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A TIME DEPENDENT FIELD RETURN MODEL FOR TELECOMMUNICATION HARDWARE

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ABSTRACT

An analysis of measured field return rates of printed circuit boards has been done in order to characterise the time dependence. The report shows that there are two types of improvement trends, one due to field screening of early failures and one due to product improvements from year to year. Previous research has shown that there is a correlation between production test yields and field performance, for high-volume boards. This correlation has been used together with the time dependency in order to predict field return rates

INTRODUCTION

Nilsson and Hallberg (1997) presented a method to estimate the accumulated amount of field failures after 5 years use of telecommunication electronics. It was shown that there is a correlation between production test yields and field return rates that can be used to estimate future field returns of new products. At that time no information was presented as to how the returns would appear during the field use time.

In order to get more detailed information on the time dependence of the return rates, the return statistics from a number of volume boards was analysed. In total several years of field experience from over 2.000.000 printed board assemblies (PBA) was collected and used for the study.

The traditional way of estimating the field return levels has been based on the so-called 'part count method'. This method is basically assuming that all components on a PBA can be characterised by an inherent failure intensity, and that the return rate of the PBA can be found by simply summing up all the failure intensity numbers from all components on the PBA.

There are several problems with this approach and a lot of criticism has been given to methods such as MIL-HDBK 217, see e.g. M. Pecht (1996). The repair process will sort out marginal and faulty PBA's. The replacement will most likely be done with much more reliable parts. This will lead to a gradually reduced return rate, normally described as following the first part of the 'bath-tub curve'.

Volume products fortunately also tend to improve in reliability from year to year due to the regular design improvements (revision updates) and also due to continuous improvements in manufacturing processing.

Thus any return rate that has been predicted based on constant failure intensities of components, will eventually become too pessimistic and estimate too large return numbers. The traditional way of coping with this problem has been to review mountains of component return statistics and to revise the failure rate numbers, e.g. by dividing them by a factor of 10.

In order to save time, money and to improve the precision of return estimates a new process for reliability prediction thus needs to be developed.

QUALIFICATION EVOLUTION

The product flow from component processing to the field service of the finished electronic equipment goes through a number of distinct steps. Figure 1 tries to depict the change of interest or responsibility between the component manufacturer, the equipment manufacturer and the telecommunication operator, Hallberg (1998).

At the beginning of the 80's, the component manufacturer developed the process, designed and verified the component, carried out lifetests and other qualification tests and screened the parts in his final test. The customer received the parts, performed his own qualification test and started then to inspect sometimes all 100% of the devices received. Then board assembly, test and system test followed before the delivery to the end customer. At site, the equipment was installed and retested again before the end customer could take over for acceptance test and put the equipment into field service.

During the 90's the improved quality made it possible to change this flow. The Vendor now became the main one responsible for component qualification and his final test replaced the incoming inspection by the equipment manufacturer. Instead a more rigorous application test took place and large efforts were given to build systems for quality data collection and analysis in the equipment manufacturer's own product flow. The trend continues so that some equipment manufacturing now becomes out-sourced so that quality information may need to be collected from outside of the equipment manufacturing company.

Thus, early field reliability information is a very important form of feedback to the equipment manufacturer as it assures that the quality is improving according to models and expectations.

Process development
Product design
Qualification
Final test
Incoming inspection
Qualification
Board testing and analysis
System testing and analysis
Field service performance

70's:----→
80's:----------→
90's:-------------------→...

Figure 1. The component manufacturer is taking a wider quality responsibility. Today, even board- and system testing may be out-sourced to external resources.

THE INSTALLED BASE

There have been around 140 millions of AXE-operated fixed telephone lines installed in over 130 countries since the beginning of the 80's. Line circuit boards house from 4 lines up to 30 lines per board. Including all other electronics for control, power distribution, information storage etc there are over 50 millions of printed board assemblies currently in service.

Field returns and repair

When a HW fault appears, a module is identified and replaced by a spare unit. The faulty board is then sent for repair at a central repair shop. Depending on the market the repair information is gathered in different local databases. By collecting such local repair information it is possible to get a good view of the global trends and to identify products that need to be further analysed and improved.

Important pieces of information that can be collected at the repair shop are e.g. fault date, original manufacturing date of the module, manufacturing site, installation site, repair code and replaced components, if any.

Installation data bases

There are different routines for storing information on the installed hardware in different markets. Some markets can trace almost each individual module by its bar code, while others can only report the number of installed units per product type number for each year or month. In order to analyse product reliability from field service data it is important to use markets that have good inventory control and a good repair loop.

METHODS FOR FIELD DATA ANALYSIS

Depending on the available statistical information and the purpose of the field reliability study, there are different methods available for the data analysis. Several tools have been developed at Ericsson Telecom AB in order to support the collection and analysis of product quality data. One object common to all these tools is giving the designers the possibility to monitor the performance of their own products and to support the improvement work.

EriView 2000

It may be that it is only possible to get information on the number of boards manufactured by each year or month and the total number of returned products each month. The central point in this software is to find a life distribution that best fits to the measured field performance, Oscarsson and Hallberg (1997). The required input for the parametric optimisation method is:

- The number of products put into service each time period (month, year etc)
- The number of products failed in service each time period.

The exact information about ***when*** and ***where*** a failed product was put into service is not necessary in this analysis. This makes it possible to analyse time dependencies from repair statistics, medical data or e.g. traffic accident statistics in a way that earlier might have been regarded as difficult. An example of such an analysis is given by Figure 2.

The tool is of a general nature, and creates many possibilities for the analysts. There are four different basic life distributions to choose from (exponential, normal, lognormal and Weibull). It is also possible to take into account the influence from up to 3 mixed sub-populations. Products with fixed service time, e.g. 20 years, can also be modelled.

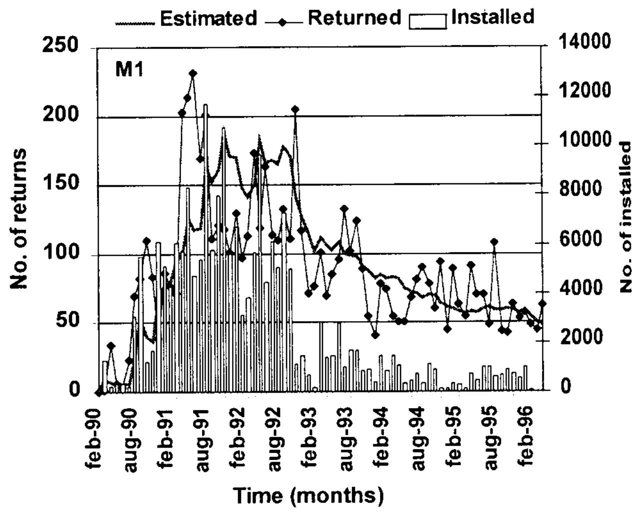

Figure 2. An example of an EriView 2000 analysis

The MYFY-application

In most markets information on the number of products manufactured and installed each year is available. If each failure report gives the manufacturing date of the returned product, a new type of analysis is possible. This method is called '**MYFY**' as it is based on the **M**anufacturing **Y**ear and the **F**ailure **Y**ear information.

The basic idea behind MYFY is that fresh, new manufactured boards most likely will be put into service after a relatively short time, say three months. The manufactured lot, delayed by this time may thus approximate the installed base of boards. In order to calculate failure levels and failure rates one must recognise this delay and take into account the ramp-up of products installed over the manufacturing year and the year thereafter. It may be the case that out of all products manufactured one year only 75% will come into service sometime during the year that they were manufactured.

In order to make the best use of the simple algorithm for MYFY-calculations a Windows application was designed. The application allows the user to choose the market and product of interest, after which he/she immediately gets a graphical report of the failure rate and the accumulated failures per manufacturing year versus field use time.

Figure 1 gives an example of an MYFY-analysis of one product. The plot shows the general good trend of accumulated failure levels by field use time for each manufacturing year for that market. The graph also shows the general good trend of annual improvements by each manufacturing year. Much of this annual improvement is due to production, testing and design improvements.

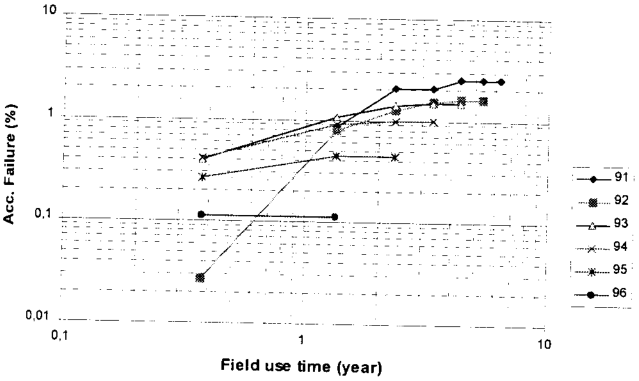

Figure 3. An example of a MYFY-analysis showing the accumulated return levels of one board type vs. different manufacturing years and field use time.

RESULTS AND GENERAL FINDINGS

A number of high-volume boards from two markets and two production sites were selected for detail study. In total around two million PBAs formed the base for the investigation. The average field use time for those boards was 4 years but many board types had been in production for up to ten years.

The failure codes for the two markets indicated that around 50% of the returned boards had a component replaced and that in almost one third no fault was found (NFF). Only 1% was related to production flaws. See Figure 4.

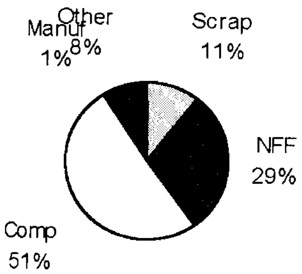

Figure 4. The distribution of failure codes

Time dependent failure rates

One general conclusion that can be drawn is that the return rate of hardware from the field drops by the time in service. This is a natural result from the fact that the 'weak' parts having component failures or very small margins will be detected early and replaced by products that on the average are much more robust.

The question about time dependent failure rates has for many years been a source of controversy. Today, we can see from field statistics that the failure rates normally are not constant in time, see Figure 5.)

Improvements by manufacturing year

Another good trend is that the hardware quality per product type in general improves from one year to the next by a factor of 1,5 in terms of accumulated failure level after say 5 years.

This improvement trend is mainly due to process improvements in the manufacturing line, and is also due to design improvements (product revisions). An example showing both these trends is given in Figure 5 where the average return rate of all printed board assemblies within one market has been compiled.

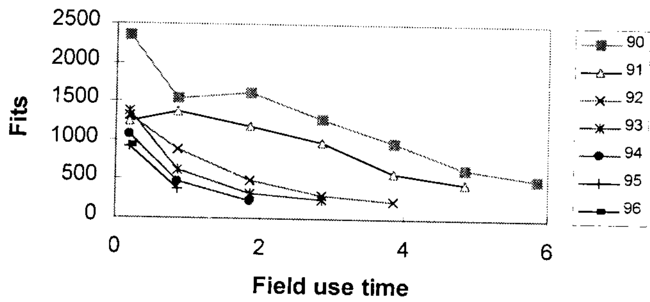

Figure 5. The return-rate development for all boards manufactured for one market, in total over 1.000.000 boards of different types in use.

The same analysis was performed for another market based on 800.000 boards in use. It gives a similar impression although occasionally a particular manufacturing year may jump upwards due to some specific reason. See Figure 6.

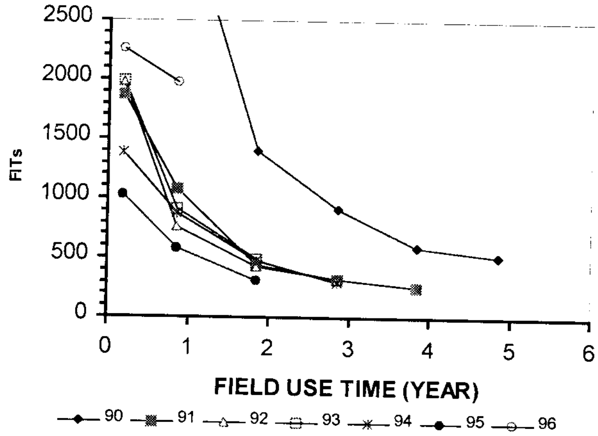

Figure 6. The return-rate of boards in an other market

Failures free electronics?

Figures 4-6 gives the impression that the return-rate after 4 or even 2 years of use drops to very low levels. A study was undertaken on 20 volume produced board types. These were selected as they all showed a very low field return rate (Figure 7). The object was to see if there was any common factor behind the good results obtained.

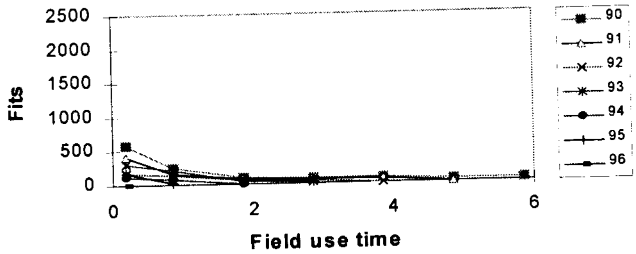

Figure 7. The failure-rate development for 20 high-quality volume board types, in total 110.000 boards.

The main conclusion was that these board types have been designed in a robust way, using good margins and well known components of high quality for their design. The boards were of mixed complexity ranging from simple strap boards to complex multilayer board types equipped with ASIC components.

Obviously, it is possible to design and produce hardware that shows a very low failure rate, even further reduced by service time. This shows that we should not expect a minimum level due to inherent component failure rates. Further failure cost reductions can be expected by developing even more robust designs.

Individual board types

Figures 5-6 are based on the return statistics from several hundreds of different board types. An individual board type will, of course, give a more scattered picture. If a quality problem occurs one year this will be visible for that manufacturing year and the failure rate may occasionally become higher than in the year before.

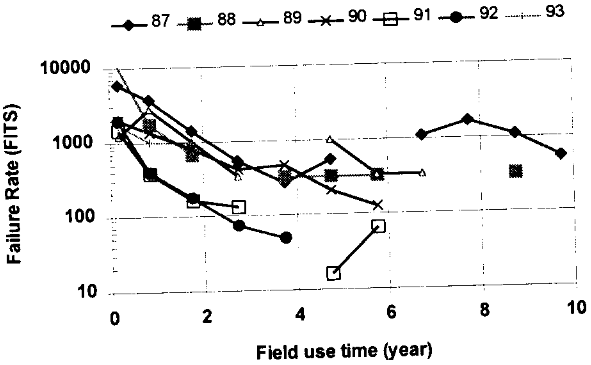

Figure 8. The return rate performance for a product that was produced between 1987-1993

As the return rate often approaches low numbers after some years it is practical to use a logarithmic scale for detailed analysis and for modelling purposes. Similar graphs were obtained from 16 different boardtypes from one market, in total 433381 individual boards, to get a picture of the general performance.

A SIMPLE IMPROVEMENT MODEL

The results obtained from the field studies may justify a model based on one fixed, constant failure intensity and on top of that a dependency of both field use time and the maturity (manufacturing years since start). A model that simulates the field return rate (RR) was put together:

$$RR = C*b(m)*(\exp(-t) + 0{,}1) \quad (1)$$

where t = the field use time in years.
C = a constant
and b(m) = a maturity factor that is reduced by each manufacturing year,
b (1) = 50; b (2) = 25; b (3)=12; b (4)=7,5; b (5)=6

This model gives a time- and maturity dependence as shown in Figure 9. The constant C has the dimension [1/time] and can be regarded as some kind of basic return-rate that can adjust the set of curves up or down in the graph. In Figure 9 the constant C is 300 fits.

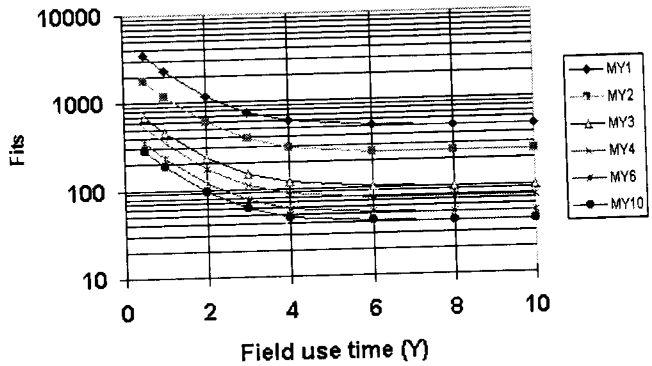

Figure 9. The model shown for the constant C=300 fits

Prediction of return rates

A software application was developed to make use of this simple improvement model (eqn. 1) to predict return volumes based on future production plans. In order to estimate the factor C in the model we used the correlation between measured test yields and field failure levels as earlier described by Nilsson and Hallberg (1997).

Definitions used. We define the failure level at board test as A % and the failure level at system test as B %. A board is normally tested for a few minutes while a complete system test of modules containing many boards may last for a number of hours at elevated temperature.

Nilsson and Hallberg (1997) estimated the return level during 5 years of field use of our systems by equation (2):

$$5Y\% = 1{,}48*(0{,}1*A+B+0{,}4) - 0{,}38 \quad (2)$$

The average return rate, expressed in fits, will then be:

$$C = 335*(0{,}1*A+B) - 87 \quad (3)$$

This number, C, is used in eqn. (1) in order to estimate an upper field return rate since the first manufacturing year. A lower level was estimated as one third of that level based on the spread in data normally seen for individual boards. It should be emphasised that the constants used here modelled the performance of our telecommunication products, but that other constants might better model the performance of other types of products produced by other companies.

A software application

The purpose. Once time dependent field-return rates have been modelled, the model should be made available for practical use. There are many areas where such a model can be of great help.

One is obvious: to estimate the future number of returns the coming years as a function of planned production volume per year.

It may also be of value to initiate corrective actions in the case that the early return levels are higher than expected according to the model.

Customer requests on estimated failure-rates or MTBF-figures may be answered in a realistic way, allowing for higher initial rates and lower mature rates.

The software. A standard Excel application was put together to facilitate the use of the model.

The user needs to specify the number of boards that will be put into service for each one of the next five years. Then it is necessary to specify the rejection rate at board testing and at system testing (A% and B%, see above).

When this is done the user can obtain estimates of returns per year, return rates, accumulated returns, MTBF numbers and more. Figure 10 gives a view of a part of the application from where results and graphs will be obtained.

Information about the use of this software is given via the internal web-sites and in separate training sessions.

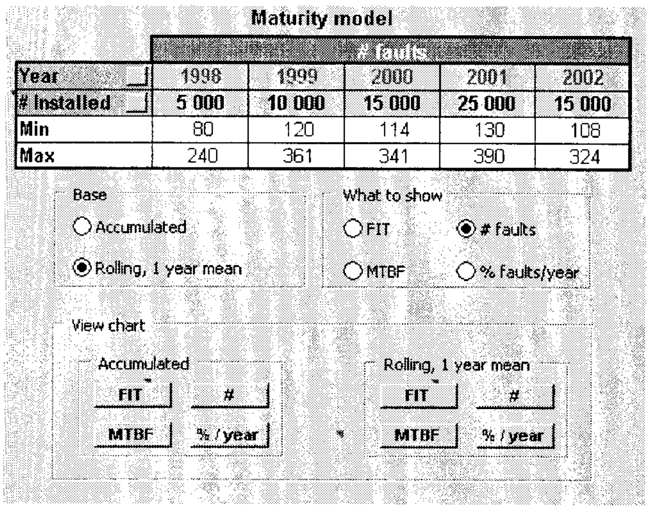

Figure 10. The output module of the tool, called PredIT.

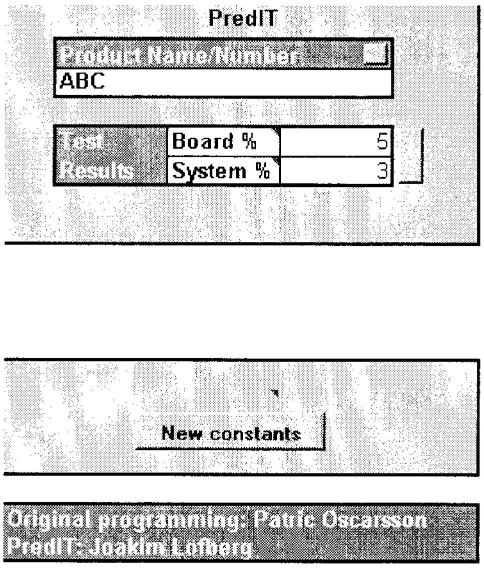

Figure 11. The input module is the place where new product names, test results or new model constants can be inserted.

RESULTS OBTAINED BY PredIT

The prediction method was applied to a number of product types manufactured since 1990 and onwards. Based on the test results for each product type (numbers A and B, see above) and the actual numbers of products produced up to 1995 the returns per year were calculated and compared with actual returns.

At the same time we also calculated the number of returns that should have been expected according to the traditional part count method.

Figure 12 shows the predicted and actual reported returns per year as an average for a number of different volume board types. The annual return is expressed as a fraction of the total accumulated volume of installed boards measured at each year. The general trend is that the new model gives a better estimate over the initial time period than the part count method does. Since our internal part count database has been updated to reflect the average performance of our installed base of equipment, it gives a fairly good estimate of the return rate after around 3 years in service. For the product types used in this study, the part-count method predicted that around 0,35% of the installed base should be returned per any year (400 fits). PredIT indicated that the values between 1.8% - .2% should be expected over the different years.

Another way to analyse the data is to calculate the number of returns for each year and to relate the numbers obtained to the actual reported numbers. This is shown in Figure 13. In this study the average prediction accuracy was around +/- 10% for PredIT and around +/-40% for the part-count method. There is also a strong trend of overestimating the returns by time in the latter case.

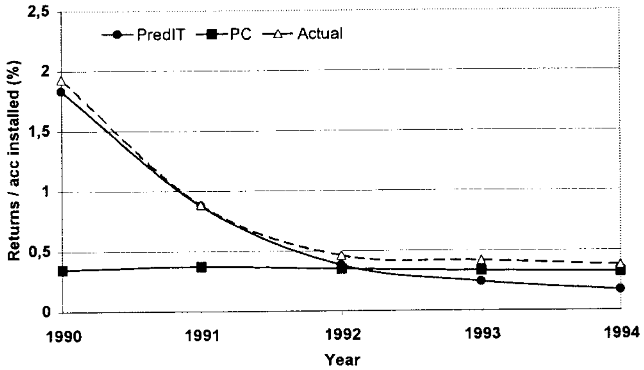

Figure 12. Returns per year as a fraction of the accumulated installed volume of 18 product types.

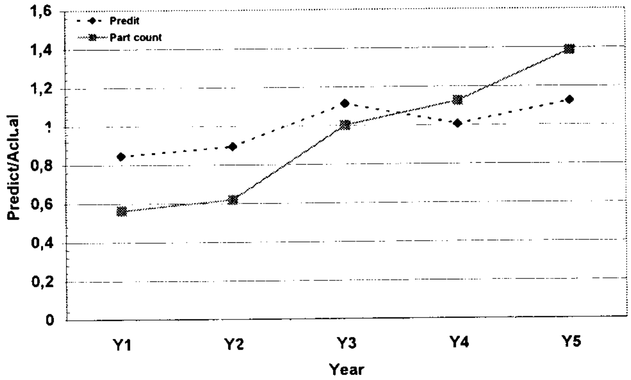

Figure 13. Predicted/reported returns per year according to the two prediction methods.

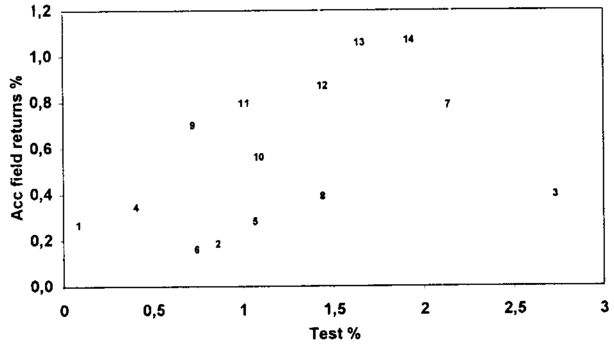

Figure 14. A plot over test- and field performance of the different volume board types

DISCUSSION

Individual data from volume boards did not always follow the model given by equation (1). In a few cases it was clear that for certain manufacturing years the return rate was higher than expected. In all those cases it was also possible to relate the high return rate to known problems.

Thus, it is important to have a realistic model that gives a picture of what return volumes that can really be expected. Any deviation from these (i.e. higher return volumes) should initiate an investigation for the reason.

Figure 14 gives a view of the analysed products in terms of their test performance as calculated by equation (2) and the total field returns in % of total base. The graph shows again that there is a relation between test yields and field performance, as expected. One board type (3) breaks this pattern since it shows a better field performance than the test results would suggest. A closer look at this board type showed, however, that the test limits deliberately had been narrowed to give better margins and to prevent field rejects as the board was known to have sensitive temperature and timing properties.

CONCLUSIONS

There appears to be two reasons for reliability improvement over time – one is due to field screening of marginal parts and one is due to product and process improvements over the production time.

By taking the time trends into account an improved accuracy in reliability prediction can be obtained, especially for the initial few years.

Reliability prediction can be based on test yield information as an alternative to the component part count method.

It is suggested that the presented method, or similar, should be used in order to better estimate future return volumes and to react on negative trends at an earlier stage.

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