ANALOG DEVICES

AN-314
APPLICATION NOTE

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14-Bit DACs Maintain High Performance Over Extended Temperature Range

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INTRODUCTION

As circuit designers look for higher performance d/a converters in instrumentation and control applications, the AD7534/AD7535 14-bit DACs from Analog Devices offer the unique combination of low power consumption and high performance over the full temperature range. What makes this possible is a proprietary low leakage configuration which keeps output leakage current very low even at high temperatures. Consequently, linearity error and gain error are much less susceptible to temperature drift. This application note shows that the devices work very well even when operated above their specified temperature range. Test results are given for devices at 200°C. To show that reliable operation is maintained at this high temperature a 1000 hour life test was carried out at 200°C. Results of this life test and a failure analysis are presented. Though the 200°C results are impressive, Analog Devices does not guarantee performance outside the specified temperature range. However, the results give an indication of the exceptional reliability of the devices in the range up to 125°C and also show the consistency of important specifications up to 125°C and beyond.

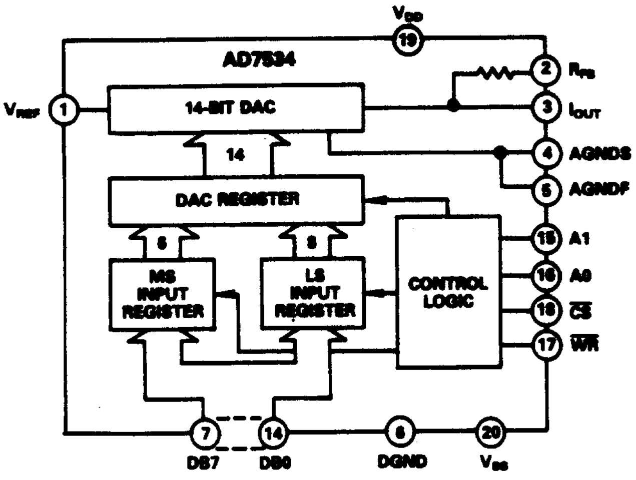

Figure 1. AD7534 Block Diagram

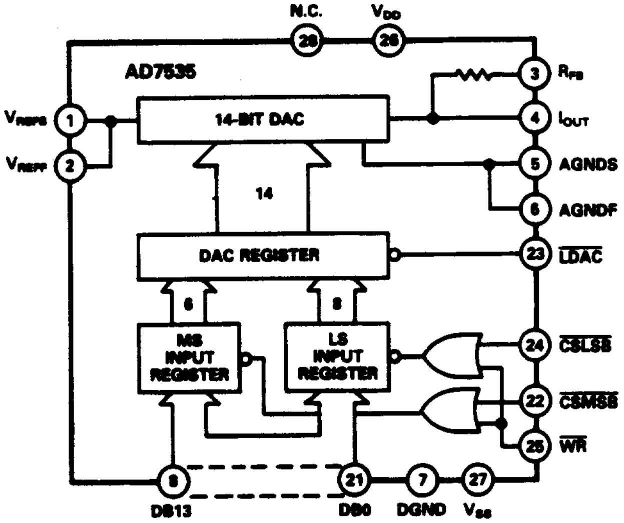

Figure 2. AD7535 Block Diagram

LOW LEAKAGE CONFIGURATION IN AD7534/AD7535

Leakage current in CMOS DACs has two components:

1. Leakage from the V_{DD} supply to the I_{OUT} terminal. This is independent of input code.
2. Leakage from the R-2R ladder through off-switches. This is a maximum for all zeros at the input and is a minimum with all ones at the input, i.e., all switches on.

To eliminate this leakage current flowing into the I_{OUT} line, the AD7534/AD7535 uses a novel configuration (patent pending). By holding the V_{SS} pin at $-0.3V$ through a simple resistor divider (see Figure 3), the leakage current is virtually eliminated. This means that any leakage current effects on linearity and gain error (usually significant above 100°C) are also eliminated.

If V_{SS} is held at 0V instead of $-0.3V$, the device will exhibit all the normal specifications degradation due to leakage. Figure 4 is a typical linearity plot of a device at 125°C, showing the effect of V_{SS} on end-point linearity.

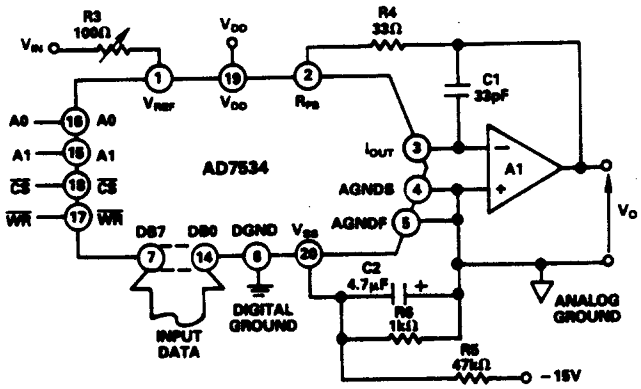

Figure 3. Unipolar Binary Operation of the AD7534

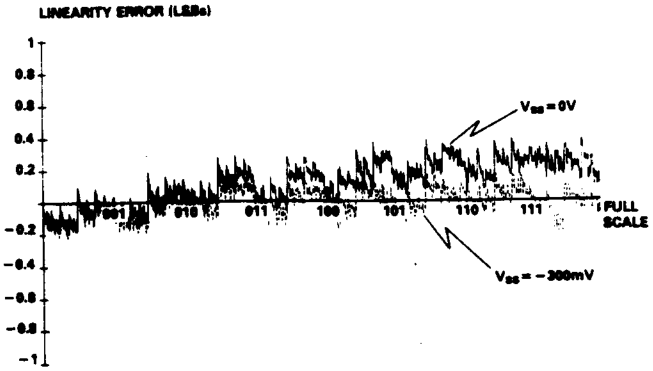

Figure 4. Effect of V_{SS} on Ad7534/AD7535 Linearity at 125°C

OPERATION AT VERY HIGH TEMPERATURES

With its excellent performance up to 125°C, and its special low leakage configuration, the AD7534/AD7535 should be considered for very high temperature operation (i.e., in the 200°C region). Before looking at the performance level at such a high temperature, it has to be realized that several factors will influence the device reliability.

1. Chemical interaction on the surface of the die can be a hazard at high temperatures. This can result in wire bond strength degradation. To ensure that this degradation did not occur with the AD7534/AD7535, a wire bond pull strength test was conducted after the high temperature life testing.
2. The aging rate of a device approximately doubles for every 10°C rise in T_J (junction temperature). The fact that the AD7534/AD7535 DACs are in CMOS is a major advantage in this respect. Table I is a comparison of the AD7534/AD7535 with a typical bipolar DAC, which has a much higher power consumption. At 200°C, T_J for the bipolar DAC exceeds that for the AD7534/AD7535 by 20°C. Thus, its life expectancy is considerably less.

In order to establish a good confidence level for 200°C operation, 7 devices were tested at the elevated temperature. Figures 5 to 8 are a record of these results.

The graph of Figure 5 shows how leakage current increases dramatically above 100°C with $V_{SS} = 0$. When $V_{SS} = -300mV$, there is a significant improvement, with leakage at 200°C limited to 10nA. The effects of leakage on

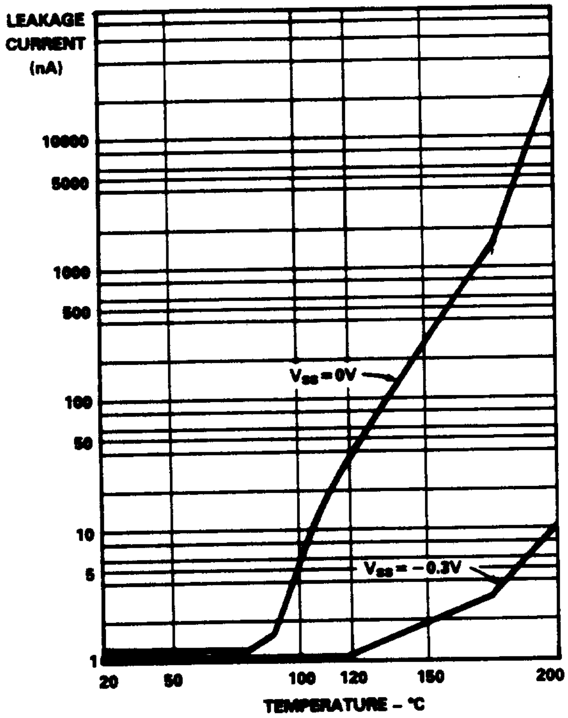

Figure 5. Leakage Current vs. Temperature for AD7534/AD7535

DEVICE	AD7534	AD7535	TYPICAL BIPOLAR DAC
Package	20-Pin Side Braze	28-Pin Side Braze	24-Pin Side Braze
θ_{ja}	80°C/W	60°C/W	65°C/W
P (Typical Power Consumption)	47.5mW	47.5mW	350mW
T_J (T_A + θ_{ja}·P)	203.8°C	202.8°C	222.7°C

Table I. Comparison of Junction Temperatures for T_A (Ambient Temperature) of 200°C linearity error and gain error are reflected in Figures 6 and 7. Without the low leakage configuration ($V_{SS}=0$) the magnitude of the linearity and gain errors make the parts unusable. By using the low leakage facility, typical linearity error is less than 1LSB and typical gain error is less than 2LSBs.

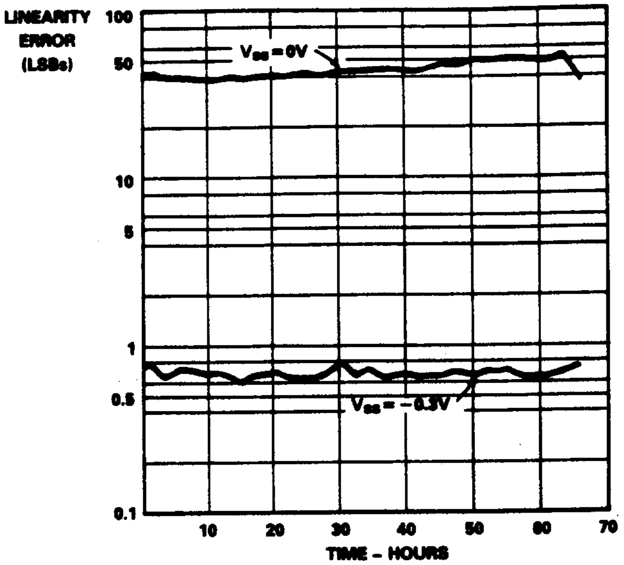

Figure 6. Linearity at 200°C

The stability of the devices over 65 hours of continuous operation is impressive. Linearity drift during this time is ±0.1LSBs while gain error drift is ±0.3LSBs. Linearity stability with temperature is shown in Figure 8. This is a typical all-codes linearity plot for the AD7534/AD7535 at two temperatures; 25°C and 200°C. Linearity error is well within 1LSB over the extended temperature range.

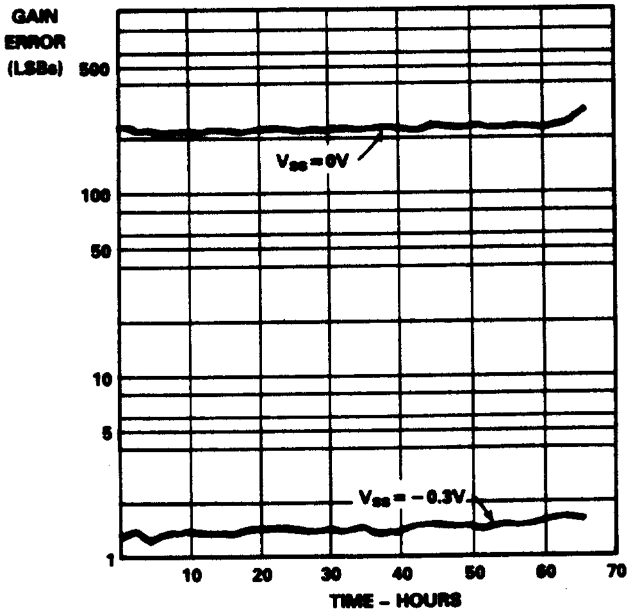

Figure 7. Gain Error at 200°C

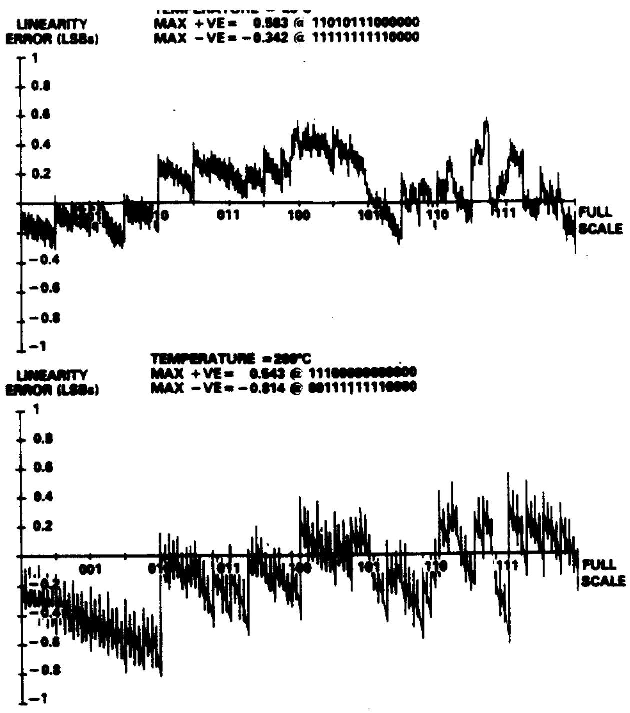

Figure 8. All-Codes Linearity Plot for the Same Unit (AD7534) at 25°C (Top) and 200°C (Bottom)

LIFE TEST

The initial operation and testing of seven devices at 200°C for 65 hours gives a good indication of device functional performance. However, at this high temperature, the devices age much faster and may exhibit some temperature-related failure. To examine the reliability of the AD7534/

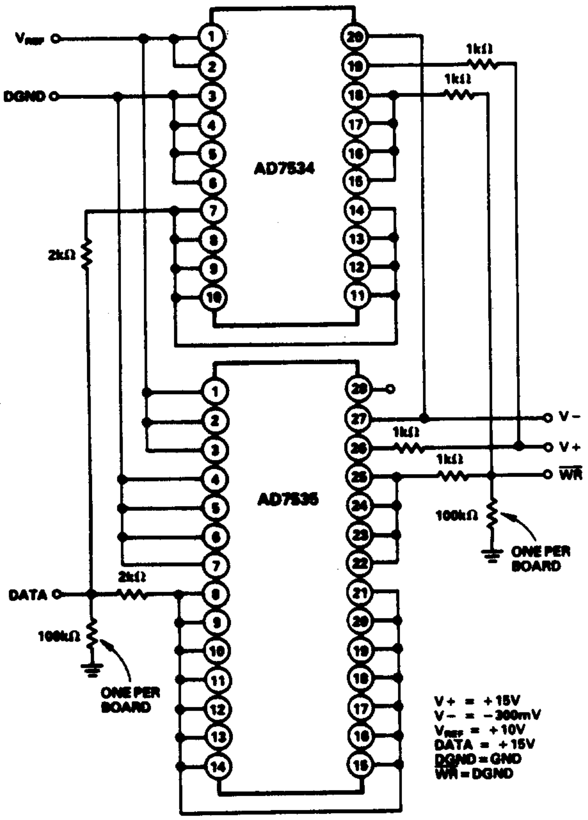

Figure 9. AD7534/35 200°C Burn-In Diagram

AD7535 at 200°C, a sample of the devices was subjected to a 200°C, 1000-hour life test. This sample contained devices taken from 2 separate production lots for each model. The life test required a special high temperature burn-in board, made from a glass polymide material. The resistors, sockets and solder used on the board had to be capable of withstanding 200°C. The life test was conducted with the devices powered up and voltage levels applied as in Figure 9.

There was a parallel life test carried out at 125°C to correlate failures. Parts from the same production lots were used in both tests. If a lot-related failure occurred at 200°C, it could be verified in the 125°C life test.

	T = 125°C				T = 200°C			
	AD7534		AD7535		AD7534		AD7535	
Initial Sample	30		29		28		24	
After 72 hrs	Pass 30	Fail 0	Pass 29	Fail 0	Pass 28	Fail 0	Pass 24	Fail 0
After 142 hrs	Pass 30	Fail 0	Pass 29	Fail 0	Pass 28	Fail 0	Pass 24	Fail 0
After 333 hrs		–		–	Pass 28	Fail 0	Pass 22	Fail 2
After 500 hrs	Pass 30	Fail 0	Pass 28	Fail 1	Pass 28	Fail 0	Pass 22	Fail 0
After 732 hrs	Pass 30	Fail 0	Pass 28	Fail 0	Pass 28	Fail 0	Pass 21	Fail 1
After 1000 hrs	Pass 30	Fail 0	Pass 28	Fail 0	Pass 27	Fail 1	Pass 21	Fail 0

Table II. Life Test Results

Table II shows the complete life test results. From an initial sample of 28, one AD7534 failed between 732 and 1000 hours at 200°C. The AD7535 failure rate was higher with three failures from an initial sample of 24. At 125°C, the AD7535 failure rate was one as opposed to none for the AD7534's.

FAILURE ANALYSIS

Table II shows that there were no AD7534 failures at 125°C. There was one AD7535 failure after 500 hours, which was due to an isolated masking defect on an aluminium line contacting to a current steering switch in the DAC ladder.

At 200°C, there was one AD7534 life test failure. This was caused by marginal drift outside its linearity specification. Table III charts this drift through life test. The total change of 0.22LSB over the 1000-hour life test is not significant. There were 3 AD7535 failures at 200°C. Two occurred after 333 hours of life test. One of these was as a result of the device being misapplied during testing, causing the bond wire at the AGNDS pin to be blown open and rendering the part unusable. The other device was a linearity failure.

Time (Hrs)	0	72	333	500	732	1000
Linearity Err. (LSBs)	1.82	1.82	1.87	1.87	1.89	2.04
Specification Limit	2LSBs					

Table III. AD7534 Which Failed after 1000 Hours

Probing revealed that the fault was in the DAC MSB latch cell. Both the MSB switches and the decoder were functional. Further failure analysis was inconclusive. There was a further AD7535 failure after 730 hours. This was due to a gate oxide rupture on an N-channel current steering switch. The nature of the 200°C life test failures suggests that there was no special temperature related failure mechanism. They are random failures of the kind normally seen in 125°C life tests.

Of further interest is the way in which certain critical specifications drift through the life test. Table IV shows four of these specifications (I_{DD} at logic level inputs of 0.8V and 2.4V, Linearity Error and Gain Error). The average, $\overline{X}$, and standard deviation, σ, of each sample is given at three stages of life test (0, 500 and 1,000 hours).

Not only that, but it is also possible to compare at a glance the drift at 125°C and 200°C. The figures show that the device specifications examined are very consistent through both the 125°C and 200°C tests.

		AD7534											
		I_{DD} (0.8V) (mA)			I_{DD} (2.4V) (mA)			LIN ERR (LSBs)			GAIN ERR (LSBs)		
		$\bar{X}$	σ	SPEC.	$\bar{X}$	σ	SPEC.	$\bar{X}$	σ	SPEC.	$\bar{X}$	σ	SPEC.
125°C	0 HRS	0.21	0.071	3	0.81	0.241	3	0.10	0.88	2	−1.26	2.2	8
	500 HRS	0.20	0.03	3	0.81	0.243	3	−0.04	0.69	2	−1.0	2.2	8
	1000 HRS	0.20	0.02	3	0.84	0.28	3	−0.09	0.71	2	−1.0	2.1	8
200°C	0 HRS	0.20	0.025	3	0.81	0.226	3	−0.16	0.86	2	−1.8	2.7	8
	500 HRS	0.20	0.026	3	0.81	0.231	3	−0.10	0.86	2	−1.8	2.8	8
	1000 HRS	0.21	0.036	3	0.82	0.22	3	0.15	0.90	2	−1.8	2.8	8

		AD7535											
		I_{DD} (0.8V) (mA)			I_{DD} (2.4V) (mA)			LIN ERR (LSBs)			GAIN ERR (LSBs)		
		$\bar{X}$	σ	SPEC.	$\bar{X}$	σ	SPEC.	$\bar{X}$	σ	SPEC.	$\bar{X}$	σ	SPEC.
125°C	0 HRS	0.31	0.12	4	1.6	0.6	4	0.23	0.40	2	0.8	1.3	8
	500 HRS	0.28	0.086	4	1.6	0.67	4	0.19	0.40	2	1.13	1.36	8
	1000 HRS	0.32	0.13	4	1.4	0.8	4	0.15	0.51	2	0.98	1.38	8
200°C	0 HRS	0.24	0.046	4	1.5	0.54	4	0.16	0.437	2	0.70	1.5	8
	500 HRS	0.24	0.038	4	1.6	0.57	4	0.23	0.41	2	0.76	1.6	8
	1000 HRS	0.24	0.037	4	1.6	0.57	4	0.19	'0.37	2	0.98	1.7	8

Table IV. AD7534 and AD7535 Drift through Life Test

WIRE BOND STRENGTH

To confirm that there was no bond strength degradation during the 200°C life test, a pull strength test was performed on 54 of the wire bonds after the 1000-hour life test. Table V compares the pull strengths obtained after the 1000-hour, 200°C life test with those obtained after a standard 1000-hour, 125°C life test. As can be seen, there is no substantial difference between both sets of figures. In fact, in this particular case, the 200°C figures are better than those for 125°C, and confirm that no bond strength degradation took place.

Pull Strength after 1000 hours (grams)			
125°C		200°C	
$\bar{X}$	σ	$\bar{X}$	σ
8.1	0.79	8.9	0.63

Table V. Wire Bond Strength Comparison

CONCLUSIONS

The AD7534 and AD7535 offer excellent high temperature performance. This is due to the novel low leakage configuration which minimizes leakage current. The 200°C operation of the devices demonstrates clearly how effective the configuration is. In addition, the life test data at 200°C shows that there is no apparent extra failure mechanism. The experimental results (both functional and life test) should be taken as a measure of exceptional device performance and reliability over the specified temperature range (−55°C to +125°C).