Proton Testing of the AD8151 Cross-Point Switch

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1. Device Description

The AD8151 Digital Crosspoint Switch manufactured by Analog Devices Inc. is capable of switching 33 inputs to 17 outputs. Because of its low power and high speed, it has potential applications in space. The maximum data rate through the switch is 3.2 Gb/s per port. The part is manufactured using CMOS/TTL technology and supports either ECL or PECL signal levels. All inputs and outputs are differential, requiring two lines for each input and each output. The inputs are connected to the outputs by programming the addresses of all the desired connections (crosspoints) into the first of two latches. After all the connections have been stored in the first latch, the data are ready to be transferred to the second latch. Once in the second latch, the data describing the connections are passed through input decoders to the 17x33 switch matrix. For testing, the manufacturer provided a part mounted on an evaluation board together with software for programming the switch, i.e., for setting the connections between the 33 inputs and the 17 outputs. Fig. 1 shows the functional block diagram of the AD8151.

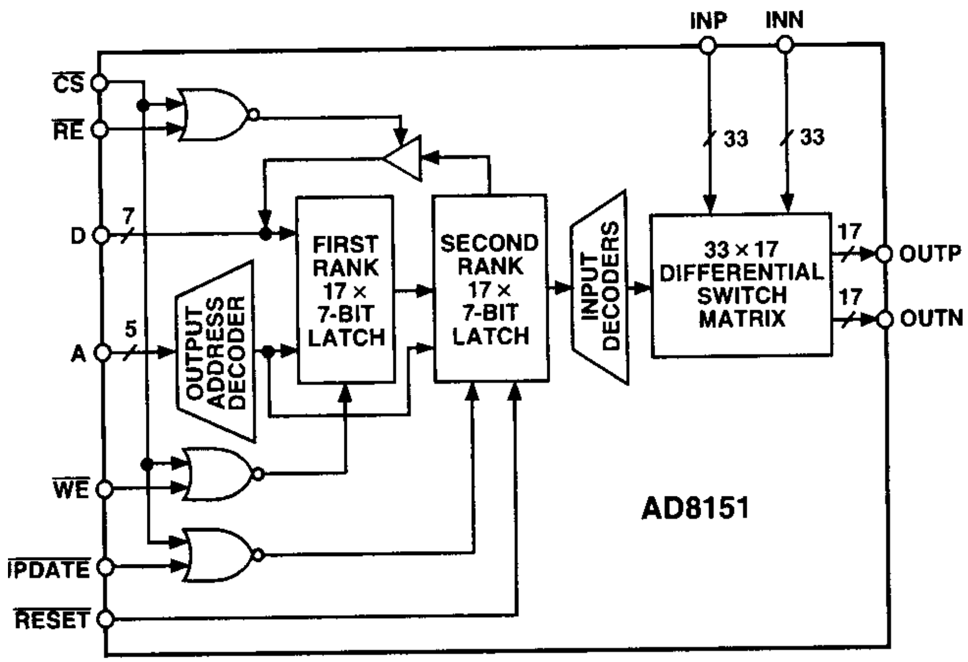

Fig. 1. Functional block diagram of the AD8151.

2. Aim of Testing

The aim of the proton testing was to assess the switch's sensitivity to single-event effects (SEEs) and to total ionizing dose (TID). A single part was tested at Crocker Nuclear Laboratory using 63 MeV protons. SEEs were manifest either by incorrect data appearing at the output of the switch, termed single-event transient (SET), or by a loss of synchronization (LOS), termed a single-event functional interrupt (SEFI). The degree of

TID damage was related to changes in the operating current (I_V_{ee}), which was continuously monitored during exposure and by the degradation of signal quality.

3. Test Setup

A bit error-rate tester (BERT) was used for SEE testing of the switch. The BERT supplied a stream of data to the switch input. The output of the switch was fed back to the BERT and compared with the input. Any differences were flagged as SETs. The signals supplied by BERT were 0.3 V peak-to-peak, NRZ, with an offset of -0.15 V. The data rate could be varied. High performance cables were used for connecting the outputs to the inputs and for connecting the switch to the BERT's.

The switch was programmed using the software supplied by the manufacturer. Two different matrix configurations were used. In the first the data stream passed from an input to an output through a single path defined by a single point connection in the matrix. In the second the data was passed through the switch five times by connecting outputs with inputs and setting five different internal matrix connections. The longer path length meant that there were more possibilities for SETs generated within the switch matrix as well as more sites in the latch that could lead to SEFIs, or loss of synchronization (LOS) as the path continuity is disrupted. In the case where the signal passed through five switches, the contributions of the switch matrix to the SEE cross-section should increase by a factor of five. So should the contributions to SEFIs caused by SEUs in the latch. Fig. 2 shows the switch configuration for the case where the signal passes five times through the switch. The path is as follows: BERT(out) ? 10(in) ? 16(out) ? 2(in) ? 14(out) ? 20(in) ? 0(out) ? 26(in) ? 2(out) ? 30(in) ? 10(out) ? BERT(in).

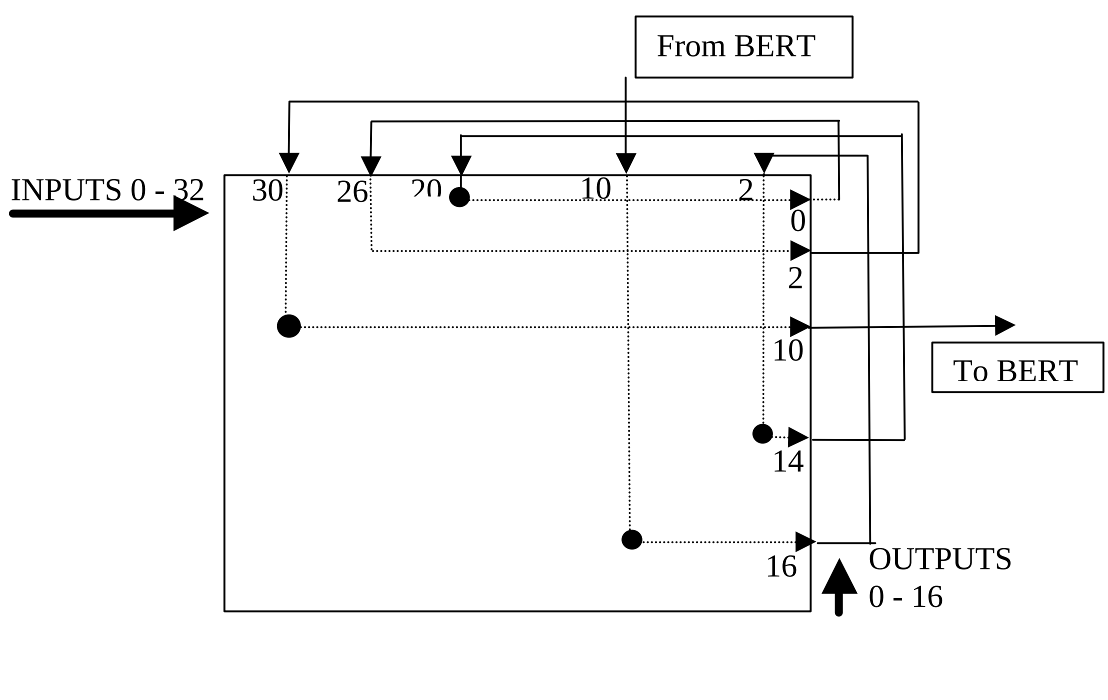

Fig. 2. Connections in the matrix connecting the inputs to the outputs.

4. Test Results

a. Single –Event Effects

Table 1 shows the SEE results for 16 different runs. "Paths" refers to the number of times the data passes through the switch, either once or five times. "Data Rate" is the rate (in MHz) at which BERT supplies data. "LOS" is the number of losses of synchronization, each loss being equivalent to a SEFI. "Errors" are the total number of errors detected by the BERT. "Burst" is a series of SETs associated with a single event. "Events" is the sum of the number of bursts and the number of singles. For instance, in run #3 the sequence of SETs read by BERT were:

3, 5, 6, 7, 8, 9, 12, 14, 17, 18, 19, 20, 21

The total number of errors recorded was 21.
The number of bursts is 5, i.e. 1 – 3, 3 – 5, 9 – 12, 12 – 14, 14 - 17.
The number of events (13) is the number of bursts (5) plus the number of singles (8) plus the number of synchronization losses (0 for this run).

Table I. Summary of SEE data.

Run #	Paths	Fluence (cm^{-2})	Data Rate (MHz)	LOS	Errors	Bursts	Events	S_{SEE} (cm^2)
1	1	1.00E+10	1,000	0	0	0	0	0.00E+00
2	1	1.00E+11	1,000	0	23	0	6	2.30E-10
3	5	1.00E+11	1,000	0	56	0	0	5.60E-10
4	5	1.00E+11	1,000	0	21	5	13	2.10E-10
5	1	1.00E+11	1,000	0	27	5	12	2.70E-10
6	1	1.00E+11	3,200	1	108	7	13	1.08E-09
7	4	4.98E+10	3,200	0	X	X	X	X
8	1	3.38E+10	320	1	0	0	1	0.00E+00
9	1	1.00E+11	320	0	4	0	4	4.00E-11
10	5	1.00E+11	3,200	0	10	1	8	1.00E-10
11	5	3.60E+10	1,600	1	7	0	8	1.94E-10
12	5	1.76E+10	3,200	1	11	2	7	6.25E-10
13	5	1.00E+11	3,200	0	84	14	35	8.40E-10
14	5	1.00E+11	3,200	0	21	4	13	2.10E-10
15	5	1.00E+11	3,200	1	36	5	23	3.60E-10
16	5	1.00E+11	3,200	0	47	6	23	4.70E-10

The table shows that:

- Except for the first run, each run was stopped either when the fluence reached 1.00+E11 particles/cm^2 or when a SEFI occurred. The last column is the cross-section for the total number of errors listed in column 6.

- Four different data rates were selected (3.2 Gbps, 1.6Gbps, 1 Gbps and 0.32 Gbps) to see whether the error rate depended on data rate (clock). There is some indication of a frequency-dependent effect because the cross-section increases from 4.0E-11 cm^2 at 320 MHz (run #6) to 1.08E-9 cm^2 at 3200 MHz (run #9).
- There appears to be very little dependence of the error rate on number of paths as evidenced by the cross-sections measured for run #4 with 5 paths and for run #5 with 1 path. The cross-section increases with a decrease in path length from 2.1×10^{-10} cm^2 for 5 paths to 2.7×10^{-10} cm^2 for 1 path.
- The BER is the defined as the total number of errors divided by the total number of bits transmitted. For run # there were 23 errors and the total amount of data sent was 10^9 bps multiplied by 117 seconds which is a bit error-rate of 1.97×10^{-10} bit errors per second.
- The origins of the error bursts vs single bit errors could not be determined.
- During run #7 errors occurred after the beam was turned off due to TID so the results are invalid.

b. Total Ionizing Dose

The effects of TID were manifested through an increase in the supply current I_V_{ee} and through functional failure. Table II shows the effects of TID on I_V_{ee}. The value of I_V_{ee} increases with the number of paths through the switch, as expected. So the increase in I_V_{ee} from run #2 to run #3 is due partly to an increase in the operating current as a result of radiation exposure, but mostly to the different configuration in which the signals passed through the switch five times. As a result, I_Vee could only be plotted as a function of TID for those configurations that were the same (denoted by * in the table). The leakage current I_V_{ee} depends on the number of paths activated but not on the data rate.

Table II. Summary of TID data.

Run	I_Vee(mA)	TID (rads(Si))
1	77*	1.35E+03
2	77*	1.48E+04
3	158	2.83E+04
4	165	4.18E+04
5	88*	5.53E+04
6	99*	6.88E+04
7	169	7.55E+04
8	101*	8.01E+04
9	117*	9.35E+04
10	214	1.07E+05
11	216	1.12E+05
12	217	1.14E+05
13	224	1.27E+05
14	143*	1.41E+05
15	146*	1.54E+05
16	160*	1.68E+05

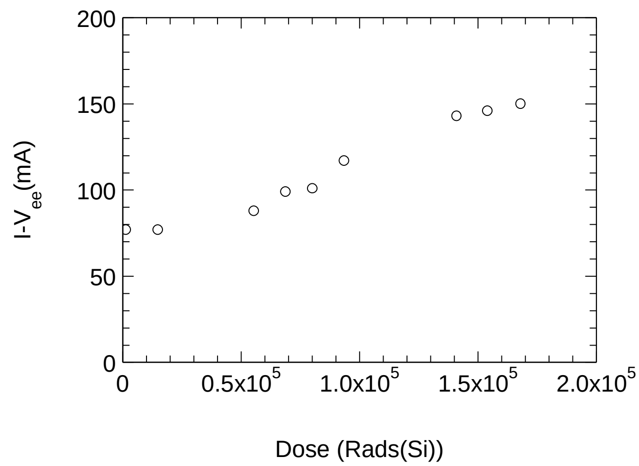

Fig. 3. Increase in operating current I_V_{ee} as a function of TID.

The other manifestation of TID is through the limiting of the signal's path length through the switch for error-free operation. After a TID of about 70 krad(Si) the switch no longer operated properly with a configuration of 5 paths and a data rate of 3.2 Gbps. However, when the path length was reduced from 5 to 4 passes through the switch, error-free operation resulted. After a TID of 114 Krad(Si) (run#14) the part could not be operated error free. To rectify the problem, the delay in the window (time during which data is read by BERT) was adjusted and error-free operation in the absence of radiation was re-established. The delay continued to drift with dose and required repeated adjustment. No attempt was made to see whether part of the TID damage annealed with time.

The chip has the capability for reading back the data from the second rank of latches, i.e., those determining the matrix switch configuration. This feature could be used to read back the matrix configuration following a loss of synchronization to determine the origin of the LOS. Unfortunately, the evaluation board did not have that feature as the drivers operated in only one direction. Therefore, it was not possible to know for sure where the LOSs originated.

5. Conclusions

The AD8151 was tested for SEE and TID sensitivity using protons. There were two types of SEEs – data errors that we classified as SETs and losses of synchronization we classified as SEFIs. The error rate depended on data rate but showed very little dependence on the number of paths through the switch. Degradation in the performance of the switch was noticed at about 70 krad(Si) and the operating current increased with dose up to 168 krad(Si). At that level of TID the part still operated, but with reduced performance as evidenced by repeated adjustment of the delay in the window to obtain error-free operation in the absence of radiation.