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Reliability of Thin (Metal) Film Resistors Impact of Pulse Screening

Abhijit D. Rane, Venkat N. Ghodke

Abstract - Field defects are the most delicate and severe failures passive components can have. The cost of the individual failed component is quite low, however, the consequential losses and liability-related costs could be extremely high. The impact of defects could go as far as "No-Go" for vehicles in automotive or aerospace applications or, even worse, in safety-relevant equipment. Specified failure levels of 0,05 ppm (parts per million) for thin-film resistors are quite common in quality assurance contracts between component supplier and customer today. That sounds quite low. But in practice that still means accepting a thousand more or less severe field defects amongst approx. 20 billion produced, sold, and used metal-film resistors world-wide per year. In a long-term study (more than 8 years) the root causes of field defects on thin-film resistors have been studied. Two major groups were isolated and Investigated intensively: Defects cause by (specified) pulse loads, and Defects caused by corrosion of resistive films. Several improvements by reengineering on product and manufacturing process were developed by project teams. The effects will be discussed in detail. As a result of this basic long-term process the failure rate of thin film resistor has been dramatically reduced by three orders of magnitude, down towards sub-ppb-level (parts per billion).Furthermore through this study new knowledge has been gained on control loops of process changes affecting field defect minimization. Paper will show the length of time after which the effectiveness of a Corrective action will become obvious in field data, and the length of time from introduction of an optimized process before significant effects on failure rates in field become measurable.

Index Terms:- Field defects, Pulse load application, Electrochemical corrosion, Failure rate, Defect level.

I. INTRODUCTION

Thin (metal) film resistors represent the best compromise amongst all available fixed linear resistor technology types (foil, wire wound, thick film, carbon film, filament, carbon composition) with regard to performance and price. Figure 1 gives an overview on types of common types of fixed linear resistors. Thin (metal) film resistors combine a host of attributes and properties suitable for professional application:

1. Easily available mass product (approx. 20 billion/a)
2. Quite low priced.
3. High accuracy (±1 % → ±0,02 %);
4. High stability (Stability class 1 → 0,05 or better);
5. Low TCR (±50 ppm/K → ±5 ppm/K);
6. Low noise (< 1 µV/V → < 0,05 µV/V);
7. Good pulse load capability (single pulse up to Pmax 70 W);
8. High AC/DC voltage (up to Umax 500 V);
9. Excellent frequency characteristics(up to GHz-ranges)
10. Best reliability.

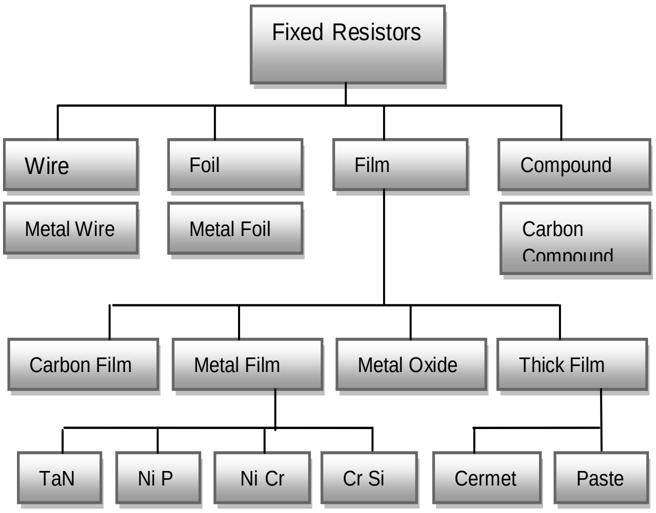

Fig. 1: Overview of Fixed Linear Resistor Types

II. METAL FILM SYSTEMS AND SOME OF THEIR PROPERTIES

Generally two different constructions of thin (metal) film resistor are common on market:

1. Cylindrical either as in the conventional leaded form, or SMD MELF construction.
2. Chip

Figure 2 shows the difference of two optimally designed surface mount components, i.e. use is made of the total available resistive film area between contacts for homogenous minimized surface loads.

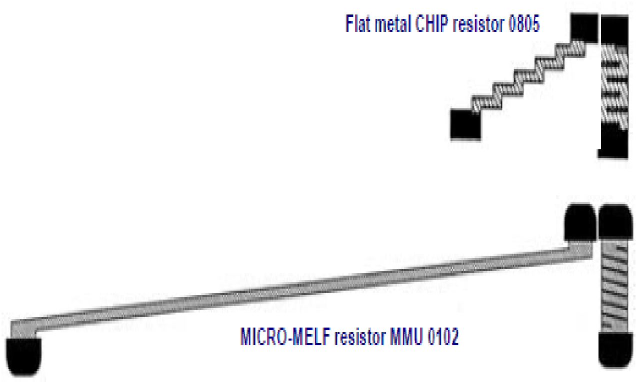

Fig. 2: SMD Cylindrical and Chip Resistors have Different Surface Load and Current Path Geometry at Same Equivalent Case Size

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* Correspondence Author (s)

Abhijit D. Rane, Electronics and Telecommunication University of Pune, Dhole Patil College of Engg. Pune, India.

Venkat N. Ghodke, Electronics and Telecommunication University of Pune, AISSMS'S Institute of Information Technology Pune, India.

To achieve the whole range of resistive values mainly four metal film systems are used. Table 1 shows the sheet resistances "*R*O" of these materials.

A. Material RO

Table I: Metal Film Materials and Achievable Ranges of Sheet Resistances *RO*

Material	Ro
NiP (nickel-phosphore)	0.05R to <0.5R
NiCrAl (nickel-chrome-aluminum)	>0.5R to 1k
CrSi (chrome-silicon)	1K2 to 12K

CrNi resistors as a mass product have been available on the market since the early 1960s. As late as 1991 General Electric has discovered "open" failures on NiCr chip resistors manufactured by an American supplier during MIL-R-55342 powered moisture test [1] Priority measures are;

1. Avoidance of metallic residues in the trim track.
2. Cleanliness during manufacturing process of Uncoated resistors (staff wearing masks and gloves),adapted clean room environment.
3. Near hermetical sealing of components by appropriate electro isolation lacquer.

As a consequence of those measures and due to the fact that stability applications and a remarkable lower range of possible sheet resistances, the CrNi resistors have gained dominance in the metal film market. We will show later that reliability data confirm NiCr resistors' excellent performance. They represent the preferred choice of thin (metal) film users in professional applications, e.g. automotive, industrial, aerospace, telecommunication, etc.

III. DEVELOPMENT OF RELIABILITY IN METAL FILM RESISTORS

To evaluate reliability of a certain component group normally data are estimated from test results. To get real failure rates from the field with a resolution in sub-ppm level it is necessary to monitor the application of billions of resistors and their behavior during use. To Achieve reliable data a good data base is necessary. A very suitable product type is the power resistor family. Over the years and traceable for us, over 50 billion of those particular resistors have been applied in field, making a reliable ppm-study feasible. The Power resistors have the following share of resistive layer systems: 10 to 15 % NiP, 70 to 80 % CrNi, and 10 to 15% CrSi. As early as the late eighties quality management tools as quality indicators were installed, e.g. failure rate of components in field, as shown in Figure 3.

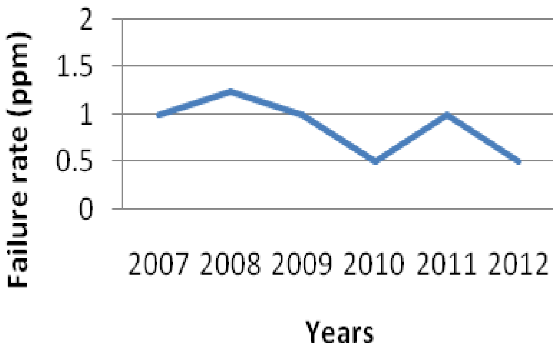

Fig. 3: Development of Field Defect Rate

Action 1: Optimization of construction (laser trim)
Action2: Cleanliness at manufacturing processes of unprotected resistors. Within our continuous improvement process two special projects (action 1 and 2) reduced the failure rate by 2005 by a remarkable 90 % to the 0,1 ppm-level.

B. Power Resistor PRO2

New demanding challenges were presented by automotive industry customers, which have defined suppliers targets for reliability:

1. Failure rate
   i) 1st year < 0,05 ppm for "zero" km
   ii) 0.01 ppm for field defects
2. Failure in time (FIT)
   i) 1st year 0,02 FIT

Now a day's those demands have become common and partly have to be confirmed and guaranteed by ppm contracts. To be able to meet those reliability demands, several projects were launched to isolate major root causes of rare field defects and to develop effective and sustainable corrective actions. The target was "zero"- defect to remain on the safe side.

IV. TYPES OF FIELD DEFECTS

The resistive value of each resistor is measured twice before release for shipment. In between these R-measurements it underwent a 100 % screening by non-linearity measurement A3 [2]. This ensures the identification of the majority of weak components in a given batch. At a good, high level thin film resistor manufacturing process usually between 500 and 5000 ppm of weak resistors were detected and rejected per batch by this method. A common observation was made regarding all these exceptional rare failed components returned from the field: neither the A3-screenings of the fresh resistor nor the A3-measurements on most of the returned defective resistors provided any hint on failure or abnormality. Group I: Failures occurred during (harsh) pulse load Application Special characteristic of "Group I" failures is change of resistive value between -10 % and -25 % or > +10 % and ∞. > 80 % of resistors which had failed during harsh pulse load conditions turned out to be helical shorts and generally show the negative changes of resistive value (= approx. 0,04 ppm).

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There are four different root causes of failure as shown in Figures 4 to 6. Figure 4 shows a field defect with a negative change in resistive value. A hole on the ceramic surface contained metallic conductive residues from the initial sputter process. These reduced the isolation distance of the trim helix. During application, a voltage surge (or multiple surges) bridged the trim helix and the resistive value changed by minus 11 %.

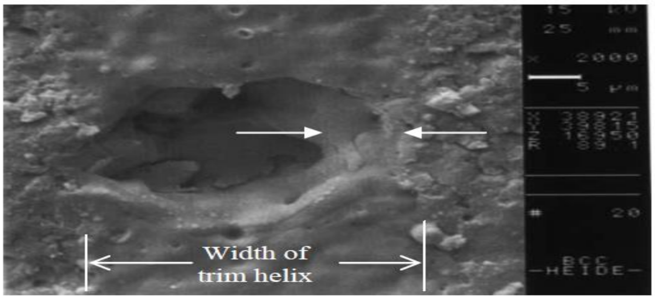

Fig. 4: Latent Resistive Bridge Due to Metallic Residues in a Hole on the Ceramic Surface

Fig. 5: Strange Materials (in this Case Brass Flakes) in Trim Cut Lower Isolation Distance

Figures 5 and 6 show latent shorts caused by different strange materials. At the release test in factory, components have shown correct resistive values. But after harsh pulse loading the limited isolation distance in trim track leads to material migration due to electric field strength, which leads finally to the bridging and shorting of trim helix.

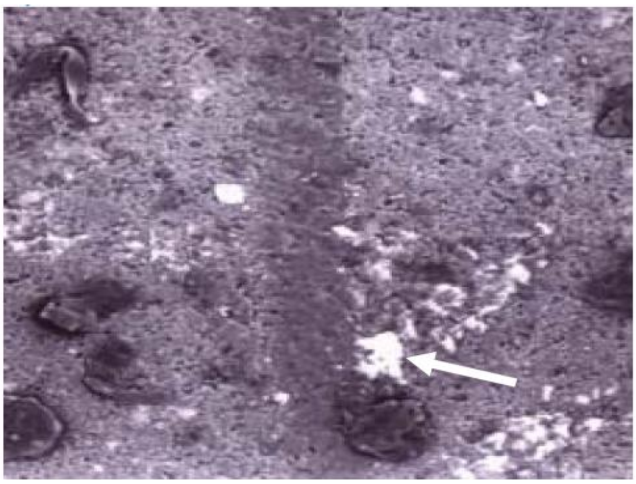

Fig. 6: Iron Containing Abrasion on Resistor's Surface (Bright Zones) Due to Attrition during Machining Have Narrowed the Isolation Distance of Trim Kerf

Another but smaller group the defective resistors returned from field (< 0,01 ppm) had changes of resistive value from > +10 % to ∞. The three possible root causes are shown in Figures 7 to 9.

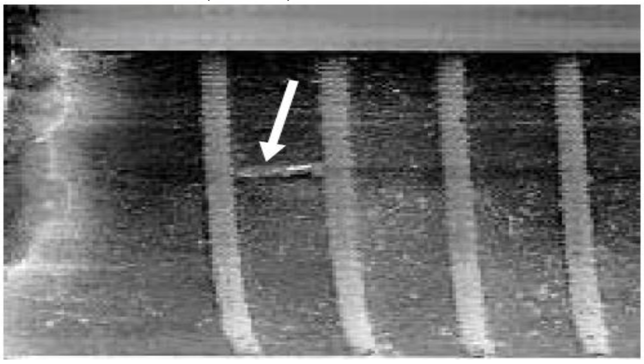

Fig. 7: Irregular single local groove in ceramic surface, causing locally irregular structure of resistive film

A single groove or outbreak in ceramic surface narrow the current path on a small limited area, isolated by the trim cut, resulting in a positive change of resistive value as shown in Figures 7 and 8. The same happens in the case of single locally adhered crumbs of ceramic material, see Figure 9. In all these cases harsh pulse applications have led to local hot spots due to contraction of potential lines. Pulse by pulse these resistive layers have been destroyed along with the neighboring zones of resistive film.

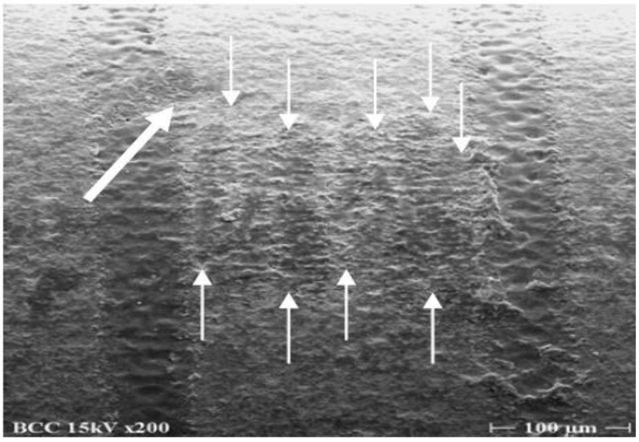

Fig. 8: Ceramic Outbreak from Trim Cut to Current Path (Big Arrow) is Narrowing it and Causing Destruction of Resistive Film (Small Arrows)

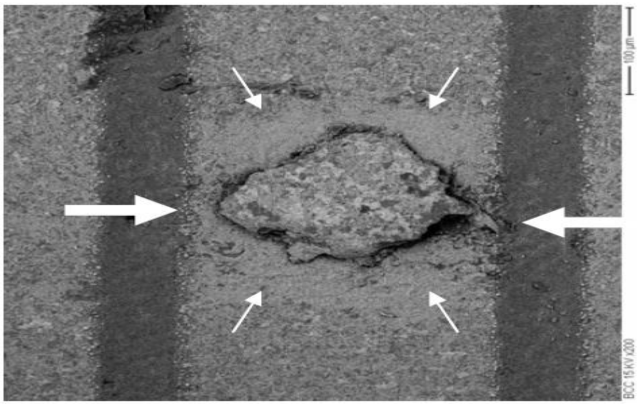

Fig. 9: Adhered Crumb of Ceramic Material Causing Shadowing Effects at Sputtering of Resistive Film. Around Adhered Particle the Structure of Resistive Film is Irregular (Small Arrows) and Current Path is Extremely Narrowed (Big Arrows)

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Further evaluation of defects' history has shown that field defects are distributed regularly over all applications. High voltage and pulse load applications accumulate the most conspicuous cases. These experiences and investigation of anomalies have thus demonstrated very clearly that numbers of root causes are quite limited and can be clearly described. A certain quantity of weak resistors could slip though our earlier production and release processes. Between 2009 and 2010 demanding or component stressing applications (voltage, pulse, wave soldering) produced 0,2 ppm field defects of that kind. It became clear that our process measures and the 100 % non-linearity screenings are a necessary but insufficient method of achieving reliabilities in thin-film resistors in the ppb-range. Details and the effectiveness of nonlinearity screenings are described in [2].

For each failure group a project was started to minimize or avoid those rare field defects.

A. Achieving PPB and Sub-PPB Reliability Levels[5]

Project - failures: Harsh pulse load application

Experience from pulse screening of leaded thin-film resistors has demonstrated a reasonably good correlation between non-linearity and pulse screening results. However, not all the components outside the A3 limit of IEC standards could be detected with this method [2], as shown above.

Pulse load screening had to be optimised and made capable of detecting all latent resistor failures as described above, especially those not discernible by non-linearity measurements or screenings.

The project team succeeded in identifying a pulse screening test that fulfilled all requirements [3]. This dedicated screening pulse test was optimized simultaneously in four areas as shown in Figure 10:

1. voltage gradient of pulse rise and fall,
2. pulse width,
3. pulse height, and
4. ΔR/R rejection limit.

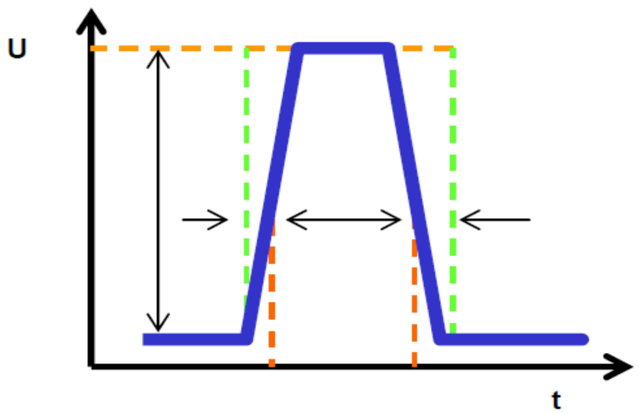

Fig. 10: Optimized Dedicated Pulse for Additional Screening of thin Film Resistors

Combined screening of parts by means of the new dedicated pulse-load test and the previous A3 test in a quadruple test station machine (as shown in Figure 11) resulted in excellent detection and rejection of weak components and near-perfect quality of remaining thin film resistors. Such resistors can meet all specification limits at stated application conditions, and harsher conditions above specification with very high confidence.

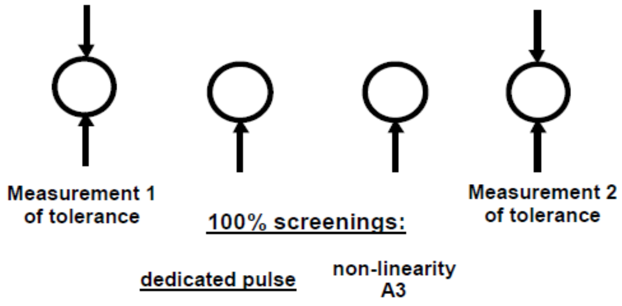

Fig. 11: Screening Principle at Improved Four Test Station Machine

In a pilot project 100 % third harmonic screened power resistors were tested and evaluated after additional dedicated pulse screening for an exceptionally harsh automotive application (motor management). Due to miniaturization necessities the customer had applied resistors at permanent pulse loading above specification. Therefore he had accepted an unusually high failure rate between 1 and 10 ppm (parts per million). Following the customer's circuit redesign, pulse overloading of resistors has increased. Within some months the customer received an enhanced, unacceptably high defect rate lse screening, the defect rate dropped to zero immediately [5], even with extremely harsh overload application conditions it is possfrom the field. After introduction of additional dedicated puible to stabilize reliability at the sub-ppb-level No further defects have occurred to date. Step by step dedicated pulse-load will be introduced into our production lines as an additional and reliable release test between September 2012 and December 2013. Shows the development of field defect rate in harsh pulse application for the whole Power resistor family (data base on approx. additional 4 billion resistors each year in use). Development of general pulse load related field defect rate after step by step introduction of dedicated pulse screening between 2011 and 2012 for whole Power resistor family.

V. The Overall Effect of Improvements

After determining the weaknesses and root causes of the past, a reliable sub-ppb-level will draw near very soon. 1: Start of 100 % dedicated pulse screening. This experience and knowledge is transferred to other thin (metal) resistor types (leaded resistors and SMD chip resistors). We have to take into consideration that the number of products in the field is significantly lower at those types, but nevertheless data show same general characteristics. We have observed a comparable level with leaded resistors and no field defect as yet.

VI. Conclusion

100 % dedicated pulse screening reduces the defect rate from > 90 ppb down to "zero" for particular harsh automotive application. Since end of 2012 all resistors > 1 k were pulse screened. Sub-ppb-level is reached reliably. Current reliability data are always superimposed by occurrences and production status from history.

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We have learnt that response time from field application at early defect problems is , greater than one year before a certain effect becomes significant, greater than 1,5 years before reaching stabilized defect levels, and - greater than two years before a failure related to a certain status of production is aged out by > 90 %. Modern thin (metal) film products have improved their reliability by three orders of magnitude in the last two years. Now a days they have reached an outstanding level, close to sub-ppb.

VII. Acknowledgment

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Abhijit D. Rane, is PG Engineering Student in electronic & telecommunication. Doing research on thin film resistor. Particularly on Pulse Screening on Thin film Resistor, In Dhole Patil College of Engineering, wagholi, pune ,Affiliated to Pune University.

Venkat N. Ghodke, is Assistant professor in Electronics and Telecommunication Department in AISSMS'S Institute of Information Technology Pune .He Had worked in various Institute as UG and PG guide for Image and Embedded system design related area. He had published books and paper in various Journal.

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