 17 block diagram shows more detail of the internal digital circuitry. When $\overline{CS}$ is taken active low, the clock can load data into the serial register on each positive clock edge, see Table II.

Table II. Input Logic Control Truth Table

$\overline{CS}$	CLK	Register Activity
1	X	No effect.
0	P	Shifts Serial Register One bit loading the next bit in from the SDI pin.
P	1	Clock should be high when the $\overline{CS}$ returns to the inactive state.

P = Positive Edge, X = Don't Care.

The data setup and data hold times in the specification table determine the data valid time requirements. The last 12 bits of the data word entered into the serial register are held when $\overline{CS}$ returns high. At the same time $\overline{CS}$ goes high it gates the address decoder which enables one of the twelve positive-edge triggered DAC registers, see Figure 18 detail.

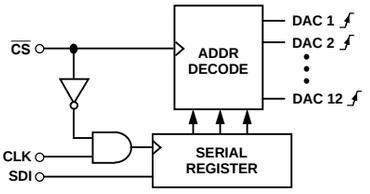


Figure 18. Equivalent Control Logic

The target DAC register is loaded with the last eight bits of the serial data-word completing one DAC update. Twelve separate 12-bit data words must be clocked in to change all twelve output settings.

All digital inputs are protected with a series input resistor and parallel Zener ESD structure shown in Figure 19. Applies to digital input pins $\overline{CS}$, SDI, $\overline{RS}$, $\overline{SHDN}$, CLK

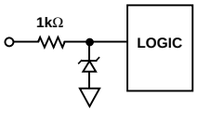


Figure 19. Equivalent ESD Protection Circuit

Digital inputs can be driven by voltages exceeding the AD8802/AD8804 V_{DD} supply value. This allows 5 V logic to interface directly to the part when it is operated at 3 V.

APPLICATIONS

Supply Bypassing

Precision analog products, such as the AD8802/AD8804, require a well filtered power source. Since the AD8802/AD8804 operate from a single +3 V to +5 V supply, it seems convenient to simply tap into the digital logic power supply. Unfortunately, the logic supply is often a switch-mode design, which generates noise in the 20 kHz to 1 MHz range. In addition, fast logic gates can generate glitches hundred of millivolts in amplitude due to wiring resistances and inductances.

If possible, the AD8802/AD8804 should be powered directly from the system power supply. This arrangement, shown in Figure 20, will isolate the analog section from the logic switching transients. Even if a separate power supply trace is not available, however, generous supply bypassing will reduce supply-line induced errors. Local supply bypassing consisting of a 10 µF tantalum electrolytic in parallel with a 0.1 µF ceramic capacitor is recommended (Figure 21).

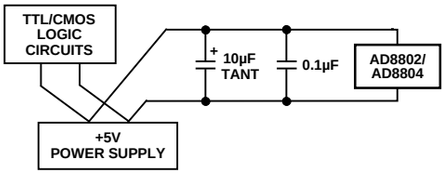


Figure 20. Use Separate Traces to Reduce Power Supply Noise

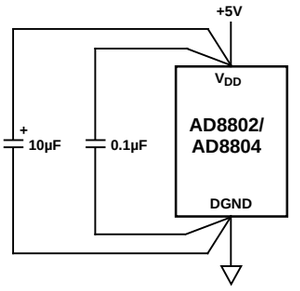


Figure 21. Recommended Supply Bypassing for the AD8802/AD8804

Buffering the AD8802/AD8804 Output

In many cases, the nominal 5 kΩ output impedance of the AD8802/AD8804 is sufficient to drive succeeding circuitry. If a lower output impedance is required, an external amplifier can be added. Several examples are shown in Figure 22. One amplifier of an OP291 is used as a simple buffer to reduce the output resistance of DAC A. The OP291 was chosen primarily for its rail-to-rail input and output operation, but it also offers operation to less than 3 V, low offset voltage, and low supply current.

The next two DACs, B and C, are configured in a summing arrangement where DAC C provides the coarse output voltage setting and DAC B can be used for fine adjustment. The insertion of R1 in series with DAC B attenuates its contribution to the voltage sum node at the DAC C output.

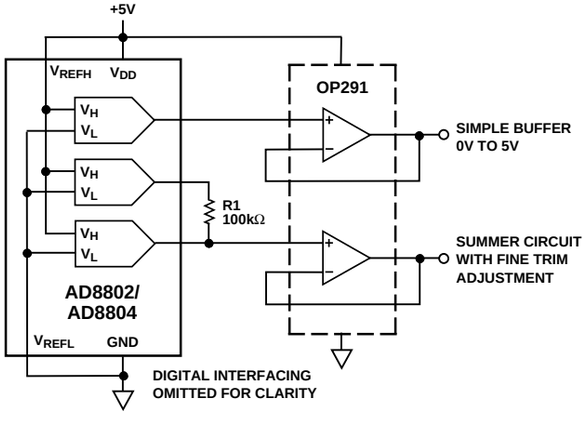


Figure 22. Buffering the AD8802/AD8804 Output

Increasing Output Voltage Swing

An external amplifier can also be used to extend the output voltage swing beyond the power supply rails of the AD8802/AD8804. This technique permits an easy digital interface for the DAC, while expanding the output swing to take advantage of higher voltage external power supplies. For example, DAC A of Figure 23 is configured to swing from –5 V to +5 V. The actual output voltage is given by:

$$V_{OUT} = \left(1 + \frac{R_F}{R_S}\right) \times \left(\frac{D}{256} \times 5\,V\right) - 5\,V$$

where D is the DAC input value (i.e., 0 to 255). This circuit can be combined with the "fine/coarse" circuit of Figure 22 if, for example, a very accurate adjustment around 0 V is desired.

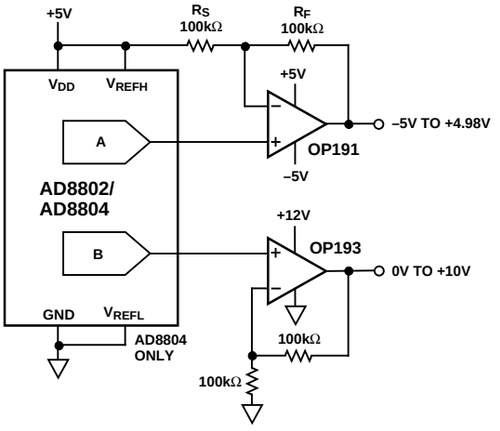


Figure 23. Increasing Output Voltage Swing

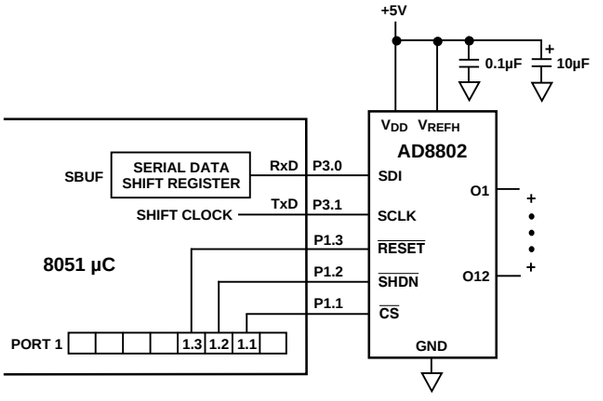


Figure 24. Interfacing the 8051 µC to an AD8802/AD8804, Using the Serial Port

DAC B of Figure 24 is in a noninverting gain of two configurations, which increases the available output swing to +10 V. The feedback resistors can be adjusted to provide any scaling of the output voltage, within the limits of the external op amp power supplies.

Microcomputer Interfaces

The AD8802/AD8804 serial data input provides an easy interface to a variety of single-chip microcomputers (µCs). Many µCs have a built-in serial data capability that can be used for communicating with the DAC. In cases where no serial port is provided, or it is being used for some other purpose (such as an RS-232 communications interface), the AD8802/AD8804 can easily be addressed in software.

Twelve data bits are required to load a value into the AD8802/AD8804 (4 bits for the DAC address and 8 bits for the DAC value). If more than 12 bits are transmitted before the Chip Select input goes high, the extra (i.e., the most-significant) bits are ignored. This feature is valuable because most µCs only transmit data in 8-bit increments. Thus, the µC will send 16 bits to the DAC instead of 12 bits. The AD8802/AD8804 will only respond to the last 12 bits clocked into the SDI port, however, so the serial data interface is not affected.

An 8051 µC Interface

A typical interface between the AD8802/AD8804 and an 8051 µC is shown in Figure 24. This interface uses the 8051's internal serial port. The serial port is programmed for Mode 0 operation, which functions as a simple 8-bit shift register. The 8051's Port 3.0 pin functions as the serial data output, while Port 3.1 serves as the serial clock.

When data is written to the Serial Buffer Register (SBUF, at Special Function Register location 99_H), the data is automatically converted to serial format and clocked out via Port 3.0 and Port 3.1. After 8 bits have been transmitted, the Transmit Interrupt flag (SCON.1) is set and the next 8 bits can be transmitted.

The AD8802 and AD8804 require the Chip Select to go low at the beginning of the serial data transfer. In addition, the SCLK input must be high when the Chip Select input goes high at the end of the transfer. The 8051's serial clock meets this requirement, since Port 3.1 both begins and ends the serial data in the high state.

Software for the 8051 Interface

A software for the AD8802/AD8804 to 8051 interface is shown in Listing 1. The routine transters the 8-bit data stored at data memory location DAC_VALUE to the AD8802/AD8804 DAC addressed by the contents of location DAC_ADDR.

The subroutine begins by setting appropriate bits in the Serial Control register to configure the serial port for Mode 0 operation. Next the DAC's Chip Select input is set low to enable the AD8802/AD8804. The DAC address is obtained from memory location DAC_ADDR, adjusted to compensate for the 8051's serial data format, and moved to the serial buffer register. At this point, serial data transmission begins automatically. When all 8 bits have been sent, the Transmit Interrupt bit is set, and the subroutine then proceeds to send the DAC value stored at location DAC_VALUE. Finally the Chip Select input is returned high, causing the appropriate AD8802/AD8804 output voltage to change, and the subroutine ends.

The 8051 sends data out of its shift register LSB first, while the AD8802/AD8804 require data MSB first. The subroutine therefore includes a BYTESWAP subroutine to reformat the data. This routine transfers the MSB-first byte at location SHIFT1 to an LSB-first byte at location SHIFT2. The routine rotates the MSB of the first byte into the carry with a Rotate Left Carry instruction, then rotates the carry into the MSB of the second byte with a Rotate Right Carry instruction. After 8 loops, SHIFT2 contains the data in the proper format.

The BYTESWAP routine in Listing 1 is convenient because the DAC data can be calculated in normal LSB form. For example, producing a ramp voltage on a DAC is simply a matter of repeatedly incrementing the DAC_VALUE location and calling the LD_8802 subroutine.

If the µC's hardware serial port is being used for other purposes, the AD8802/AD8804 DAC can be loaded by using the parallel port. A typical parallel interface is shown in Figure 25. The serial data is transmitted to the DAC via the 8051's Port 1.6 output, while Port 1.6 acts as the serial clock.

Software for the interface of Figure 25 is contained in Listing 2. The subroutine will send the value stored at location DAC_VALUE to the AD8802/AD8804 DAC addressed by location DAC_ADDR. The program begins by setting the AD8802/AD8804's Serial Clock and Chip Select inputs high, then setting Chip Select low

```
;
;  This subroutine loads an AD8802/AD8804 DAC from an 8051 microcomputer,
;  using the 8051's serial port in MODE 0 (Shift Register Mode).
;  The DAC value is stored at location DAC_VAL
;  The DAC address is stored at location DAC_ADDR
;
;  Variable declarations
;
PORT1           DATA    90H                     ;SFR register for port 1
DAC_VALUE       DATA    40H                     ;DAC Value
DAC_ADDR        DATA    41H                     ;DAC Address
SHIFT1          DATA    042H                    ;high byte of 16-bit answer
SHIFT2          DATA    043H                    ;low byte of answer
SHIFT_COUNT     DATA    44H                     ;
;
                ORG     100H                    ;arbitrary start
DO_8802:        CLR     SCON.7                  ;set serial
                CLR     SCON.6                  ;data mode 0
                CLR     SCON.5
                CLR     SCON.1                  ;clr transmit flag
                ORL     PORT1.1,#00001110B      ;/RS, /SHDN, /CS high
                CLR     PORT1.1                 ;set the /CS low
                MOV     SHIFT1,DAC_ADDR         ;put DAC value in shift register
                ACALL   BYTESWAP                ;
                MOV     SBUF,SHIFT2             ;send the address byte
ADDR_WAIT:      JNB     SCON.1,ADDR_WAIT        ;wait until 8 bits are sent
                CLR     SCON.1                  ;clear the serial transmit flag
                MOV     SHIFT1,DAC_VALUE        ;send the DAC value
                ACALL   BYTESWAP                ;
                MOV     SBUF,SHIFT2             ;
VALU_WAIT:      JNB     SCON.1,VALU_WAIT        ;wait again
                CLR     SCON.1                  ;clear serial flag
                SETB    PORT1.1                 ;/CS high, latch data
                RET                             ; into AD8801
;
BYTESWAP:       MOV     SHIFT_COUNT,#8          ;Shift 8 bits
SWAP_LOOP:      MOV     A,SHIFT1                ;Get source byte
                RLC     A                       ;Rotate MSB to carry
                MOV     SHIFT1,A                ;Save new source byte
                MOV     A,SHIFT2                ;Get destination byte
                RRC     A                       ;Move carry to MSB
                MOV     SHIFT2,A                ;Save
                DJNZ    SHIFT_COUNT,SWAP_LOOP   ;Done?
                RET
                END
```

Listing 1. Software for the 8051 to AD8802/AD8804 Serial Port Interface

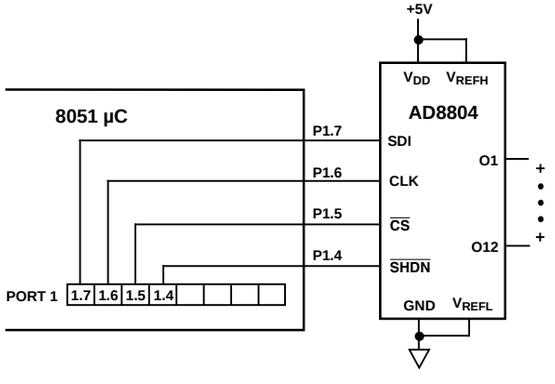


Figure 25. An AD8802/AD8804-8051 µC Interface Using Parallel Port 1

to start the serial interface process. The DAC address is loaded into the accumulator and four Rotate Right shifts are performed. This places the DAC address in the 4 MSBs of the accumulator. The address is then sent to the AD8802/AD8804 via the SEND_SERIAL subroutine. Next, the DAC value is loaded into the accumulator and sent to the AD8802/AD8804. Finally, the Chip Select input is set high to complete the data transfer

Unlike the serial port interface of Figure 24, the parallel port interface only transmits 12 bits to the AD8802/AD8804. Also, the BYTESWAP subroutine is not required for the parallel interface, because data can be shifted out MSB first. However, the results of the two interface methods are exactly identical. In most cases, the decision on which method to use will be determined by whether or not the serial data port is available for communication with the AD8802/AD8804.

```
;  This 8051 µC subroutine loads an AD8802 or AD8804 DAC with an 8-bit value,
;  using the 8051's parallel port #1.
;  The DAC value is stored at location DAC_VALUE
;  The DAC address is stored at location DAC_ADDR
;
;  Variable declarations
PORT1           DATA    90H                     ;SFR register for port 1
DAC_VALUE       DATA    40H                     ;DAC Value
DAC_ADDR        DATA    41H                     ;DAC Address (0 through 7)
LOOPCOUNT       DATA    43H                     ;COUNT LOOPS
                ;
                ORG     100H                    ;arbitrary start
LD_8804:        ORL     PORT1,#11110000B        ;set CLK, /CS and /SHDN high
                CLR     PORT1.5                 ;Set Chip Select low
                MOV     LOOPCOUNT,#4            ;Address is 4 bits
                MOV     A,DAC_ADDR              ;Get DAC address
                RR      A                       ;Rotate the DAC
                RR      A                       ;address to the Most
                RR      A                       ;Significant Bits (MSBs)
                RR      A                       ;
                ACALL   SEND_SERIAL             ;Send the address
                MOV     LOOPCOUNT,#8            ;Do 8 bits of data
                MOV     A,DAC_VALUE
                ACALL   SEND_SERIAL             ;Send the data
                SETB    PORT1.5                 ;Set /CS high
                RET                             ;DONE

SEND_SERIAL:    RLC     A                       ;Move next bit to carry
                MOV     PORT1.7,C               ;Move data to SDI
                CLR     PORT1.6                 ;Pulse the
                SETB    PORT1.6                 ;CLK input
                DJNZ    LOOPCOUNT,SEND_SERIAL   ;Loop if not done
                RET;
                END
```

Listing 2. Software for the 8051 to AD8802/AD8804 Parallel Port Interface

An MC68HC11-to-AD8802/AD8804 Interface

Like the 8051 µC, the MC68HC11 includes a dedicated serial data port (labeled SPI). The SPI port provides an easy interface to the AD8802/AD8804 (Figure 27). The interface uses three lines of Port D for the serial data, and one or two lines from Port C to control the $\overline{SHDN}$ and $\overline{RS}$ (AD8802 only) inputs.

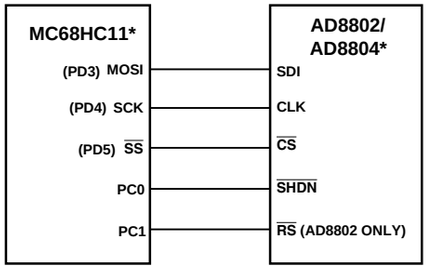


Figure 26. An AD8802/AD8804-to-MC68HC11 Interface

A software routine for loading the AD8802/AD8804 from a 68HC11 evaluation board is shown in Listing 3. First, the MC68HC11 is configured for SPI operation. Bits CPHA and CPOL define the SPI mode wherein the serial clock (SCK) is high at the beginning and end of transmission, and data is valid on the rising edge of SCK. This mode matches the requirements of the AD8802/AD8804. After the registers are saved on the stack, the DAC value and address are transferred to RAM and the AD8802/AD8804's $\overline{CS}$ is driven low. Next, the DAC's address byte is transferred to the SPDR register, which automatically initiates the SPI data transfer. The program tests the SPIF bit and loops until the data transfer is complete. Then the DAC value is sent to the SPI. When transmission of the second byte is complete, $\overline{CS}$ is driven high to load the new data and address into the AD8802/AD8804.

```
*
* AD8802/AD8804 to M68HC11 Interface Assembly Program
*
* M68HC11 Register definitions
*
PORTC     EQU     $1003     Port C control register
*                           "0,0,0,0;0,0,RS/, SHDN/"
DDRC      EQU     $1007     Port C data direction
PORTD     EQU     $1008     Port D data register
*                           "0,0,/CS,CLK;SDI,0,0,0"
DDRD      EQU     $1009     Port D data direction
SPCR      EQU     $1028     SPI control register
*                           "SPIE,SPE,DWOM,MSTR;CPOL,CPHA,SPR1,SPR0"
SPSR      EQU     $1029     SPI status register
*                           "SPIF,WCOL,0,MODF;0,0,0,0"
SPDR      EQU     $102A     SPI data register; Read-Buffer; Write-Shifter
*
* SDI RAM variables:        SDI1 is encoded from 0H  to 7H
*                           SDI2 is encoded from 00H to FFH
*                           AD8802/AD8804 requires two 8-bit loads; upper 4 bits
*                           of SDI1 are ignored. AD8802/AD8804 address bits in last
*                           four LSBs of SDI1.
*
SDI1      EQU     $00       SDI packed byte 1 "0,0,0,0;A3,A2,A1,A0"
SDI2      EQU     $01       SDI packed byte 2 "DB7–DB4;DB3–DB0"
*
* Main Program
*
          ORG     $C000     Start of user's RAM in EVB
INIT      LDS     #$CFFF    Top of C page RAM
*
* Initialize Port C Outputs
*
          LDAA    #$03      0,0,0,0;0,0,1,1
*                           /RS-Hi, /SHDN-Hi
          STAA    PORTC     Initialize Port C Outputs
          LDAA    #$03      0,0,0,0;0,0,1,1
          STAA    DDRC      /RS and /SHDN are now enabled as outputs
*
* Initialize Port D Outputs
*
          LDAA    #$20      0,0,1,0;0,0,0,0
*                           /CS-Hi,/CLK-Lo,SDI-Lo
          STAA    PORTD     Initialize Port D Outputs
          LDAA    #$38      0,0,1,1;1,0,0,0
          STAA    DDRD      /CS,CLK, and SDI are now enabled as outputs
*
* Initialize SPI Interface
*
          LDAA    #$53
          STAA    SPCR      SPI is Master,CPHA=0,CPOL=0,Clk rate=E/32
*
* Call update subroutine
*
          BSR     UPDATE    Xfer 2 8-bit words to AD8402
          JMP     $E000     Restart BUFFALO
*
* Subroutine UPDATE
*
UPDATE    PSHX              Save registers X, Y, and A
          PSHY
          PSHA
*
* Enter Contents of SDI1 Data Register
```

```
*
                LDAA        $0000           Hi-byte data loaded from memory
                STAA        SDI1            SDI1 = data in location 0000H
*
* Enter Contents of SDI2 Data Register
*
                LDAA        $0001           Low-byte data loaded from memory
                STAA        SDI2            SDI2 = Data in location 0001H
*
                LDX         #SDI1           Stack pointer at 1st byte to send via SDI
                LDY         #$1000          Stack pointer at on-chip registers
*
* Reset AD8802 to one-half scale (AD8804 does not have a Reset input)
*
                BCLR        PORTC,Y $02     Assert /RS
                BSET        PORTC,Y $02     De-Assert /RS
*
* Get AD8802/04 ready for data input
*
                BCLR        PORTD,Y $02     Assert /CS
*
TFRLP           LDAA        0,X             Get a byte to transfer for SPI
                STAA        SPDR            Write SDI data reg to start xfer
*
WAIT            LDAA        SPSR            Loop to wait for SPIF
                BPL         WAIT            SPIF is the MSB of SPSR
*
                INX                         Increment counter to next byte for xfer
                CPX         #SDI2+1         Are we done yet ?
                BNE         TFRLP           If not, xfer the second byte
*
* Update AD8802 output
*
                BSET        PORTD,Y $20     Latch register & update AD8802
*
                PULA                        When done, restore registers X, Y & A
                PULY
                PULX
                RTS                         ** Return to Main Program **
```

Listing 3. AD8802/AD8804 to MC68HC11 Interface Program Source Code

An Intelligent Temperature Control System—Interfacing the 8051 µC with the AD8802/AD8804 and TMP14

Connecting the 80CL51 µC, or any modern microcontroller, with the TMP14 and AD8802/AD8804 yields a powerful temperature control tool, as shown in Figure 27. For example, the 80CL51 µC controls the TrimDACs allowing the user to automatically set the temperature setpoints voltages of the TMP14 via computer or touch pad, while the TMP14 senses the temperature and outputs four open-collector trip-points. Feeding these trip-point outputs back to the 80CL51 µC allow it to sense whether or not a setpoint has been exceeded. Additional 80CL51 µC port pins or TMP14 trip-point outputs may then be used to change fan speed (i.e., high, medium, low, off), or increase/decrease the power level to a heater. (Please refer to the TMP14 data sheet for more applications information.)

The $\overline{CS}$ (Chip Select) on the AD8802/AD8804 makes applications that call for large temperature sensor arrays possible. In addition, the 12 channels of the AD8802/AD8804 allow independent setpoint control for all four trip-point outputs on up to three TMP14 temperature sensors. For example, assume that the 80CL51 µC has eight free port pins available after all user interface lines, interrupts, and the serial port lines have been assigned. The eight port pins may be used as chip selects, in which case an array of eight AD8802/AD8804s controlling twenty-four TMP14 sensors is possible.

The AD8802/AD8804 and TMP14 are also ideal choices for low power applications. These devices have power shutdown modes and operate on a single 5 Volt supply. When their shutdown modes are activated current consumption is reduced to less than 35 µA. However, at high operating frequencies (12 MHz) the 80CL51 consumes far more energy (18 mA typ) than the AD8802/AD8804 and TMP14 combined. Therefore, to achieve a low power design the 80CL51 should operate at its lowest possible frequency or be placed in its power-down mode at the end of each instruction sequence.

To use the power-down mode of the 80CL51 µC set PCON.1 as the last instruction executed prior to going into the power-down mode. If INT2 and INT9 are enabled, the 80CL51 µC can be awakened from power-down mode with external interrupts. As shown in Figure 28, the TLC555 outputs a pulse every few seconds providing the interrupt to restart the 80CL51 µC which then samples the user input pins, the outputs of the

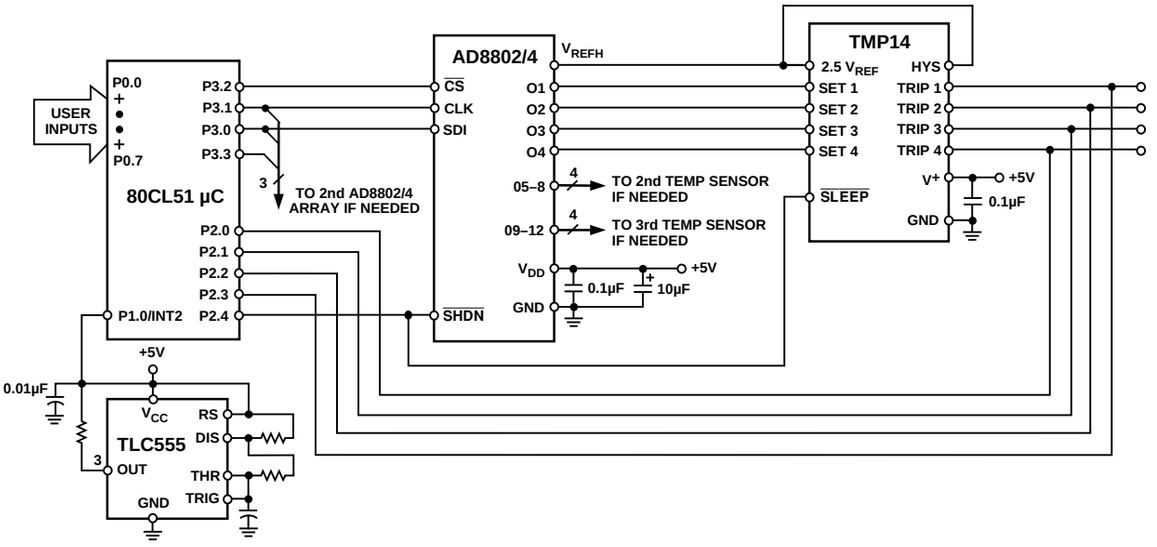


Figure 27. Temperature Sensor Array with Programmable Setpoints

TMP14, and makes the necessary adjustments to the AD8802/AD8804 before shutting down again. The 80CL51 consumes only 50 µA when operating at 32 kHz, in which case there would be no need for the TLC555, which consumes 1 mW typ.

12 Channel Programmable Voltage Controlled Amplifier

The SSM2018T is a trimless Voltage Controlled Amplifier (VCA) for volume control in audio systems. The SSM2018T is the first professional quality audio VCA in the marketplace that does not require an external trimming potentiometer to minimize distortion. The TrimDAC shown in Figure 28 is not being used to trim distortion, but rather to control the gain of the amplifier. In this configuration up to twelve SSM2018T can be digitally controlled. (Please refer to the SSM2018T data sheet for more specifications and applications information.)

The gain of the SSM2018T is controlled by the voltage at Pin 11. For maximum attenuation of –100 dB a control signal of 3.0 V typ is necessary. The control signal has a scale of –30 mV/dB centered around 0 dB gain for 0 V of control voltage, therefore, for a maximum gain of 40 dB a control voltage of –1.2 volts is necessary. Now notice that the normal +5 V to GND voltage range of the AD8802/AD8804 does not cover the 3.0 V to –1.2 V operational gain control range of the SSM2018T. To cover the operating gain range fully and not exceed the maximum specified power supply rating requires the O1 output of AD8802/AD8804 to be level shifted down. In Figure 28, the level shifting is accomplished by a Zener diode and 1/4 of an OP420 quad op amp. For applications that require only

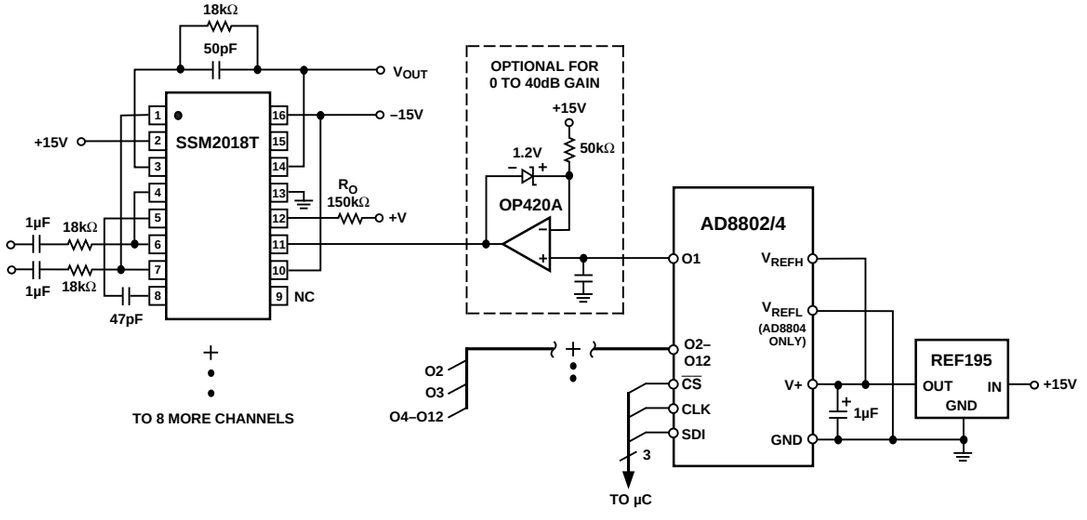


Figure 28. 12-Channel Programmable Voltage Controlled Amplifier

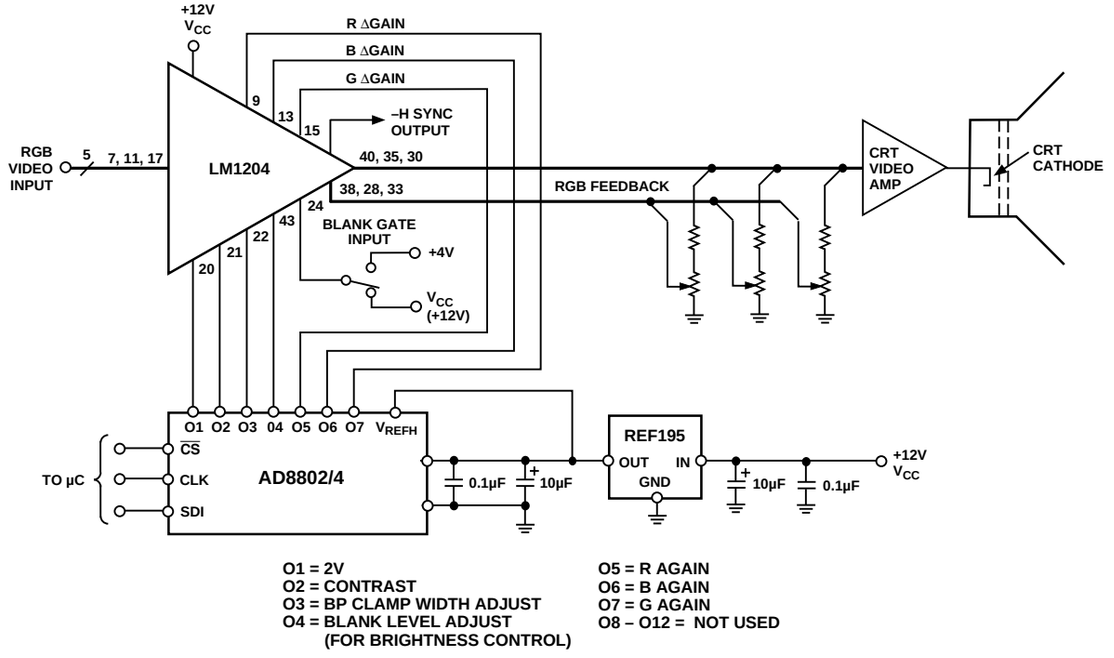


Figure 29. A Digitally Controlled LM1204—150 MHz RGB Amplifier System

attenuation the optional circuitry inside the dashed box may be removed and replaced with a direct connection from O1 of AD8802/AD8804 to Pin 11 of SSM2018T.

When high gain resolution is desired, V_{REFH} and V_{REFL} may be decoupled from the power rails and shifted closer together. This technique increases the gain resolution with the unfortunate penalty of decreased gain range.

A Digitally Controlled LM1204 150 MHz RGB Amplifier System

The LM1204 is an industry standard video amplifier system. Figure 29 illustrates a configuration that removes the usual seven level setting potentiometers and replaces them with only one IC. The AD8802/AD8804, in addition to being smaller and more reliable than mechanical potentiometers, has the added feature of digital control.

The REF195 is a 5.0 V reference used to supply both the power and reference voltages to the AD8802/AD8804. This is possible because of the high reference output current available (30 mA typical) together with the low power consumption of the AD8802/AD8804.

A Low Noise 90 MHz Programmable Gain Amplifier

The AD603 is a low noise, voltage-controlled amplifier for use in RF and IF AGC systems. It provides accurate, pin selectable gains of –11 dB to +31 dB with a bandwidth of 90 MHz or +9 dB to +51 dB with a bandwidth of 9 MHz. Any intermediate gain range may be arranged using one external resistor between Pins 5 and 7. The input referred noise spectral density is only 1.3 nV$\sqrt{\text{Hz}}$ and power consumption is 125 mW at the recommended ±5 V supplies.

The decibel gain is "linear in dB," accurately calibrated, and stable over temperature and supply. The gain is controlled at a high impedance (50 MΩ), low bias (200 nA) differential input; the scaling is 25 mV/dB, requiring a gain-control voltage of only 1 V to span the central 40 dB of the gain range. An overrange and underrange of 1 dB is provided whatever the selected range. The gain-control response time is less than 1 µs for a 40 dB change. The settling time of the AD8802/AD8804 to within a ±1/2 LSB band is 0.6 µs making it an excellent choice for control of the AD603.

The differential gain-control interface allows the use of either differential or single-ended positive or negative control voltages, where the common-mode range is –1.2 V to 2.0 V. Once again the AD8802/AD8804 is ideally suited to provide the differential input range of 1 V within the common-mode range of 0 V to 2 V. To accomplish this, place V_{REFH} at 2.0 V and V_{REFL} at 1.0 V, then all 256 voltage levels of the AD8804 will fall within the gain-control range of the AD603. Please refer to the AD603 data sheet for further information regarding gain control, layout, and general operation.

The dual OP279 is a rail-to-rail op amp used in Figure 30 to drive the inputs V_{REFH} and V_{REFL} because these reference inputs are low impedance (2 kΩ typical).

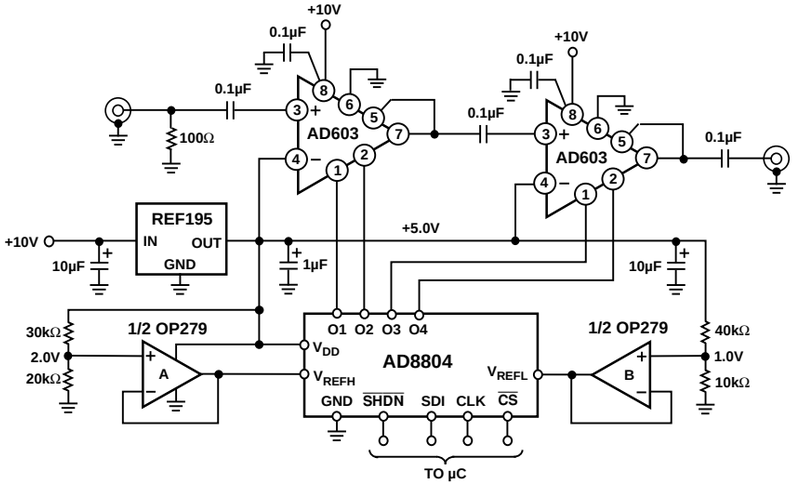
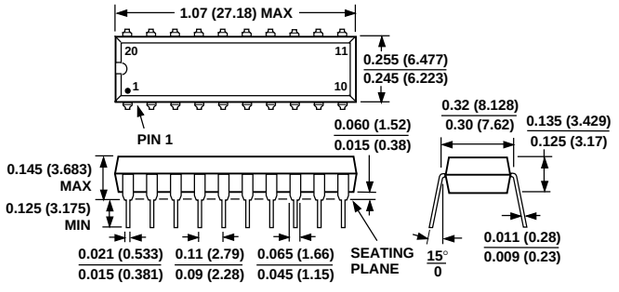


Figure 30. A Low Noise 90 MHz PGA

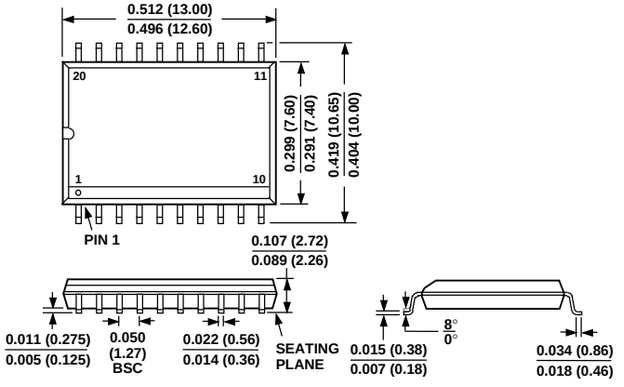
OUTLINE DIMENSIONS

Dimensions shown in inches and (mm)

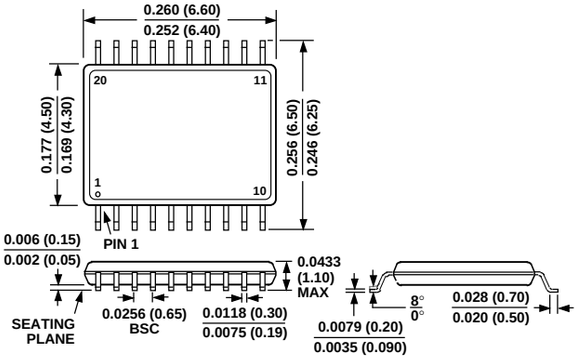
20-Pin Plastic DIP Package (N-20)



20-Lead SOIC Package (R-20)



20-Lead Thin Surface Mount TSSOP Package (RU-20)



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