Single Event Effects and Total Dose Test Results for TI TLK2711 Transceiver

R. Koga, Member, IEEE, P. Yu, and J. George

Abstract— TLK2711 transceivers belonging to the Class V dice manufactured by Texas Instruments were tested for their sensitivity to radiation. We measured single event effects as well as total ionizing dose effects.

I. INTRODUCTION

VARIOUS types of COTS transceivers have been examined for their sensitivity to radiation [1]-[4]. The sensitivity may encompass bit errors as well as total ionizing dose effects. Recently, we carried out radiation testing of the Class V TLK2711 transceiver. Testing took place at the Lawrence Berkeley Laboratory (LBL) 88-inch cyclotron facility, the Radiation Effects Facility at TAMU, and the Indiana University Cyclotron Facility (IUCF). We utilized protons at LBL and IUCF, while heavy ions were made available at TAMU and LBL. Samples of heavy ions used for testing are shown in TABLE 1. Radiation tests are made up of (1) SEU (single event upset)/SEL (single event latchup) testing with protons, (2) SEU/SEL testing with heavy ions, and (3) total ionizing dose (TID) testing with 50 MeV protons.

TLK2711 is a 1.6 to 2.7 Gb/s transceiver (XCVR) manufactured by Texas Instruments [5]. It is also called a Serializer/Deserializer (SERDES). Our test samples were a part of the Class V dice. One group of samples was obtained in 2005, while another group of samples was obtained in 2007. A block diagram of TLK2711 is shown in Fig. 1. A device may be configured for a transmitter (TX) or a receiver (RX). It belongs to the TI CMOS (epi) 25C10 technology device may be configured for a transmitter (TX) or a receiver (RX). It belongs to the TI CMOS (epi) 25C10 technology

Table 1
CHARACTERISTICS OF HEAVY IONS

<table>
<thead>
<tr>
<th>Ions</th>
<th>AMU Energy (MeV)</th>
<th>LET (MeV/(mg/cm²))</th>
<th>Range in Si (µ)</th>
</tr>
</thead>
<tbody>
<tr>
<td>B</td>
<td>11</td>
<td>108</td>
<td>0.9</td>
</tr>
<tr>
<td>O</td>
<td>18</td>
<td>185</td>
<td>2.2</td>
</tr>
<tr>
<td>Ne</td>
<td>22</td>
<td>216</td>
<td>3.5</td>
</tr>
<tr>
<td>Ne</td>
<td>22</td>
<td>550</td>
<td>1.7</td>
</tr>
<tr>
<td>Ar</td>
<td>40</td>
<td>400</td>
<td>10</td>
</tr>
<tr>
<td>Cu</td>
<td>63</td>
<td>606</td>
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<td>Kr</td>
<td>86</td>
<td>885</td>
<td>31</td>
</tr>
<tr>
<td>Kr</td>
<td>84</td>
<td>2100</td>
<td>29</td>
</tr>
<tr>
<td>Xe</td>
<td>136</td>
<td>1330</td>
<td>59</td>
</tr>
<tr>
<td>Xe</td>
<td>129</td>
<td>3225</td>
<td>38</td>
</tr>
</tbody>
</table>

Note: Selected ions available at TAMU and LBL are listed.

II. EXPERIMENTAL

Test setups for all of our radiation tests were essentially identical. Each test setup is schematically presented in Fig. 2. Two test samples (one in the transmit mode while the other in the receive mode) were mounted on a PCB (printed circuit board). Both samples were exposed simultaneously during irradiation.
Fig. 1 Block diagram of TLK2711

Fig. 2. TLK2711 XCVR radiation testing setup.
Fig. 3. Picture of test board.

Fig. 4. Eye pattern of the TLK2711 1.6 Gb/s output at pre-rad. level. (200 mV/div and 195 ps/div).
A test system made up of a signal generator and a BERT (bit error rate tester) was placed away from the PCB. A photo of the PCB is shown in Fig. 3. A thermistor to monitor the case temperature may be adhered with epoxy for each device on some PCBs. Signals (single-ended RX input 210-230 mV; ref. to $V_{ID}$, which is the “receiver input voltage differential”) from the test system were led to the receiver on the PCB [5]. The parallel 8b data and the receiver clock signal were directed from the receiver to the transmitter on the board. The transmitter output (serial/differential 10b encoded data) was checked for upsets at the BERT. This made it possible for a real-time BER testing at a 2.5-Gb/s serial link rate. The serial link transmitted a continuous flow of packets each of which consisted of a 4-byte preamble and a 4096-byte frame followed by a 24-idle-byte string (24-byte long). Within one frame (4096 bytes) two bytes were used for the packet checksum. One byte was made up of one 8-bit word in the parallel domain. The checksum as well as any errors in each 10b word was used to identify upsets (non-burst errors). A burst error (a large number of upsets in the stream of 10b words) could be also detected. A burst error sometimes made it impossible at RX to re-construct the original bit pattern in the packet, and consequently a drop in the packet resulted. Therefore any event that was associated with a lost packet belonged to a sub-set of burst errors. Continuous power-on testing of test samples made it possible to monitor device bias current in real-time. This information could be used for latchup detection. The eye pattern is shown in Fig. 4 for pre-irradiation sample obtained in 2007. $V_{OD}(ppp)$ [differential, peak-to-peak output voltage with low pre-emphasis] is about 1,360 mVp-p. Jitter, which may be a result of a random variation in timing, etc, may be observed. The differential output signal rise ($t_r$) and fall ($t_f$) times are less than about 150 picoseconds.

III. RESULTS AND DISCUSSION

A. Proton Induced SEU/SEL Sensitivity

50 MeV protons at LBL as well as higher energy ones at IUCF were used to measure SEU/SET (single event upsets/single event transients) and single event latchup (SEL). Some upsets were made up of a one-bit error (or a few-bit errors in some cases) in the stream of 10b words as detected by the BERT (please see Fig. 2.) We call these bit errors. The other type consisted of events with many upset bits (often larger than 100 bits, but normally less than about 1000 bits) in the stream of 10b words. We call these burst errors. Proton induced upsets are shown in Fig. 5. The tests were carried out with test samples obtained in 2007. Bit error cross-sections are shown with black diamonds, while burst error cross-sections are shown with white squares. The cross-sections for burst errors were consistently larger than those for bit errors. It should be noted again that the number of bits in one burst is numerous. The cross-sections for upsets were measured while the two test samples (RX and TX) were irradiated simultaneously (thus, “set” in the vertical axis). We used several sets of devices for this group of tests. We did not expose the devices with protons with lower energies than 50 MeV. No SEL was detected. The upset cross-sections were obtained with the serial link of 2.5-Gb/s. Taking the number of transmitted bits in the system into consideration, we have calculated BERs for bit-error cross-sections as shown in Fig. 6.

![Fig. 5. Proton upset test results for TLK2711 XCVR. Test samples were obtained in 2007.](image1)

![Fig. 6. Proton induced BER. Test samples were obtained in 2007.](image2)

BER often depends on the bit rate with respect to the particle (e.g., proton) flux. An example of this phenomenon is shown in Fig. 7 for an ATTDA215B transmitter (silicon bipolar PECL device for fiber channel communication) operated at 1 Gb/s rate. BERs tend to increase (often drastically) when the
transmission rate reaches the critical point with respect to the particle flux. During data collections we have paid attention to the existence of micro pulsation of the beam flux. At LBL, for example, the pulse width is about a few nanoseconds every several tens of nanoseconds. At flux values close to what we utilized, the micro pulsation has minimum effect on our measurements. Test samples obtained earlier (~2005) showed similar responses to proton irradiations. The SEE sensitivity is shown in Fig. 8. The number of bit errors was comparable (within a factor of two) to that of burst errors. The upset cross-sections were obtained with the serial link of 2.5-Gb/s. Taking the number of transmitted bits in the system into consideration, we have calculated BERs for bit-error cross-sections. Relevant BER for these results are shown in Fig. 9. BER in Fig. 9 seems comparable to that in Fig. 6.

The cross-sections were measured while the two test samples (RX and TX) were irradiated simultaneously (thus, "set" in the vertical axis). We used two devices (SN9 and SN12 obtained in 2005) for this group of tests. No SEL was

B. Heavy Ion Induced SEU/SEL Sensitivity

Heavy ions were used to measure SEU and SEL sensitivity of the transceiver to these ions available at TAMU and LBL. As in the protons’ cases, some upsets were made up of a one-bit error (or a few-bit errors in some cases) in the stream of 10b words as detected by the BERT (please see Fig. 2.) We again call these bit errors. The other type consisted of events with many upset bits (often larger than 100 bits, but normally less than 1000 bits) in the stream of 10b words. We again call these burst errors. The number of burst errors consistently was larger than that of bit errors for each irradiation, as shown in Fig. 10.

The cross-sections were measured while the two test samples (RX and TX) were irradiated simultaneously (thus, "set" in the vertical axis). We used two devices (SN9 and SN12 obtained in 2005) for this group of tests. No SEL was
detected. For SEL tests with these samples the case temperature was about 60 degrees (Centigrade), while the fluence was about $1 \times 10^6$ particles/cm$^2$ at the LET value of 60 MeV/(mg/cm$^2$). In order to extend SEL testing range, we plan to test samples obtained in 2007 at higher temperatures with increased values of fluence. No LOS was detected during irradiation.

C. Total Ionizing Dose Sensitivity

1) BER vs. TID

TID sensitivity was measured for SN1 (obtained in 2005) while observing the functionality of the test samples as well as BER. BER is defined as the ratio of the number of upset bits to the number of transmitted bits as defined before [8]. We used only non-burst errors for this analysis. (An analysis that involves burst errors is shown below in section C-2.) The flux of the 50 MeV proton was about 5.5 rd (Si)/sec. We applied a 20 krad (Si) of dose, and measured degradation of the sample before applying additional 20 krad (Si). For each 20 krad (Si) of dose (during which about $3 \times 10^8$ packets were compared), we measured the number of upsets. No upsets were observed except for the 100 krad (Si) window as shown in Fig. 11. TID effects were observed when the TID was between 120 and 140 krad (Si). This was characterized by the functional degradation of the transceiver as well as eye pattern measurements. No major bias current change took place. For another sample obtained in 2007, no measurable TID effects were detected at 140 krad (Si). An eye pattern measurement was taken as shown in Fig. 12. $V_{pp}$ [differential, peak-to-peak output voltage with low pre-emphasis] is 1,340 mVp-p. Jitter, which may be a result of a random variation in timing, etc, may be observed. The differential output signal rise ($t_r$) and fall ($t_f$) times are less than 150 picoseconds.

2) The Number of Dropped Packets vs. TID

TID sensitivity was measured for SN1 obtained in 2005 while observing the number of dropped packets. A burst error sometimes made it impossible to re-construct the original bit pattern in the packet, and consequently a drop in the packet resulted. Therefore any event that was associated with a dropped packet belonged to a sub-set of burst errors. We used only burst errors for this analysis. During this run all burst errors ended up in a dropped packet. (An analysis that involves non-burst errors is shown above in section C-1.) The flux of the 50 MeV proton was about 5.5 rd (Si)/sec. For each 20 krad (Si) of dose (during which about $3 \times 10^8$ packets were compared), we measured the number of dropped packets as shown in Fig. 13. TID effects were observed when the TID was between 120 and 140 krad (Si). This was characterized by the functional degradation of the transceiver as well as eye pattern measurements. No major bias current change took place.

IV. Conclusion

The Class V TLK2711 devices were tested for single event effects as well as proton induced total dose effects. Single event upsets are made up of two types of errors: (1) one-bit error (or a few-bit errors in some cases) in the stream of 10b words and (2) a burst of errors with many upset bits in the stream of 10b words. A burst of errors sometimes made it impossible to re-construct the original bit pattern in the packet and consequently a drop in the packet resulted. The proton induced total dose limit was beyond 100 krad (Si). This is based on results including (1) functional and (2) eye pattern measurements. (We have not included parametric test results with gamma ray irradiation.) These results show that this device type is less sensitive to SEU effects for both heavy ions and protons than some device types of the previous generation (e.g., ATTDA215B). No single event latchup was detected up to the LET value near 60 MeV/(mg/cm$^2$). Devices such as VSC7216 (fiber optic transceiver) and TI SN65LVDS95/96 (LVDS SERDES transmitter) have shown to be SEL immune at this LET range (Sept, 2000 testing with VSC7216 and May 2007 testing with SN65LVDS95/96) [9,10]. We plan to test for SEL with TLK2711 beyond this LET range in the near future. No LOS was detected during irradiation.
Fig. 12. Eye pattern of the TLK2711 1.6Gb/s output after 140 krd (Si) radiation. (200 mV/div and 195 ps/div).

Fig. 13. The number of dropped packets vs. TID for TLK2711 XCVR. Test sample was obtained in 2005.

V. REFERENCES