Preserving Precision: Conformal Coatings Applied to Thin Film Resistors

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ABSTRACT

As new electronic applications emerge, packaging densities increase, higher voltages are applied, and systems become more complex, electronic assemblies are armed with additional protection from harsh environmental conditions using a variety of conformal coatings and application methods. This application note examines the suitability of commonly used coating classes on thin film resistors and addresses potential application mistakes. Six different automotive-grade thin film resistor types from five manufacturers were mounted on test boards. After applying four types of coating materials by dip coating and spray coating processes, the boards were subjected to an accelerated damp heat (85 °C, 85 % RH, bias voltage applied) test for 1000 hours. It is shown that the stability of thin film resistors can be impaired by conformal coating under severe conditions. However, there are resistor series that generally preserve precision with all conformal coating classes tested, and that certain coatings are fully compatible with all resistor series tested.

1. INTRODUCTION

As the power density of electronic devices increases, these systems are becoming smaller and more complex while maintaining the same reliability requirements in challenging environments. Therefore, additional protection is required for printed circuit boards (PCBs) and mounted components to withstand harsh conditions. Conformal coatings are used to provide electrical insulation as well as protection against environmental attacks that can otherwise cause corrosion and electrical failure. Coatings are also applied to protect electronic devices from salt atmospheres, sulfur gases, abrasion, organisms, chemicals, and radiation. A wide range of conformal coating materials is available, allowing circuit and system designers to select the one that best meets their requirements. These may include:

- Electrical properties such as insulation resistance, dielectric constant, and dissipation factor
- Mechanical properties, such as Young's modulus of elasticity, thermal expansion coefficient, and abrasion resistance
- Chemical compositions such as purity, solvents, and additives
- Chemical properties such as permeability, absorption, stability, and resistance
- Economic considerations, such as material cost, coating process, and shelf life

The specific properties of conformal coatings are highly dependent on their chemistry.

2. TYPES OF CONFORMAL COATING CHEMISTRIES

According to IPC-CC-830C, the following classes of conformal coating chemistry are recommended [1]:

Type AR	Acrylic
Type ER	Epoxy
Type SR	Silicone
Type UR	Polyurethane
Type XY	Paraxylylene
Type SC	Styrene block copolymer

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Acrylic (AR)

Acrylic coatings are applied as prepolymerized acrylates in solutions that solidify under curing conditions as the solvent evaporates. Inexpensive, easy to apply, and quick-hardening (< 1 h), this is the most widely used coating material. Acrylic coatings provide excellent electrical insulation properties, and good moisture protection and scratch and abrasion resistance. Operating temperatures reach up to 125 °C. These coatings have poor solvent resistance. Thus, the coating can be selectively removed for rework. [2], [3], [4]

Epoxy (ER)

Epoxy resins polymerize by means of curing agents to form highly cross-linked, three-dimensional solids when exposed to heat or UV light, depending on the curing mechanism. Epoxy coatings exhibit good electrical properties, remarkable moisture barrier properties, excellent adhesion, strong abrasion resistance, and excellent chemical resistance to moisture, salt spray, organic solvents, and chemicals. The highly cross-linked nature of the cured epoxy structure results in poor stress dissipation, embrittlement, inflexibility, and difficult removal. [2], [3], [4]

Silicone (SR)

Silicone resins cure by cross-linking using heat and / or catalysts through a polyaddition or polycondensation reaction that releases by-products. Silicones are not based on hydrocarbon networks, but on silicon-carbon networks, which results in rather high temperature stability exceeding 200 °C and non-flammability. Silicones possess a low Young’s modulus of elasticity, which dampens vibrations and makes them resistant to vibrational stress. They maintain good electrical properties over a wide temperature range, are water repellent, and difficult to remove. [2], [3], [4]

Polyurethane (PU)

Polyurethane coatings are low cost materials that provide a high degree of stability while at the same time being flexible, and providing mechanical and abrasion protection. These coatings have excellent moisture and chemical resistance and very good dielectric properties. Good adhesion to various surfaces makes them difficult to remove. On the downside, they have long curing times and often require additional equipment. [2], [3], [4]

Paraxylylene (XY)

Polymerized paraxylene, or more common parylene coatings, are vapor-deposited to provide complete surface coverage, even below and around the board’s components. The coating is applied in a batch process using specialized equipment. Processing times are long, with condensation taking 12 to 20 hours. The resulting coating is extremely thin, of high purity, extremely moisture impermeable, and chemically resistant. [2], [3], [4]

Styrene Block Copolymer (SC)

Styrene block copolymers consist of hard thermoplastic polystyrene segments acting as cross-links to connect elastomeric segments in a network. The coatings are available as solutions converting to a rubber-like, flexible material by physical drying. Therefore, the solvent resistance of this coating material is rather limited. These coatings possess a low moisture permeability and absorption, and excellent electrical properties, even in humid environments. [4]

3. MOISTURE FAILURES DESPITE CONFORMAL COATING

The protection requirements for coatings depend primarily on the field of application and operating conditions for the electronic device. In addition to electrical insulation, coatings can provide protection against premature failures caused by environmental influences. Here, moisture ingress is one of the most important factors contributing to the failure of electronic devices and components. Not only does moisture itself cause failure, but it also leads to the mobilization of contaminants, electrochemical migration, and electrolytic corrosion. Unfortunately, all polymers are permeable to gas or vapor to some degree. Permeation occurs in three steps:

1. Sorption / dissolution
2. Diffusion
3. Evaporation / desorption

It takes place continuously from the side with high concentration of water vapor to the side of low concentration. Thus, the concentration increases at the latter side. The amount of moisture permeating through a polymer depends on the polymer’s properties (thickness, area, defects, solubility coefficient, degree of cross-linking, crystallinity, diffusion coefficient, and polarity) as well as environmental conditions (temperature, relative humidity, and pressure). The rate of moisture permeating through a polymer is a measure for the coating’s ability to protect against moisture.

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4. MATERIALS AND METHODS

In this study, automotive-grade thin film chip resistors from six series and five manufacturers with ohmic values between 100 kΩ and 220 kΩ were tested to investigate the compatibility of conformal coatings with the resistor's materials (Table 1). The resistors were mounted on boards by reflow process using no-clean solder paste, cleaned, oven dried, and subsequently coated within a maximum of two days. The tests have also been performed under adverse conditions and with improperly applied coatings.

TABLE 1: THIN FILM RESISTORS USED IN TEST

BRAND	SERIES OR ACRONYM	CHIP SIZE	OHMIC VALUE
Vishay	TNPW e3	1206	200 kΩ
Vishay	TNPW e3	1206	220 kΩ
Vishay	MCA AT 100K	1206	100 kΩ
Vishay	MCA AT 220K	1206	220 kΩ
Brand 1	BR1	1206	200 kΩ
Brand 2	BR2	1206	200 kΩ
Brand 3	BR3	1206	182 kΩ
Brand 4	BR4	1206	196 kΩ

Four types of coating materials applied by dip coating and spray coating processes on test boards with 10 resistors each are investigated. The coating materials were selected to cover different curing / solidification methods (drying: solvent evaporation; thermal: curing by thermal treatment; UV: UV curing; H_2O: moisture curing; and O_2: oxidation). The liquid applied coatings were cured according to the methods recommended by the suppliers. Coating types, coating materials, and curing procedures are given in Table 2.

TABLE 2: COATING TYPES USED AND PROCESS PARAMETERS

TYPE		THICKNESS (1)	DIP COATING	SPRAY COATING	CURING / SOLIDIFICATION
AR	Acrylic	Thin	x		Drying
AR	Acrylic	Thin		x	Drying
SR	Silicone	Thick	x		Thermal
SR	Silicone	Thick		x	H_2O
UR	Polyurethane	Thick	x		UV + H_2O
UR	Polyurethane	Thick		x	H_2O
UR	Polyurethane	Thin	x		UV + H_2O
UR	Polyurethane	Thin		x	Drying + O_2
SC	Styrene block copolymer	Thin	x		Thermal

Note

(1) Classification according to suppliers

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Established standard test methods for reliability, electrical properties, climatic impacts, chemical resistance, and mechanical properties are available for various operating environments and conditions. The damp heat test, or temperature humidity bias (THB) test, is standard for coatings (IEC 61086 [5]) as well as for electronic components such as resistors (IEC 60115-1 [6]) and PCBs (IPC-9201 [7]). This is because moisture protection is one of the key properties of conformal coatings and moisture resistance is critical for thin film resistors. Therefore, this study performs accelerated damp heat 85 °C / 85 % RH tests (hereafter called biased 85/85 tests) for 1000 hours with 63 V bias applied to resistors mounted on boards covered with conformal coatings. As reference, non-coated test boards were tested in parallel.

5. FACTORS INFLUENCING MOISTURE STABILITY

5.1 CLEANLINESS

Ionic contamination, especially when combined with moisture, can cause corrosion and etching of the metal film of the thin film resistors. With sufficient time, moisture will diffuse through the conformal coating and provide an opportunity for mobilization of contaminants. The migration of ions is directed when an additional bias is applied. The interaction of ions (salt, sulfur, and water) with the metal components of the resistors leads to their corrosion or decomposition, and ultimately to the resistors' failure. Therefore, it is recommended that PCB assemblies are cleaned to remove contaminants such as solder flux residues or fingerprints.

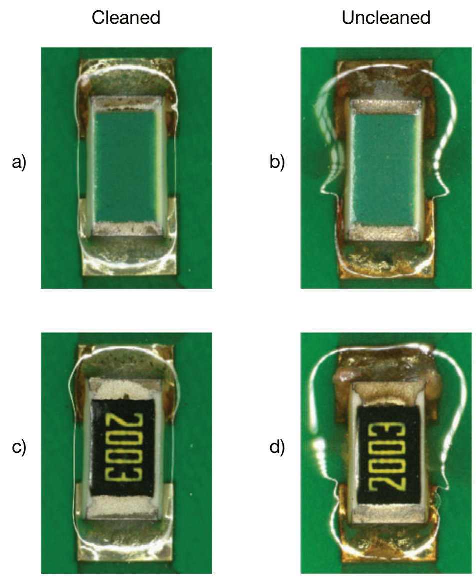

Fig. 1 - Cleaned and uncleaned resistors with UR coating applied by spray coating, after 1000 h biased 85/85 test:
a) TNPW e3 cleaned b) TNPW e3 uncleaned c) BR1 cleaned d) BR1 uncleaned; image width: 3.9 mm

Resistors were mounted on boards using no-clean solder paste and subsequently coated with and without a prior cleaning step. Uncleaned boards, despite no-clean solder, show significantly more visual solder and contact degradation than cleaned boards when subjected to the accelerated damp heat test (Fig. 1). The coatings of the uncleaned boards are buckled above some of the contacts, indicating delamination of the coating.

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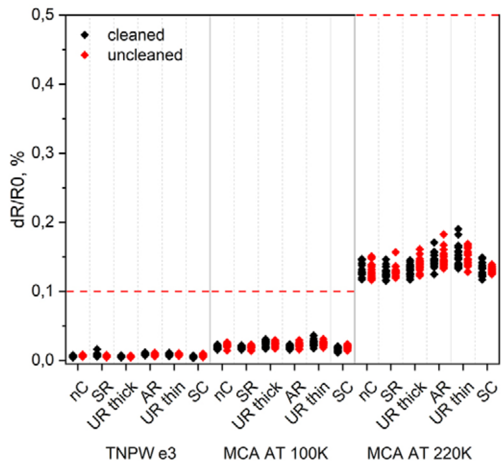

Fig. 2 - Resistance drift of cleaned and uncleaned Vishay resistors without and with different coating materials applied by dip coating, after 1000 h biased 85/85 test: n = 20; dashed red lines: specification limits; nC: no coating

Surprisingly, the differences in resistance drift between cleaned and uncleaned resistors are only marginal and do not show a clear trend (Fig. 2). All values are within the biased 85/85 test specification limits (TNPW e3: 0.1 %, MCA AT 100K: 0.1 %, and MCA AT 220K: 0.5 %). This could be attributed to sufficiently clean process conditions and the use of no-clean solder paste. To avoid corrosion, conformal coating should only be applied to cleaned boards, even if no-clean solder pastes are used.

5.2 DRIED VS. BEDEWED SAMPLES

Another common coating problem is the inclusion of water beneath the coating because of insufficient drying or storage of boards in unheated warehouses, causing moisture to condense on the surface prior to the coating process. To get moisture on the boards in a reproducible manner, in this study the boards were cooled to 13 °C (± 3 °C) in a refrigerator and treated with water vapor right before dipping in the coating liquids.

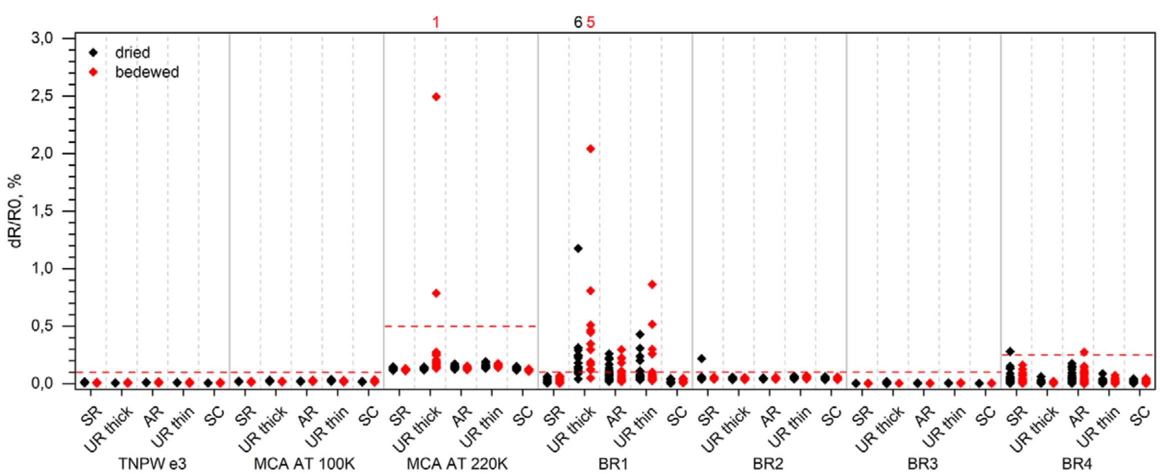

Fig. 3 - Resistance drift of dried and bedewed chip resistors with different coating materials applied by dip coating, after 1000 h biased 85/85 test: n = 20; dashed red lines: specification limits; numbers above figure: values out of displayed range

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Most thin film resistors tested withstand the moisture applied prior to coating and testing (Fig.3). Only two types show sensitivity to moisture with resistance drift values greatly exceeding specification limits. In both cases, UR-type coatings are involved. After removal of the conformal coating and topcoat, some failed resistors reveal decomposition of the resistive layer at multiple locations because of electrolytic corrosion (Fig. 4).

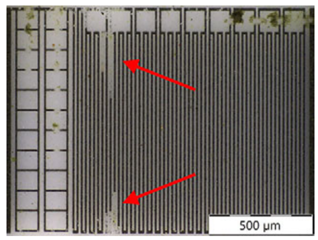

Fig. 4 - Stripped BR1-type resistor after failure in biased 85/85 test

5.3 THICKNESS OF COATINGS

Depending on the coating chemistry, IPC-CC-830C recommends thicknesses of less than 200 µm, 75 µm, 50 µm, or 12.5 µm, depending on coating type. However, coating material suppliers specify thickness ranges beyond these limits. Thicker coatings are assumed to increase protection, but coatings that are too thick can cause defects in the coatings and fail to cure completely, which in the worst case can result in damage to the mounted components. Shrinkage of the coating polymer during curing creates stresses that can lead to cracking, crazing, and loss of protection against vapors, gases, and liquids. A mismatch in the coefficient of thermal expansion between the coating and the PCB or its components can cause stress, cracking, and delamination in changing thermal regimes (thermal shock), especially in coatings that are too thick. In coatings that solidify by solvent evaporation, the solvent may be trapped in the coating layer if it is too thick. This may cause voids and blisters that increase the permeability of the coating.

Although thick conformal coatings are usually produced by multilayer coating, thick coatings in this study are achieved by pretreatment of the coating liquids to increase their viscosity and by increasing the withdrawal speed in the dip coating process. The thicknesses are three to five times higher than the recommended thicknesses, except for the UR thick coating, which is still below the possible 1000 µm limit (according to the supplier).

Some of the UR (thick type) coatings applied too thickly show partial delamination and cracks starting at the resistor edges, indicating stress evolution (Fig. 5a). Contacts as well as solder pads are massively corroded. UR (thin type) coatings are cracked in a shell-shaped manner next to the contacts, while the resistors beneath are only slightly corroded (Fig. 5b). Resistors with too-thick AR- and SC-type coatings do not show any corrosion and the coatings are intact (Fig. 5c and Fig. 5d).

a) b) c) d)

UR thick | UR thin | AR | SC

Fig. 5 - Vishay resistors with too-thick conformal coatings after 1000 h biased 85/85 test:
a) TNPW e3 with UR thick coating; b) MCA AT 100K with UR thin coating; c) MCA AT 100K with AR coating; d) MCA AT 100K with SC coating

The resistance drift values of the Vishay resistors tested are mainly within the specification limits for the test and the maximum values drifted less than twice (Fig. 6). Even if the contacts of UR (thick type) coated resistors are badly corroded, the values are not as affected as they appear to be, because the functional resistor layer is well-protected inside the chip. Nevertheless, crack evolution and corrosion indicate insufficient curing of the too-thick coating, which keeps coating components (photo-initiator, isocyanate) unreacted and potentially harmful. Also, the increased values of resistors with AR-type coating may be a matter of trapped solvents impairing the MCA AT 100K resistor.

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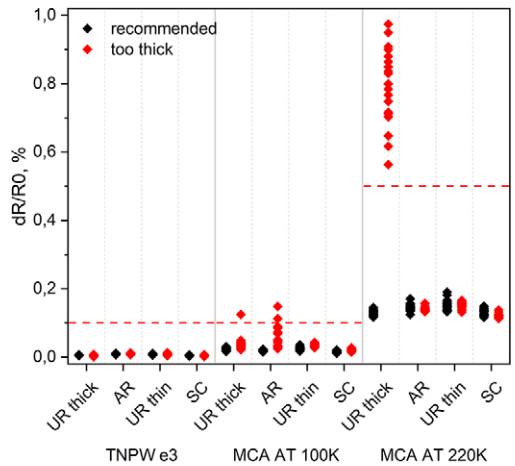

Fig. 6 - Resistance drifts of Vishay resistors with different coating materials applied by dip coating in recommended and too-thick dimensions, after 1000 h biased 85/85 test: n = 20; dashed red lines: specification limits

5.4 PROPERLY APPLIED CONFORMAL COATINGS

Four classes of coatings were applied to six automotive-grade thin film resistor types using two application methods (dip and spray), avoiding the processing mistakes discussed, and under the conditions recommended by the coating material suppliers. Reference resistors without any coating were tested in parallel for the dip coating and spray coating test runs. The resistance drifts of 20 resistors of each combination are shown in Fig. 7.

Resistor Type

TNPW e3, MCA AT 100K, and BR3 resistors are not affected by any coating at all, keeping their resistance values in the same range. MCA AT 220K resistors show variations in resistance drift, but the values are all within specification. Chip resistors from supplier 1 (BR1) show by far the most failures, especially with UR- and AR-type coatings. Coated resistors of type BR2 and BR4 show a few out of tolerance values.

In summary, there are significant differences between manufacturers, independent of applied coatings.

Coating Type

SR-type coatings result in resistance drift values only slightly above the limit. The application of UR-type coatings, which were already conspicuous in previous sections, leads to the most outliers and failures. With AR-type coatings, two types of chip resistors show outliers. The most stable resistance values are observed with SC-type coatings, which are all within their specification limits.

Uncoated vs. Coated Resistors

The resistance drift values of uncoated and coated resistors are the same for only two resistor types. All other resistors are to a certain extent affected by coatings. In one case, coatings seem to have a positive effect on the stability of the resistors under test conditions (BR4).

Application Method

The different application methods - dip coating and spray coating - give consistent results except for AR- and UR-type coatings. These concern mainly the weakest resistors of type BR1. In these cases, the different compounds, such as solvents or hardeners, that are part of the particular used coating formulation may play a role.

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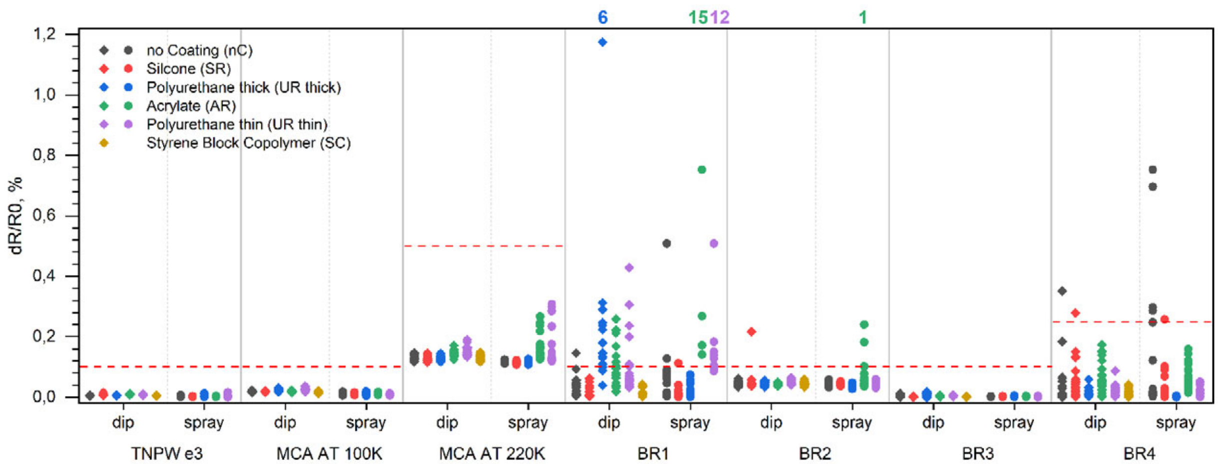

Fig. 7 - Resistance drift of resistors of various suppliers without and with different coating materials applied by dip coating (♦) and spray coating (•), after 1000 h biased 85/85 test: n = 20; dashed red lines: specification limits; numbers above figure: values out of displayed range

6. SUMMARY AND CONCLUSIONS

- Conformal coating should only be applied to cleaned boards to avoid corrosion, even if no-clean solder pastes are used
- Resistor stability is increased if the boards are dried and water condensation is eliminated prior to coating. UR-type coatings cause failures on bedewed boards by electrolytic corrosion, even though they consume water in the second curing step
- Overly thick coatings will crack and delaminate due to stress buildup, reducing the barrier properties of the coatings. In addition, solvents are trapped and may chemically interact with the resistance materials. Therefore, the coating thickness should be as thin as the protective function requires
- Even properly applied coatings (cleaned and dry boards, as thick as necessary) can have a negative effect on the performance of the resistor. Three out of the six coated thin film chip resistor types withstand the tests and remain within their specification limits, regardless of the type of coating applied (TNPW e3, MCA AT, BR3). One chip resistor series performed better with coating materials than without (BR4). Other types of resistors show out of tolerance drift values or failures, mostly with AR- and UR-type coatings (BR1, BR4)
- UR-type coatings lead to numerous failures, which is possibly related to coating components (isocyanates, solvents, etc.). The only coating type producing not even one single value out of tolerance in the damp heat test is the SC-type coating

Some resistors are more affected by the coating material than others. Conversely, there are coating materials that have more influence on resistors than others. It seems that specific combinations of resistors with coatings, or more precisely, resistor materials with coating compounds (solvents, hardeners, etc.) lead to adverse interactions. Therefore, the compatibility of resistors not only with types of coating materials but also with special products must be checked in advance to achieve the required protection.

7. DISCLAIMER

All findings are based on results obtained in damp heat tests (85 °C, 85 % RH, bias) and are therefore limited to these conditions and not applicable to other operational requirements. In addition, there are numerous manufacturers on the market offering too many formulations to test them all. The suitability of a specific conformal coating formulation shall be qualified by appropriate means to ensure the long term stability.

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8. REFERENCES

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