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New Reliability Assurance Method Effective For Economical Satellite On-board Equipment

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NEW RELIABILITY ASSURANCE METHOD EFFECTIVE FOR ECONOMICAL SATELLITE ON-BOARD EQUIPMENT

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Abstract

This paper describes a new reliability assurance method of implementing generally used parts (GUPs) in terrestrial radio equipment for satellite on-board equipment. To assure high reliability, specially tailored expensive parts (STPs) have been normally implemented in satellite on-board equipment. In recent years, however, the reliability of GUPs has become as high as that of STPs. Furthermore, GUPs are generally inexpensive because of mass production. The procedure of the new method is the following. First, the failure rates of GUPs used in terrestrial radio equipment are investigated. Secondly, specifically selected GUPs whose structure was not qualified previously, are subjected to several qualification tests, such as shock, vibration and radiation. Finally, the transponder-level burn-in test is carried out in order to confirm there is no latent defects in the parts. NTT takes part in Japan's ETS-VI program by developing fixed and mobile multibeam communications on-board equipment. This new method has been applied to this equipment. Many GUPs, up to about 70% of all parts, were implemented. A transponder-level burn-in test was carried out for over 3500 hours. No failure parts were found. The method presented here will reduce the cost of satellite on-board equipment and promoting satellite communications.

1. Introduction

Normally, satellite on-board equipment is implemented with specially tailored parts (STPs) to ensure high reliability. Discrete semiconductors qualified as JANS, microcircuits qualified as class S, various kinds of parts defined as GRADE 1 [ref. 1], or parts qualified by specific space agencies are usually used. However, STPs are very expensive, because they are manufactured under specifically qualified production lines and are controlled under special specifications in order to detect and remove defect parts or failed parts at the part-level. They are also subjected to a series of various screening tests including burn-in tests on each part. Another reason for the high cost is that usage is small compared with terrestrial equipment and moreover, many kinds of STPs are necessary to develop on-board equipment. These specialities make STPs very expensive and this is one of the reasons why satellite on-board equipment is very expensive.

On the other hand, generally used parts (GUPs) implemented for terrestrial radio equipment in public telecommunication systems, have become as reliable as STPs. This is because the recent manufacturing technologies have been greatly improved in parts manufacturer's facilities, mainly due to the efforts of the part manufacturers. Furthermore, GUPs are inexpensive because of mass production.
So if GUPs can be implemented in satellite onboard equipment, especially for communication transponders, cost reduction will be achieved. To achieve this, a new reliability assurance method of implementing GUPs for satellite onboard equipment will be established. This paper discusses the following items in establishing this method; (1) Field data of GUPs, (2) Space environment evaluation of GUPs, (3) Economical detection method of latent defects or failed parts. Furthermore, hybrid modules implemented with GUPs are described. These modules are developed to reduce cost as well as make transponders small and light.

2. Field Data of GUPs

In order to verify high reliability of GUPs, an investigation of the part failure rates in NTT’s terrestrial radio equipment was conducted. The result indicated that the failure rates of almost all GUPs are smaller than/or equivalent to, the failure rates conventionally apportioned to parts in communication transponders. Figure 1 shows the ratio of the field data to apportioned failure rates of some kinds of parts. This figure indicates that GUPs will be effective for space use.

![Failure Rate Ratio Graph](image)

**Fig. 1 Failure Rate Ratio**

3. Space Environment Evaluation of GUPs

Almost all GUPs cover parts necessary to manufacture communication transponders and are capable of space environment endurance because of their structure. But there are some GUP parts that have no flight heritage or new structure. Therefore, additional tests such as vibration and shock, thermal cycles and thermal shocks, and radiation, have to be performed. These tests are called delta-qualification. This decision was based on our experiences obtained from the thorough investigation, evaluation and reliability assessment of CS-2 and CS-3 transponder parts [ref. 2, 3]

4. Economical Detection Method of Latent Defects or Failed Parts

An economical method of detecting latent defects or failed parts was studied.

Figure 2 shows the manufacturing flow when STPs are implemented in transponders. As shown in Fig. 2, a series of various screening tests are carried out on each part at the part-level. The many test items make the cost expensive. So, to reduce cost, only specific screening tests shown in Table 1 are selected on the basis of heritage of GUPs. Those screening test items are considered to be more effective in detecting latent defects. Some semiconductors are still subjected to thermal cycles or burn-in tests depending on their heritage. The screening test items shown in Table 1 have to be carried out on all GUP parts.

After the specific screening tests and the evaluation described in section 3, the transponders are manufactured as shown in Fig. 3. Figure 3 shows
a new manufacturing flow when GUPs are implemented. After the manufacturing of transponders, it is necessary to confirm that there are no failed parts implemented in the transponders, even though there have been almost no faults observed in the GUPs field data. Burn-in test or aging tests are considered to be a very effective way in detecting latent defects or failed parts. So a transponder-level burn-in test is carried out. Failed parts should be detected during the beginning usage stage. A transponder-level burn-in test has become effective for the first time now that the reliability of GUPs has become very high. Furthermore, the cost of the transponder-level burn-in test is less than the total cost of the individual part-level burn-in tests.

The transponder-level burn-in time must be determined. It was determined that if the stress level to which parts are subjected in the transponder-level burn-in test, is equivalent to that in the part-level burn-in test of STPs, then the detection level of latent

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**Table 1 Screening Test Items for GUPs**

<table>
<thead>
<tr>
<th>Part type</th>
<th>Test Items</th>
</tr>
</thead>
<tbody>
<tr>
<td>Semiconductors</td>
<td>Hot Temperature Aging</td>
</tr>
<tr>
<td></td>
<td>Seal Test</td>
</tr>
<tr>
<td></td>
<td>PIND test</td>
</tr>
<tr>
<td></td>
<td>Electrical Performance</td>
</tr>
<tr>
<td>Capacitors</td>
<td>Voltage Aging</td>
</tr>
<tr>
<td></td>
<td>Electrical Performance</td>
</tr>
<tr>
<td>Resistors, Inductors, etc</td>
<td>Electrical Performance</td>
</tr>
<tr>
<td>Hermetic Sealed Parts</td>
<td>Seal Tests</td>
</tr>
</tbody>
</table>

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**Fig. 2 The Manufacturing Flow when Specially Tailored Parts are Implemented in Transponders**

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**Fig. 3 The Manufacturing Flow when Generally Used Parts are Implemented in Transponders**
defects or failed parts in a transponder-level burn-in test is considered to be equivalent to that in the part-
level burn-in tests of STPs. Therefore, the burn-in time is derived from the following Arrhenius equation
on the basis of the relationship between the burn-in time and the temperature.

\[ L = L_0 \times \exp\left(-\frac{E_a}{k \times (1/Tr - 1/T)}\right) \]

\( L \) : Burn-in time at transponder-level (hours)
\( L_0 \) : Burn-in time at part-level of STPs (hours)
\( E_a \) : Activation Energy (eV)
\( k \) : Boltzmann's constant (8.6 x 10^{-5} eV/Kelvin)
\( Tr \) : Temperature at part-level burn-in of STPs (K)
\( T \) : Operating Temperature at transponder-level
burn-in (K)

\( L_0 \) and \( Tr \) are derived from the STP's burn-in condition. As typical STPs, JANS and class S part
conditions derived from MIL specifications are shown in Table 2. Figure 4 shows the relationship between
the burn-in time and the activation energy related to failure modes. This figure is calculated with a burn-in
temperature of 125 deg. C and a 240 hour burn-in time of microcircuits for class S. This condition was
selected because of the rather severe burn-in condition shown in Table 2. If the activation energy is
0.3 eV and the burn-in temperature is 30 deg. C, then about a 3500 hour burn-in time is necessary. If
transponders are operated at 70 deg. C in a thermal
chamber, then the necessary burn-in time will be
decreased to about 1000 hours.

5. Hybrid Modules Implemented with GUPs

There are many circuits that have the same
function or performance, and are frequently used in
communications transponders. If commonly used
circuits are extracted from those circuits and are made
into one module, like one part, then these modules
will make transponders not only smaller and lighter,
but also cheaper than assembling individual parts.
This is because many circuits can be replaced by one
kind of module. Module circuits are designed to
detect defects of implemented chips from the outside
of the module, especially semiconductor bare chips.
Check items are also selected on the basis of heritage
of the parts.

<table>
<thead>
<tr>
<th>Table 2 Burn-in Condition of STPs</th>
</tr>
</thead>
<tbody>
<tr>
<td>Small signal transistor(&lt;5W)</td>
</tr>
<tr>
<td>Power transistor(&gt;5W)</td>
</tr>
<tr>
<td>Microcircuit</td>
</tr>
</tbody>
</table>
6. Space Use Verification of GUPs through ETS-VI Program

NTT takes part in Japan's ETS-VI (Engineering Test Satellite -VI) program by developing fixed and mobile multibeam transponders. [ref. 4] The ETS-VI program provides a good opportunity to verify whether GUPs are really applicable in actual space use. ETS-VI multi-beam transponders shown in Fig. 5 are made up of about 100 units and about 27000 parts are implemented. Many GUPs, up to about 70% of all parts in the transponders, are implemented. Figure 6 shows units that are implemented with GUPs by meshes. Table 3 shows the kinds and amounts of usage of modules developed for ETS-VI.

![Fig. 5 Multi-Beam Transponders Installed on ETS-VI](image)

![Fig. 6 ETS-VI Multi-Beam Transponders](image)

<table>
<thead>
<tr>
<th>Function</th>
<th>kinds</th>
<th>number used</th>
</tr>
</thead>
<tbody>
<tr>
<td>VHF----30GHz Amplifier</td>
<td>10</td>
<td>114</td>
</tr>
<tr>
<td>PIN ATT</td>
<td>2</td>
<td>23</td>
</tr>
<tr>
<td>Phase Comparator for Local OSC.</td>
<td>4</td>
<td>28</td>
</tr>
<tr>
<td>Linearizer Circuit</td>
<td>2</td>
<td>24</td>
</tr>
<tr>
<td>Switch Module(1GHz)</td>
<td>1</td>
<td>48</td>
</tr>
<tr>
<td>Mixer</td>
<td>1</td>
<td>5</td>
</tr>
<tr>
<td>Power Controller</td>
<td>8</td>
<td>118</td>
</tr>
</tbody>
</table>

Table 3. Developed Modules for ETS-VI

Upon completion of the transponder construction, a 3500 hour burn-in test was carried out at room temperature. The units were turned on/off about 140 times. Trends in transponder performance, such as gain, output power and
frequency, were within the measurement errors shown in Fig. 7. There were no failures in parts during the test. Based on this test results, the transponders were considered to have no latent defects.

7. Conclusion

A new reliability assurance method was studied for implementing GUPs instead of STPs to reduce the cost of satellite on-board equipment, especially communications transponders. This method is based on the high reliability and low cost of GUPs. In the first procedure of this new method, the failure rates of the GUPs implemented in NTT terrestrial radio equipment shall be investigated and confirmed to be equal to or smaller than apportioned values to transponder parts. Secondly, specifically selected GUPs that have a new structure or no flight heritage have to be tested in a space environment. After the specific screening tests of the GUPs are completed, the transponders are manufactured. A 3500 hour transponder-level burn-in test has to be carried out in order to confirm that there is no failed parts. This new method was applied to communication transponders installed on Japan's ETS-VI. This program provides a good opportunity to prove whether or not GUPs are capable of being used in space. After the 3500 hour transponder-level burn-in test, no part failures and no degradation of the transponder performance were observed. Based on this test result, the GUPs implemented in the transponders are considered to be of the same quality as the STPs.

The method presented here will contribute significantly toward reducing the cost of satellite on-board equipment and promoting satellite communications.

References


