A product performance optimised test flow

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Abstract

A general test philosophy has been outlined to support a profit driven product improvement process. The test philosophy is applied to the area of volume production of telecommunication hardware but may be applied in any production environment. A simple algorithm is given to identify the failure level under which sample testing may become economically more justified than 100% screening. Finally, a procedure to compress and store information on batch related parametric distributions is proposed to support the analysis and corrective actions due to field returns.

Introduction

Complex and sophisticated products such as Telecommunication systems are produced along a flow where several test steps are incorporated. Today most standard components are mounted on to the printed circuit assemblies without any proceeding testing being performed. This is a consequence of the continuous improvement in component manufacturing that has taken place over the past 10 years. Also subassemblies such as printed board assemblies may show very high quality after some time and another look at the test philosophy might be justified.

New methods for field data analysis [1] have made it possible to follow the quality trends over field use time. This gives a possibility to predict when it would be useful to review current test practice to minimise the total test- and failure costs for a product.

Recent findings [2] regarding the relationship between production test yields and field reliability performance have also made it possible to model the total test- and failure costs in a more straight-forward way than before. Thus, a closer look at the total Life Cycle Costs from a test- and failure cost point of view is highly motivated.

Knowledge of the cost elements involved in a product’s life cycle enables better use of product profitability calculations for product improvement purposes. A generalised profit driven process for product improvement is a powerful tool when it is combined with a set of realistic cost estimates relevant for the product area being optimised.

It is also very important to have access to production test data in order to support the analysis of returned parts from field use. We present some examples of field reject analysis where full product traceability back to original test data has been of good use. A generalised procedure to compress parametric data distributions for later use in field return analysis is proposed.

Definitions

Definitions are given for various test activities referred to in the following.

Standard tests

Component testing: An activity often referred to as incoming inspection. The purchasing or producing company had to verify that the components met the agreed specification.
Board testing: After assembly the printed board (PBA) is tested to verify that the basic functions are as specified and that no catastrophic defect is there.
Sub-system testing: A limited set of PBAs is mounted together in a sub-system that can be tested for its functions, margins and e.g.transmission characteristics. This type of test often requires a standard system to stimulate the object for testing. The test may be performed at elevated temperature and/or elevated voltages, clocking frequencies etc.
System testing: Since there is a strong trend to deliver fully functioning systems (called cabinets) to the customers there is a need for full testing of the individual packaged system before delivery. This is similar to the sub-system testing except for that all stimulating electronics is new and has to be tested for the first time as well. This in turn will require external stimulation equipment.
Installation testing: The final testing at site will be a major test effort in the case that the system has not been pretested at the factory before. If full cabinet testing has been performed the installation testing will be reduced to a much less of an effort.
Field service: This is the normal operation of the system as it has been designed and produced for. During field service there are different forms of scheduled, preventive maintenance as well as emergency maintenance caused by alarms.

Accelerated tests

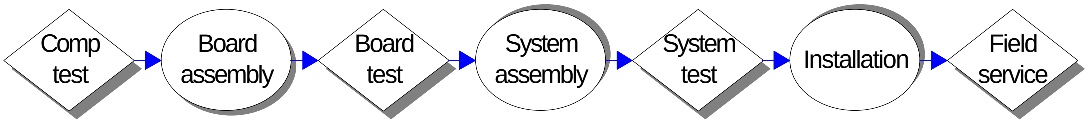
HALT: Highly Accelerated Life Tests. This is a test normally run on a few samples to detect the functional and destructive limits of the product. It may relate to vibration, temperature, and voltage, clock frequency or any other stress.
HASS: Highly Accelerated Stress Screening. As the name implies this is a screening test, i.e. is applied to 100% of the products. As such it is necessary that the stress is not detrimental to the product, causes no unnecessary yield loss but still gives an increased assurance that the product will meet the specified requirements. This means that the stress limit is defined somewhere between the specification limit and the functional limit determined from the HALT.
SST: Step Stress Testing. This test is one way of carrying out the HALT. It tests the function after a certain stress has been applied to the product. Then an increased stress is applied and the functionality is tested again. To determine the functional limit the test is performed at each stress level, to determine the destructive limit the test is performed at nominal stress after each stress period.
HAST: Highly Accelerated Stress Testing. This acronym is merely used for accelerated moisture testing where a combination of high temperature and high humidity is used. Such a test may e.g. be a biased pressure cooker test that is run at 121 ^{o}C and 85% RH.

Cost elements

Test cost (T): The cost for performing the test including inventory and labour costs.
Test failure cost (f): The cost for replacing, repair and retest of a product that was rejected during test.
Failure cost (F): The cost caused by a failing product in the following steps after the test. This may be the cost for field replacement and repair at site.
Maintenance cost (M): The cost for scheduled preventive maintenance when relevant

Test logistics

Figure 1 gives a generic picture of the product flow including test stations. Each cost element is defined by its relevant subscript where c refers to component, b to board s to system and f to field.



Test costs	T_c	Tb	T_s	M
Test failure costs	f_c	f_b	f_s	F_m
Failure costs	f_b	f_s	F	F
Reject levels	r_c	r_b	r_s	r_f
Sampling rate	s_c	s_b	s_s	N/A

Figure 1. Cost definitions used for the different steps.

In case that there is no component testing being performed by the equipment manufacturer the ‘reject level’ that would have been detected at component testing is being transferred to the next step, the board testing. To simplify the model discussion we will assume that we will not perform incoming inspection of components in this example.

Board testing

This is normally a test of basic functions and characteristics at room temperature. It is highly automated and is normally done within 10 minutes per board. The test equipment and work force is of high standard so the test cost may amount to a few $ per board. Often the tests are run to cover the specified limits, occasionally overrated tests are perform to assure wide enough margins to the spec limit. This may be the case for certain board types that are known to be temperature or timing sensitive so that the test yield is deliberately reduced in order to improve the field reliability. During this test most of the process related catastrophically failures are detected and corrected.

The failure cost at this level is based on the cost for failure identification, repair and retest of the device.

System testing

For AXE equipment it is standard procedure to perform fully functional testing of the sub-systems in a complete AXE environment. The tests are performed at elevated temperature in order to assure the functionality within the specified temperature limits. Since there are both thermal time constants (to heat up the equipment) and tedious transmission tests to consider, the total test time may range from 5 up to 16 h before the test is finished. In this test non-conformances are detected by tests that have not earlier been performed at board level or due to failures that are temperature related, marginally functioning devices or may be due to time-dependent mechanisms.

It has been shown [2] that there is a relationship between the reject level at system testing and the field reliability performance. The rational behind these findings is that marginally designed products are likely to cause rejects both at system testing and later on at normal field service. In order to obtain an effective screening of these marginal devices the system test need to be sharpened to a higher screening level (HASS) and in that case the relationship will no longer hold true.

The test cost per board may run at 10-20$ while the failure cost per rejected board will be higher since a new system test needs to be performed in addition to the failure identification (that may be complicated) and repair costs.

Field service

In field service the only test cost that is relevant would be the costs for scheduled maintenance if that is applied. A correction (e.g. board replacement) performed at a scheduled maintenance visit would be much less costly than an action caused by a subscriber alarm causing unscheduled repair travels maybe at night. Therefore one might need to distinguish between these two different failure costs, f_m and F (see figure 1).

According to ref. [2] typical AXE hardware have shown a linear dependence between the reject rates in production testing (r_b and in particular r_s) and the accumulated field returns during 5 years of service. This relationship will be used in the next chapter for defining optimal test strategies.

Total costs vs. test strategy

In sake of simplicity, let us first assume that only two steps are performed in the test flow; a system test and the following field service. It is then possible to estimate the total test and failure costs depending on the test strategy chosen at the system testing. If the quality is good it may be feasible to introduce some sample testing instead of a more expensive 100% screening.

Total cost at 100% screening

$$C_{100}=T_s+r_s*f_s+A*r_s*F \qquad \text{…. (1)}$$

The total cost comprises of the test cost, the reject level at testing times the failure cost at test plus the field failure cost that is assumed to be linearly dependent on the reject level at system testing in this case.

Total cost at 10% screening

In this case we assume that only 10% of the boards are tested which might be justified if the quality is very high, the reject level very low and test costs rather high.

$$C_{10}=0,1*(T_s+r_s*f_s)+(0,9*r_s+A*r_s)*F \qquad \text{…(2)}$$

Here only 10% of the earlier test and failure costs need to be counted. Instead, 90% of the earlier system reject level is assumed to cause additional field failures and extra costs. The field rejects expected due to the correlation between system test rejects and field performance will not change due to this sample testing.

The sample testing break-even point

By making $C_{100}=C_{10}$ we will find the break-even point [3], i.e. the reject level at system testing under which it makes sense to adopt a sample testing approach.

$$T_s+r_s*f_s+A*r_s*F=0,1*(T_s+r_s*f_s)+(0,9*r_s+A*r_s)*F$$

$$\mathbf{r_s = T_s /(F-f_s) \qquad …(3)}$$

Note that this break-even point is independent of the choice of screening level. The simple formula may be used to determine if unnecessary screening costs are spent on routine just because the specification says so. This may be an important issue as the production volumes increase and the quality and production processes constantly improve.

Figure 2 gives a graph over equation (1) for the case that the test failure cost is 200 SEK. It shows the break-even point where sampled testing may be considered as a function of test costs and field failure costs.

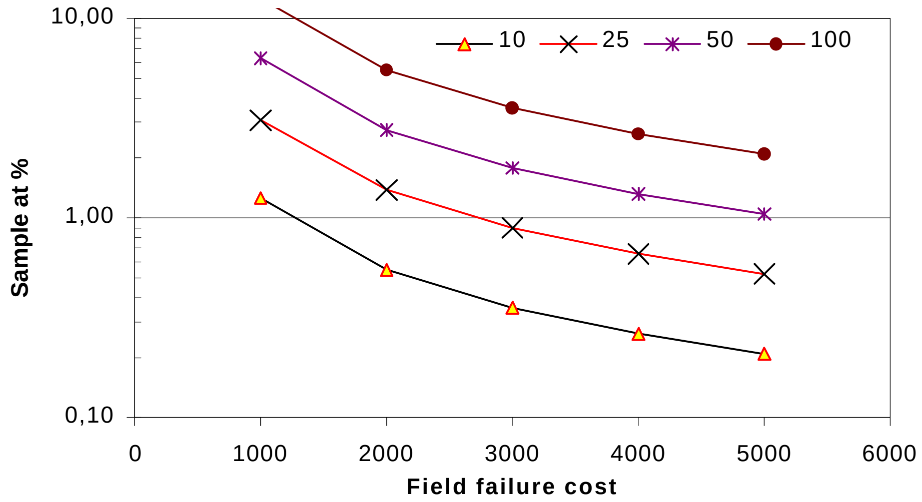


Figure 2. The reject levels at test where sampled testing may be reasonable to consider. Parameters are test cost (10-100 SEK) and field failure costs (0-6000 SEK). A test failure cost of 200 SEK per reject is assumed for this graph.

Test characteristics and their distributions

During production testing of electronic equipment, e.g. a printed board assembly, a lot of parametric data is collected. This raw data will most likely be deleted by time due to storage reasons so it will not be possible to go back to this data to compare with the characteristics of a returned device from the field.

We have, though, had the possibility to perform such comparisons on some products and found some very valuable information useful for the improvement activities.

Traceability on Ericsson telecommunication products

Each produced unit, both on board and system levels are given a unique serial number. Test records and serial numbers are saved in a test database. When a unit is returned for service the serial number is logged together with information on the fault- and trouble shooting results. The serial numbers may then be used to see if the returned units deviated already at production test.

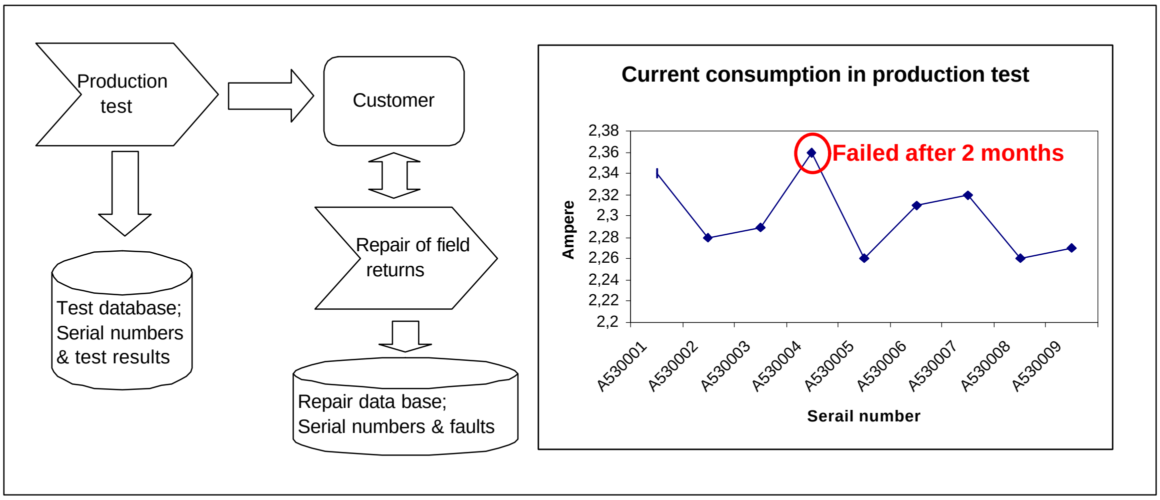


Figure 3. Simplified picture of how traceability may be used to point out which units from a production batch did fail in service.

Example of found correlation

A radio frequency power amplifier product for radio base equipment had a high field service rate. The cause of failure was in most cases a power transistor. Analysis of components revealed process problems at a vendor that caused some components to have a weakness. Improvement actions were initiated, but the question arose if we could assure component quality without going back to the days of incoming inspection or implementing extensive parametric testing at the vendor.

Results from board test were analysed together with information from field service. Through the serial numbers on the units, it was possible to compare their performance in board test to occurrences of component failures in field use.

One production week batch with high field service rate was analysed, 483 units were tracked during their first year in service. 15 of the 483 had failed due to the power transistor failure, the original board test records where compiled and compared to see if they revealed which units where prone to fail, the result is shown in figure 4.

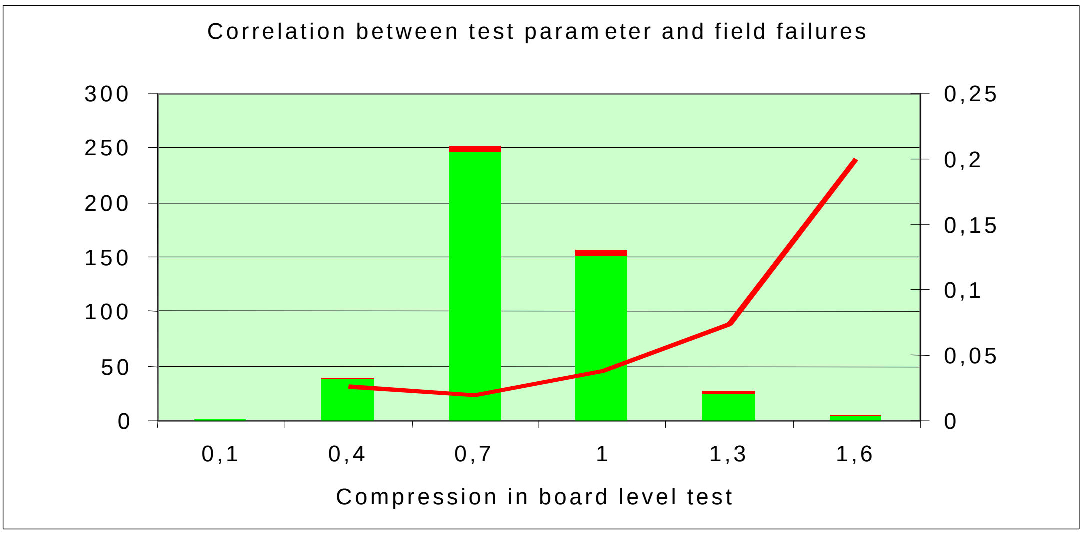


Figure 4. Many “obvious” parameters such as power consumption or linearity did not correlate to the defect rate, but the parameter “compression” did.

(The compression test verifies that there is a marginal between specified and maximum output power, the lower compression the better.) The correlation may be calculated in several ways, only the graphical indication is given in the picture.

The results where presented to radio designers who agreed that the found component weakness could show in the compression test. There was no way of telling which units had bad components assembled, but the skewness of the distribution may well be caused by a higher mean compression for the weaker components.

The knowledge makes it possible to do early evaluations of initiated component improvements.

Example of no correlation

On another radio frequency power amplifier it was suggested to tighten the board test limit for current consumption. The suggestion aimed at decreased field returns, which should compensate the extra cost of decreased board test yield.

The underlying assumption was that units with poor efficiency are prone to fail and that these may be screened out in production. To verify this assumption 30 serial numbers from field returns that had failed after about three years in service where gathered and their test records compared to a random sample of other units that passed board test at the same period of time. The result is given in figure 5.

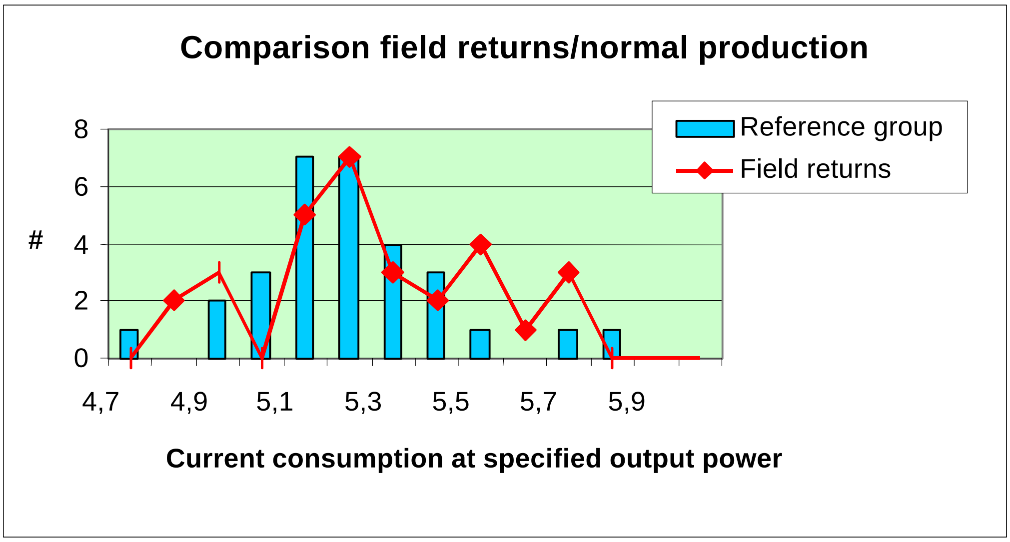


Figure 5. The units returned from field did not deviate in any major way from other units produced at the same time. Trying to screen out units prone to fail later on would not be possible using this parameter.

The underlying assumption that poor efficiency is connected to the risk of failure is not questioned. The board test current consumption measurement could however not be used for screening in this case.

Conclusions from several studies

On radio base equipment it is not easy to find test parameters that describe the risk for failure; correlation is often obscured by measurement error. This knowledge may be used to avoid screening activities. Tough test limits and low production yield does not always mean that the units shipped to the customer are any better than the units filtered out in production.

If a production test parameter and field failures correlate significantly there are several options on how to improve MTBF:

1. Change the product distribution on the critical parameter.
2. Use tighter limits to screen out units prone to fail later on.
3. Find and correct the cause of the correlation.

Since it is rare to find parameters that may be used for screening it is preferable to stop considering screening as an option to increase MTBF. It would be better to track parameter mean values and standard deviations on batches. Rather than changing test limits we must improve our products, this is easy to verify by the batch descriptive test statistics. Product parameter changes may be compared to field returns per batch. By focusing on describing batches rather than having individual test records there is more room for statistic sampling, which should be economically advantageous.

Having original batch descriptions also gives opportunities for analysing returns that no faults are found on, so called NFF units (No Fault Found). Only a few returns are needed to make a hypothesis testing to see if they deviate from their original batch. Deviations between original batch description and NFF returns may have been caused by parameter drift in use or were present already at production test. Either way a parameter that may be beneficial to improve has been pointed out.

In order to make sure that such data is available for most products we need to compress the data in a very efficient way. The following procedure is proposed:

- Introduce a batch identification that makes it possible to determine from which production batch a returned product is coming.
- Describe automatically the parametric distributions for the tests performed on each batch by a median value and its standard deviation. Normally it is enough by just two numbers per parameter.
- Store the data in an easily retrievable database on the web to make it possible to compare the characteristics of a returned or failed device with the typical data from the same original batch.

The product improvement process

The improvement process covers monitoring and improvements of product quality characteristics during both production and field use until the final phase-out of the product.
The controlling activities are based on product Life Cycle Costs and the annual quality goals that are defined per product.
The improvement activities shall:

- Be continuous
- Be based on facts and total quality feedback
- Lead to measurable cost reductions

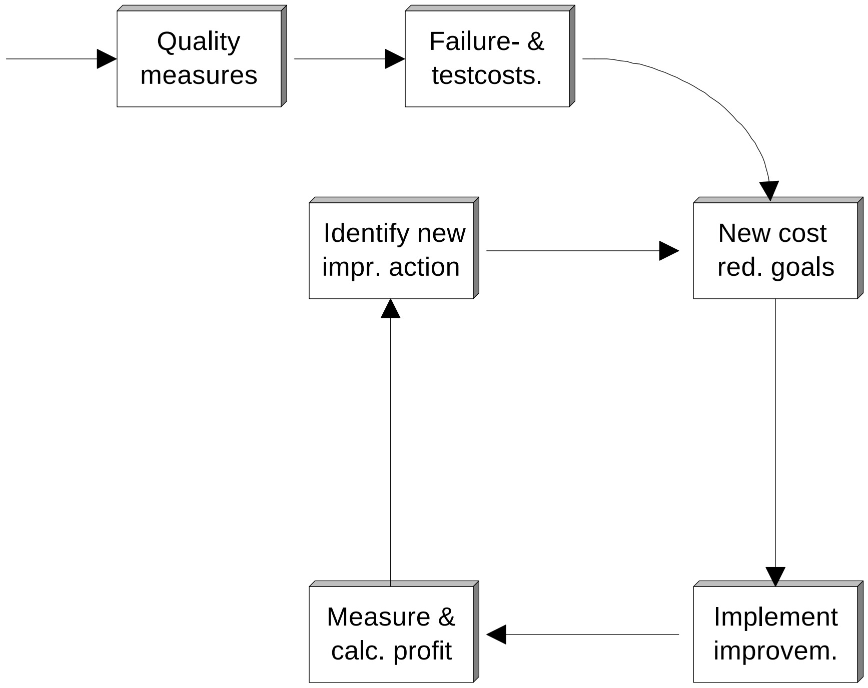


Figure 6. After defining quality aspects and related cost elements the improvement process will run as long as it is profitable for the project or product.

The process has been used as a base for several failure cost- and test cost reduction projects that always turned out to be very profitable.

References

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