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Qualification Report

NGK Insulators Ltd

Back-End Opto-transceiver Modules (TRx)

Internal Report

CMS-TK-TR-0030

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Document History			**Distribution**
Created	–	03/11/2003	F.Vasey, K.Gill, E.Noah (CERN)
Last Revision	–	30/10/2003	M.Sugiyama (NGK Insulators Ltd)
Approved	–		

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1 Qualification programme

This is an internal qualification report for the back-end optoelectronic transceiver modules (TRx) supplied by NGK Insulators Ltd as batch T0 under the terms of CERN Order CD1000973. The qualification procedure consisted of evaluation tests described in "Back-End Opto-transceiver Module (TRx) Test Procedure" (Document ID: CMS-TK-QP-0011).

1.1 Qualification programme workflow

Twenty five transceiver modules were supplied to CERN by NGK. All twenty five modules passed through the test flow shown in Figure 1.

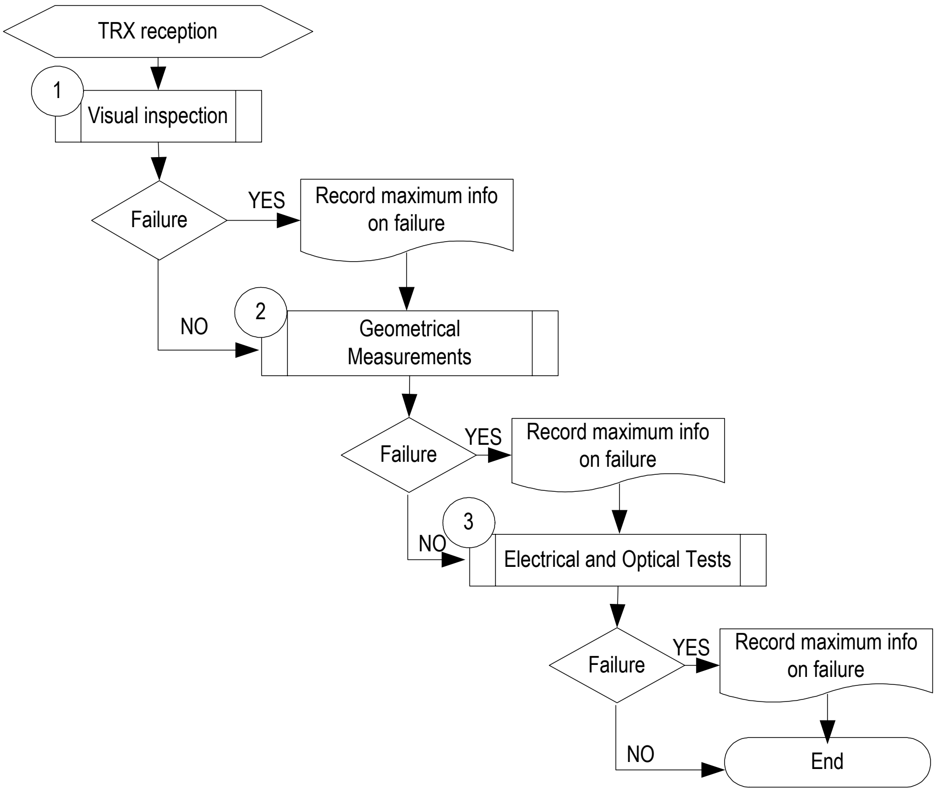

Figure 1: Qualification Flow from CMS-TK-QP-0011

1.2 Qualification programme description

The test procedures described in CMS-TK-QP-0011 were followed unless mentioned in the list below.

- Tx test: The maximum differential input voltage achievable with the test system was ±500mV. Most tests were performed with a differential input voltage of ±400mV which is the specification minimum. The power dissipation test was performed with a ±500mV differential input voltage.
- Rx test: The software methods which discriminate between good and bad Rx response need a clock pattern. A clock pattern was therefore used instead of a pseudo-random bit pattern.
- Bit rate: All tests were performed with a bit rate of 80Mb/s. The specification minimum was tested for a few of devices and was seen to be below 2Mb/s.
- Bit error rate: The bit error rate was not tested.[†]

[†] Previous measurements of the bit error rate yielded a value below $3x10^{-13}$ for the full digital link system. [A.M.Sandvik et al., *80Mbit/s Digital Optical Links for Control, Timing and Trigger of the CMS Tracker*, Proceedings of the Eighth Workshop on Electronics for LHC Experiments, CERN/LHCC/2002, 2002].

1.3 Notes on the qualification test system

This section discusses briefly a couple of general observations made during the qualification tests which were determined to be related to the test system and which were therefore not characteristic of the TRx modules.

- Eye patterns: The eye patterns show rise and fall edge features related to the non-optimised termination of the TRx output cabled to the oscilloscope. These features were minimised as much as possible and the resulting patterns were considered good enough to extract parameters of interest such as electrical output amplitude, skew and jitter.
- MPO-MU 12-way fibre: All tests at room temperature were performed with a 12-way MPO-MU fibre with a very rigid ruggedized ribbon cable. Any twist in the cable was transmitted to the MPO connector interface with noticeable consequences on the reproducibility of tests such as the Tx optical modulation amplitude and average launch power test. This should not cause a problem for the CMS control links since the ribbon used will be naked and thus more flexible. A similar ribbon was used during tests performed at operating temperatures between 30 and 70°C.

2 Technical qualification

2.1 Compliance with technical requirements

The samples provided by NGK Insulators Ltd are deemed to meet the technical requirements.

Table 1 shows the specified performance of the TRx modules against which the received samples were tested. The table also gives a summary of the results obtained in comparison with the specifications.

Table 1: Specification test targets taken from the technical specification. Cells in grey indicate parameters not measured during qualification.

#	Specification to be tested	Specifications @ 25°C				CERN Qualification Results		
		min	typ	max	unit	min	max	Qualified?
5.1	Bit Rate	2		80	Mb/s	2	80	YES
5.2	Bit error rate			10^{-12}				
5.3	Skew			1	ns		<1	YES
5.4	Jitter			0.25	ns		<0.25	YES
5.5	Operation rate		4000		hrs/year			
5.11	Number of Tx channels	4				4		YES
5.12	Number of Rx channels	4				4		YES
5.13	Module size	(38.27±0.3)x(30.23±0.3)x(9.5±0.1)			mm	Avg. 38.5x30.25x9.47		YES
5.21	Differential input voltage	±400	±600		mV	±400		YES
5.22	Input impedance		100		Ω			
5.23	Differential output voltage	±600			mV	±809	±932	YES
5.24	Output impedance		100		Ω			
5.25	Power supply	3.1	3.3	3.5	mV	3.1	3.5	YES
5.26	Power dissipation			2	W	0.88	0.91	YES
5.31	Wavelength	1260	1310	1360	nm			
5.32	Average launch power	-13		-3	dBm	-11.8	-6.2	YES
5.33	Optical modulation amplitude	-12		-3	dBm	-11.6	-6.4	YES
5.34	Rx sensitivity			-20	dBm	-27.1	-22.8	YES
5.35	Rx saturation (d.c.)	-4			dBm	-3.7	-2.7	YES
5.36	Optical connector	MPO				MPO		YES
5.51	Operating temperature	0		70	°C		50	YES‡
5.52	Operating humidity			60	%RH			
5.53	Storage temperature	-20		70	°C			
5.54	Reflow temperature			260	°C			

‡ The specifications in table 1 were defined for operation at 25°C, with the exception of specification 5.51, 5.53 and 5.54. The TRx modules operate within these specifications up to a temperature of 50°C, above which, the RX saturation falls below specification.

2.2 Validation test results

2.2.1 Visual Inspection

The visual inspection results are summarised in Table 2. All TRx modules passed the visual inspection test. The height and length of a few modules were recorded to be slightly below specification but this is of no particular concern.

Table 2: Visual inspection results.

Box	Transceiver number	Check for physical damage	Dimensions (mm)			Pin Count (11+21+11)	Channel Count	
			l = 38.27±0.3	w = 30.23±0.3	h = 9.5±0.1		Tx	Rx
1	380001	✔	38.60	30.30	9.40	43	4	4
	380002	✔	38.45	30.20	9.50	43	4	4
	380003	✔	38.55	30.20	9.45	43	4	4
	380004	✔	38.64	30.26	9.48	43	4	4
	380005	✔	38.57	30.23	9.46	43	4	4
	380006	✔	38.52	30.28	9.50	43	4	4
	380007	✔	38.55	30.26	9.50	43	4	4
	380008	✔	38.52	30.22	9.44	43	4	4
2	380009	✔	38.57	30.25	9.48	43	4	4
	380010	✔	38.56	30.26	9.42	43	4	4
	380011	✔	38.50	30.28	9.44	43	4	4
	380012	✔	38.54	30.24	9.52	43	4	4
	380013	✔	38.46	30.25	9.50	43	4	4
	380014	✔	38.46	30.26	9.50	43	4	4
	380015	✔	38.44	30.20	9.40	43	4	4
	380016	✔	38.50	30.28	9.48	43	4	4
3	380017	✔	38.49	30.26	9.39	43	4	4
	380018	✔	38.60	30.24	9.56	43	4	4
	380019	✔	38.42	30.25	9.50	43	4	4
	380020	✔	38.36	30.24	9.48	43	4	4
	380021	✔	38.46	30.27	9.48	43	4	4
	380022	✔	38.49	30.26	9.48	43	4	4
	380023	✔	38.42	30.26	9.52	43	4	4
	380024	✔	38.38	30.20	9.46	43	4	4
4	380025	✔	38.45	30.24	9.49	43	4	4

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2.2.2 Tx Test

Figure 2 shows the optical modulation amplitude and the average launch power for each of the 4 channels of the 25 modules tested. All modules passed the Tx test, as the data shown in Figure 2 demonstrate. The optical modulation amplitude is close to the specification limit on a few channels.

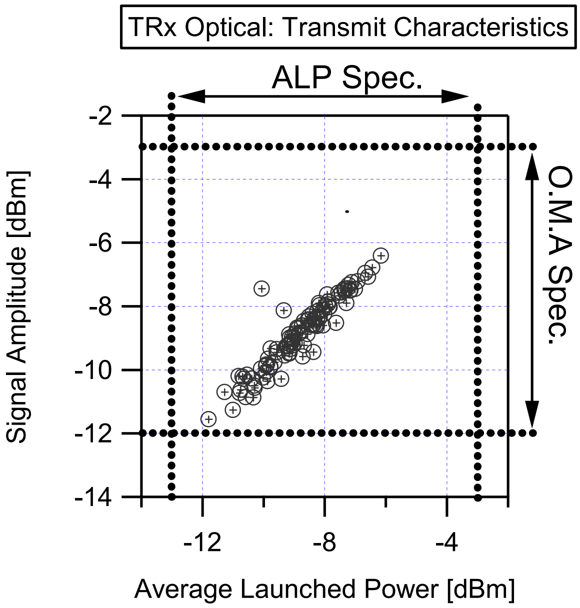
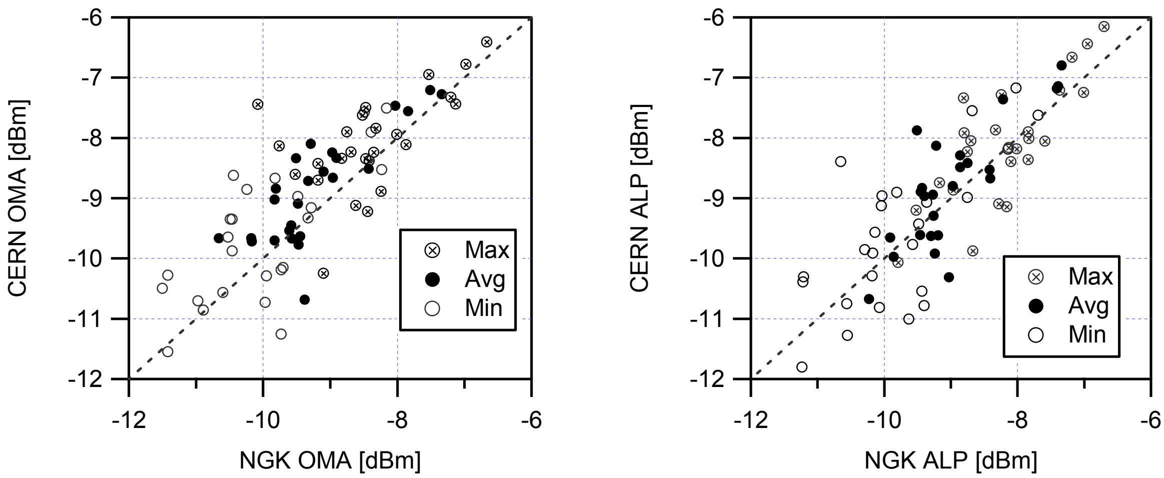


Figure 2: TRx signal optical modulation amplitude and average launch power.

Data specific to each of the 4 channels of every TRx were not available from NGK. Maximum, minimum and average values for each TRx were provided by NGK. Figure 3 shows CERN data plotted against NGK data. The agreement between the two sets of data is reasonable in general, when the variations in measurement through optical connection reproducibility (e.g. connecting the optical fibre onto the TRx optical head) are considered.

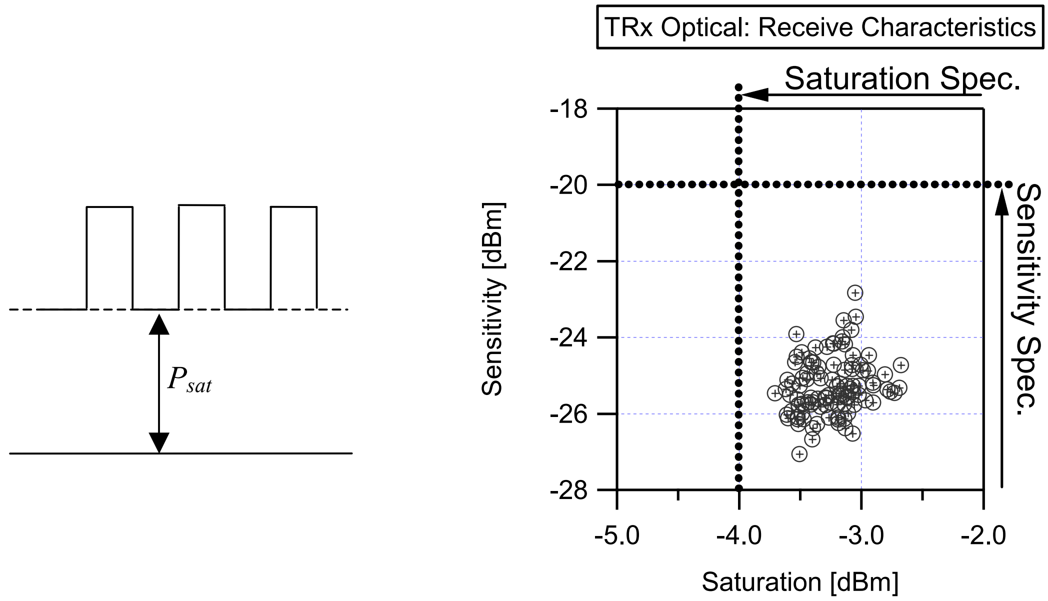


a. Optical modulation amplitude. *b. Average launch power.*

Figure 3: Comparison between CERN and NGK data.

2.2.3 Rx Test

The saturation level was calculated for the worst possible case, which corresponds to the low level of the modulated input signal, Figure 4 (a.). The data from the TRx Rx sensitivity and saturation test are shown in Figure 4 (b.). The saturation results are very close to the specification limit.



a. Calculation of saturation. *b. Sensitivity and saturation data.*

Figure 4: TRx Rx sensitivity and saturation.

The specification for the transceiver electrical output is a minimum swing of ±600mV for $R_{ext} = \infty$. The equivalent external resistance in the test system was R_{ext}=~320Ω. A conversion factor (100Ω TRx output impedance in parallel with 320Ω) was used to compare test system data with the specification. The data in Figure 5 take account of the conversion from test system to specification.

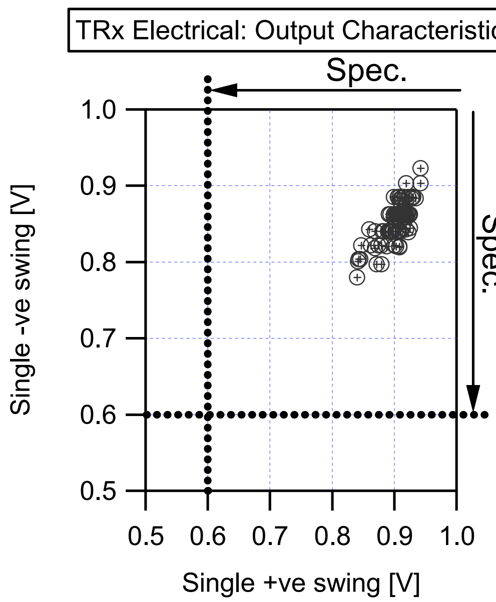


Figure 5: TRx output voltage swing.

2.2.4 System test

Eye patterns of the electrical output were recorded to evaluate the TRx modules qualitatively. Further analysis of these eye patterns is possible although this was not deemed necessary for the purposes of comparing TRx response against specifications (See section 1.3.). The TRx response always proved to be well within specifications. Figure 6 shows a typical eye pattern for a channel where the input optical modulation amplitude is 10μW.

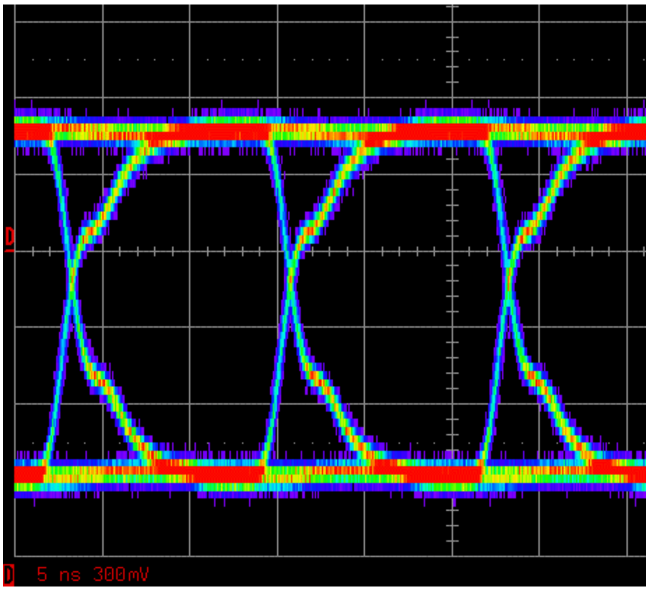


Figure 6: Typical electrical output eye pattern for a 10μW input optical modulation amplitude [5ns/div horizontal scale, 300mV/div vertical scale].

Eye patterns were also recorded for skew and jitter. These are shown in Figure 7 (jitter) and Figure 8 (skew). The test system is not optimised for measuring skew and jitter since the Arbitrary Waveform Generator used in all measurements produces a signal with non-negligible jitter. The eye patterns give an upper limit of the skew and jitter for the combination of TRx under test and test system. In reality the TRx response is better than that shown in Figures 7 and 8. The jitter is around 500ps pk-pk to be compared with the 250ps rms specification.

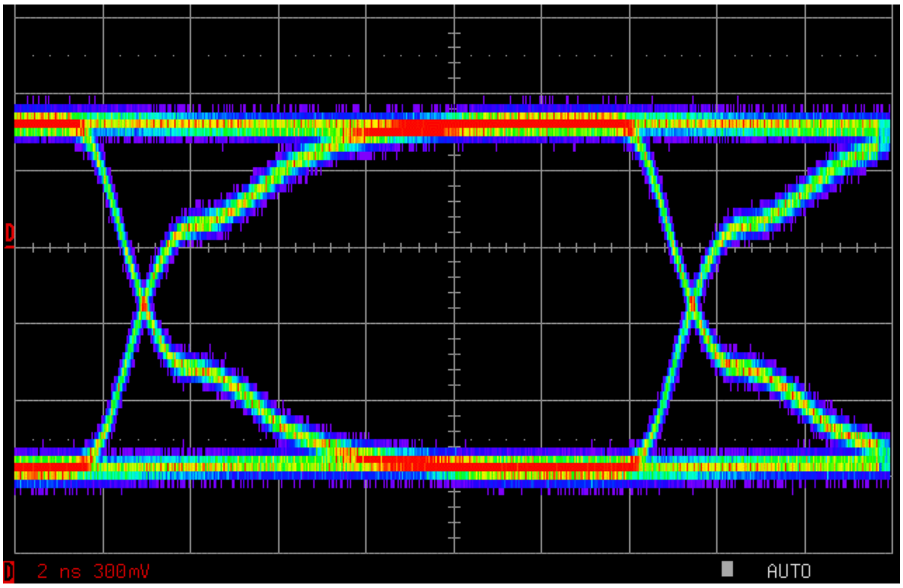
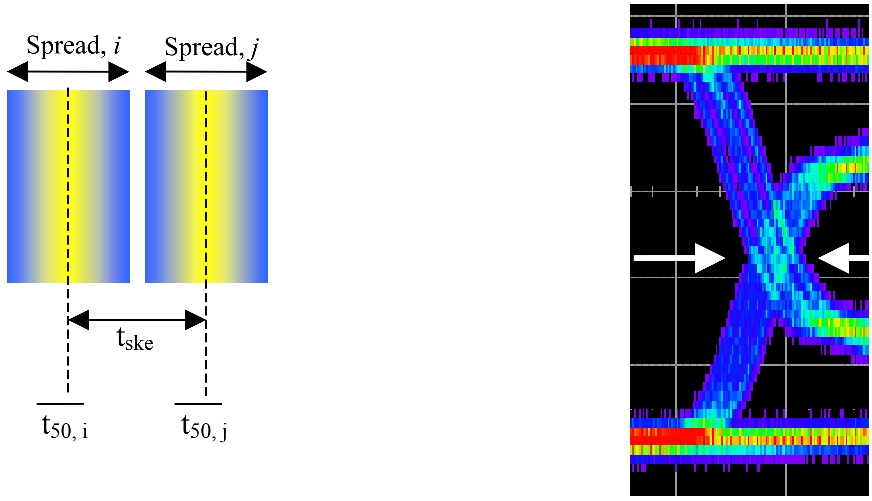


Figure 7: Typical electrical output eye pattern showing jitter on one of the channels [2ns/div horizontal scale, 300mV/div vertical scale].

In the specification, the definition of skew for two channels *i* and *j* is taken to be the difference in time between the average time, $\overline{t_{50}}$, it takes for a step response signal to reach 50% of its end value on each channel:

$$t_{skew} = \overline{t_{50,j}} - \overline{t_{50,i}}$$

The specification is for a skew figure of 1ns for all channels. The observed skew is approximately 1ns pk-pk, which includes the spread of the time at which a step response signal reaches 50% of its end value, and is therefore well within specification, Figure 8 (b.).



a. Definition of skew found in specification document.

b. Typical electrical output eye pattern showing skew for 4 channels of a TRx module [2ns/div horizontal scale].

Figure 8: Definition of skew and data showing typical TRx skew.

2.2.5 Power supply

The power dissipation was measured to be 0.897W on average, with the maximum value of 0.912W fitting well within the 2W specification limit. Electrical output eye patterns were recorded with the TRx input voltage supply set to the extremes of the specified range, 3.1V and 3.5V. No significant degradation of the TRx response was observed for all modules at these extremes.

2.2.6 Operating temperature

The number of modules to be tested at various operating temperatures was not explicitly mentioned in CMS-TK-QP-0011. Three modules were tested at temperatures of 30, 50 and 70°C. The modules were left powered for 1hour before measurements were performed at any given temperature.

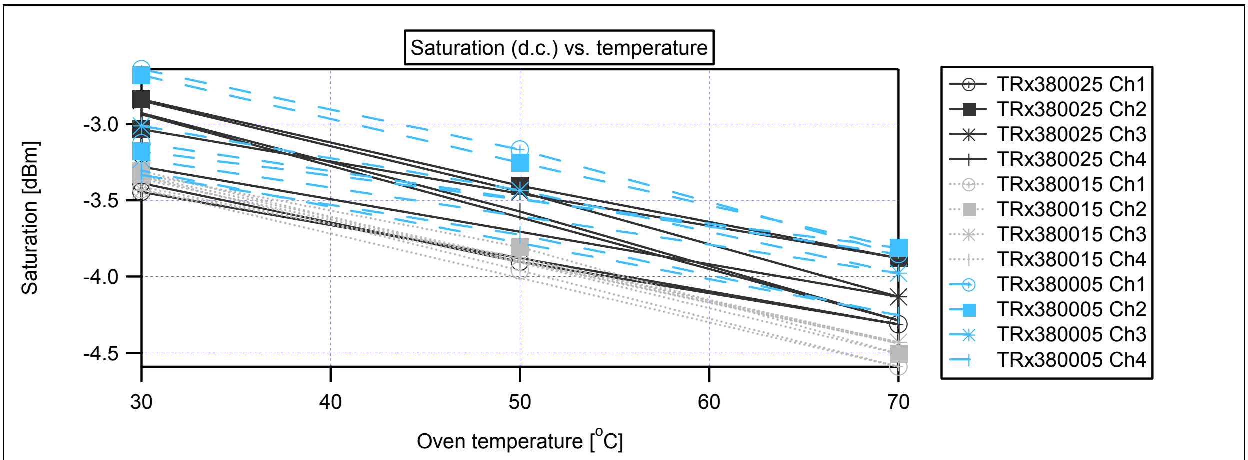
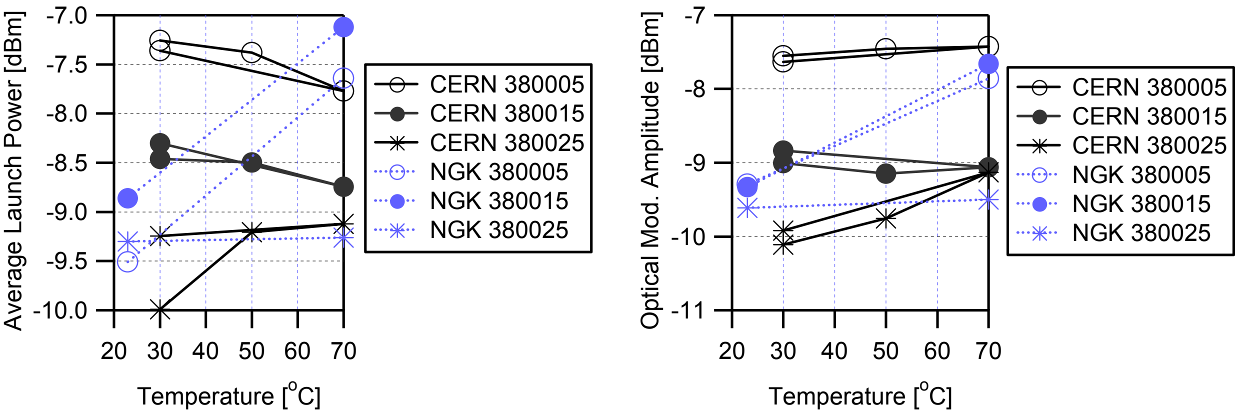


Figure 9: Temperature dependence of TRx d.c. saturation.

Most of the TRx characteristics did not degrade significantly with increasing operating temperature. The d.c. saturation, which was already observed to be close to the -4dBm specification limit, degraded beyond this limit at a temperature of 70°C for the majority of channels tested, Figure 9. The -4dBm limit is calculated as the worst possible power level launched from the Digital Opto-Hybrid assuming highest efficiency laser driver and laser transmitter, and zero losses in the optical link to the TRx. The probability of this happening jointly with a TRx operating temperature higher than 50°C is considered low enough to accept this behaviour.

The CERN data in Figure 10 suggests that there is no significant dependence of ALP and OMA on temperature. NGK have measured ALP and OMA for all 25 TRx modules at 23°C and 70°C. The NGK data shown in Figure 10 for the corresponding TRx serial numbers (for comparison with the CERN data) seem to indicate an increase of ALP and OMA with increasing temperature. A closer look at the data available from NGK for all TRx modules reveals that there is no obvious dependence of the TRx Tx characteristics on temperature. The average ALP for all 25 modules at 23°C is -8.976dBm, and at 70°C it is -8.527dBm. The corresponding values for OMA are -9.210dBm at 23°C and -8.785dBm at 70°C. The standard deviation in all cases is around 0.9dBm, which indicates that the apparent small increase in ALP and OMA (~0.4dBm over 47°C) is not a significant trend.



a) Average launch power. *b) Optical modulation amplitude.*

Figure 10: Comparison of NGK and CERN test data for measurements taken at different temperatures. Each point is an average value over the 4 channels on a given TRx.

2.2.7 TRx output electrical noise

When no modulation is present on the optical signal input of any given TRx Rx channel (for optical signals below the saturation threshold and above the sensitivity threshold) there is a significant amount of noise on the corresponding TRx electrical output. The amplitude of this noise is around 1.1V pk-pk on the differential output which can be seen in the persistence plot shown in Figure 11. It was first thought that the receiver ASIC in the TRx module had a squelch function and that the squelch functionality was enabled, in which case the ASIC output would be low for an optical input with little or no modulation (i.e. no data on the optical input). It is now clear that there is no such function on the receiver ASIC and therefore noise is present on the electrical output when there is no data present on the optical input of a given channel.

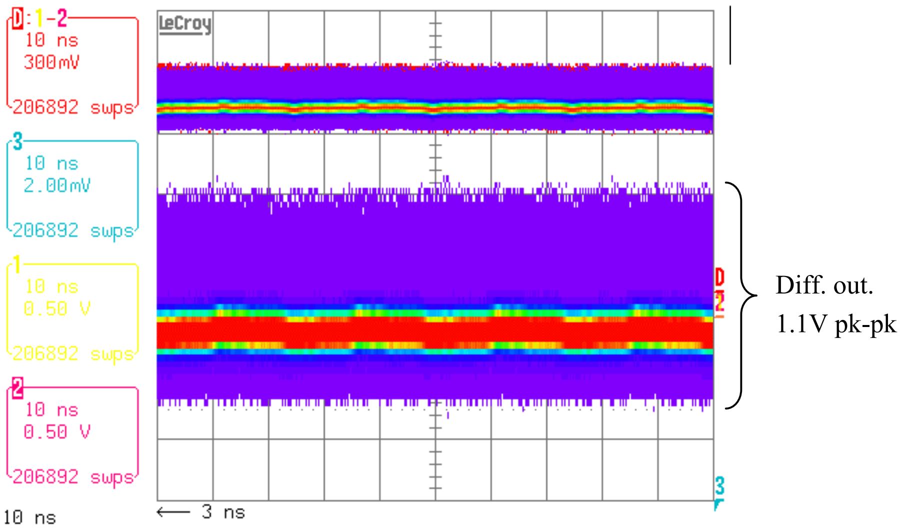


Figure 12: TRx Electrical output with a 150 µW flat optical input (i.e. no modulation). [300mV/div vertical scale].

3 Conclusions

The back-end optoelectronic transceiver modules (TRx) supplied by NGK Insulators Ltd as batch T0 are deemed to have passed the qualification tests. The Tx optical modulation amplitude and the Rx saturation are close to the specification limits and should be monitored closely.

The saturation threshold was seen to decrease by 0.03dBm/^{o}C. The degradation of the saturation threshold to below the specification limit at an operating temperature of 70^{o}C was noted but is not considered to be of concern for the operation of these devices. A further study of this effect could be initiated should the saturation on any given channel fall below -3.5dBm at room temperature on modules from future batches.

The absence of the squelch function on the receiver ASIC was also noted and measures have been taken by CERN to ensure that the resulting noise on the TRx electrical outputs under certain conditions is understood and controlled.