ZVEI:
Die Elektroindustrie

Guidelines for the

Long-Term Storage of Components, Subassemblies and Devices

Electronic Components and Systems Division
and PCB and Electronic Systems Division

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Long-Term Storage of Components, Subassemblies and Devices

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1. Preface

Many functions and products would not be achievable without advances in electronics. In particular, the wide variety of new, high-volume applications has increased the pace of innovation in the development of components, subassemblies and devices. The component industry is advancing at an exponential rate in accordance with Moore's Law, which observes that the number of transistors on integrated circuits doubles approximately every two years.

Innovation cycles are getting shorter and components more powerful year on year. Memory chips, for instance, have shrunk tenfold in the last 10 years. The consequence of this miniaturisation is that they become obsolete every one to two years. There is no foreseeable end to this rate of progress beyond 2020 (source: ZVEI Technologieroadmap 2020 – Elektronische Bauelemente und Systeme [17]).

Yet at the same time there is a desire for durable products and correspondingly robust security of supply that will last for years. This applies in particular to the replacement demand for subassemblies, systems and devices as well as for raw materials, components and circuit boards as required for instance by the aerospace, automotive, railway or industrial automation industries. But it is not always possible to manufacture the required products for prolonged periods. Action must therefore be taken to maintain supplies even when parts are no longer in series production. Consequently, all manufacturers of components, subassemblies etc. must consider the availability of their products right from the development phase.

These guidelines on long-term storage are intended to help develop a supply strategy for components which need to be warehoused, processed and used beyond the storage period guaranteed by the manufacturer. It is essential to consider which factors may affect components during storage, or adversely affect their subsequent processing or performance.

Ageing mechanisms and their error patterns which have a bearing on component storage or subsequent processing are classified and described below. These guidelines also offer readers recommendations for designing processes for long-term storage, including storage and monitoring strategies.

Raising awareness of storage issues during the development of subassemblies, sub-systems and devices is a further consideration. Choosing the correct materials and components during the design phase is the key to successfully extending the storage capabilities of components and raw materials. The important thing is to maintain processing capability and operational performance.

These 'Guidelines for the long-term storage of components, subassemblies and devices' are intended to supplement the ZVEI White Paper ‚Langzeitversorgung der Automobilindustrie mit elektronischen Baugruppen'.

2. Basic aspects

'Long-term storage' in this context means storing components beyond the manufacturer's guaranteed lifetime whilst retaining their functional integrity (fit, form, function). It is vital to retain component integrity so as to ensure safe subsequent processing using appropriate assembly and connection technology. The manufacturer alone can assess whether the components under consideration are suitable for long-term storage, or whether they will suffer from loss of functionality, and should be contacted in any event. If the planned storage period is shorter than the shelf life guaranteed by the manufacturer, no further action is required.

The choice of storage method depends largely on the intended storage period. Beyond the manufacturer's recommended shelf life, special storage conditions and processes must be created which significantly slow down ageing processes whilst retaining processing capability and performance. No further measures can be taken to extend the maximum shelf life of certain components (e.g. batteries). Basically, it is important to prevent harmful media from reaching sensitive areas in the first place. If components are to be stored for an extended period, the manufacturer must be contacted beforehand so that, if necessary, a joint approach can be agreed.

Packaging can influence long-term storage capabilities. Consequently, 'long-term packaging' may be considerably more expensive than standard packaging. Consideration must also be given to the many instances where items need to be partially unpacked and then repacked. Packaging must be carefully chosen to ensure that items can be handled if necessary (e.g. removed or separated) during long-term storage. The packaging must provide ESD (electrostatic discharge) and moisture protection - if needed - throughout the chosen storage period.

Ideally 'fresh goods' should be used for storage. If this is not possible, the previous storage conditions must be taken into account, for example climatic conditions.

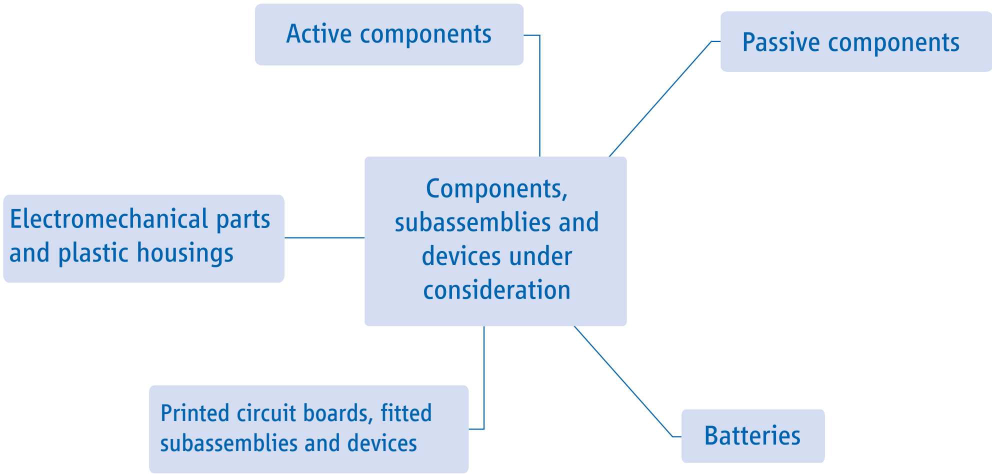
In addition, changes to the production and processing of subassemblies, devices, components and raw materials may arise due to environmental legislation, restrictions and legislative changes to framework conditions. For instance, the effects of storage-related ageing may occur considerably earlier if lead-based surface coatings are replaced with modified coating systems.

In this case it is important to ensure that processing conditions relating to specific components, such as thermal profiles for soldering/housing and pretreatments, are archived and can be readjusted. This avoids having to redefine production conditions. These processes must be established throughout the entire supply chain. In the event of production relocation, storage and process parameters must be adopted without change and requalified if necessary.

It is advisable to carry out a risk assessment with regard to performance and processing capability in order to assess all constraints and critical factors. Important considerations must take into account during the product design phase wherever possible.

3. Components under consideration

The following diagram shows the components under consideration. In these guidelines we use the general term ‘components’ when referring to all components, subassemblies etc. listed below.



Components under consideration

Unassessed aspects:

1. Wafers, bare dies, known good dies (KGD): These items are to be stored by manufacturers and/or specialists.

2. Interactions between packaging materials (bags, outer wrappings, films, labels) are not assessed on account of their complexity.

3. New materials introduced as a result of environmental legislation: At present there is no reliable information regarding the long-term storage of lead-free products, copper bonding, potting compounds etc. However, it is likely that previous failure mechanisms will also affect lead-free materials. This compounds the basis for assessing long-term storage.

4. General factors affecting storage and error patterns

Factors and error patterns affecting many components and subassemblies are described below. Proper storage requires these factors to be addressed and eliminated. Factors relating to specific products are addressed in the sub-chapters.

These guidelines do not claim to provide an exhaustive list of all ageing mechanisms. Furthermore, the factors and error patterns are not listed in order of importance.

4.1 Contamination

Contamination can occur as a result of gas emissions from surrounding materials. 'Incorrect' choice of material can lead to failures despite compliance with recommended storage conditions. For instance, if temperature limits are exceeded, plasticisers in the outer packaging are likely to release gases.

4.2 Corrosion

Corrosion is the general term for describing how a material reacts with its environment. The term oxidation refers only to oxygen corrosion. Some corrosive products such as tin dioxide (SnO_2) or nickel oxide (NiO) are used for passivation. The majority of corrosive products, however, have a destructive effect. The products of decomposition form, for example, acid compounds which attack other metal parts and metal coatings in addition to the points of contact and interfaces. This may result in:

- Loss of shielding
- Reduced conductivity of switch and plug-in contacts
- Leakage from housing

It should be borne in mind during subsequent processing that corrosion generally reduces solderability and increases contact resistance. Corrosive mechanisms may be affected by the following factors:

- High air humidity
- Temperature
- Aerosols (marine climates)
- Harmful atmospheres, e. g. chlorine gas (Cl_2), nitrogen oxides (NOx), and sulphur compounds such as sulphur dioxide (SO_2) and hydrogen sulphide (H_2S) (exhaust gases from power stations, chemical plants, vehicles, etc.)
- Gas emissions from plastics (housings, sealants, paints and varnishes)

It is also important to be aware that the microclimates present within devices, subassemblies and components can severely impair operational and storage capabilities.

Example of corrosion on an electrical contact

Source: Elesta Relays

Example of corrosion on a pin

Source: Elesta Relays

4.3 Diffusion

Solid-state diffusion most commonly associated with electronics is a physical effect where particles from one substance become mixed with those from another. This phenomenon, which is dependent on time, environmental conditions and the presence of diffusion particles, can have the following negative effects:

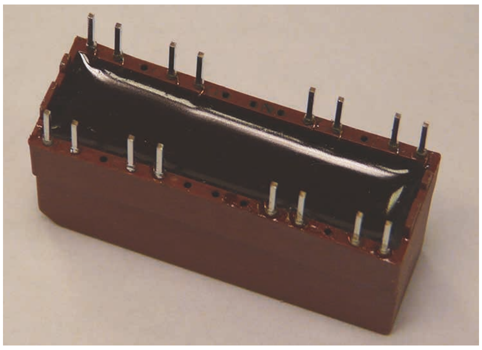
- Change in solderability due to ageing mechanism and zone growth
- Change in contact layers which affects contact resistance
- Impairment of mechanical/thermal properties due to altered moisture content

Diffusion barriers can in some circumstances have a positive effect on long-term storage capabilities. However, some diffusion barriers, such as passivating agents, may impair the processing capability of the component.

Consequently, special treatments may be needed before further processing or deployment of the component.

4.4 Moisture

4.4.1 Moisture absorption

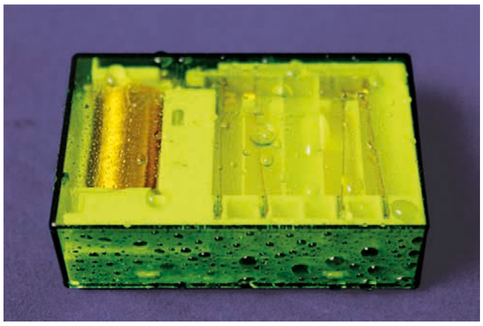


Source: Vacuumschmelze

Plastics absorb moisture from the environment to a certain extent. This moisture tends to accumulate at the interface between the potting compound and the internal structures of the component. During a rapid rise in temperature, e.g. during soldering operations, this moisture evaporates. The resulting increase in volume may cause cracks to appear in the plastic or delamination of internal interfaces. Condensation may arise in many components as a result of excess moisture.

4.4.2 Moisture extraction

During moisture extraction plastics tend to become brittle and lose their shape and dimensional accuracy.



Example of condensation in a relay

Source: Elesta Relays

4.5 Example of condensation in a relay

Ultraviolet light (wavelength range 100 nm – 400 nm) is a form of electromagnetic radiation which is not visible to the human eye. The shorter the wave length, the more energy-rich the radiation. The input of energy from UV radiation from lighting can be harmful to organic compounds. Many plastics can sustain damage such as cloudiness or embrittlement, depending on the intensity and duration of exposure. For this reason, it is generally advisable to use light-proof, and more especially UV-proof packaging for the long-term storage of electronic components.

4.6 Embrittlement

Embrittlement is the loss of ductility of a material. The use of brittle materials increases the likelihood of components being mechanically damaged or destroyed during assembly or in operation. Temperature, radiation and/or gases promote irreversible embrittlement. Reversible embrittlement can occur during storage under low air humidity.

4.7 Solderability: Wetting, dewetting, non-wetting

Three distinct soldering mechanisms occur, depending on the extent to which the solder is able to form a stable bond on substrates; wetting, dewetting and non-wetting.

Wetting describes the ability of a molten solder to form an intermetallic bond with the base metal, whilst non-wetting is the inability of molten solder to form a metallic bond with the basis metal.

Dewetting describes a condition that can arise as a defect after actual wetting.

The appearance of wetting, dewetting and non-wetting can easily be distinguished by visual inspection. Wetting forms a largely uninterrupted solder joint characterised by the contact angle at the respective joint or interface (soldered surface).

Dewetting occurs when the solder recedes from zones that were initially wet leaving irregularly shaped mounds of solder that are separated by non-solderable areas, which cannot be rewetted.

Figure: Example of dewetting

Source: Prüflabor QM 3, Siemens SC Karlsruhe

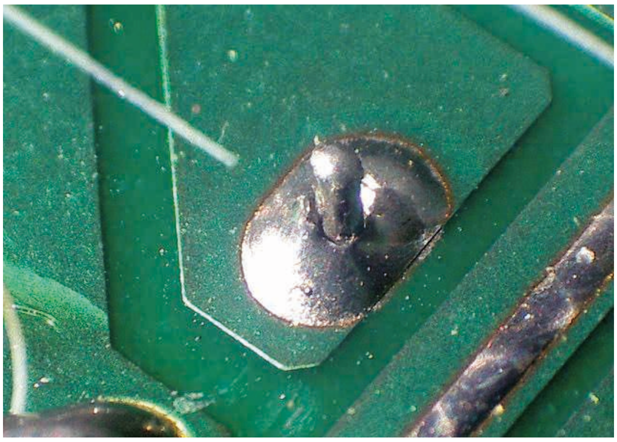


Figure: Example non-wetting (Source: IPC-A-610)

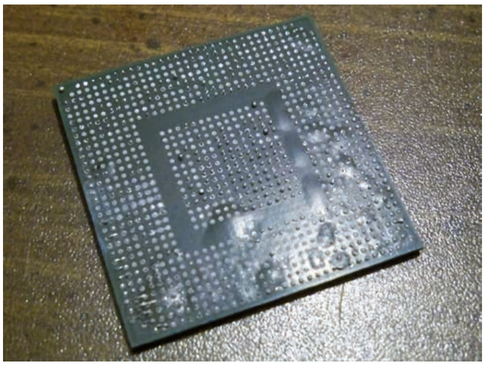
Source: Coronium – Wikipedia

4.8 Popcorn effect

'The popcorn effect can occur when components are stored incorrectly, e. g. if moisture-sensitive electronic components are stored outside the moisture-proof packaging for too long. The storage of such components is regulated in IPC/JEDEC J-STD-020.

As a result of hygroscopy of the plastic in components, up to 0.5 percent by weight of water can accumulate predominantly in the potting compound of the housing. Inside the reflow oven, the moisture vaporises due to the rapid rise in temperature, leading to a sudden expansion in volume. This can cause the housing to crack or the substrate interfaces to delaminate.'

(Source: Wikipedia)



Example photo: BGA package destroyed by the popcorn effect and moisture in the housing

Source: Creative Commons – Wikipedia

4.9 Whisker formation

'Whiskers are hair-shaped mono-crystals which can reach a length of several millimetres and typically range in diameter from 0.2 µm to 10 µm. Whiskers form metal bridges e. g. between conducting paths on printed circuits and other metal surfaces. In addition to tin whiskers, which have been known about for some time, whiskers can also occur with zinc, silver, aluminium, lead, gold and other alloys. Apart from internal and external microstructural stresses, whiskering may arise due to factors such as temperature, temperature fluctuations and in some cases environmental effects such as air humidity and atmospheric pollution.

Whisker growth is exacerbated by moderate temperatures. At low temperatures atoms tend to be less mobile. At higher temperatures material stresses are more readily relieved. The mean temperature range for tin (part of the soldering material) lies between room temperature and 80 °C.

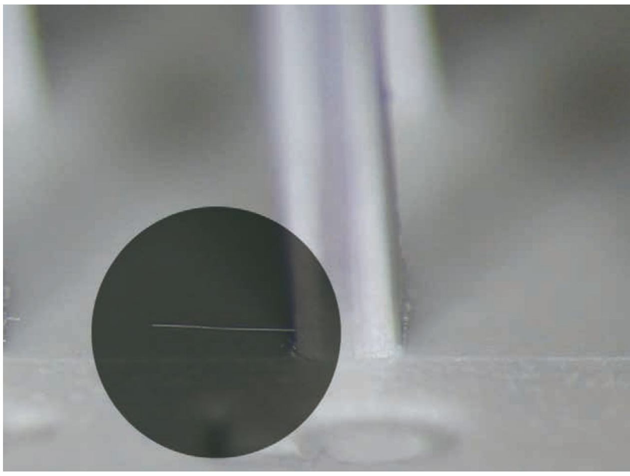
Whiskering occurs particularly readily with subassemblies containing lead-free tin solders, and can cause short-circuits on galvanised printed circuit boards or between components.

Whiskering can be minimised by reducing mechanical stress exerted on circuit boards and subassemblies.

This also includes mechanical forces on clamp and bolted connections for subassemblies.

Applying a conformal coating to the circuit board to protect against moisture and dirt can slow down whisker growth, but not prevent it.

Tin whiskering is not generally considered to be a long-term effect because the crystals can grow spontaneously.'
(Source: Wikipedia)



Whiskers on galvanised Sn layers

Source: Pancon

4.10 Tin pest

Tin pest is a temperature-dependent change in the crystalline structure of tin whereby silvery metallic tin (known as the ß-form) is transformed into grey tin (known as the α-form) at temperatures below 13.2 °C. The typical characteristics and material integrity of the metallic ß-tin are lost in this process. However, the ß-tin remains stable within a temperature range of 16 °C to 181 °C. The notable aspect of this phenomenon is that, on the one hand, the tendency to undergo transformation increases as temperature decreases until the ideal conversion temperature at -48 °C is reached, yet on the other hand, the reaction speed decreases. The transformation process begins at several centre points and gradually spreads out; indicators of tin pest are relatively large spots followed by pressure-sensitive, wart-like blisters occurring at the surface.

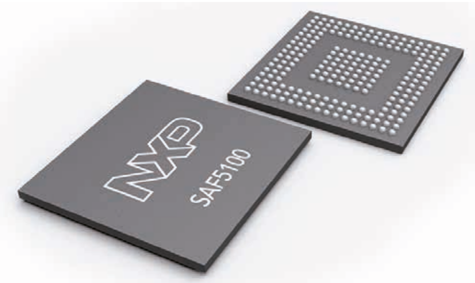
In addition to temperature-dependency, the tendency to undergo transformation is also accelerated by alloying components such as zinc or aluminium, whereas antimony or bismuth can retard this phenomenon or eliminate it altogether.
(Source: Wikipedia)

5. Specific factors

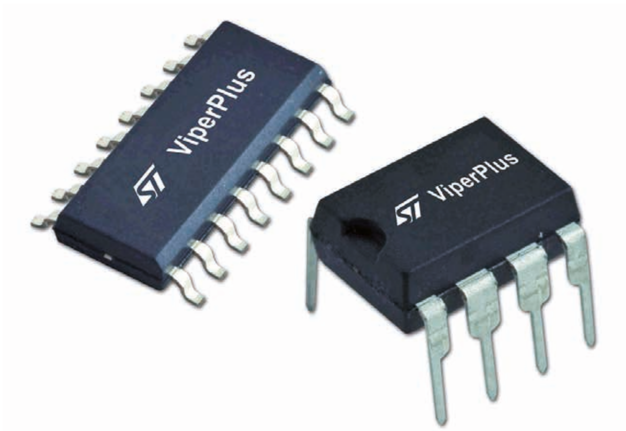
5.1 Features of active components

Preliminary remarks and special information

A number of factors can impair the performance and processing capabilities of active components.



Source: NXP Semiconductors Germany



Source: STMicroelectronics Application

Factors affecting performance

The following known factors/disruptive influences can damage components or lead to failure:

- Electrostatic discharge (ESD = Electrostatic Discharge)
- Loss of data as a result of charge decay in non-volatile storage devices (e. g. for reprogrammable components)
- Moisture can damage the component (e. g. the popcorn effect or corrosion)

Factors affecting processing capability

It is important to ensure that the temperatures at which active components are stored does not accelerate significant diffusion processes (e. g. intermetallic layers).

Mechanical factors

Examples of damage include:

- Deformation/bending of connections – coplanarity damage
- Loss of solder balls due to incorrect handling

Moisture

Moisture can diminish the wettability of surface layers. In addition, moisture penetration can initiate the popcorn effect and damage the component as a result of internal delamination. For this reason, it is essential to classify devices according to moisture sensitivity levels (MSL = Moisture Sensitivity Level) as per JEDEC J-STD-020 [2]. Even moisture-proof bags must be provided with an adequate supply of desiccant and a moisture indicator card. If the moisture indicator card is positive, it may be necessary to pre-dry (bake) before assembly.

Corrosion

Plastic housing alone does not provide adequate protection to prevent air humidity or harmful gases penetrating the interior of the housing and the connecting pins. Harmful gases may also be released from unsuitable packaging. Consequently, these components must be protected during storage from external and internal corrosion and moisture.

Packaging/transport and storage

Packaging must be carefully selected to make any necessary handling of components as easy as possible during long-term storage. It is not generally possible to dry plastic-wrapped components due to the temperatures required (deformation of packaging materials). Long-term storage in bakable materials such as trays (by agreement between manufacturers and users) is recommended in many cases.

Packaging must provide reliable moisture protection throughout the entire storage period.

Summary/recommendations

During component storage, ageing and failure mechanisms mainly compromise solderability as a result of corrosion/oxidation.

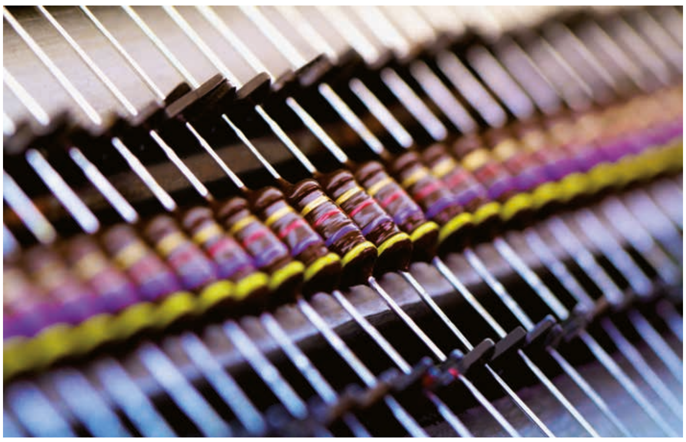
Packaging must provide reliable protection against moisture (atmospheric), contamination (harmful gases) and radiation (UV) throughout the entire storage period.

5.2 Features of passive components

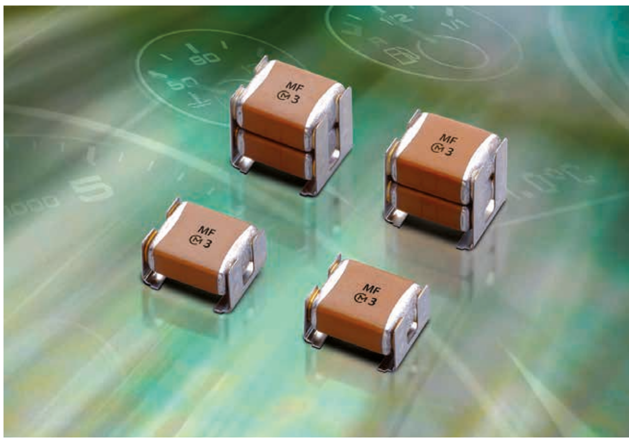
Preliminary remarks and specific information

The aforementioned general and specific factors also apply to passive components such as resistors or inductors since they are essentially determined by the housing and connection technology and not by internal ageing mechanisms. Capacitors are a special case.

Since passive components are made from a very wide variety of different materials and perform very diverse functions, it is always advisable to clarify with the manufacturer whether any specific considerations relating to the technology or function should be taken into account before undertaking long-term storage.

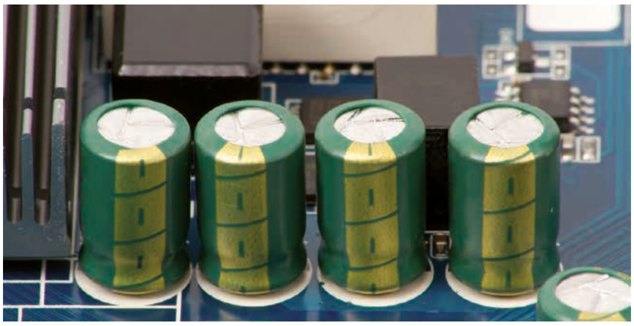


Source: Epcos



Source: Murata Elektronik

Factors affecting performance



Source: SG-Design – Fotolia

Aluminium electrolytic capacitors

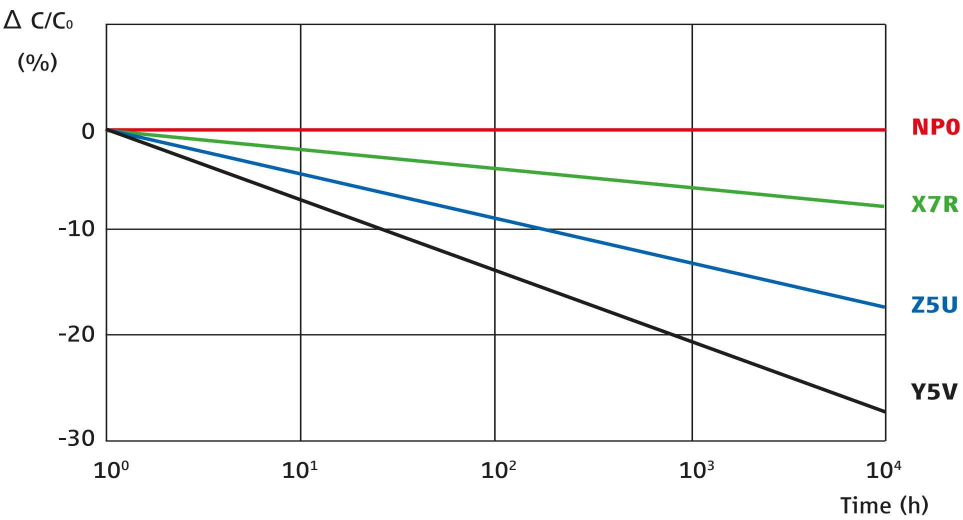
Two different phenomena can adversely affect the blocking ability of the capacitor:

- **Oxide degeneration:**
  Depending on electrolyte class and temperature, ionic parts of the electrolyte can diffuse into the dielectric and oxide, thereby altering the crystalline structure of the oxide. Electrical defects and ionic charge carriers are then produced in the oxide.
- **Post-impregnation effect:**
  The oxide can be electrochemically formed in the component only where it is also coated with electrolyte and is connected electrically to the cathode foil via the electrolyte, thus allowing the required forming current to flow in these regions. In a new capacitor, this is the case on more than 99.9 percent of the oxide area to be formed.

When voltage is subsequently applied after a prolonged period of storage, it may initially increase the regeneration leakage current. It remains relatively high shortly after a DC voltage is first applied to it and then drops after several hours to a low operating leakage current.

Ceramic capacitors

Ceramic capacitors with NP0 dielectrics have only a negligible loss of capacitance. There is a reversible loss of capacitance with ferroelectric materials such as X7R, Z5U and Y5V. A thermal process of over 120 °C (e. g. reflow soldering) can restore the original capacitance. If capacitors do not undergo these thermal processes, the capacitance changes must be allowed for in the design.



Typical ageing of ceramic capacitors during operating and storage periods

Source: Elcap – Wikipedia

Plastic foil capacitors

Plastic foil capacitors succumb to ageing processes. Irreversible capacitance changes are caused by high temperatures such as those occurring during soldering or high current loads. These capacitance changes are caused by slight shrinkage of the plastic film. Reflow soldering can alter the capacitance value of SMD types by up to 10 percent and by 1 to 5 percent for wired, wave-soldered foil capacitors.

Reversible changes to loss factor and insulation resistance occur as a result of the uptake and release of water.

Tantalum capacitors with solid electrolyte

Tantalum is not known to have a limitation on shelf life. Furthermore, the error rate is unlikely to increase over the decades. A service life of > 40 years is achievable if used correctly (no excess voltage, no 'occasional' current peaks).

There are no limitations on the service life of tantalum electrolyte capacitors resulting from drying processes.

Factors affecting processing capability

The general factors already described in the 'active components' chapter also apply to passive components.

Allowances must be made for increased leakage current once aluminium electrolytic capacitors have been assembled on the circuit board during the subsequent test programme. The electrolytic capacitor must be given sufficient time to regenerate. If these effects cannot be dampened during the test programme, the electrolytic capacitor must be preformed before assembly.

High moisture absorption levels during soldering can lead to localised delamination of the interface/materials of plastic foil capacitors. Moisture absorption during storage must therefore be avoided.

Packaging, transport and storage

Packaging for transport and storage must provide components with adequate protection from moisture, harmful atmospheres, impurities (contamination) and exposure to heat.

Summary and recommendations

Passive components are suitable for storage provided that the aforementioned factors and ageing mechanisms are taken into account.

Aluminium electrolytic capacitors are the exception. Storage for more than three years is not recommended without additional measures (testing leakage current and reformatting) or additional information from the manufacturer.

5.3 Special features of batteries (and accumulators)

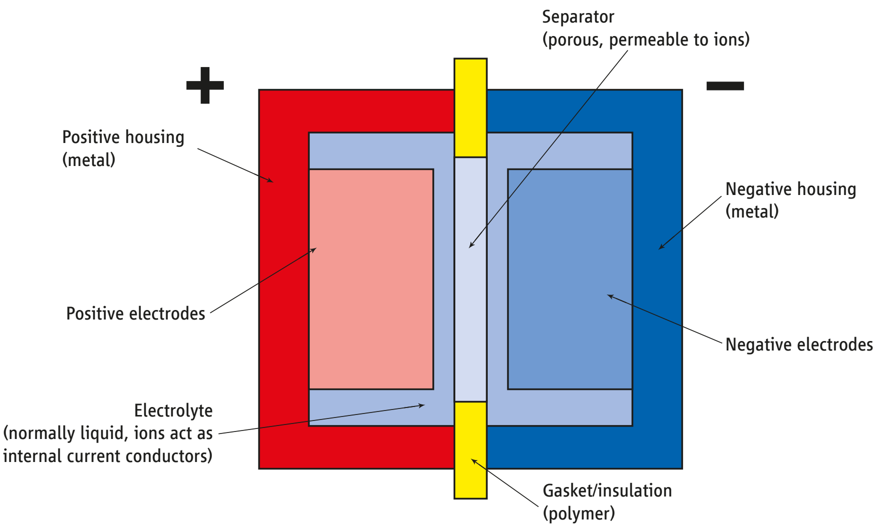
Source: Varta Microbattery

Source: Varta Microbattery

Preliminary remarks and specific information

Batteries and accumulators differ from other components in that they contain an electrochemical reaction mechanism, or 'ageing' mechanism. When the product requires current, ions flow through the separator until the voltage is interrupted.

Depending on the battery system and design, minimal current flow during storage cannot be avoided. This makes batteries unsuitable for long-term storage without severely impairing their functionality, i. e. their ability to provide energy.



Basic structure of a battery

Source: Varta Microbattery

The following electrochemical systems are technically relevant:

- Rechargeable wet cell (liquid electrolyte):
  - Pb/PbO_2 (H_2SO_4)
  - NiMH (KOH)
- Rechargeable organic electrolyte:
  - Li-Ion (also Li polymer)
- Primary wet cell (liquid electrolyte):
  - Alkaline-manganese (Zn/MnO_2)
  - Zinc-silver oxide
  - Zinc-air
- Primary organic electrolyte or dry cell:
  - Primary lithium (Li/MnO_2, $Li/SOCl_2$ etc.)

Factors affecting performance

Three different mechanisms limit storage capacity:

- Chemical/physical changes within the cell
- Ambient conditions (temperature, air humidity, light)
- Interactions with applications (device/components), when connected

1) Chemical or physical changes within the cell

Various chemical and physical changes within the cell can reduce the battery's usable capacity:

- Changes to the crystalline structure of the electrode materials
  - Formation of larger, less active $PbSO_4$ crystals in lead batteries
  - Changes to the crystalline structure of nickel hydroxide in NiMH batteries (conversion from beta-Ni $(OH)_2$ to alpha-Ni $(OH)_2$)
- Fine electrode material may be eluted into the electrolyte during storage, transported through the separator and then discharge the negative electrode
- Trace impurities may bring about self-discharge due to 'shuttle reactions' (repeatedly shuttling back and forth between electrodes) (examples: $Fe^{2+} \leftrightarrow Fe^{3+} + e^-$, $NH_4^+ + 8\,(OH)^- \leftrightarrow NO_2^- + 6\,H_2O + 6\,e^-$)
- Electrode material may be discharged without the stored electrical energy having been used due to parasitic reactions (examples: $Zn + H_2O \rightarrow ZnO + H_2$, $4\,NiO\,(OH) + 2\,H_2O \rightarrow 4\,Ni\,(OH)_2 + O_2$

As a general rule, these effects limit the lifetime of rechargeable batteries to one till two years for wet cell systems such as lead batteries or NiMH batteries and up to six years for lithium ion systems.

2) Ambient conditions

External effects can further reduce storage capabilities, especially in the case of lithium-ion systems. Increased temperatures cause reaction rates to rise exponentially (Arrhenius).

Moisture can diffuse through sealants (especially after age-induced embrittlement) and trigger decomposition reactions in the cell (example $2\,Li + 2\,H_2O \rightarrow 2\,LiOH + H_2$). Diffusion of water from the cell can cause the cell to dry out.

External corrosion of metallic housing material can result in subsequent contact problems.

Furthermore, external conductive fluid bridges can lead to self-discharge, often associated with corrosion.

3) Interactions

Leakage current causes external discharge when batteries are inserted in devices (1 µA leakage current corresponds to 8.76 mAh charge loss per year). This is particularly relevant to small batteries: button cells, for example, have a capacity ranging from 10 – 100 mAh.

Internal protection circuits can cause lithium-ion batteries to discharge even when they are not connected to devices.

Factors affecting processing capability

Functional limitations are generally more dominant. Possible contact problems caused by corrosion of external terminals are thus of secondary importance (when it's drained, it's drained).

Packaging, transport and storage

The storage area should be clean, cool, dry, well-ventilated, weather-resistant and protected from direct sunlight. The storage temperature should lie between +10 °C and +25 °C and may not exceed +30 °C. Humidity levels above 95 percent and below 40 percent relative air humidity for prolonged periods, as well as condensation, are to be avoided.

Batteries should be stored inside devices or in packaging that has been approved by the battery manufacturer.

The aforementioned recommendations also apply to storage conditions during shipping over longer periods of time.

Summary and recommendations

Battery discharge rates must be taken into account when designing devices/components. Batteries are not suitable for long-term storage. Measures to increase the long-term storage capabilities of batteries are essentially based on reducing ion transport within the battery. However, this transport cannot be entirely prevented.

The 'best before' date of primary batteries can be summarised as follows:

- Zinc-air cells: two till four years
- Alkaline-manganese button cells: seven years
- Lithium primary cells: eight till 15 years (in reality a little longer than specified)
- Not normally specified for rechargeable batteries

'User replaceable' standard batteries should not be stored. Instead, replacement batteries should be purchased and used only when required.

The storage capacity of accumulators can be increased by regular recharging (every twelve months).

Literature on storage conditions:
IEC 60086-1 [13], IEC 60086-2 [14],
IEC 62133 [16].

5.4 Special features of printed circuit boards, assembled subassemblies and devices

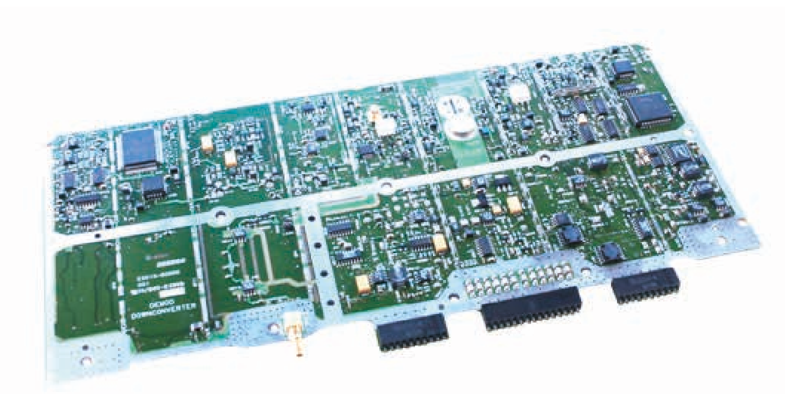
Preliminary remarks and special information

Whilst at component level the choice of suitable long-term storage conditions is determined largely by the individual design of the components itself, the definition of long-term storage at subassembly level (assembled, partially assembled circuit board) is fundamentally different.

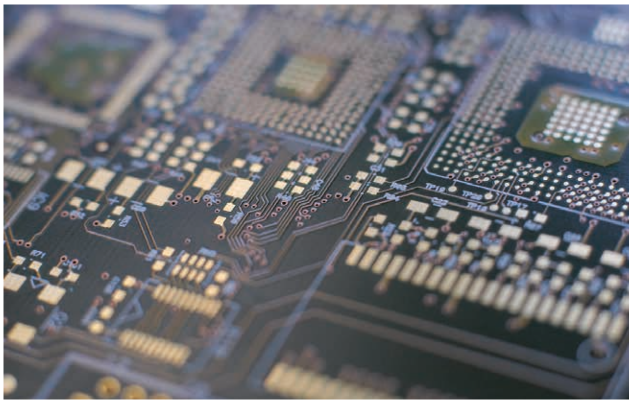
The same is true of the circuit board (unassembled) itself, which in turn is regarded as an individually designed part (drawing). Restocking of these circuit boards depends largely on the availability of the base materials, which is generally a given.

The shelf life of circuit boards is crucially dependent on the final finish and therefore they are not suitable for long-term storage over several years.

With subassemblies it is essential to identify the component which is the first to show the effects of ageing in terms of processing ability and performance.



Source: Zollner Elektronik



Source: Polytron Print

Factors affecting performance

Initially, performance is limited purely by the constraints of the shelf life of the respective components. The individual shelf lives of components may be reduced by interactions arising from processing operations which have already taken place. For instance, typical curing conditions for silver conductive adhesives or heat conducting systems require thermal processes which trigger similar ageing effects as those arising from soldering processes. The ageing mechanism of cured adhesives and potting materials is largely similar to that of plastics. Apart from a tendency for pre-processed adhesives and potting compounds to become brittle, reduced interfacial adhesion also occurs.

Factors affecting processing capability

Subassemblies should ideally be stocked fully assembled, i. e. the assembly and connection technology including all manufacturing processes should be completed. The manufacturer's recommendations for subassemblies with protective coatings (e. g. paints) should be observed prior to and during storage.

If they can be only partially assembled, their suitability for further processing and storage must be reassessed after every process involving heat. For example, with partially assembled subassemblies it is advisable to pre-solder the areas to be brazed before the final solder.

Packaging, transport and storage

At subassembly level, all component requirements should be broadly satisfied. This essentially means that the greatest possible compatibility must be ensured with regard to moisture, storage temperature, ESD protection etc.

Particular attention must be paid to sourcing suitable, durable, low-emission packaging since there are no universally suitable packaging solutions for subassemblies.

Summary and recommendations

Comprehensive recommendations for the long-term storage of subassemblies cannot be given since the specific area which is most sensitive to ageing and the ageing mechanism limit storage in a highly individual manner.

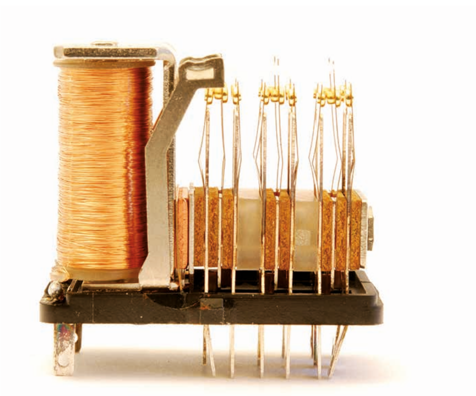
Any long-term storage at subassembly level reduces the residual life of the product still to be fully assembled in terms of processing capability and performance.

5.5 Special features of electromechanical components such as plastic housings and structural parts

Preliminary remarks and special information

Electromechanical components such as connectors, switches, relays or fuses are generally points of separation or connection of electric conductors. The processing capability and performance of some components remains virtually constant during prolonged periods of storage, whilst others are virtually unusable after the manufacturer's recommended shelf life. For this reason, it is important to distinguish between different types of component. The manufacturer's recommendations should be obtained and used as the basis for developing a storage strategy right from the product development stage. For example, an industrial connector for large loads must be distinguished from Flat Flexible Cable (FFC) connector.

Source: TE Connectivity



source: Jean-Marc Richard – Fotolia

Source: Marquardt

Factors affecting performance

Housings and structural elements are an integral part of electromechanical components. Processing capability and performance can be severely impaired by the effects of ageing. Embrittlement and shrinkage of plastic parts can result in dimensional changes which may make it no longer possible to achieve a positive fit with connectors. The microclimate inside electromechanical components also has a major impact on corrosion, for example. To combat this it may be necessary to alter the design or select higher grade housing materials such as ceramics, metals, glass and emission-free plastics, which, when combined with a protective atmosphere in an inert gas or under vacuum, will protect the functional elements for prolonged periods.

The electrical load in the application plays an important role on the long-term storage capability of functional elements of electromechanical components, such as switch and plug-in contacts. High voltage and current will remove any layers of contamination. High contact forces generated by switching contacts or high frictional forces generated by plug-in connectors also have a cleaning effect.

Suitable protective measures such as high-quality surfaces or passivation, however, are required for low electrical loads. The shape of contacts can also have a positive effect on shelf life.

Factors affecting processing capability

Detachable contacts such as screw connections, spring clamp terminals and blade terminals are well-suited to long-term storage. However, it may be important to select materials and coatings which provide good resistance to harmful environmental conditions. It may also be necessary to pretreat contact points with preservatives.

Non-detachable connections such as crimp, rivet, IDC (insulation displacement connector) or compliant pin types achieve a good connection by means of a positive fit. Insufficient layer thickness or absence of barrier layers in the contact zones leads to diffusion of the base material into the contact layer during long-term storage. If this occurs, a gas-proof connection can no longer be guaranteed.

The surface quality is of paramount importance for jointing processes such as soldered and welded or adhesive and bond connections. Before processing, connection points must be examined and appropriate surface activation or cleaning undertaken, especially where connection points have been protected by means of preservatives or other means prior to long-term storage.

Packaging, transport and storage

The choice of packaging material has a particular impact on the performance of electromechanical components. Plastic packaging which emits gases, has an insufficient UV protection or an excess of residual moisture in the packaging may damage contacts. On the other hand, a packaging microclimate that is too dry may contribute to embrittlement or shrinkage of housings and functional components.

Alternative packaging using metal or glass and routine interim inspections are to be included in the storage strategy.

Storage conditions for electromechanical components are similar to those of other components.

Summary and recommendations

Avoiding the potential malfunctioning of electromechanical components as a result of long-term storage is a particular challenge. The complexity of the determining factors, error patterns, their effects and solutions can be only partially covered here.

6. General recommended procedure for storing components

The following flow diagram describes in generic terms all activities required for long-term storage. Individual companies can allow for and include any specific company requirements.

In these guidelines we have confined ourselves to the storage of and processing preparations for the components under consideration. Their suitability for storage, including packaging, must be discussed with the manufacturer beforehand.

Semi-finished lots and semi- or fully assembled components must be considered separately as different processing states during discontinuous processes can in turn initiate their own error modes. In this case the critical subcomponents must be individually assessed to determine their suitability for long-term storage.

6.1 General checklist

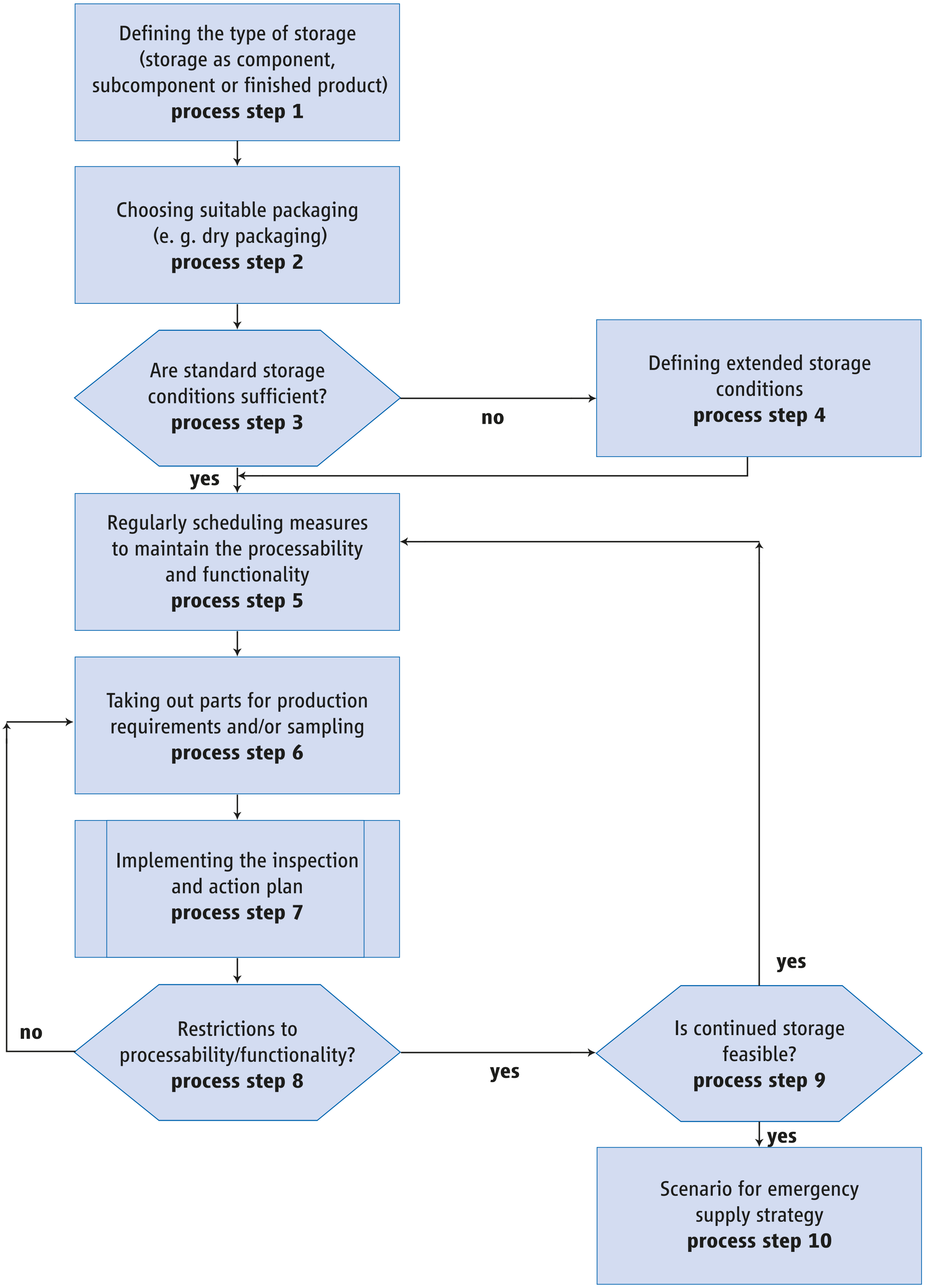
The answers to the following questions provide the basis for continued planning of component storage:

- Is the item an original product?
- Does it have a known storage history?
- Are the transport conditions and supply chain known?
- Does the as-delivered condition of the packaging comply with the manufacturer's recommendations?
- Is there known to be an unavoidable limitation on shelf life caused by ageing mechanisms?

If these questions cannot be answered satisfactorily, it is best to reorder the components in the packaging recommended by the manufacturer. The starting point for the recommended general storage procedure is that goods are delivered in suitable packaging.

Source: CMS Electronics

6.2 Flow diagram for long-term storage



6.3 Explanation of individual process steps

Process step 1: Establishing the type of storage (storage as component, subcomponent or finished product)

If components are to be stored long-term, it is important to check in what form they may be available throughout the entire time.

- Storage as unfinished manufactured goods (component)
- Storage as (partially assembled) printed circuit board
- Storage as device, module or system

It is important to consider whether the storage of components, subcomponents or finished goods provides the better option for maintaining delivery capability. Particular attention must be paid to the following points:

- Failure mechanisms, verifiability/testability, processing capability
- Availability of devices, software, technology, materials
- Storage costs, assembly costs, reprocurement costs

Production of aluminium-electrolyte-capacites

Source: Epcos

If consideration is not given to these points at a sufficiently early stage, a large part of the shelf life guaranteed by the manufacturer will often have already elapsed. It must then be decided what form best meets the availability needed for the remaining storage period. 'Best' in this context means demonstrating awareness of the technical and commercial consequences of long-term storage. The questions below must be answered in order to reach a decision on long-term storage at component level.

By this stage at the latest, it is advisable to perform a risk assessment of the storage process, for example using failure mode and effects analysis (FMEA). The FMEA should provide answers and estimates to the points in the checklist below.

Checklist:

- Have optimal storage conditions been defined by the manufacturer?
- Is the packaging suitable for long-term storage?
- Has the manufacturer recommended storage conditions to extend the shelf life?
- Can a resealed (welded seal) original packaging be stored?
- Does the desiccant/moisture indicator need to be topped up/replaced?

Process step 2: Choosing suitable packaging (e. g. dry packaging)

If the manufacturer has not issued recommendations to extend the shelf life, it is advisable to pack the originally packaged goods in an extra MBB (MBB = moisture barrier bag) for storage. In so doing, it is important to ensure that moisture indicators (in the original packaging) can be clearly seen through the bag. The extra bag must also contain desiccant and moisture indicators in sufficient quantity for the intended storage period.

Component-rolls with moisture barrier bag, moisture guard and moisture indicator

Source: S.E.T. Electronics

The following values have proven successful for components in the absence of any specific storage recommendations:

- Temperature: as constant as possible between 15 °C - 40 °C
- Humidity: 30 percent rH - 70 percent rH
- Low-pollution atmosphere and packaging (sulphur compounds, nitrogen oxides etc.)
- Possibility of storage in an atmosphere of nitrogen or oxygen
- Protection from (UV) light
- Protection from dust
- ESD protection
- Protection from mechanical stress (e. g. shocks, vibrations)
- Lot size for packaging unit = production lot (where possible)

The recommended ambient storage conditions for correctly packed components must be examined specifically with regard to further processing. It is also important to ensure that partially assembled components are suitably packaged.

Process step 3: Are standard storage conditions sufficient?

Due to the wide variety of component types, housings and packaging, a separate inspection must be carried out for each component under consideration.

The following aspects should be inspected:

- Effect of long-term storage on failure mechanisms (corrosion, solderability, etc.)
- Effect of long-term storage on housing (dimensions, embrittlement, etc.)
- Changes to mechanical or visual characteristics on exposure to light (embrittlement, discolouration, etc.)
- Effect of processing condition (e. g. partially assembled circuit board) on performance and processing capability

Process step 4: Defining extended storage conditions

Extended storage conditions are defined on the basis of the outcome of the decision-making process in process step 3. The dominant failure mechanisms can be taken directly from the FMEA (see process step 1). Measures that can be taken to prevent harmful effects arising in the first place include reducing air humidity, reducing oxygen levels in the storage atmosphere and storing in inert atmosphere, e. g. nitrogen.

Process step 5: Planning routine measures to maintain processing capability and performance

The condition of stored goods should be inspected at regular intervals so that any negative effects of long-term storage can be identified in good time and appropriate countermeasures can be taken.

If regular production is planned using the stocks of stored goods, a random inspection can be performed alongside routine production.

If this parallel inspection is insufficient, additional measures can be defined in a test plan in order to identify changes to processing capability and performance in good time.

Extra supplies of components should be scheduled to replace those used during these tests.

Containers for random inspections can be assembled in advance to avoid repeatedly opening the original packaging needlessly.

It is also important to define how and how often the external packaging can be inspected and replaced. The packaging manufacturer can assist with this.

The test plan (random inspection) should include the following points:
- Definition of the sample size, test interval and test type (wetting test, dip and look, etc.)
- Definition of the assessment parameters

For a small number of components it may be helpful to specify further measures to extend the storage time. These include:
- Energisation/reformatting
- Refreshing
- Reprogramming

This concerns the total number of stored goods.

source: Industrieblick – Fotolia

Process step 6: Removing production requirements and/or samples

The following steps should be taken when removing from storage the number of units required for production, in-process inspections and/or interim inspections (see planning in Chapter 5):
- Compare the actual number of units with the target number listed in the warehouse inventory
- Visually inspect the packaging (damage, anomalies, moisture indicator, etc.)
- Check for compliance with specified ambient conditions (temperature, humidity, etc.)
- Comply with specified removal processes (choice of container; sequence for opening packaging/outer packaging including ambient conditions)
- Comply with any other safety precautions (ESD protection, use of airlocks, etc.)

Process step 7: Implementing the inspection and action plan

Product-specific regulations must be complied with when removing goods from storage for production and/or inspection purposes. Visual anomalies such as squashed, warped or damp outer packaging call for an immediate inspection of the packaged components. This allows the storage strategy (as defined in process step 4) to be adapted early on.

If the packaging unit is larger than needed for an intermediate inspection, remaining products to be stored according to the conditions previously defined.

Performing the inspections defined in the test plan to monitor the quality of the stored goods:

- Visual properties
- Processing capability
- Electrical properties
- Mechanical properties

Performing the measures defined in process step 5 on the total volume of stored components.

Observations made during production provide information about the condition of the stored goods, e. g.:

- Malfunctions affecting assembly and connection technology
- Wetting problems
- Bonding problems
- Adhesion problems
- Malfunctions caused by corrosion of solderless connection technology

Information obtained when carrying out inspections and measures must be correspondingly assessed and documented.

Process step 8: Deciding if processing capability/performance will be compromised

If the inspection results do not indicate any non-permissible deviations or anomalies, the goods may remain in storage (process step 6). Any errors found during the random inspection or production are to be analysed and then appropriate action taken (process step 9).

Process step 9: Is continued storage feasible?

If errors or anomalies were discovered, it must be decided whether continued storage is possible in principle.

It may be necessary to modify the storage conditions and/or inspection conditions:

- Change the packaging
- Change the storage conditions
- Shorten the inspection interval
- Increase the inspection scope

Storage can continue provided that subsequent processing can be ensured through approved adaptations to production processes, e. g. highly activated flux, refresh or reballing.

Storage must be discontinued if it becomes clear that the measures taken or proposed will not be sufficiently effective.

Process step 10: Scenario for emergency supply strategy

If storage by permissible means is no longer possible, the supply strategy must be reviewed. Due to the sheer diversity of components and associated number of possible functional impairments and problems, it will be necessary to tailor individual solution accompanied by individual risk assessments (e. g. FMEA) to each case.

Emergency measures may include:

- Assembly/further processing of existing residual stocks for storage at the next level of the value chain
- Assembly with additional risks for storage at the next level of the value chain (e. g. soldering with highly activated flux)
- Use of alternative components or even redesign
- ...

7. Minimising risks during long-term storage

In addition to the processes described for long-term storage, the following suggestions can help to increase security of supply:

Design rules:

- Do not use discontinued components
- Make use of standardisation and modularisation to achieve compatibility (interchangeability)
- Preferably, use components with second source availability
- Avoid using exotic components
- If possible, use components which have a longer shelf life (e. g. gold contacts)
- Backwards compatibility

8. Summary and outlook

The trend in recent years indicates a shortening of innovation cycles in terms of both components and products. At the same time, customers are demanding longer and longer service lives with correspondingly longer spare parts availability. In the face of these two opposing trends, producers of electronic devices are forced to ensure long-term availability. One possible strategy for addressing this is the long-term storage of electronic components.

Source: Robert Bosch

It is not possible to make a general statement about storage times and conditions due to the diversity and technological dynamism of the components market. Experience has shown that it is perfectly possible to continue using components after the maximum storage period specified by the manufacturer has expired. However, in so doing the risk is transferred from the component manufacturer to the user.

Using the flow diagram included in these guidelines, this risk can be minimised and storage can be undertaken in a controlled and monitored manner.

The costs of long-term storage can be reduced if consideration is given to long-term availability and storage capability right from the time of component design and selection. In future, greater emphasis will be placed on statutory framework conditions and restrictions.

9. Editorial staff, members of the working group

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VIA Electronic
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ZVEI

The working group 'Lagerfähigkeit' during a working session (not all members are present)

Source: ZVEI

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