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DESIGN AND RELIABILITY ASSESSMENT OF AN AVIONICS TFT-LCD DISPLAY

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Abstract: In avionics application it's fundamental that each system, sub-system or a component achieves a high level of reliability. To this aim, reliability prediction and an accurate test planning are required in the design phase in order to avoid undesirable fault or failure during the operating life cycle of any aeronautics equipment.

In this paper, a research activity concerning the design and reliability assessment of TFT-LCD for avionics application are presented. The results obtained by the development, characterization and reliability analysis of a customize display which will be installed in a military aircraft cockpit are discussed. Being the device under test an innovative display, it's fundamental an evaluation and analysis of the reliability performances. Then some test on the display has been performed to validate the customizing process.

Keywords: TFT-LCD; reliability analysis; thermal tests; optical measurement; avionics application.

1. INTRODUCTION

In comparison with other electronic applications, avionic devices must be able to guarantee higher reliability requirements. Many critical factors influence the reliability of avionic devices: harsh environment conditions, mechanical stress, maintenance activities and so on. Moreover, test sessions based on the use of an aircraft are time and cost expensive procedures to carry out, therefore the reliability analysis represent a key issue.

Considering this critical aspect in avionics design, this research is focused on the development, characterization and the reliability analysis of a customized active matrix TFT-LCD (Thin Film Transistor – Liquid Crystal Display) size 5”x5”, which will be installed in a military aircraft cockpit.

In order to evaluate the reliability performance of such display for avionics application, a detailed reliability analysis to estimate the MTBF (Mean Time Between Failure) of the device is necessary [1], [2]. Since the reliability prediction is recommended to perform particular test on the display in order to validate the customizing process. The whole test plan has been characterized and some results are reported in the paper.

2. RELIABILITY ASSESSMENT

An estimation of the reliability performance represents a fundamental step before a detailed development of the display. In the aeronautic field, the reliability prediction is nearly always requested to be drawn up using the Military Handbook 217-FN2 [3], [4]. As this, however, was last updated in 1995 it does not consider reliability models of elements such as, for example, the nematic cell of an active matrix LCD display. It has therefore been necessary to elaborate a new model which allows the insertion of this element inside a reliability prediction of a complex system.

The first step was to individuate a criteria according to which the failure mode can be defined in an unequivocal way. It was decided to use as an acceptance criterion, a condition regarding the maximum number of pixel not functioning on the entire display so that it can be considered working, that is to say, without losing the information visualized.

Let's see the hypothesis of the model:

- Constant failure rate; there is no doubt that microscopically, very few failure mechanisms strictly satisfy a "constant rate" type occurrence law. However the dispersion of many failure mechanisms, although they are cumulative and therefore increasing with time, is such that they can be deemed to be constant over the time interval considered. Moreover, the growth of the large number and diversity of components, even on a single board, will be close to a constant. For these reasons, the assumption of a constant failure rate is still the most relevant approach for estimating the predicted reliability of a system [4], [5].

- Independent failures; the failure of any one component is statistically independent of the failure or success of any other.

- All the pixels functioning at the first display switching-on;

- The only elements to be considered from the reliability point of view inside the active matrix are the MOSFET, since it is assumed that all the plastic parts of the pixel (polarized filters, color filters, alignment layers, etc.) and the liquid crystal itself, are characterized by a negligible failure rate.

According to the proposed model we consider the failure rate in only one of the three dots which compose a pixel. Based on the previous hypothesis, the reliability model of a MOSFET contained inside the MIL-HDBK 217 (λ_{dot}) can be used.

To be able to obtain a reliability prediction which takes into account the effective working of the display, it is necessary to know the numbers of hours in which it is functioning during the year. In this way, the duty cycle can be determined and, through this, the single dot failure rate weighed on the annual mission profile ($\lambda_{dot\_Duty\_cycle}$). If, instead, the device's annual mission profile is unknown or if it is not taken into account in a prediction, then simply the dot failure rate without weighing it will be used.

The next step consists in the estimate of failure rate of a single pixel and to do this the condition of the failure must be introduced. The customer has established that a pixel must be considered as fault when all three dots which go to form it are out of working order. A system of this kind is describable through the parallel functional configuration. By means of the use of this model's reliability formulas the pixel's failure rate (λ_{pixel}) is obtained.

The last step of the model consists in calculating the MTBF of the entire display. Since a criterion of acceptability based on the maximum number of not working pixels admissible has been used, the system functional configuration is a k-out-of-n configuration, where n is the total number of pixels and k is the minimum number of pixel which have to work so that display is considered to be operative. Using the reliability formulas of this kind of configuration, the MTBF and the failure rate of the whole nematic cell can be calculated. This has been estimated equal to 143.462 hours with a corresponding failure rate of about 6,97 failures/10^6 hours.

We have already mentioned that in aeronautic field, reliability predictions are carried out using the MIL-HDBK 217 as in practically always requested. Recently, however, Airbus and other aeronautic industry have introduced FIDES [5] as a new reliability methodology for electronic systems. This guide being much more recent compared to the MIL-HDBK 217, makes provision for reliability models made up of modern components such as, for example, the nematic cells of the active matrix LCD display.

FIDES methodology allows to make accurate reliability predictions on the basis of numerous aspects taken into consideration: a detailed mission profile of the device under examination, the specific stress level of each phase of the mission profile, the operator's level of qualification, the case in which some operations concerned with increase of reliability and regular maintenance take place etc.

By applying the FIDES approach the failure rate of the 5"x5" display's nematic cell, object of this research has been estimated. As results a failure rate of 1355 FIT (Failure In Time) that is 1355 failures in a billion hours, corresponding with MTBF equal to 738.003 hours (about 84 years). The results obtained are compliance with the requirements established for a military aircraft cockpit.

3. A NEW TECHINQUE FOR TFT-LCD DESIGN & EXPERIMENTAL TESTS

Once the preliminary evaluation of reliability has been carried out, the review and development of the original panel sized 5"x7" is implemented. The supplier was requested that the electronic board could be easily shifted and so to be in a position to control the panel both in its original size and in 5"x5" squared one.

Successively, the display was divided. In the area of the cut, a very thin layer of UV glue was laid as a mechanical barrier against humidity and various other forms of contaminations that can lead to amplify ion's effects [6-10].

After the cut and seal phases, two layers of glass were glued onto the polarizing filters by means of a silicone gel distinguished by such a consistency that it enables a certain freedom of movement in the deformation caused by change of temperature: a too stiff glue in fact, could cause the separation, so making critical the use of the display in extreme atmospheric conditions.

The front glass is treated with a covering of ITO (Indium-Tin Oxide) so as to insure to protection against electromagnetic interference (EMI) [11], [12]. Since this treatment is based on metallic oxides, it is very reflective in the case of incident light, so a further antiglare treatment is necessary in order to assure an excellent vision of the display even in the presence of incidental solar light, see Figure 1.

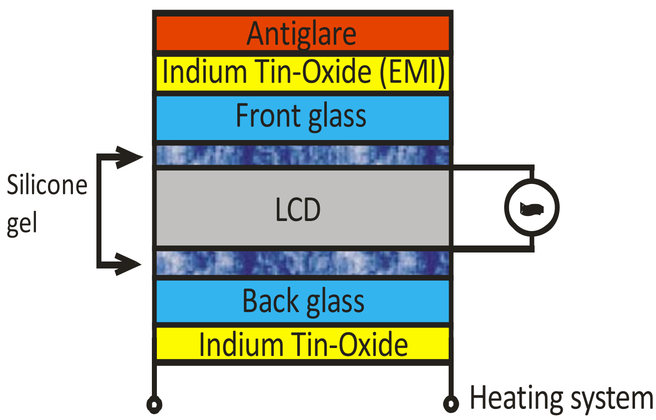

Figure 1 – Preliminary LCD display configuration.

The treatment of the back glass instead, is part of heating system which starts working automatically when the display reaches temperatures below –45°C. Heat is radiated for Joule effect, due to a layer of ITO left which acts as a resistance to the electric current which crosses it.

It needs to be specified that the two pieces of glass previously described, are a few millimeters longer than the size of the display, so that cavity is created inside which UV glue is injected. In this way a sort of cap is obtained which serves as a further mechanic barrier against humidity.

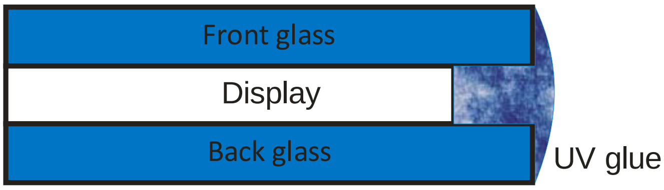

Figure 2 - UV glue injected between front and back glass.

What has been described is the configuration of the LCD assembled that was initially adopted for the 5”x5” display at the centre of this study.

Once the assembly of the glass was finished thermal tests were carried out as the customer has requested that the device be in a position to function correctly after having worked for an hour at a temperature of 90°C (a much more severe condition compared with a typical one of 70°C).

After an hour in the climatic chamber at 90°C, two marks appeared on the display: a halo like a scratch which appeared near the UV glue seal and a perimeter halo that was present on all sides except the one where the LCD has been cut.

To be able to understand the reasons behind the presence of the haloes, we carried out, one by one, all the steps which lead to the first configuration developed of the display and after each step we performed the thermal tests required. Haloes appeared exclusively following the sticking of both pieces of glass and the placing of the UV glue cap.

In this way we understood that the nonconformities are due to the stress generated because of thermal deformation of the glass and because of the rigidity of their constraints as regards the display (UV glue). Deformation induced by stress modifies the cell’s geometric characteristics, so disturbing the piloting of the liquid crystal molecules which in fact, no longer answer in the way expected by the applied electric field. We have therefore realized that the phenomena behind the onset of the haloes are mechanic-electrical.

Having to reduce the number of ties so as to make the system less rigid, keeping the legible solar condition both of EMI compatibility and working at low temperatures we developed one single piece of glass with a triple function: protection against electromagnetic interference, heating system and antireflex and substituted the previous adhesive (UV glue) with a softer gel.

The new solution is denoted as “*combined glass*” and it is shown in Figure 3.

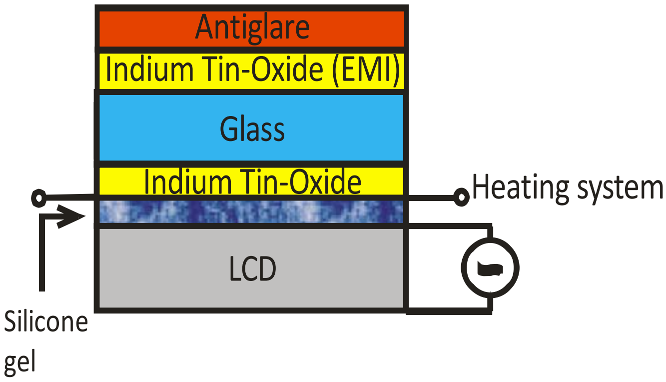

Figure 3 – “*Combined glass*” display configuration.

In Figure 4, an image of the 5”x5” display carried out with the “Combined glass” technique is shown.

Figure 4 – A photo of the 5”x5” display and the electronic control board.

The display on which the combined glass has been stuck was put under stress for an hour in a climatic chamber at 90°C and did not present any kind of halo, confirming the wildness of the new proposed solution.

In order to verify the validity of the silicone glue and of the entire system compared to humidity, two different tests were carried out one according to the Military Standard 810F [13]; it is important to underline that the test method standard that is approved for use by all Departments and Agencies of the Department of Defense (DoD). Although prepared specifically for DoD applications, this standard may be tailored for commercial applications as well. The other test, more severe, was carried out according to the standard RTCA DO-160E [14] that is a standard for environmental test of avionics hardware.

In Figure 5 and 6 are shown the tests profiles, in function of the temperature and humidity level for each standard. These levels have been chosen so that different failure mechanisms are not introduced.

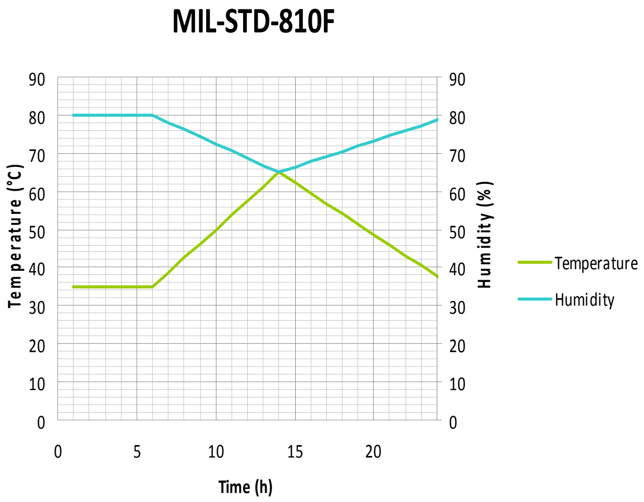

Figure 5 – MIL-STD-810F test profile.

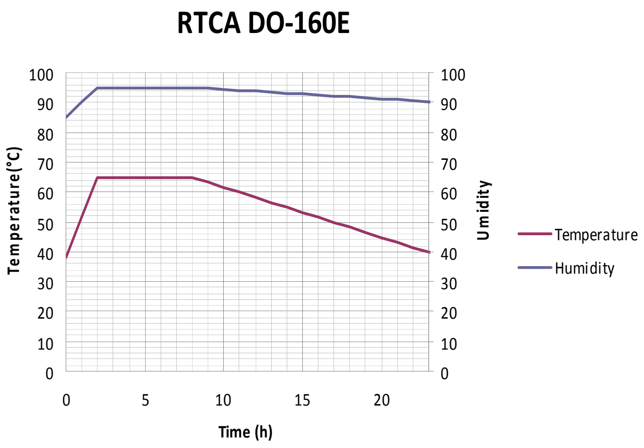

Figure 6 – RTCA DO160E test profile.

The duration of each test was 10 days and at the end of each the display did not present any nonconformity, confirming the effectiveness of the silicone glue and of the whole display in comparison with the project reliability requirements.

Subsequently the backlight system of the display was also carried out. Through an accurate choice of components we were able to satisfy the requirements concerning the luminosity of the display.

Finally the following optical qualification tests were carried out on the nematic cell and the backlight system:

- Chromatic coordinates measurement varying the angle of view;
- Chromatic coordinates measurement varying the temperature;
- Analysis of chromatic coordinates tolerance;
- Image retention assessment.

The measurement system that has been carried out to execute the qualification test phase is shown in Figure 7.

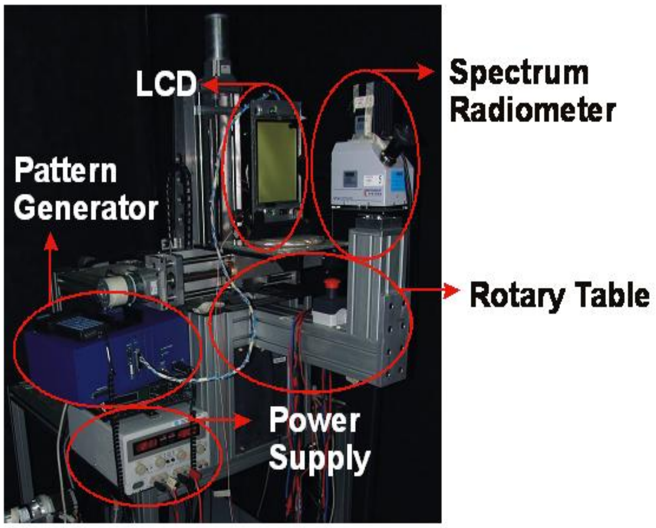

Figure 7 – Optical qualification test measurement set-up.

It is made up by a spectrum radiometer controlled by a PC and a rotary table to change the display position in function of the type of optical test. The display is connected to the power supply and to a patter generator.

The display, after each test, satisfied the specific requests of the customer.

4. CONCLUSIONS

Any devices involved in avionics application requires a detailed reliability assessment in order to be able to work on the field. For this reason aeronautic application represents a challenge in technical diagnostic topics.

According to the reliability requirements needed in the aeronautics context, in this paper, a new approach has been introduced for the development and design of LCD displays which will have to be used in the avionics application.

The introduction of a new design technique denoted as "*Combined glass*", besides reducing the rigidity of the system, allows to the cost of production to be halved.

Jointly with the new design technique, an original reliability model has been proposed for the assessment of the failure rate of an LCD display's nematic cell that, to our knowledge, it has not been addressed before in the existing technical and scientific literature. The model so developed will be able to be used in any reliability prediction regardless of the operative environment and the size of the display.

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