STORAGE DEGRADATION MECHANISM ANALYSIS AND STORAGE LIFE PREDICTION OF THE OPTOELECTRONIC COUPLER BASED ON MULTI-CHANNEL DEGRADATION TESTING DATA

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Abstract:

Optoelectronic coupler, characterized by long life and high reliability, is one typical kind of optoelectronic devices. Accelerated degradation testing is mostly utilized to assess optoelectronic coupler storage life. However, in engineering, integrated optoelectronic coupler may be nagged with the fusion of multi-channel degradation data. To solve the problem, the paper firstly conducts accelerated storage degradation testing on a certain type optoelectronic coupler, and analyzes the main degradation model and mechanism of optoelectronic coupler under storage environment. Meanwhile, the paper gives an access to processing multi-channel degradation data based on pseudo life, which can be also employed to assess other integrated devices, like memories, with their accelerated degradation data.

1 Introduction

Along with the development of reliability research, the scope of reliability is no longer confined to the design, manufacture and usage phases, and many products have long storage time before the only one shot. So, increasing attention is been paid to the storage reliability, and the storage life becomes an essential index when the storage reliability level is measured [1]. The optoelectronic devices are extensive used in Communication as new types of devices. Among these, the photoelectric coupler, which consists of source and sensor of light, is the most representative category. The previous reliability research on the photoelectric coupler was focused on the operational reliability. In the 1980s, Bajenesco Titu [2-3] researched the main failure mode-CTR degradation, and came up with the dominant mechanism of the degradation. Adithya Thaduri et al [4] also came up with similar CTR degradation formulas and CTR degradation mechanism, and designed the testing circuits, to verify the degradation process. Aibin Xu et al. [5-6] took the lead in carrying out types of screening and reliability tests on various types of hermetic sealing photoelectric coupler of main domestic manufacturers, and figured out the major failure mode and failure mechanism of domestic through analysis [7]. Shiman Xiao [8] came up with the failure mode in which the materials and technological parameters are included based on Fuyan Tian and Weidong Wang’s research. But in practical storage, the common operational failure mechanisms (e.g. current transfer ratio parameter

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degradation caused by external quantum efficiency decrease while working) don't exit. So, the storage degradation mechanism of optoelectronic couplers should be studied.

The existing storage life evaluation mostly adopts accelerated storage testing methods, and the life evaluation based on the testing has made a certain progress. In recent years, research on accelerated storage testing and life evaluation of electronic parts and components has been widely carried on [9-10], but still there is no accelerated storage testing case of optoelectronic couplers. At the same time, for integrated circuits like optoelectronic couplers which have multi-channel, there isn't such accelerated degradation data processing method. In this paper, firstly we conduct the accelerated storage degradation test of optoelectronic couplers, then analyze the storage degradation mechanism, then take the testing data as an example to introduce the multi-channel accelerated degradation testing data processing method.

2 Optoelectronic couplers accelerated storage degradation test

In the paper, we chose a certain type of optoelectronic coupler. The optoelectronic coupler has 4 independent channels, which functions as signal transmission and isolation. The schematic circuit diagram is as shown in Fig. 1.

The primary performance parameter of this optoelectronic coupler is current transfer ratio. In the accelerated storage degradation test, the temperature stress was selected as accelerated stress, and the Arrhenius model was selected as acceleration model. 32 devices were sampled from a certain patch of products to proceed the accelerated storage degradation tests, and the stress and grouping is as shown in Table 1. For etch stress level, the tested devices were divided into group A and B according to the different number of test. For group B, the parameters were only measured before and after the test. For group A, the parameters were also measured during the test repeatedly. The different measurement frequencies for group A and B were set to analyze the influences of parameters measurements on the devices during the accelerated storage degradation tests. In the test, for group A of all stress level, the performance parameter was measured every 72 h.

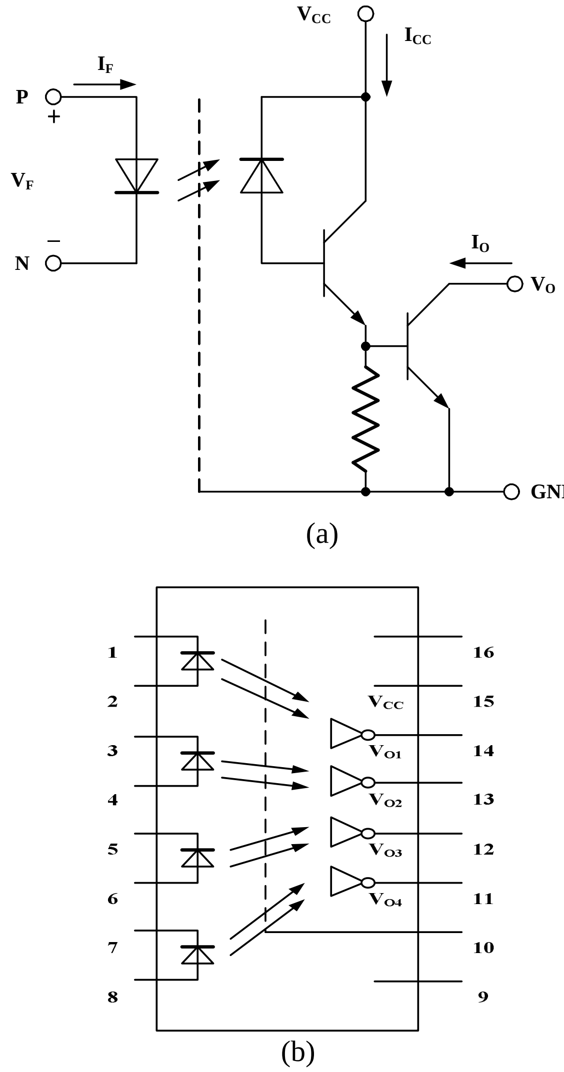


Figure 1. The schematic circuit diagram: (a) Single channel, (b) Entire schematic circuit diagram.

Table 1. Stress level and numbers of samples in the test.

Stress Level(℃)	Groups	Samples Number
100	A	4~8
	B	9~11
125	A	12~16
	B	17~19
150	A	20~24
	B	25~27
175	a	28~32
	b	33~35

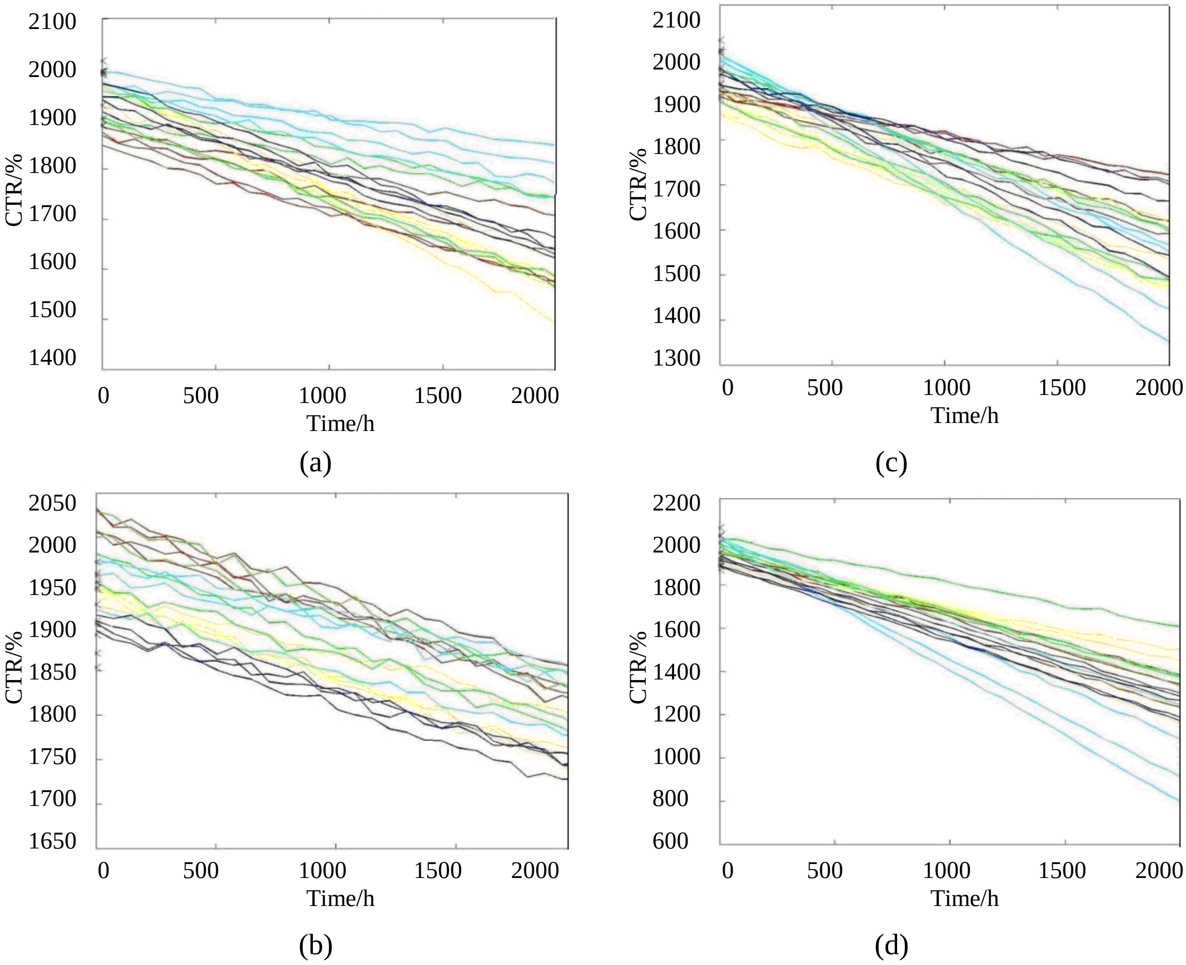


Figure 2. CTR degradation paths: (a) CTR degradation paths under 100, (b) CTR degradation paths under 125, (c) CTR degradation paths under 150, (d) CTR degradation paths under 175.

The accelerated storage test stopped after 1920 h as the scheduled testing profile, and there wasn't any catastrophic failure. Through comparative analysis, CTR was determined as the degradation parameter, and the degradation trend was drawn according to the CTR degradation data under every stress levels, as shown in Fig. 2. By comparing the degradation path of group A and the degradation data of group B (only initial data and final data, represented by *X*), it can be concluded that the degradation velocity of the 2 groups were basically the same. So, the influences on the degradation of samples caused by measuring operation can be excluded.

3 Storage degradation mechanism analysis of the optoelectronic couper

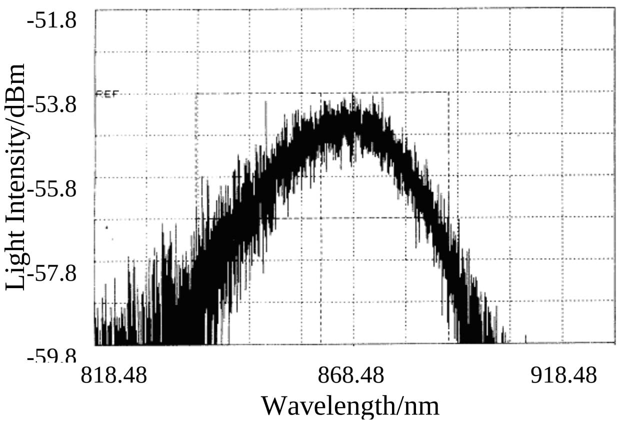
After the degradation test, some samples were selected to do further test. The internal gas content was detected, the results was as shown in Table 2. Through the comparison, we can conclude that with the rise of test temperature, the nitrogen content decreased gradually, and the CO_2, moisture, H_2, organic gases contents increased. It indicates that the air permeability performance of those samples gradually declined under high temperature, and external gases started to get into the devices. Meanwhile organics oxidized inside the device which produced organic gases.

To distinguish the main location of the failure, we chose samples under different temperature stress, measured the power of the light source and the luminescent spectrum characters while these samples were proper functioning. Figure 3 shows the results. According to the comparison we can know that: the light source power dramatic declined under high temperature stress, decreased to only 70 % of which under low temperature. Then further

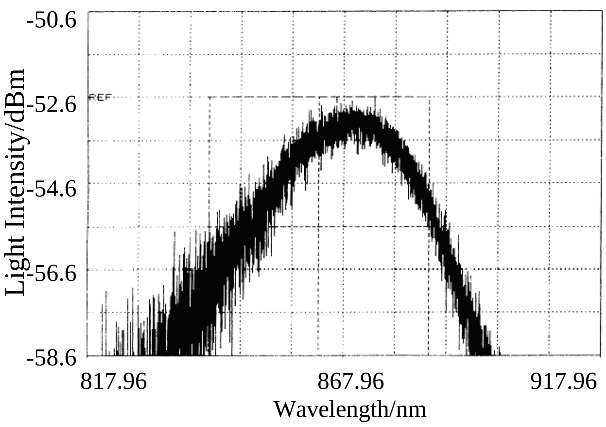
Table 1. Internal gas content after the test of the selected samples.

Composition	unites	4#	9#	12#	17#	20#	25#	30#	33#
Temperature Level	^oC	100	100	125	125	150	150	175	175
Air Pressure	torr	5.1	3.9	5.6	3.6	5.6	4.1	6.4	5.4
N_2	%	95	97.7	88.6	98	91.2	91	38.8	75.8
Ar	ppm	0.02	0.02	0.02	0.05	0.02	0.02	628	0.01
CO_2	%	318	393	214	ND	426	469	5.57	1,257
Moisture	%	4.03	1.45	3.88	1.29	6.86	6.91	6.3	13.9
H_2	ppm	0.019	0.01	0.11	0.03	1.39	1.48	1,278	9.4
He_2	ppm	6,171	7,606	6,099	5,940	3,730	4,180	48.8	1,467
Hydrocarbon	ppm	546	ND	ND	ND	859	892	1,179	1,705
IPA Polymer	ppm	ND	ND	ND	ND	ND	ND	736	270
Methylbenzene	ppm	<100	<100	150	<100	363	328	289	3,638
Acetone	ppm	ND	ND	ND	ND	120	134	980	1,064
Carbinol	ppm	ND	ND	6.76	ND	ND	ND	163	ND

Annotations: ND represents undetected



(a)



(b)

Figure 3. Luminescent spectrums under different temperature stress: (a) Device 04 light source 1 (100), (b) Device 31 light source 1 (175).

analyzed the source 1 had CTR of 1815 and 1242, which was similar to the light source power degradation. So, we can presume that the dominant degradation of this type of device happens in the light source part.

To sum up, through preliminary analysis of the test data, we know that the main degradation model of this type of optoelectronic coupler is CTR degradation. Through analysis of the tested sample, it is speculated that the main reason which lead to the degradation of CTR is that the luminous chip oxidizes and in turn causes the decrease of glow power.

4 Multi-channel accelerated degradation data processing method based on pseudo life

Any unit of the optoelectronic coupler fails will lead to the failure of the device. In practical life test, usually we only get the degradation data of single units or channels. While doing reliability or life assessment of these devices with the data, the single units, channels degradation data need to be transformed into degradation paths or Life characteristics of the devices which can be realized using the life assessment method based on pseudo life. By independently fitting and extrapolating every degradation path of all samples, the expected failure time also called the pseudo failure life of samples can be obtained, thus realize the life extrapolation under different stress levels, and obtain the forecasted life under storage condition. There are some cases using the pseudo life method to process the accelerated degradation test data [11-13]. We improved the data processing method of single sample, and came up with the photoelectric devices storage life assessing method based on pseudo life. The basic flows are as shown in Fig. 4.

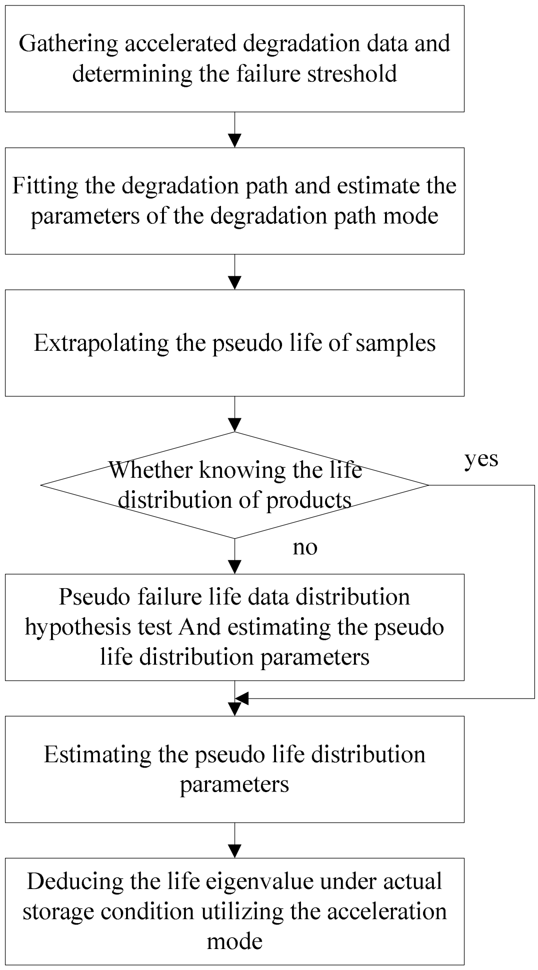


Figure 4. Photoelectric devices storage life assessing method flows based on pseudo life.

Step 1: Conducting the accelerated degradation test, gathering the accelerated degradation test data, and determining the failure threshold of the degradation parameter *Df*.

Step 2: Fitting the degradation paths of different samples under different stresses, estimating the parameters of the degradation path model of every sample.

Step 3: Utilizing the model got in step 2, according to the given failure threshold *Df*, we can extrapolate the pseudo life of every sample as t_1, t_2, …, t_n. For example, suppose the degradation path model of a sample is $y = \hat{\alpha} \cdot t + \hat{\beta}$ ($\hat{\alpha}$ and $\hat{\beta}$ are the estimations of the model parameters), let y equals failure threshold *Df*, then the determined t is the pseudo life of the sample. If the life distribution of the product is unknown, then proceed step 4; otherwise jump to step 5.

Step 4: Proceeding distribution hypothesis test to the pseudo failure life data, choosing the possible distribution (Common distribution include: normal distribution, Weibull distribution, lognormal distribution…), test which is the fits best and go on step 5.

Step 5: Fitting the life distribution with the pseudo life data and estimating the distribution parameters

Step 6: Regarding the pseudo failure data obtained from previous steps as complete life data, according to the chosen distribution and parameters, determine the life eigenvalue, and then infer the life eigenvalue under actual storage condition utilizing the acceleration model.

5 Photoelectric coupler storage life prediction based on multi-channel degradation test data

The Photoelectric coupler is made up of internal LED and photic chip two parts. Though research on the LED degradation mechanism has got some achievements [14-15], but the degradation mechanism of the photic chip is still unclear [16-17]. Without empirical degradation path, in this paper we selected common used degradation path, fitting the degradation path one by one. Considering that the initial degradation values and degradation slopes were different for different stress levels in the typical test, devices under different stress levels were fitted independently.

The least square method was adopted while fitting to solve the unknown parameters in the model. While evaluating the goodness of fit, chose the mean values of fitting evaluation criterion of all degradation paths as the integrated assessment value.

From Table 3 we can see that among all the paths, linear and exponential degradation paths are better

Table 2. Goodness of fit test results of degradation paths.

Path types \ Indexes	Residual error	Error sum of squares	R^2
Linear	6.435	1118	0.9908
Exponential	6.302	1072	0.9911
Power	26.14	1.844e+004	0.8475
Logarithmic	25.09	1.699e+004	0.8595
Lloyd-Lipow	49.65	6.657e+004	0.4496

(residual error and error sum of squares are smaller and R^2 is closer to 1). By means of contrastive analysis we can know that though the exponential type is slightly better than linear type, the degradation paths curves are almost the same. So, to be convenient for analysis and calculation, the linear degradation path was chosen as the best degradation path. For that the device life is determined by the shortest life light channel, the light channel life must be translated into device life. So, we can analyze every light channel of every sample, choose the light channel with the shortest life as the key channel, and regard the degradation path of the key channel as the degradation path of the corresponding device. The shortest light channels of each device are as shown in Table 4. Choose the fitting result of the key light channel as the degradation path fitting result of the device from light channel degradation path fitting result. The degradation path fitting results are as shown in Table 5. On the basis that the failure threshold was determined 500 %, extrapolated the degradation path, and obtained the pseudo life values of devices as shown in Table 6. Normal distribution, 2-parameter Weibull distribution, lognormal distribution and inverse Gauss distribution are chosen to fit the pseudo life for devices under each stress level. The log likelihood function was adopted to carry out the test of goodness of fit. The results are shown in Table 7.

Table 3. Numbers of the shortest life light channels of all devices.

Device number	Light channel number	Device number	Light channel number	Device number	Light channel number	Device number	Light channel number
4	1	12	2	20	4	28	3
5	2	13	2	21	3	29	4
6	2	14	1	22	3	30	1
7	4	15	1	23	3	31	2
8	1	16	3	24	2	32	2

Table 4. Sample devices degradation paths fitting results.

Device number	Degradation slope /h^{-1}	Initial degradation value	Device number	Degradation slope /h^{-1}	Initial degradation value
4	0.10671	2023.790	20	0.15742	1902.152
5	0.10259	1942.639	21	0.21000	1889.921
6	0.10240	1982.320	22	0.21219	1914.264
7	0.07319	1921.274	23	0.31574	1981.958
8	0.08653	1894.898	24	0.22858	1956.320
12	0.14676	1864.782	28	0.34789	1927.021
13	0.23513	1968.743	29	0.38231	1925.053
14	0.16560	1899.613	30	0.31724	1971.807
15	0.10898	1959.174	31	0.38336	2012.583
16	0.16669	1976.971	32	0.37977	1929.546

Table 5. Pseudo life values of devices.

Device number	Pseudo life /h	Device number	Pseudo life /h	Device number	Pseudo life /h	Device number	Pseudo life /h
4	14280.05	12	9299.56	20	8907.31	28	4101.88
5	14061.53	13	6246.60	21	6618.79	29	3727.44
6	14475.88	14	8451.70	22	6664.95	30	4639.40
7	19418.24	15	13389.54	23	4693.66	31	2497.14
8	16120.91	16	8860.72	24	6371.18	32	3764.29

Table 6. Test of goodness of fit of each stress level.

Temperature level distribution	100℃	125℃	150℃	175℃	Total
Inverse Gauss	-44.7907	-45.5343	-43.0352	-40.2873	-173.648
Logarithmic	-44.851	-45.6001	-43.097	-40.3443	-173.892
Normal	-45.1817	-45.9025	-43.1613	-39.9436	-174.189
Weibull	-45.6435	-45.9698	-43.2349	-39.6163	-174.465

Smaller test value of goodness of fit means better the fitting. So, the best distribution was inverse Gauss distribution. Supposed that device life Y_i under each stress level i obeys the inverse Gauss distribution IG(μ_i,λ_i), then the parameter estimations of each stress level are shown in Table 8.

Table 7. Parameters estimations of each stress level.

Temperature level Parameter estimation	100℃	125℃	150℃	175℃
μ_i	15671.3	9249.62	6651.18	3746.03
λ_i	1.06E+06	151889	157955	84770.9

Considering that temperature was the acceleration stress it typical photoelectric device accelerated storage test, the Arrhenius model was chose. Linear transform the Arrhenius model:

$$\ln \mu = \ln A + \frac{E}{k} \cdot \frac{1}{T} \tag{1}$$

Let $y = \ln \mu$, $x = \frac{1}{T}$ $a = \ln A$, $b = \frac{E}{k}$.

Then get the equation of linear regression:

$$y = a + bx \tag{2}$$

Using least square method, estimated the parameters in the acceleration model, got a=1.4172，b=3080.2. For distribution parameter λ, firmly believed that it belonged to the same distribution family as μ, which Meant λ_i=$c\mu_i$. Similarly, using least square method obtained that c = 32.7. And then extrapolated the storage life distribution parameters under storage condition temperature of 25^{o}C : μ_0=126753.56, λ_0=414482.31.

Finally we can obtain the mean life of this typical photoelectric device under storage condition was 126753.56 h, which was 14.47 years.

6 Conclusion

This paper analyzes the primary degradation mode and degradation mechanism on the basis of accelerated storage degradation test of a certain type of optoelectronic coupler. This paper meanwhile gives an access to processing multi-channel degradation data based on pseudo life, which can be also employed to assess other integrated devices and presents the accelerated storage degradation test data of a certain type of photoelectric coupler as an example and gives the life evaluate. The paper also gives the storage degradation mechanism of photoelectric coupler, which can be used to guide the improvement work on the reliability. And the method can also be used to process the accelerated storage degradation test data of ICs which have complex repetitive structures.

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