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CORROSION PREVENTION & CONTROL APPLICATIONS GUIDE

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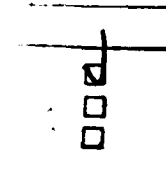
Analytics, Inc.
766 Shrewsbury Avenue
Tinton Falls, NJ 07724

Charles P. Lascaro
(201) 741-3353

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Corrosion Prevention & Control (CPC) Applications Guide

1. Introduction

The purpose of this Guide is to provide Life Cycle corrosion prevention and control information, and guidance to design engineers, quality control personnel, inspectors and procurement and contractual personnel, who are involved in the development, testing and acquisition maintenance, storage and repair of CECOM electronics and communication equipments. The scope of this guide is limited to the prevention and correction of corrosion failures, and control of associated design and manufacturing measures, which relate to CECOM electronics. The guide includes a short tutorial on corrosion mechanisms, a listing of related electronic failure types, prevention and quality control measures necessary during acquisition, warranties, and preventive maintenance measures necessary during storage, fielding, repair, and overhaul.

2. Corrosion Mechanisms, Tutorial

2.1 General

Corrosion is the undesirable deterioration of materials resulting from reactions of the materials with their environment. In electronic equipments, some corrosion forms are not always apparent. It can be very difficult to detect hidden deterioration during a catastrophic electronic or mechanical failure. Many times corrosion is a root cause of electrical failures; which can only be discovered after a thorough failure analysis.

Current technology, such as Large Scale Integration (LSI) or Very High Speed Integrated Circuitry (VHSIC), protects complete sensitive circuit functions in a sealed package but can still be subject to corrosion because of defective seals and contaminants contained in the package. Such failures can occur with minute corrosion situations, but while minute, their effect can be catastrophic because of the miniaturized scale of design and the critical function of the circuit. .

It has been postulated that corrosion is one of the greatest cause of failures in electronics and that annual costs of such failures nationwide, due to resulting lack of system availability and maintenance is in the hundreds of billions of dollars.¹

2.2 Basic Corrosion Mechanism Types

All of the various types of corrosion situations or occurrences can be grouped into two basic types as follows:

Direct Chemical Attack

Galvanic Corrosion Cell

2.2.1 Direct Chemical Attack

Direct chemical attack results when materials corrode and deteriorate as a result of exposure to a corrosive environment such as: Chemical fumes, acids, activated solder fluxes, water or moisture intrusion, and, in many cases, moist air. Reaction rates and extent of damage depends on the materials involved, their area of contact and temperatures in which the reactions occur. This type of corrosion usually occurs on electronic hardware such as: cases, panels, clamps, shafts, contacts, waveguides, screws, bolts, etc. On painted surfaces, protection of the paint is lost when the paint lifts, bubbles or blisters; due to surface damage or poor adhesion at the paint-to-the-metal interface. Usually, such corrosion is easily identified because it is visible. This type of corrosion usually does not immediately cause failure, but its immediate effect is cosmetic. Protection against direct chemical attack is usually achieved by good quality platings, paints, coatings or treatments which form a protective nonreactive films.

2.2.2 Galvanic Corrosion

Galvanic corrosion is a form of electrochemical corrosion that occurs when two dissimilar metals are in contact with one other in the presence of an electrolyte. This type of reaction, similar to that which occurs in a simple battery, causes a flow of current from anode to cathode (Figure 2.2.2). The reaction at the anode is always oxidation which tends to destroy the anode metal by causing it to go into solution as ions. The reaction at the cathode is always reduction; involving the liberation of hydrogen and the formation of alkali.

Theoretically, only the anode should corrode because the metal cathode normally cannot be further reduced (i.e., bare metal), but the cathode can be corroded by alkali. Thus, when two dissimilar metals form a galvanic cell and the cathode metal is soluble in alkali, both the anode and the cathode may corrode. Corrosion at the anode, however, usually occurs at a faster rate. There are many variations of a galvanic corrosion cell. Further descriptions can be found in the referenced texts on corrosion or as shown in Figure 3.6.3 of the Para 3.6 which describes a complicated example of galvanic corrosion occurring in a plastic coated transistor.

Galvanic corrosion occurs when two dissimilar metals are coupled together in an electrolyte. For example, if a part made of iron and copper is exposed to an electrolytic solution, that is a solution containing free ions and anions such as sodium chloride, current will flow between the iron (anode) and copper (cathode) as shown. The reaction products, ferrous chloride at the anode and sodium hydroxide at the cathode, meet in the middle to form ferrous hydroxide which absorbs further oxygen and produces hydrated ferric oxide or yellow rust (TO-1-2 Aircraft Weapon System, Corrosion Prevention and Control).

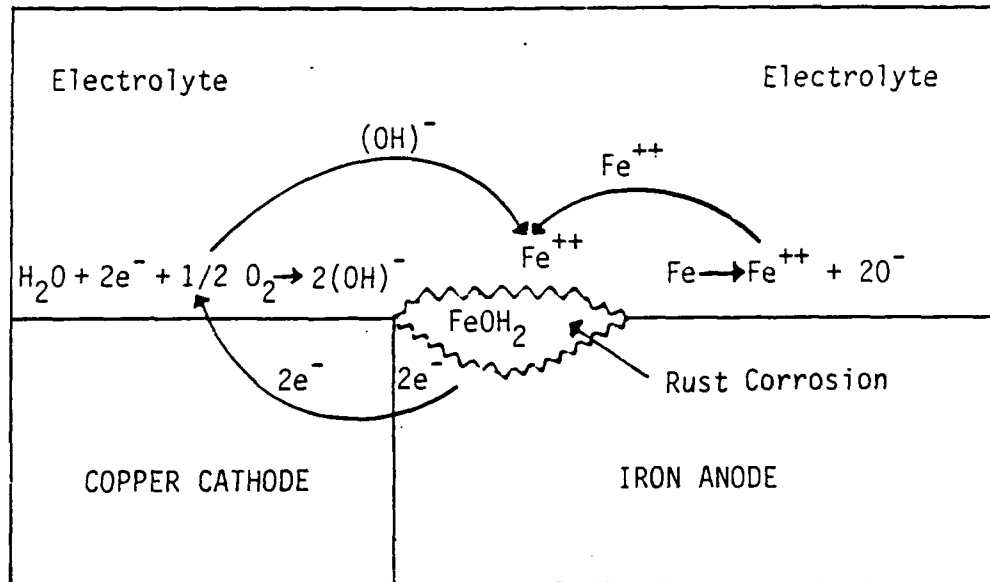


FIGURE 2.2.2 TYPICAL GALVANIC CORROSION CELL

$FeOH_2$ = Yellow Rust

Electrolyte = Water and Contaminant

2.2.3 Corrosion Rate Factors.

Since corrosion is a progressive action, once it starts, it is important to know under what conditions the rate of corrosion will accelerate; since this will determine how soon, from the onset of corrosion, a catastrophic failure can occur. Whenever an onset of corrosion is discovered, it should be regarded as a potentially catastrophic failure; which will occur in time depending upon the following factors:

2.2.3.1 Temperature

Corrosion is generally accelerated by rising temperature. A good rule-of-thumb is that all chemical reactions double their acceleration rate with every increase of 10^oF temperature. This would also apply to corrosion rates.

2.2.3.2 Time

Corrosion progresses with time, as long as the corrosion conditions exist. Its progress can be interrupted by changes in conditions, i.e. dryness, or eliminated by cleaning away contaminant and applying MFP coatings, etc. but will continue if and/or when conditions for corrosion are reestablished. Eventually, corrosion, once started, will continue until a catastrophic failure occurs,

unless effective corrective measures are applied. Failures, due to corrosion, have been experienced under tropical conditions from 3 to 6 months. For this reason, no slight corrosion spot can be ignored as harmless or considered acceptable in CECOM material.

2.2.3.3 Moisture

Since contaminants must be in solution, moisture or humidity is an essential element of corrosion. Items stored in a dry desert condition corrode slowly or not at all, while items stored in a damp tropical or marine condition corrode rapidly. Moisture is an essential ingredient in corrosion mechanisms, in addition to a contaminant; which can be present everywhere.

2.2.3.4 Contaminants

Electronic hardware and circuitry can be subjected to contaminants from manufacture, storage, field usage and transportation. Contaminants can cause direct chemical attack and, with moisture, can form the electrolyte necessary for galvanic corrosion. Any contaminant that will, in solution with moisture, provide ions and anions for conductivity will also accelerate corrosion processes. Contaminants can be classified as follows:

a. Industrial Contaminants:

During the production process(es), equipment components can be exposed to vapors, handling or contact contamination, fluxes, etchants, ozone, outgassings, nitrates, and sulfates, etc. Nitrates occur in rain water and are present in much higher concentrations in the tropics due to decaying vegetation. However, most nitrate contaminates result from industrial processes. Sulfur dioxide and other sulfates also occur in smoke and industrial gases. The combination of ozone, nitrate, sulfate, and dust particles also contributes to deterioration of organic insulation.

b. Processing Contaminants:

When packaged or sealed in the case or container, equipments and/or components can be exposed to the outgassing from incompletely cured plastics, rubbers, pottings, fluxes or any synthetic organic compounds that were used in the manufacturing or in the sealing process. Self-generating vapors usually result from the outgassing or decomposition of plastics and other organic materials or from the plating processes. Phenolic base materials which can be used as insulators, standoffs, circuit boards, knobs, etc., can emit ammonia and formic acid if not properly baked out. The formic acid vapors react with the

lead in solder to form the grey-white lead deposits; often seen on printed circuit boards. Zinc, cadmium, magnesium, lead, and copper are very susceptible to corrosion from ammonia vapors.

Plastics, and some other organic materials such as packing containers, when not completely cured, often liberate a host of corrosive vapors. Moisture, hydrogen sulfide, and hydrochloric and organic acids are the most prevalent. Outgassing is dangerous during storage when the equipment is stored in a closed area. Even small amounts of vapor can have a deleterious effect; especially in miniaturized circuitry. Although outgassing occurs at normal room temperatures, it is accelerated in high temperature or low-pressure environments.

The most common source of corrosive vapors is from incompletely cured organic material; examples of which are listed in Table 2.2.3.4.1. The extent of the attack depends on the degree of cure, the plasticizer used, the temperatures, the type assembly, and whether the assembly is in a closed or open container. Each material use could be made of a plastic, which by choice could be severely corrosive, somewhat corrosive, or not corrosive; provided all other properties are satisfactory for the application.

Table 2.2.3.4.1

ORGANICS AS SOURCE OF CORROSIVE VAPOR

Material Use	Severely Corrosive	Somewhat Corrosive	Not Corrosive
Adhesive	Ureaformaldehyde Acetic Silicone	Phenol- formaldehyde	Epoxy Non-Acetic Silicone
Gasket	Neoprene/asbestos Resin/Cork	Nitrile/asbestos Glue/cellulose	--
Insulation (wire)	Vinyl Polyvinylchloride Vinylidene Fluoride	Teflon Nylon Polyimide	Fluorothene Polyurethers Polycarbonate Polyethylene
Sealer	Polysulfide Acetic Silicone	Epoxy	Non-Acetic Silicone
Sleeving	Vinyl Polyvinylchloride	Silicone	--
Tubing	Neoprene, shrinkable		
Plastics	Melamine ABS Phenolic	Polyester Diallyl Phthalate	Silicone Epoxy
Varnish	Vinyl	Alkyd	--

Paper and wood also emit harmful vapors. Paper liberates hydrogen sulfide, which tarnishes silver, copper, and brass. Acid vapors from wood, especially oak, chestnut, and cedar, also attack metals. These products are no longer generally used in electronic assemblies; except in packaging materials.

c. Field Contaminants:

In the field, moisture, salt, fungus, insect and rodent debris, and outgassing from decaying flora can provide corrosive elements. Tropical and marine atmospheres provide more corrosive contaminants than temperate exposures. Marine atmospheres are usually the most corrosive of field environments. Sea saltfog and mists, have been measured as far in land as 5 miles from the coast. The effect of time and location, jungle and/or marine, under tropical conditions, is shown in Figure/Table No. 2.2.3.4.2 below.

Table/Figure 2.2.3.4.2

FIELD TROPICAL FAILURE MECHANISMS*

<u>Mechanism</u>	<u>Number of Part Types With Failures</u>		
	<u>Jungle</u>	<u>Shore</u>	<u>Total</u>
Lead Wire Corrosion (LWC)	2	13	15
End Seal Migration (ESM)	2	15	17
Element Corrosion (EC)	5	7	12
Electrolytic Corrosion (ELC)	5	7	12
Solder Corrosion (SC)	4	5	9
Silver Migration (SM)	3	2	5
Case Corrosion (CC)	<u>2</u>	<u>2</u>	<u>4</u>
	23	51	74

A study in the Panama Canal Zone exposed 18 different types of approved military standard quality parts, in sample lots of 50 each per exposures site, to tropical conditions. The Table shows that exposure at the shore, due to salt effects, can be twice as corrosive. *"Corrosion of Army Electronic Equipment," by Charles P. Lascaro, USAET&DL, ECOM, Fort Monmouth, published in 1972 Tri-Service Conference on Corrosion.

2.2.3.5 By-products of Corrosion

The nature of the corrosion by-product can accelerate or deter further corrosive action by virtue of its physical or chemical nature, i.e. aluminum oxide is dense, tough and adherent and forms a protective film on the aluminum surface. Copper oxide is a dielectric, which can increase contact resistance. The green patina on copper surface, copper sulfide, is also a protective layer, reducing but not eliminating further corrosive action. In many cases, the nature of the by-product of corrosion provides a protective layer to preserve structural integrity as on an aluminum structure or it may cause conductivity circuit failures as on a contact, switch or relay surface or a ground contact on an aluminum chassis or ground plane. In some instances the by-products of corrosion can act as a rectifier to AC signals.

2.3 Specific Forms of Electronic Corrosion:

While many forms of corrosion can and does occur in vehicle, truck, tank or such structural forms, this guide will be confined only to those forms of corrosion that have occurred and which can or will affect the operational integrity of CECOM electronic, communication or electrical systems. When a system failure occurs, system failure analysis pinpoints the failure to a circuit function; and/or circuit element or part. Quite often, the root cause can be corrosion. Forms of corrosion which are important to electronic hardware and circuitry are as follows:

2.3.1 Pitting Corrosion

Pitting is a common and severe form of localized corrosive attack on thin metal sheets such as printed circuit paths, etc. which are especially vulnerable since penetration of the metal at pit sites can result in perforation. Perforation and the progressive nature of corrosion will surely cause reduction in service life and possible catastrophic failure. Pitting usually occurs in grain boundaries, porous finish areas at highly anodic points on the metal surface. It is primarily the result of localized cell action. Concentration-cell action (differences in oxygen level) will contribute to the formation of damage-causing corrosion products that usually accumulate in such pits. It also occurs with porous

gold plating on copper alloy contacts. The plating pores create a little corrosion cell which continues to expand until a hole or pit is created. The initiation of localized or pit type corrosion can occur because of incomplete films or coatings (e.g., damaged protective oxide films), conformal coatings, etc; or in the presence of substances that partially shield small areas on metal surfaces (e.g., oxide scale or debris). Corrosive agents in solution will accelerate pitting in such cases.

Some examples of pitting corrosion are shown in Figure 2.3.1.1, 2.3.4.2, 2.3.4.3.

Figure 2.3.1.1 shows spring wire contacts which failed because corrosion products at the contact area plus make and break arcing, creating a concentration cell and resultant pitting.

Figure 2.3.1.2 shows a gold-plated printed circuit connector pin which pitted because of porous gold plating.

Figure 2.3.1.3 shows a closer view of the same connector pins with a generally pitted surface.

All of the above failures could have been prevented with a nickel underplate on as polished pin surface followed by a 50 microinch gold plating.

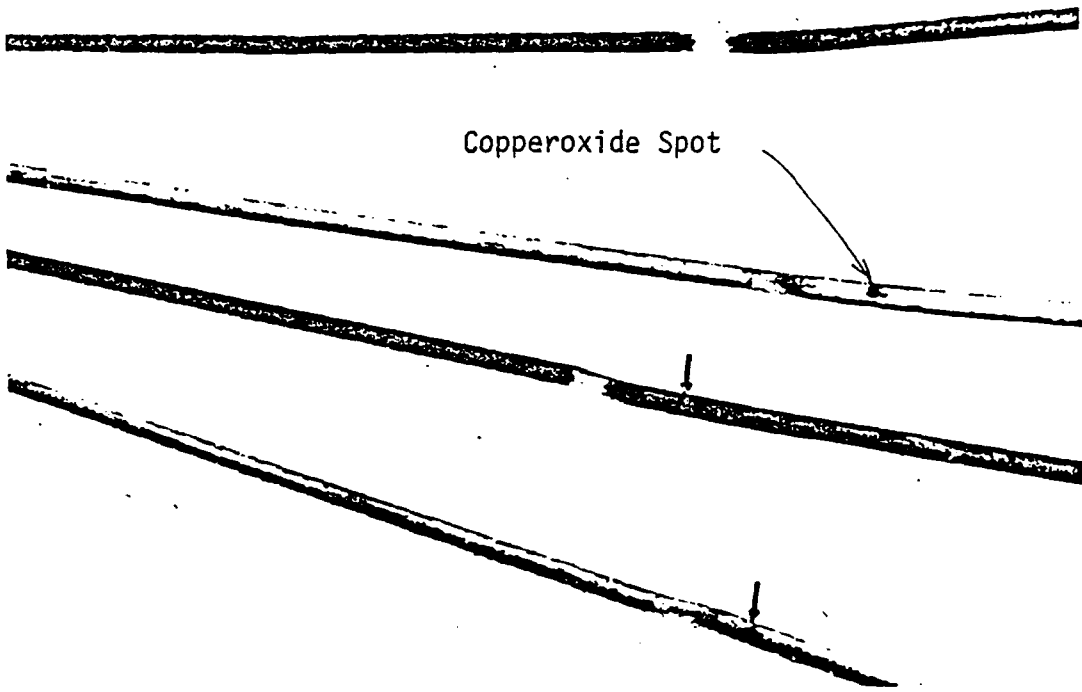


FIGURE 2.3.1.1 CORRODED BERYLLIUM COPPER SPRING WIRE CONTACTS



FIGURE 2.3.1.2 CORROSION OF GOLD PLATED PINS



FIGURE 2.3.1.3 CORROSION GROWTH AT PIN HOLES

Corrosion on aluminum and magnesium first appears as a white or gray powdery blotch on the metal surface. When the deposits are cleaned away, tiny pits or holes are visible. The by-products of such corrosion can cause loss of seal in an equipment container or open circuit in a contact or printed circuit element. Prevention can be effected by plating on smooth or polished surfaces and/or thicker nonporous platings. Usually an undercoating of nickel plating under gold would be required.

2.3.2 Galvanic Couples

Galvanic couple corrosion occurs when two dissimilar metals are in contact with one another in the presence of an electrolyte (solution containing free ions and/or anions). It can be easily seen that in a complex assembly as a communication system, subsystem, module, printed circuit board assembly and/or a part, that couples can occur in many instances and forms. In each case, the more anodic metal will corrode sacrificially. Referring to Figure 2.3.2.1; attaching a copper lead to a steel end cap of a fixed composition resistor caused the steel to corrode. If a gold lead is bonded to an aluminum land in an integrated circuit as shown in Figure 2.3.2.2, the gold lead will eventually debond due to corrosion of the aluminum if contaminants are present. If a copper wire is grounded to an aluminum ground plane, the aluminum will corrode causing a poor or lost ground connection. Most attachments to a magnesium

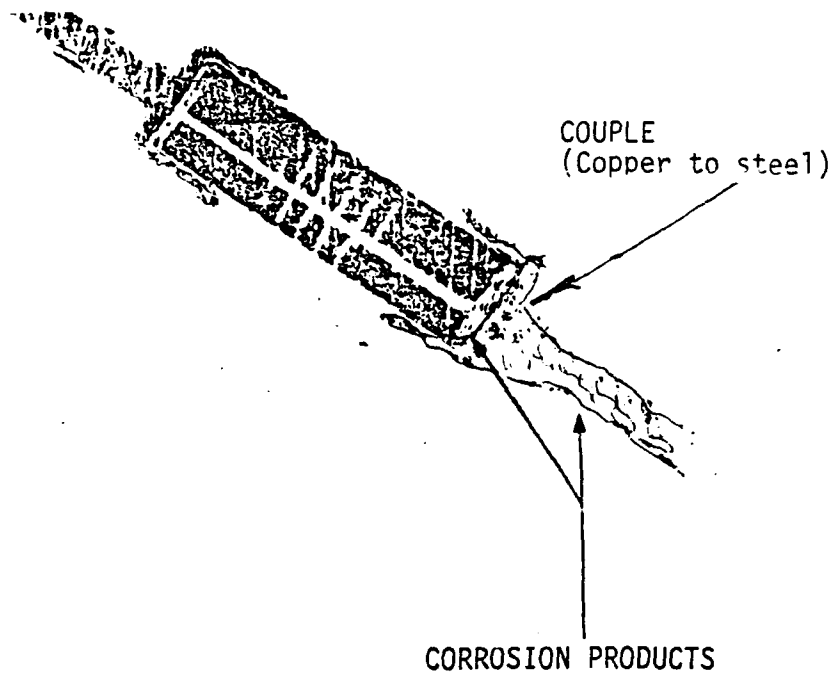


FIGURE 2.3.2.1 ELECTROLYTIC CORROSION (ELC)
SECTIONED VIEW FIXED COMPOSITION RESISTOR

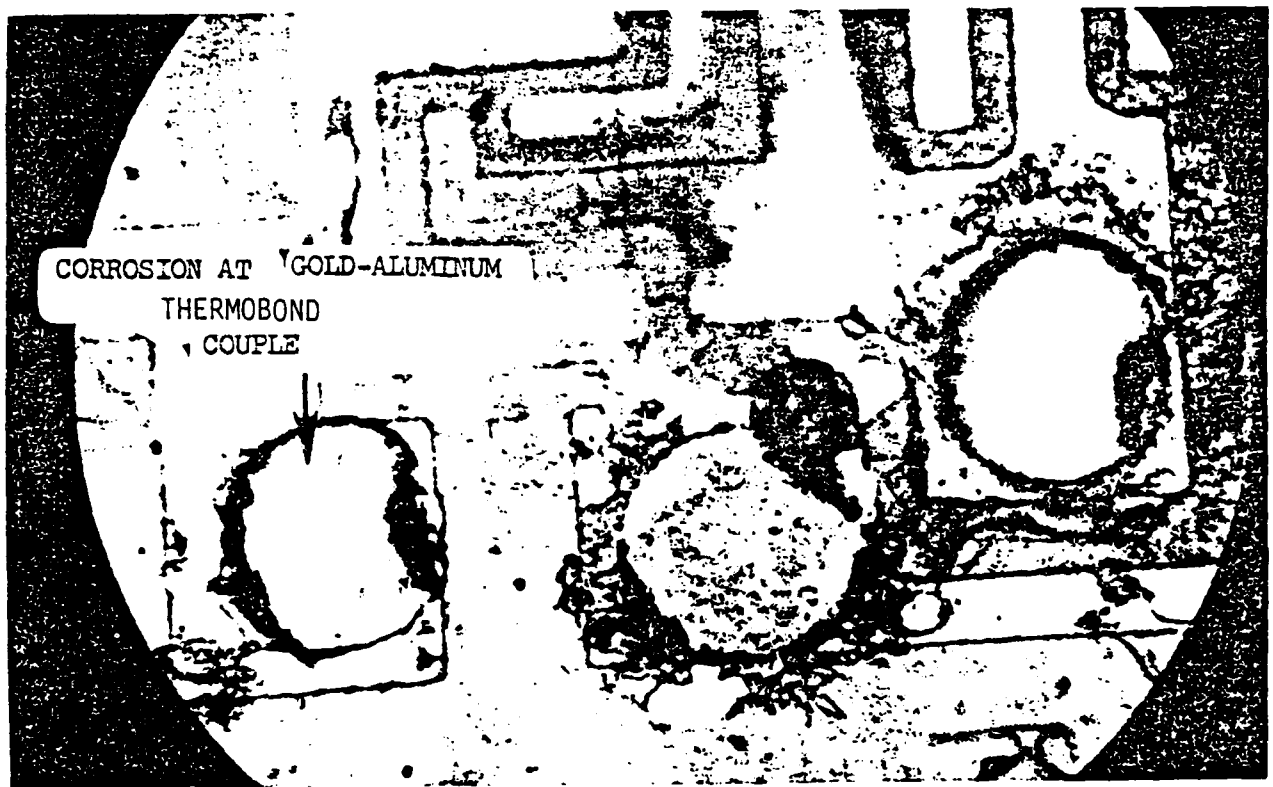


FIGURE 2.3.2.2 TRANSISTOR BOND COUPLE CORROSION PLASTIC TRANSISTOR

case will cause the magnesium to corrode. Stray potentials or currents may either inhibit or accelerate corrosion; depending on polarity and presence of an electrolytic medium. Corrosion is usually prevented by not coupling metals outside the acceptable groupings and preventing contaminants from coming in contact with either metal by using coatings or barriers to separate anode and cathode. Where possible, the area of contact for the anode should be as large as the design will permit. This will spread the corrosion over a larger area and permit a larger EMF in the allowable sample. See Figure 2.4.1.1, which is really Table V of MIL-F-14072.

2.3.3 Stress Corrosion

Stress corrosion failure results from a combined effect of tensile stress and corrosion. Cold-working or straining, quenching (in heat treatment), grinding, or welding may produce internal stresses. Applied stress may be local or general, uniform and static, or varying and cyclic. Stresses may exist in many combinations/causes. The most destructive type of stress, however, is that which is local and nonuniform. Under such conditions, the stressed zones are subject to accelerated corrosion.

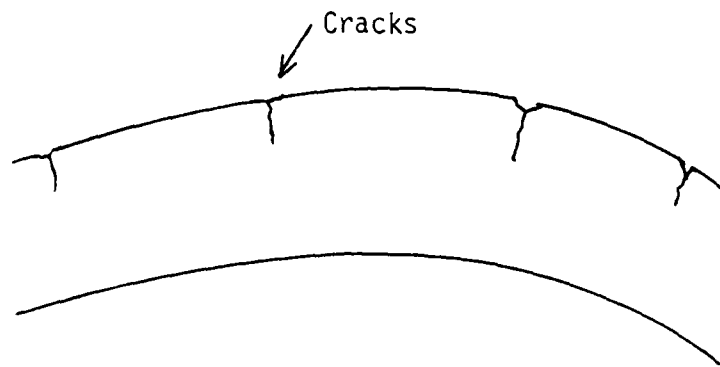
Metals that are subjected to applied stresses will develop a more anodic nature at such areas under corrosive conditions. Adjoining

unstressed areas or less stressed areas will be less anodic or more cathodic. Figure 2.3.3.1 shows a schematic of a stressed metal spring with corrosion initiated at notches. Figure 2.3.3.2a shows a Kovar lead stressed at the insertion hole of the printed circuit board where flux residues existed. Figure 2.3.3.2b is another schematic illustrating stress corrosion at a soldered feed through hole. Figure 2.3.3.3 is an actual photograph of a stressed Kovar lead and resultant stress corrosion crack.

There are two principal types of failure associated with the combined actions of stress and corrosions; these are stress-corrosion cracking, and corrosion-fatigue failure. In stress-corrosion cracking, fissures can be initiated and propagated by corrosion of anodic areas that are generally concentrated intergranularly. The presence of tensile stresses, residual or applied, will accentuate concentration of the anodic action resulting in rapid and localized intergranular cracking. With intergranular cracking, high stress loads can be imposed on metal adjacent and communicating with the crack, and can lead to transgranular cracking.

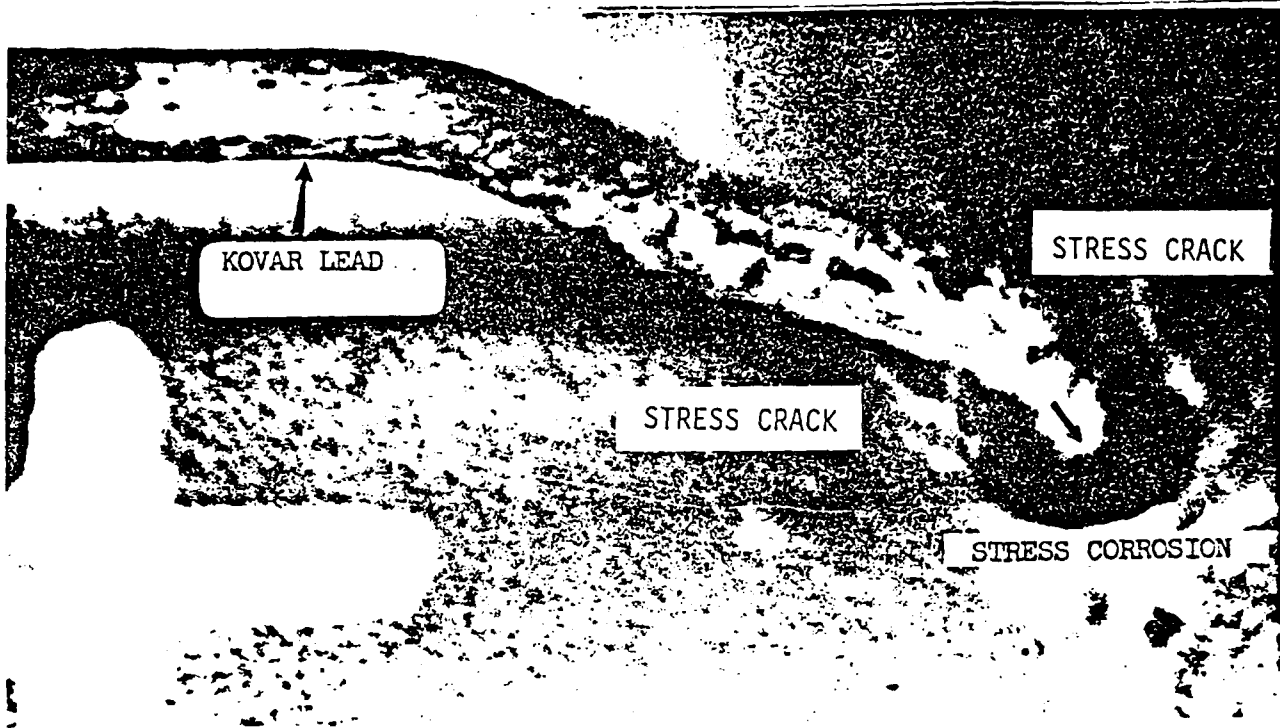
Factors controlling stress corrosion include the type and amount of stress in the metal; the nature, concentration, and temperature of the corrosive environment; and the period of exposure. Any stressed metal or high strength alloy is vulnerable to stress-corrosion failure under certain conditions.

Corrosive Environment

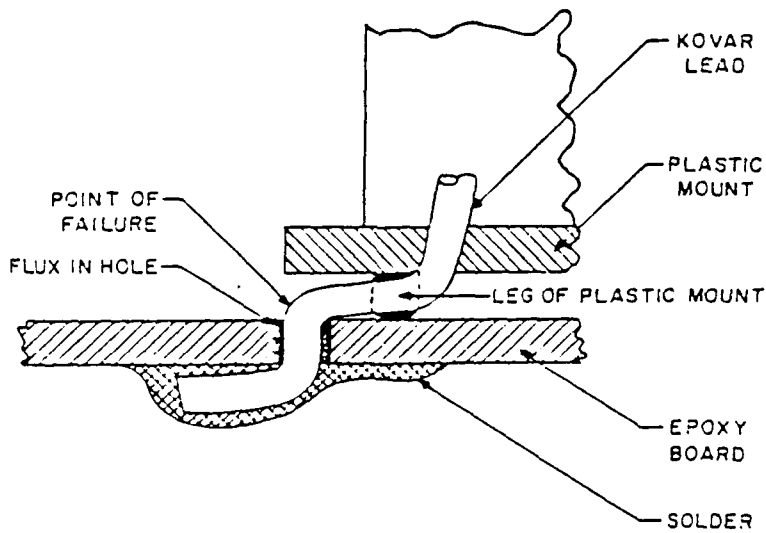


Example of Stress Corrosion Cracking

FIGURE 2.3.3.1



a. Stress Corrosion of Lead Wire



b. Illustration of Mounted 2N2273 Transistor

FIGURE 2.3.3.2 ILLUSTRATION OF STRESS CORROSION CRACKING OF A KOVAR LEAD WIRE IN A PRINTED CIRCUIT BOARD

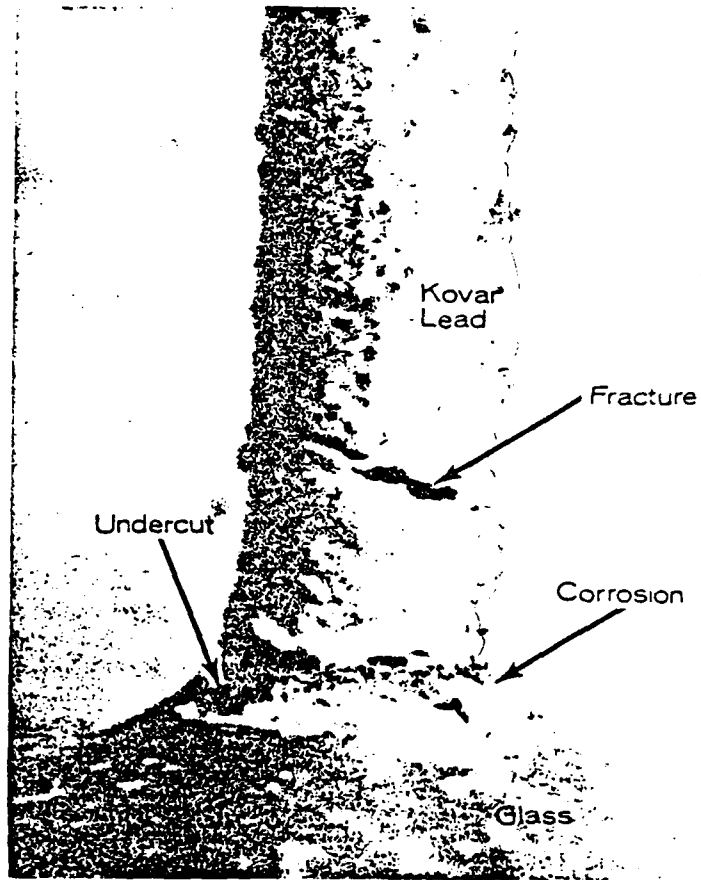


FIGURE 2.3.3.3 CORRODED HERMETIC SEAL PIN KOVAR TO GLASS

Stress corrosion cracking can occur with some alloys of stainless steels when they are exposed to chloride environments such as sodium chloride, calcium chloride, etc. The ferric stainless steels will suffer severe pitting from chloride exposure but are more resistant to stress corrosion than the austenitic or martensitic alloys.

Copper alloys are also susceptible to stress-corrosion cracking. Environments containing ammonia compounds in the presence of carbon dioxide or oxygen are highly corrosive to the copper alloy. The rate at which stress corrosion cracking occurs is greatly accelerated with exposure to elevated temperatures. Cold-worked brass with residual stresses is very susceptible to intergranular cracking. The damaging effect of stress corrosion can be reduced by avoiding residual stresses. High zinc content of brass increases the susceptibility to this type of attack. Brasses that are resistant to this form of deterioration usually have a zinc content of less than 15 percent.

Aluminum alloys containing substantial amounts of such elements as copper, magnesium, and zinc are also susceptible to stress-corrosion cracking. This is especially true of the heat treated, high strength 2000- and 7000-series alloys. Failures in these alloys appear to be caused by fabricating or assembly stresses in relatively thick sections. Annealing and thermal stress relieving

treatments will reduce the residual stresses, but they may also change the characteristics of the alloy. Mechanical treatments such as shot peening can be used to counteract the tensile stresses that result after shearing. Stress corrosion usually occurs with steel springs, bent leads, formed containers, flexible waveguides, etc.

2.3.4 Fretting Corrosion

Fretting corrosion is the term commonly applied to a type of metal damage that may occur when two metal surfaces are in contact, under load, and subjected to vibration, or slight relative motion. This action, combined with some slipping, can open up unprotected spots of activated metal and cause galvanic attack, that may result in pitting and scarring and eventually cause fatigue or structural failure.

2.3.5 Hydrogen Embrittlement

Hydrogen embrittlement is closely associated with stress corrosion in that it causes surface and structural damage in high-strength, iron-base and nickel-base alloys, and titanium. When these high strength (or highly stressed) metals are cleaned, pickled, electroplated, or welded, they may absorb hydrogen. The hydrogen that is trapped in voids and cracks builds up pressure and causes the metals to blister and crack in what is known as "delayed

fracture". If high strength steel is not stress-relieved immediately after plating, fracture can occur in as few as five minutes. Hydrogen is easily picked up by titanium and causes marked brittleness in the metal. Electrolyte tough-pitch copper is also subject to hydrogen embrittlement when "bright annealed" in an atmosphere containing hydrogen. The corrosion process, which liberates hydrogen, may itself contribute to the hydrogen embrittlement process.

Once hydrogen has been absorbed into a metal, it is very difficult to remove. Therefore, special precautions must be taken to prevent hydrogen absorption. Anodic pickling, oxidizing acid baths, and heating cycles minimize absorption during pickling. Proper pickling procedures before plating and careful control of the plating bath and operating conditions also reduces the amount of hydrogen absorbed.

Another way of preventing embrittlement is to avoid acid cleaning, pickling, and electroplating. For example, use organic coatings, or vacuum deposited film or electroless coating processes instead of electroplating. If plating is necessary, one of the following procedures should be followed:

1. Use alkaline baths or other processes designed for low-hydrogen pickup.

2. Use cadmium instead of zinc or chromium plate.
3. Shot peen before plating.
4. Stress relieve before plating and immediately afterward.

Materials not subject to hydrogen embrittlement, such as 300 series 18-8 corrosion-resistant steels or oxygen-free or deoxidized copper, may also be used. Hydrogen embrittlement has been experienced in springs and switch shafts.

2.3.6 Intergranular Corrosion

Intergranular corrosion is the attack that occurs at the grain boundaries of some copper and nickel alloys. Improper heat treating or welding of some chromium-nickel stainless steels causes this alloy to become highly susceptible to intergranular corrosion. Frequently, the grain boundaries are anodic to the main body of the grain. If an electrolyte is present, rapid selective corrosion of the grain boundaries occurs. Figure 2.3.6 shows intergranular corrosion of 7075-T6 aluminum alloy adjacent to a steel fastener. In this example, the grain boundaries are anodic to both the main grain body and the steel fastener.

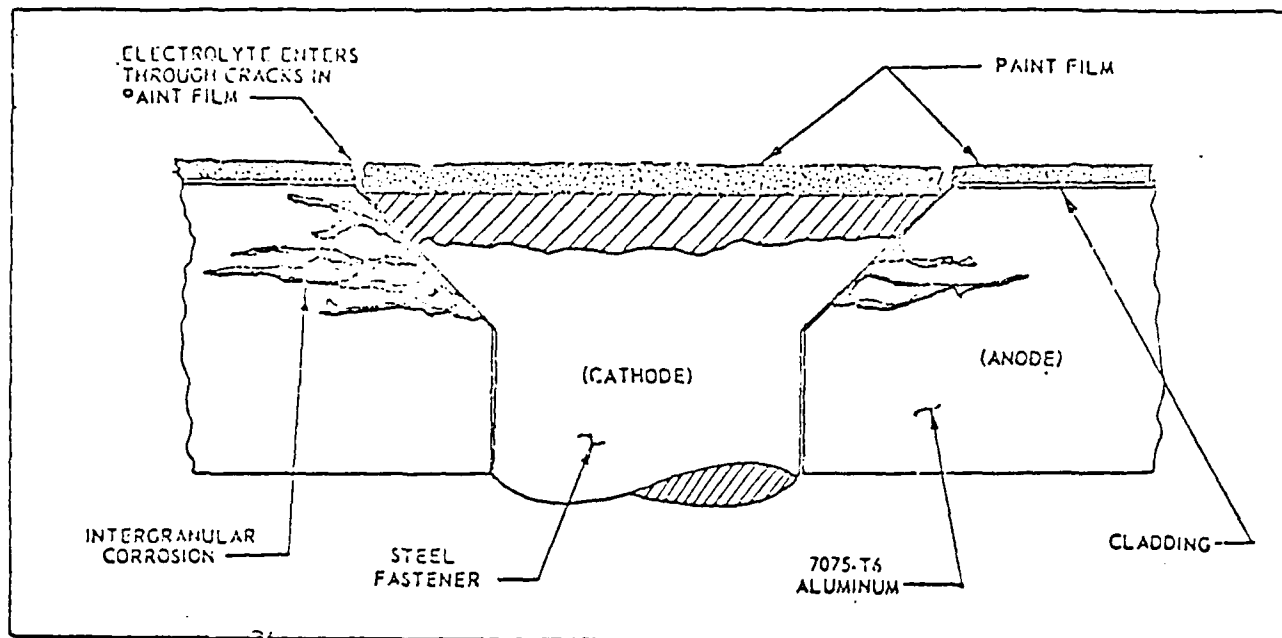


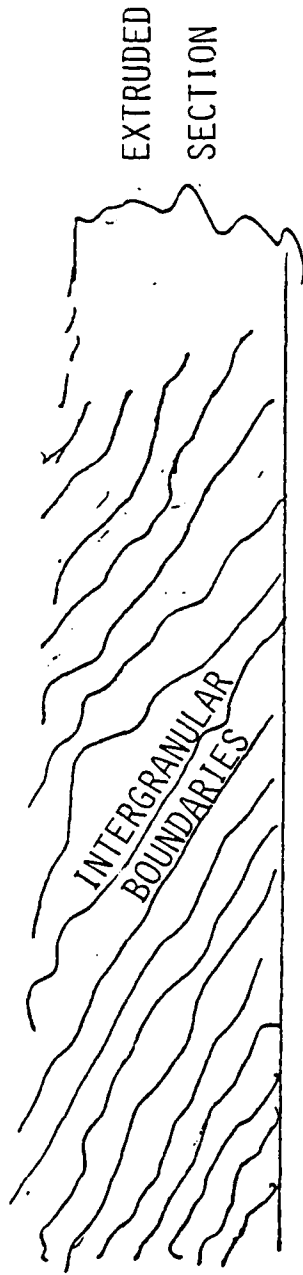
FIGURE 2.3.6 INTERGRANULAR CORROSION OF 7075-T6 ALUMINUM
ADJACENT TO STEEL FASTENER

2.3.7 Exfoliation Corrosion

Exfoliation is a form of intergranular corrosion that is revealed by a "lifting up" of the surface grains of a metal by the force of expanding corrosion products occurring at the grain boundaries just below the surface. It is visible evidence of intergranular corrosion that most often occurs on extruded sections of metal where grain thicknesses are usually less than in rolled forms. Figure 2.3.7 shows intergranular corrosion becoming visible at the surface as exfoliation corrosion. Exfoliation corrosion is found primarily in aluminum sheet around steel fasteners. Its prevention involves separation between aluminum and steel with a barrier such as zinc-chromate primer, for example, at the interface.

2.3.8 Filiform

Filiform corrosion takes the form of threadlike lines of strands. It occurs on metal surfaces, under water-permeable coatings of clear lacquers and varnishes, under paints, and sometimes under thin, noncontinuous electro-deposits. It is often found on steel surfaces, but may also develop on aluminum or zinc. Chemical conversion treatment of the metal before application of organic coatings will inhibit filiform corrosion.



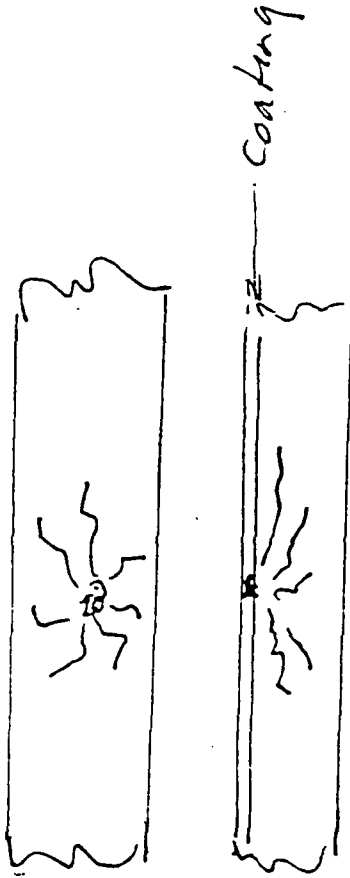
WHEN ELONGATED GRAIN STRUCTURE IS SLIGHTLY PARALLEL TO A SURFACE, THE EXPANSIVE FORCE OF INTERGRANULAR CORROSION PRODUCTS WILL EXPAND AND FORCE GRAIN BOUNDARIES APART AND CREATE A LAMINAR OR LAYER CORROSION KNOWN AS EXFOLIATION CORROSION.

FIGURE 2.3.7 EXFOLIATION CORROSION

The individual threads or filaments of corrosion radiate from islets of corrosive salts. Thread growth is the result of differences in concentrations of oxygen between the advancing head and thread body. The head is more anodic than the body. Filiform corrosion is accelerated in environments with relative-humidity levels of 65 percent to 95 percent. Filiform corrosion is illustrated in Figure 2.3.8.

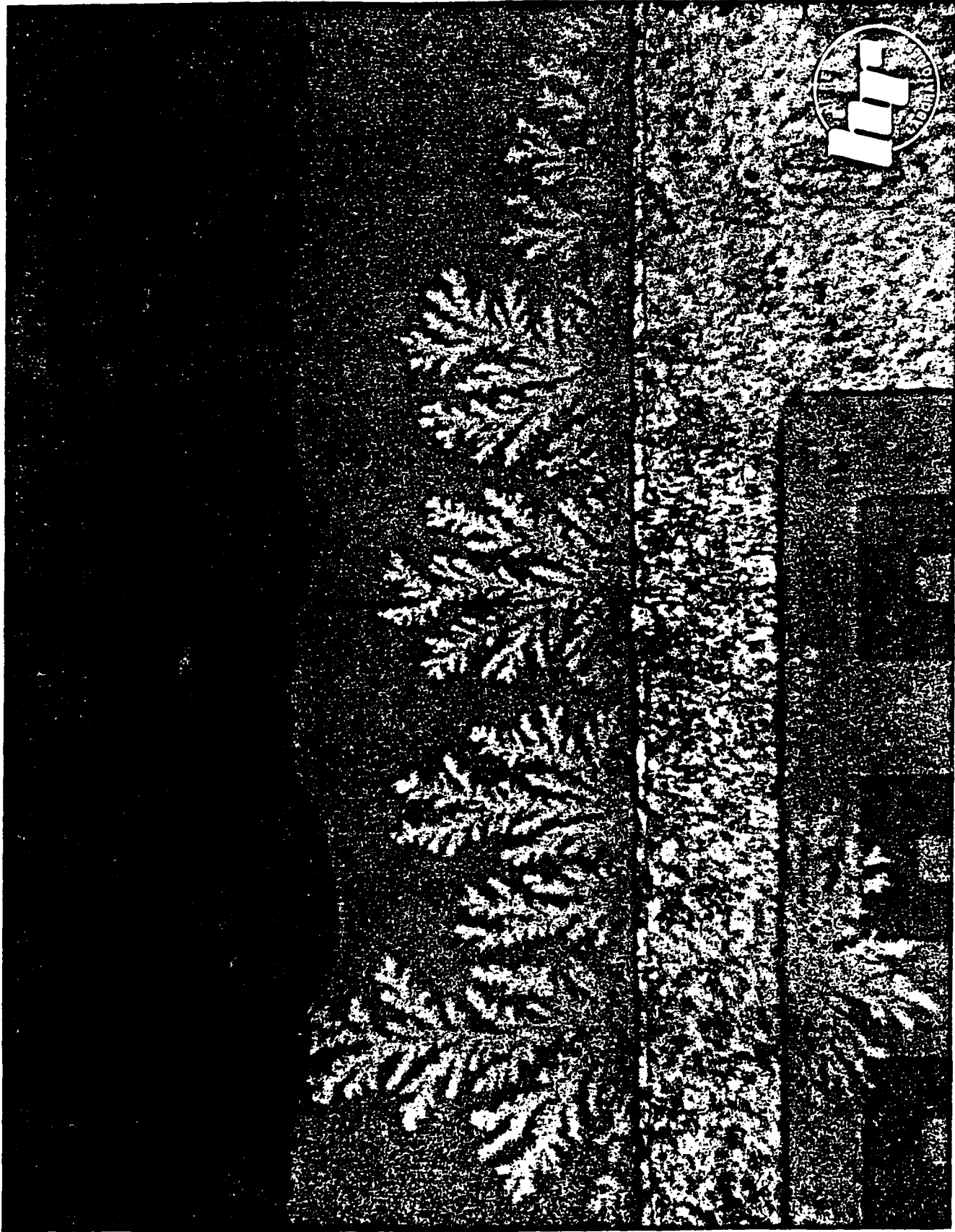
2.3.9 Silver Migration

Under certain conditions, where metallic silver has been utilized as a contact, such as in a relay, switch or electrolytic capacitor, migration can cause failures due to silver migration. In the capacitor, a standard dc potential is maintained. The sulfuric acid absorbs moisture from the air, and a liquid conducting path is maintained. A small fraction of the water disassociates into hydroxyl ions. The metallic silver combines with the hydroxyl ion to form a photosensitive silver hydroxide that, in the presence of light, is converted to silver oxide. At the cathode, the silver ion is reduced to metallic silver in the form of dendrites that can be seen with the naked eye. In time, the dendrite grow towards the opposite polarity like fine fingers, usually on an insulating surface or through an insulator with fibers or fillers causing a short circuit. Figure 2.3.9.1 shows growth on the edge of a thin film chip resistor. Figure 2.3.9.2 shows growth on a variable ceramic capacitor.



FILIFORM CORROSION IS A SPECIAL FORM OF OXYGEN-CELL CORROSION OCCURRING BENEATH ORGANIC OR METALLIC COATINGS ON STEELS, ZINC, ALUMINUM, OR MAGNESIUM. THE ATTACK RESULTS IN A FINE NETWORK OF RANDOM "THREADS" OF CORROSION PRODUCTS DEVELOPED BENEATH THE COATING MATERIAL WITH SHALLOW GROOVING OF THE METAL SURFACE.

FIGURE 2.3.8 FILIFORM CORROSION



HEL LABORATORIES, INC • 911 S Mountain Ave., Monrovia, CA 91016 • (818) 357-6083 • TWX 910 585 3242

Pretty—pretty when it looks like frost on a window pane at Christmas. It is actually silver dendrite growth on the edge of a thin film chip resistor. It spells trouble in River City with a capital "T."
By Sheryl Elen

FIGURE 2-3-9-1

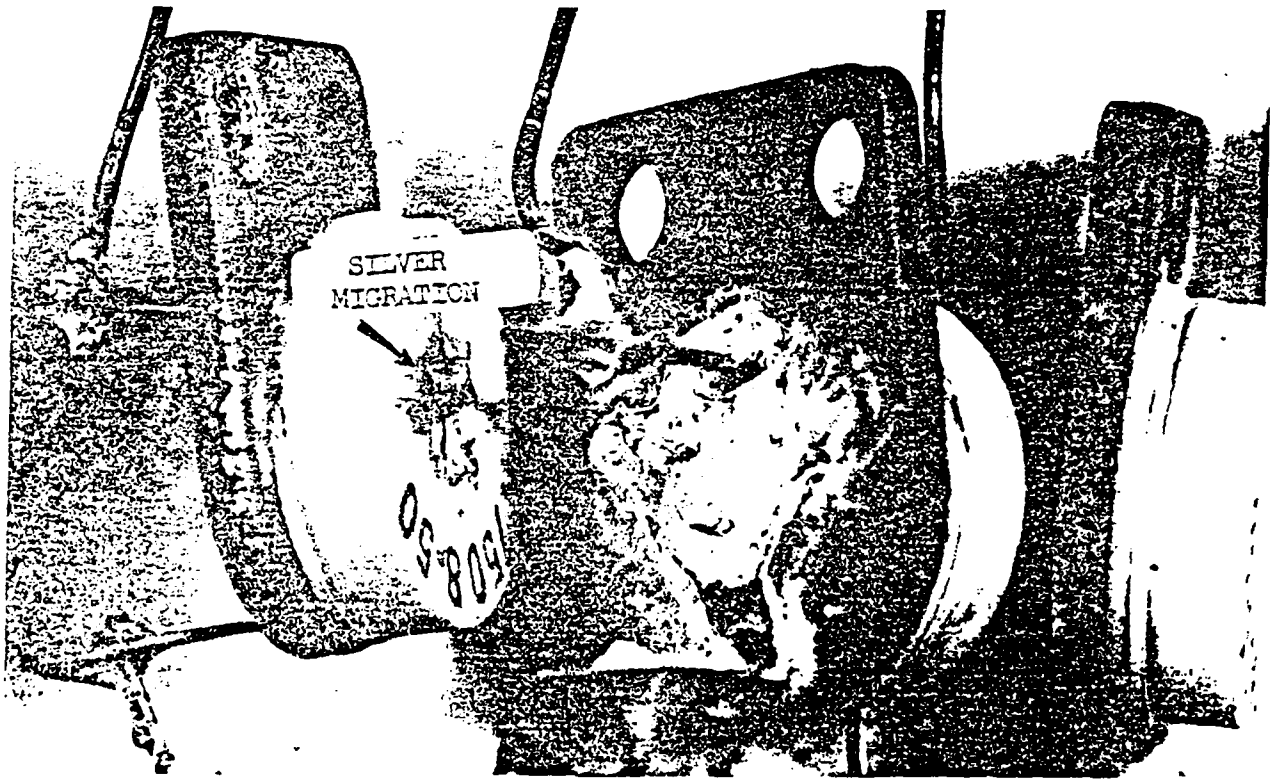


FIGURE 2.3.9.2 SILVER MIGRATION (SM)
VARIABLE CERAMIC CAPACITORS

2.3.10 Direct Chemical Corrosion

A form of direct attack results from direct contact between metals and corrosive liquids. As a first example, the green discoloration of gold-plated copper circuitry on simple circuit boards is considered. These circuit boards are commonly prepared by silk-screening a pattern on the copper clad of an epoxy laminate. The circuit pattern on the silk screen consists of solid lines of polymerized resin. An organic coating material is transferred through the silk screen, usually by a roller, to the copper surface so that all of the copper, except for the circuit pattern, is coated. After the coating material has dried, the entire laminate and the exposed circuit pattern are gold-plated. After plating, the coating on the laminate is removed with a suitable solvent, and the unplated copper is etched away in a solution of ferric chloride. What remains is the gold-plated circuit pattern on the epoxy laminate.

In one case, a green deposit was noted on circuit boards that had been stored for about two years. Investigation revealed that minute traces of ferric chloride etchant were trapped beneath portions of the gold plating that projected beyond the edge of the copper circuitry. Copper at the sides of the circuitry was not fully protected from corrosion by the ferric-chloride residue (See

Figure 2.3.10.1). With subsequent processing of the printed board and exposure to highly humid atmospheres, the area shown as a corrosion site becomes green with copper chlorides.

Solder fluxes also contribute to direct chemical attack. Soldering flux is a "substance that facilitates the wetting of a metal by molten solder". For many metals, a good solder bond can be obtained without flux if the surfaces are clean and free of oxides. It is very difficult and expensive, however, to clean all metal surfaces to be soldered. A more economical method is to use an appropriate flux. (Caution: Many types of flux are activated and as a result can leave highly corrosive residues.) The major functions of the flux are to remove the oxide layers and form a protective film on the exposed surface to prevent further oxidation before the solder is applied.

The fact that the flux can remove the often tenacious oxide film indicates that it is chemically active. This implies that it is also potentially corrosive, extreme care should be used when approving the use of activated or mildly activated fluxes. It is essential that all residues be removed immediately following soldering operations. Fluxes remove oxides at near normal soldering temperatures, i.e., above 350°F. Corrosion, on the other hand, generally occurs near or just above room temperatures. In addition, the flux may only react with the oxide layer and be inactive with regard to the metallic subsurface.

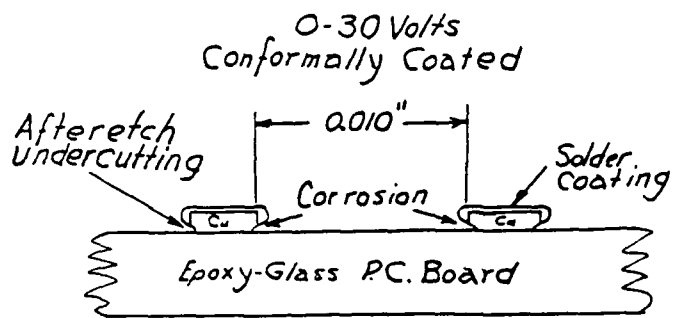


FIGURE 2.3.10.1 PWA CONDUCTOR CORROSION

The terms "nonactivated", "mildly activated", and "activated" are used to describe rosin-base soldering fluxes. Two government specifications define these terms and specify the methods for describing the corrosiveness of a flux. These are Federal Specification QQ-S-571, which covers solid and flux-cored solders used in hand-soldering operations, and Military Specification MIL-F-14256, which covers liquid fluxes such as those used in machine soldering.

QQ-S-571d specifies three types of rosin-core solders, type R (nonactivated), type RMA (mildly activated), and type RA (activated). In the case of liquid fluxes, as specified in MIL-F-14256C, only two types are covered, type W (nonactivated), and type RMA (mildly activated). Generally speaking, the cored solder flux, type R, and the liquid flux, type W, are considered to be equivalent, as are type RMA and type A. There is currently no government specification for a liquid flux equivalent to type RA, CECOM does not permit the use of RA flux in CECOM materiel. In addition, RMA flux may only be used where approved cleaning and inspection facilities exist.

Residues from active fluxes can degrade circuitry in two ways:

(1) by corroding solder joints or nearby regions where flux fumes may settle and, (2) by reducing insulation resistance, particularly of printed circuit boards and mounted parts (See Figure 2.3.10.2 and

Figure 2.3.10.3). The deposition of flux on relay contacts and other mechanical components, either from fumes formed during soldering or from flaking of dried material, can cause serious corrosion problems within a system.

Figure 2.3.10.2a shows corrosion of the edge board contact areas with products of corrosion providing conducting paths between adjacent printed lines. Figure 2.3.10.2b shows bare copper which will corrode and provide conducting paths between printed lines. Figure 2.3.10.3 shows corroded lead wires, the product of which has migrated across the insulated body to the other lead, thereby providing a conductive path.

Chlorides and, in some cases, bromides, are added to rosin-base fluxes to improve surface wetting by the molten solder. When these halides are in the form of water-soluble compounds, they can, under the proper environmental conditions, corrode metallic surfaces and become highly conductive electrolytes.

Given sufficient time and the proper conditions, corrosion can cause complete failure of solder joints, conductors, and entire components. Even a little corrosion, because of its progressive nature, is serious. For instance, corrosion can reduce the size of a conductor to such a degree that circuit resistance is increased, power dissipation is reduced, overheating can occur. A wire lead

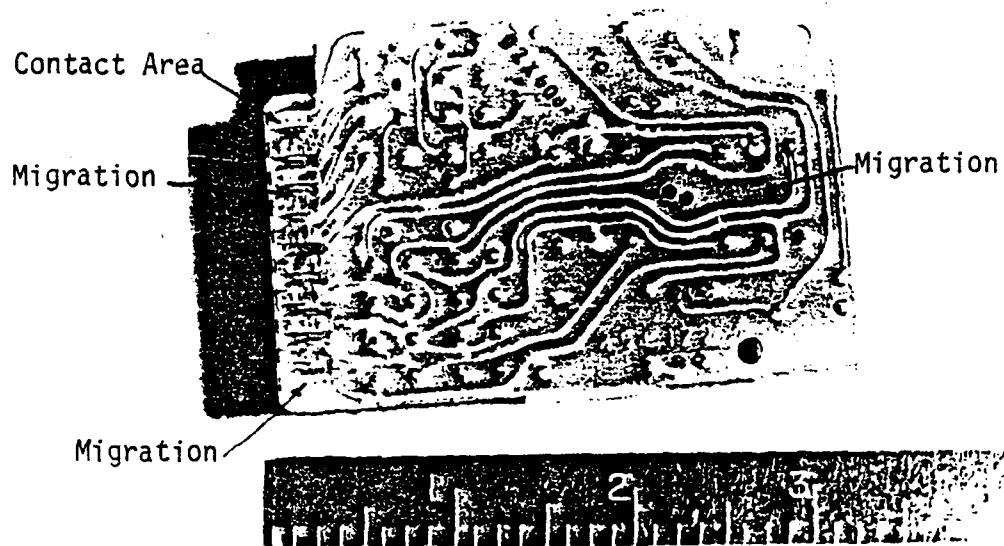


FIGURE 2.3.10.2a PRINTED CONTACT CORROSION AND MIGRATION OF CORROSION PRODUCTS

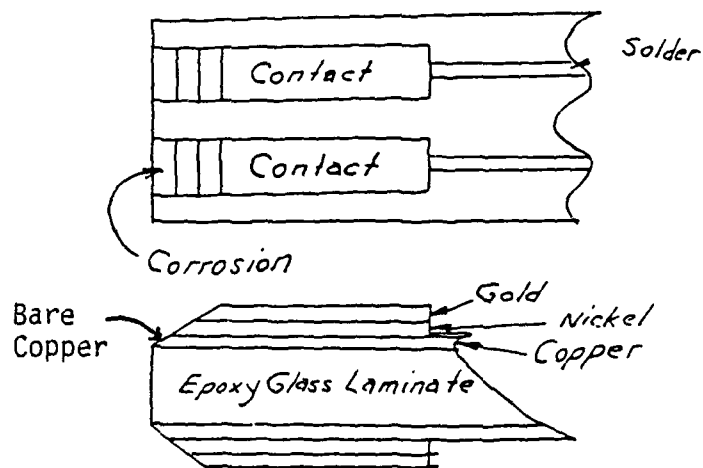


FIGURE 2.3.10.2b BOARD EDGE CORROSION

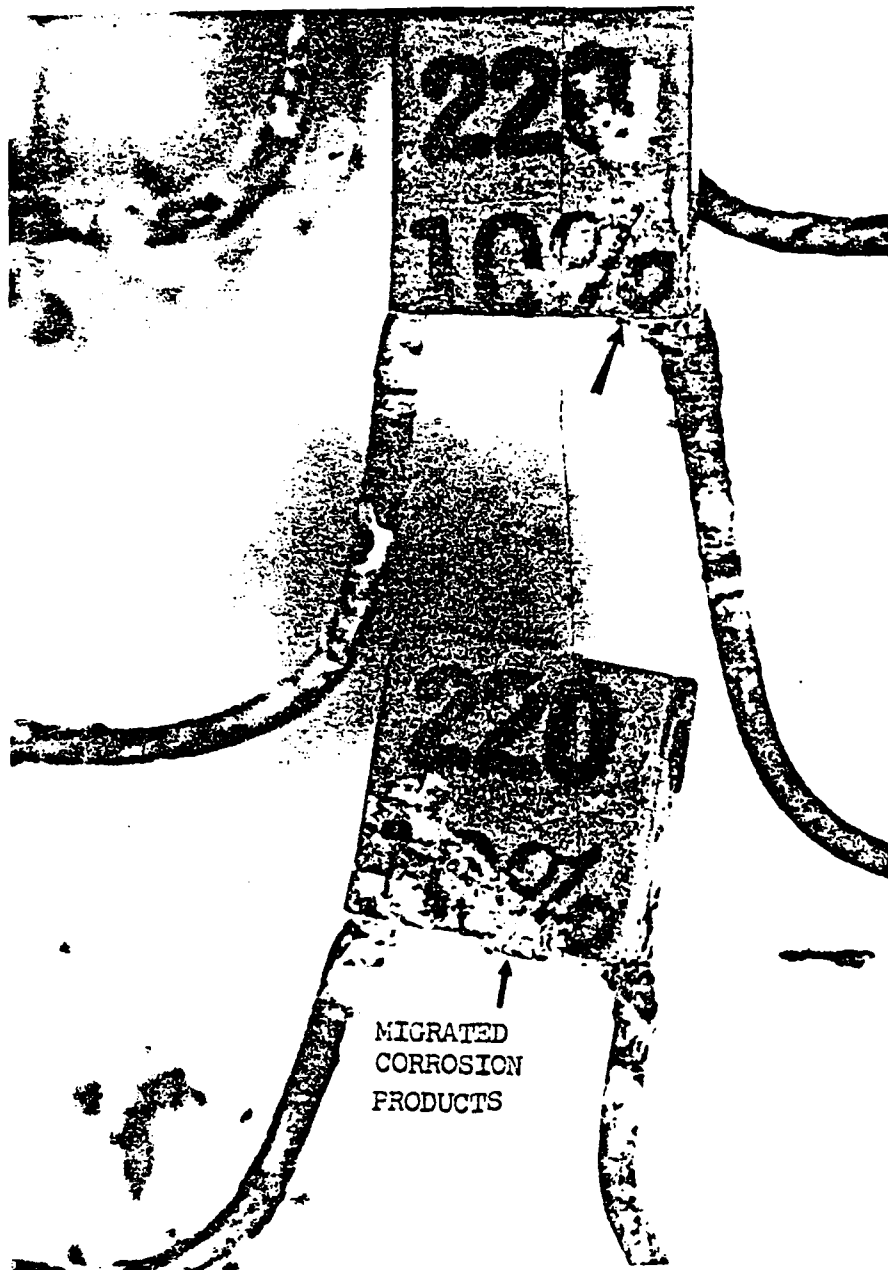


FIGURE 2.3.10.3 END-SEAL MIGRATION (ESM)
FIXED CERAMIC CAPACITORS

may become weak or brittle and eventually fracture, particularly when the equipment is subjected to vibration or shock (See Figure 2.3.10.5.)

Circuit performance can be affected not only by flux residues but also by corrosion products that produce leakage currents, short circuits, rectification of signals, or failure of mechanical components.

Batteries are another source of corrosive liquids that develop leaks either as a result of poor seals or of buildup of pressure. The corrosive electrolyte and fumes resulting from such leaks may attack practically all materials in the area. This type of corrosion is particularly evident in battery operated C-E equipments.

Electrolytic capacitors, often found in electronic systems, are filled with sulfuric acid and contain a tantalum plate in silver housing.

In this type of capacitor, the glass seal through which the lead wire engaging the tantalum plate egresses sometimes leaks sulfuric acid into the surrounding area, causing extensive corrosion of the entire system.

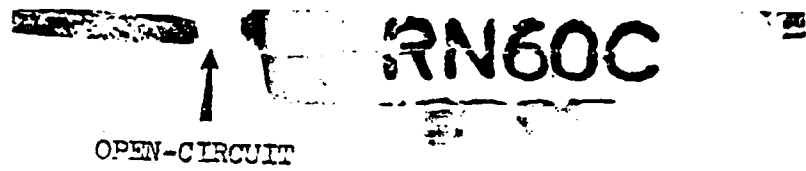


FIGURE 2.3.10.5 LEAD WIRE CORROSION (LWC)
FIXED METALLIC FILM RESISTOR

Discoloration of mounted parts due to direct chemical attack will make part markings indistinguishable and difficult to replace (See Figure 2.3.10.6). This figure shows some tantalum capacitors which have silver coated case which has turned black with silver sulfides. A clear plastic coating would have prevented this.

Fungus growth and its by-products can as a result of enzymatic action by the fungus in digesting organic materials; including contaminants, will provide a more active contaminant as a by-product contribution to susceptible metals used as lead wires, contacts (See Figure 2.3.10.7). This figure shows fungal growth on a transistor header probably due to contaminant (fingerprint) which provided nutrients to fungal spores. Subsequent growth and its enzymatic action accelerated corrosion and failure of the lead joint.

2.4 Electronic Design Factors

2.4.1 Galvanic Couples

In any electronic assembly, module or part, it is essential that the coupling EMF of any metals joined together not exceed the values provided in Tables 2.4.1.1. The compatible couple is limited to metals that fall between the white dot o (most cathodic) to those marked with a black dot o (most anodic), i.e.:

Cathodic (protected) o \longrightarrow • Anodic (corroded)

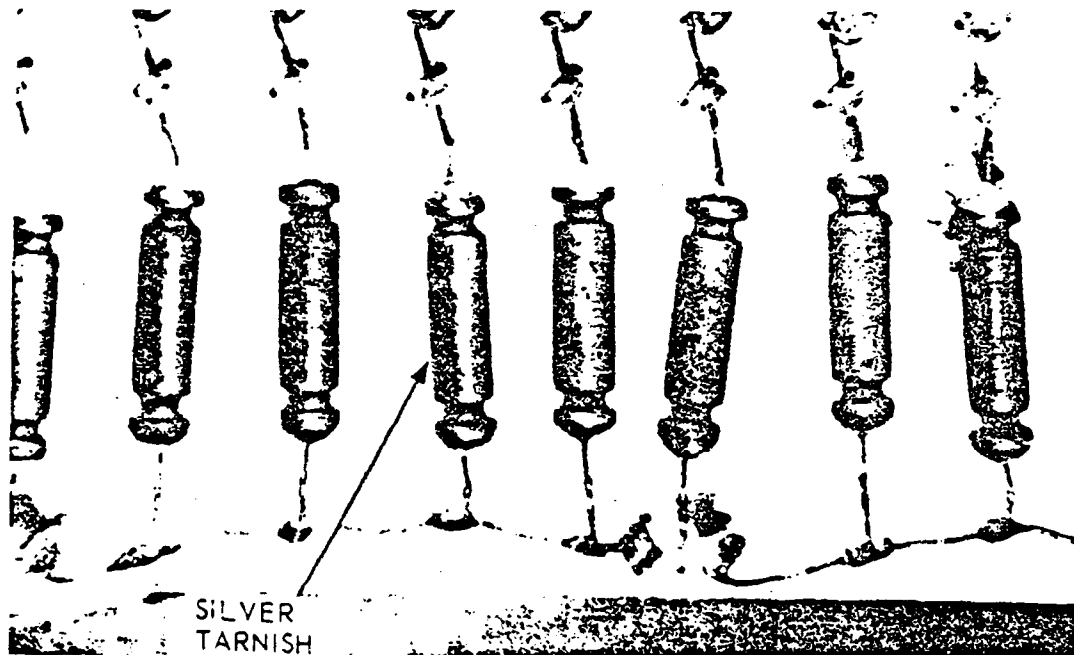


FIGURE 2.3.10.6 CASE CORROSION FIXED TANTALUM
ELECTROLYTIC CAPACITORS

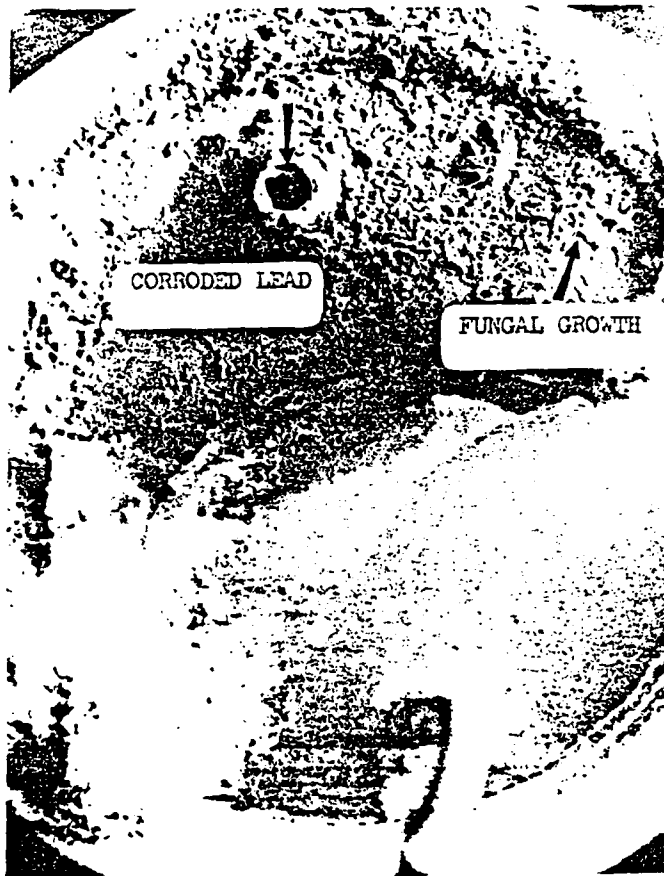


FIGURE 2.3.10.7 MICROBIAL CORROSION (MC)
BOTTOM VIEW OF TRANSISTOR HEADER

Whenever it is unavoidable, the contact should then be cleaned thoroughly to remove any trace of a contaminant and that the couple be sealed to keep out moisture and contaminants. The use of magnesium and lithium or any compounds of such extreme anodic nature, used because of weight gains obtainable with these metals, should be pursued only when sufficient preventative measures have been provided. In all couples, small contact areas should be avoided, since small contact areas concentrate the corrosion rate in a small area, making it prone to early failure. It is also possible, in certain designs, to use isolating barrier shims or washers in between adjoining metals. This reduces the EMF potential between adjacent metals in contact.

In the design of complex assemblies, careful consideration should be given to which metal and/or its alloy, should be coupled together. The following guides, Tables 2.4.1.1, 2.4.1.2, can be helpful, but it is recommended that a humidity and/or Salt fog test be conducted during development to confirm that the couple, and the application process as protected, is usable without incurring corrosion.

The rate at which the corrosion proceeds depends on the amount of current generated within the galvanic cell. The amount of current, in turn depends on several factors: (1) the existing electrode potentials, (2) the ratio of the anode and cathode areas, and (3) the polarization of the electrodes.

TABLE V. Compatible couples.

Group No.	Metallurgical Category	EMF (Volt)	Anodic Index (0.01 V)	Compatible Couples (see note below)
1	Gold, solid and plated; gold-platinum alloys; wrought platinum	+0.15	0	○
2	Rhodium plated on silver-plated copper	+0.05	10	● ○
3	Silver, solid or plated; high silver alloys	0	15	● ● ○
4	Nickel, solid or plated; monel metal, high-nickel-copper alloys	-0.15	30	▼ ● ○
5	Copper, solid or plated; low brasses or bronzes; silver solder; German silver; high copper-nickel alloys; nickel-chromium alloys; austenitic corrosion-resistant steels	-0.20	35	▼ ● ● ○
6	Commercial yellow brasses and bronzes	-0.25	40	▼ ● ● ○
7	High brasses and bronzes; naval brass; Muntz metal	-0.30	45	▼ ▼ ● ● ○
8	18 percent chromium type corrosion-resistant steels	-0.35	50	▼ ▼ ● ● ○
9	Chromium, plated; tin, plated; 12 percent chromium type corrosion-resistant steels	-0.46	60	▼ ▼ ● ● ○
10	Tin-plate; terneplate; tin-lead solder	-0.50	65	▼ ▼ ● ● ○
11	Lead, solid or plated; high lead alloys	-0.55	70	▼ ▼ ● ● ○
12	Aluminum, wrought alloys of the duralumin type	-0.60	75	▼ ▼ ● ● ○
13	Iron, wrought, gray, or malleable; plain carbon and low alloy steels, armco iron	-0.70	85	▼ ▼ ● ● ○
14	Aluminum, wrought alloys other than duralumin type; aluminum, cast alloys of the silicon type	-0.75	90	▼ ▼ ● ● ○
15	Aluminum, cast alloys other than silicon type; cadmium, plated and chromated	-0.80	95	▼ ▼ ● ● ○
16	Hot-dip-zinc plate; galvanized steel	-1.05	120	▼ ● ○
17	Zinc, wrought; zinc-base die-casting alloys; zinc, plated	-1.10	125	▼ ●
18	Magnesium and magnesium-base alloys, cast or wrought	-1.60	175	● ●

Note: ○ = Indicates the most cathodic members of the series.
 ● = Indicates an anodic member.
 Arrows indicate the anodic direction.

The following Table also lists some general do's and don'ts guides in designing intermetallic couples that cannot be avoided.

Table 2.4.1.2
PREVENTING GALVANIC CORROSION

Problem	Solution	Example
Dissimilar Metals	1. Select metals in "Permissible Couples" in Table 2.4.1.1	Use nickel, not copper or brass, next to silver
Dissimilar Metals	2. Plate with compatible metal to reduce potential difference	Tin coat steel and bronze used together. Use nickel over copper as an underplate to gold.
Dissimilar Metals	3. Keep affected area of less noble metal (anode) as large as possible	Stainless steel hardware in aluminum may be satisfactory because of large area of aluminum
Dissimilar Metals	4. Apply corrosion inhibitors such as zinc chromate paste	Assemble dissimilar metal hardware with zinc chromate
Contact	5. Interpose inert barrier or gaskets to prevent contact (be sure to extend 1/4 in. beyond joint)	Vinyl tape, cadmium plated washer, rubber gasket
Contact	6. Paint cathode, or both metals, with alkali resistant organic coating	MIL-F-14072
Electrolyte	7. Avoid designs where moisture can be trapped	
Electrolyte	8. Use desiccant	
Electrolyte	9. Seal joint with organic insulator, alkali resistant	MIL-F-14072
Electrolyte	10. Seal faces of metal against contact with electrolyte	Primer, paint or sealant
General	11. Use cadmium in preference to zinc plating	MIL-F-14072
	12. Use tin or nickel plated hardware	MIL-F-14072
	13. Avoid use of magnesium	MIL-F-14072

A guide to finishing intermetallic couples is contained in para 3.13 of MIL-F-14072. It was developed as a guide for use in CECOM materiel with consideration to many types of couples that can occur. Because of the many variables that can occur and affect corrosion possibilities, an environmental test should finally be applied to assure that the design is corrosion resistant. The guide is quoted in its entirety to provide maximum coverage of all galvanic couple situations, as follows:

Beginning of quote:

"MIL-F-14072, Para 3.13 Intermetallic-couples. The finishing of metallic areas to be placed in contact presents a special problem, since intermetallic contact of dissimilar metals results in electrolytic couples which promote corrosion through galvanic action. Table V (Table 2.4.1.1 of this guide) shall be used in determining the need or degree of protection to be applied to couple members depending on the relative position of the coupled members in the galvanic series. Table V shows metals and alloys (or plates) by groups which have common electro-motive forces (EMF) within 0.05 volt when coupled with a saturated calomel electrode in seawater at ordinary room temperatures. All members of a group regardless of metallurgical similarity or dissimilarity are considered compatible. Compatible couples between groups have been specified in Table V based on a potential difference of 0.25 volt maximum.

Permissible couple series are shown in Table V by the graphs at the right. Members of groups connected by lines will form permissible couples. An "o" indicates the most cathodic member of each series, "•" an anodic member, the arrow the anodic direction, Table V shows, in addition the EMF against a calomel electrode, a derived "anodic index" with Group 1 (gold, etc.) as 0 and Group 18 (magnesium, etc.) as 175. Subtraction of one group anodic index from another gives the EMF difference in hundredths of a volt. To provide the corrosion protection required in ground electronic equipment, intermetallic couples should be restricted, where possible, to those permitted in Table V which have minimal tendencies to interact galvanically.

3.13.1 Use of compatible couples. The following should be considered in the selection and application of compatible couples:

- a. Passivated coatings. For couple selection, passivated coatings specified herein shall be ignored and only the plating or basis metal considered. For example, all chromate or phosphate treatments of zinc or cadmium specified in Tables II and III shall be ignored in making couple selections and only zinc or cadmium considered as acting in galvanic corrosion. Hard anodic films on aluminum-base alloys are impervious nonconductors and, therefore, contact may be made with any dissimilar metal.

- b. Surface area of contacting metals. In intermetallic couples, the member with the higher anodic index is anodic to the member with the lower anodic index and will be susceptible to corrosion in the presence of an electrolytic medium. If the surface area of the cathodic part is significantly greater than that of the anodic part, the corrosive attack on the contact area of the anodic part may be greatly intensified. Material selection for intermetallic contact parts, therefore, should establish the smaller part as the cathodic member of the couple.
- c. Platings. For couple selection only the contacting metallic surfaces shall be considered for compatibility. For example, when a plated part is intended for assembly with aluminum, the compatibility of the plating, not the basis metal, with aluminum shall be considered. Likewise, when two plated parts are intended to be coupled, the compatibility of the platings, not the basis metal, is to be considered.

3.13.2 Exceptions to Table V. The following exceptions apply to the selection of compatible couples in accordance with Table V:

- a. Special service conditions. Table V is for use when part and equipment will be exposed to the military service conditions of ground electronic equipment. For special conditions or

considerations, Table V may not be applicable. Such considerations may include such factors as temperature differences between parts, plating thicknesses, longevities, polarity reversals, multiple contacts, etc. For instance, zinc may become cathodic to iron in hot tap-water, and tin anodic to iron in tap-water at ordinary temperatures. Both of these, as isolated cases, vary from the general experience reflected by the compatibility graphs of Table V. In isolated cases, where couples are not exposed to weather or to salt-laden air but are subject to wide temperature and humidity variation with probable accompanying condensation, restriction of couple members to those shown in Table V might serve to provide part life abnormally longer than the functional requirements of the equipment. In such cases, finish needs may be met by extending the anodic index differences to 50. Generally, under special conditions, couple selection should be governed by experience with such special conditions.

- b. Sealed members. The requirements specified above do not apply to intermetallic contact members which, in a clean and dry condition, are permanently sealed in noncorrosive embedding or encapsulating materials, or hermetically sealed containers that are impervious to atmospheric conditions.

c. Magnesium. Table V does not permit intermetallic contact between magnesium and any other metal. If the use of magnesium in contact with a dissimilar metal is required, the metals shall be separated by a tape in accordance with MIL-T-23142. The tape shall extend at least 0.32cm (1/8 inch) beyond the periphery of the joint. The use of cloth supported tapes is prohibited.

d. Fasteners for magnesium. Although not allowed by Table V, the use of aluminum alloy 5056-H32 rivets and aluminum alloys 5052, 5056, 6053, and 6063 washers and shims will be allowed for assembly of magnesium alloy members. Bolts and nuts will be restricted to 6061 aluminum alloy, anodized, and dipped in zinc chromate primer conforming to TT-P-1757 prior to insertion.

3.14 Finish selection. Unless otherwise allowed by the contracting officer, any finish applied to equipment shall be one of those specified by Tables I, II or III. Insofar as possible, selection of finishes for any particular application shall be made in accordance with Table VI. Any restrictive conditions applicable to finish selection not appearing in Table VI must be considered prior to making a choice of finish. In this connection, it may be noted that Tables I through IV contain finish selection requirements applicable to particular finishes. Paragraphs 3.14.1, 3.14.2 and 3.14.3 regarding finishes covered by this document, apply to finish selection and shall be used in conjunction with Table VI.

It should be noted that Table V of MIL-F-14672 is a design and finishing guide which lists allowable couples and it is different than Tables which simply list metals in order of EMF potentials depending on what type of electrolyte was used."

End of Quote:

Using The Tables

When consulting Table 2.4.1.1 the following factors should be considered:

- a. The surface metal is the one involved, whether it be solid plated, dipped, sprayed, or laminated.
- b. Graphite acts like a metal, and forms galvanic cells.
- c. Different alloys of the same metal (especially aluminum and copper) can form a galvanic cell. The Table will show some to be acceptable.

In a galvanic corrosion, the relative area of the anodic (attacked) and the cathodic (more noble) metal is of great importance. When the anodic area is large, the rate of corrosion is less rapid than when the area is small. The potential voltage differential is not

changed, but since the current is spread over a larger area, the current density is lower. The areas considered are only those wetted by the electrolyte. If an assembly is totally immersed, all the metal is part of the galvanic cell. But if moisture is present only in local pockets, as from condensation around a joint, only the wet surfaces are part of the cell. The influence of area explains why steel nuts and bolts may be used satisfactorily in a large aluminum structure, while aluminum hardware on a steel sheet would be quickly corroded away.

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The current flow and effective potential difference between dissimilar metals in an electrolyte may also be reduced by polarization. Polarization may occur at the anode as a result of the accumulation of corrosion products, or at the cathode as a result of the accumulation of hydrogen bubbles at the cathode surface. In either case, the result is a decrease in electrochemical action. The deposition of hydrogen is the more influential deterrent and may produce a strong barrier to galvanic corrosion.

Corrosion is generally accelerated by rising temperature. An increase in temperature results in increased conductivity of the electrolyte and an increase in the solubility and diffusion rate of normally protective corrosion products. Cathodic depolarization by dissolved oxygen increases as temperatures rise because oxygen is

diffused more rapidly at higher temperatures. On the other hand, at 80°C or above, oxygen becomes less soluble and the corrosion rate decreases.

Anything that reduces the difference in potential between the metals involved, prevents metal-to-metal contact, or removes the electrolyte, prevents galvanic corrosion. Proper control of relative area minimizes attack. As Table 2.4.1 indicates, there are ways to preclude corrosion even when dissimilar metals must be used since it is not the inherent corrosion resistance of a metal that matters, but the difference in potential between it and those it contacts. The greater the difference in potential between two metals, the more the care that must be taken to protect the metals from corrosion.

2.4.2 Contacts

2.4.2.1 General

Contacts are the most unreliable functions in electronics designs. The recent development of solid state switching has minimized this somewhat, but connector pins and edge board connections, make and break types still contribute heavily to failures; especially corrosion types. Contacts of parts used on front panels are engineered to do very special tasks, and their contacts are designed

for long and reliable life. Therefore, they should be of MIL-STD hi-rel quality. Troubles occur with printed circuit board contacts which are of either edge type or pin and socket designs. Many contact metals, such as printed copper or extruded copper alloy pins, will oxidize in storage. To avoid cleaning them, they are usually gold plated to avoid tarnishing. Due to the high price of gold, plating can be much thinner than required resulting in porosity of the gold plating. With rough or unpolished surfaces, the deposited gold is more porous allowing the copper alloy to migrate through the pinholes and become copper oxide (black, an insulator). For prevention, it is necessary to initially deposit 50 microinches of electroless nickel under the 50 microinches of gold to prevent corrosion and open circuit contacts.

2.4.2.2 Pin and Socket Corrosion

The use of discrete daughter boards, which plug into motherboards, is made possible by the use of multipin module connectors to accommodate interconnections from module to module. Typical pins are illustrated in Figure 3.4.2.

Each module may have as many as 20 to 250 pins. The average number of pins per board is 100 and there may be an average of 5000 boards in an average size communication center or a total of 500,000 connections. It is an accepted fact that the most unreliable type

connection in electrical and electronic circuitry can be the dry-circuit, sliding make-and-break contact, such as is found in these connectors. Failure rates of 01×10^{-6} failures/hour have been observed for each connection.² For a 500,000 connection system, unless good quality is obtained, one failure per day can be expected. While there are many mechanical type failures, usually dirty, oxidized, or corroded surfaces are the main causes of failures. All pins and receptacles used today are gold plated. Because of surface roughness, which is difficult to minimize on pins of the sizes in usage, pinholes occur in the gold and resultant black copper oxides or green copper chlorides will coat the contact area as is shown in Figure 2.3.1.2. Similar type failures are shown on gold plated pins with a silver barrier underplating as is shown in Figure 2.3.1.3.

Many current specifications call for soft gold, on hard gold, over nickel plated beryllium copper. The soft gold provides a lubricating easily cleaned and wiping contact. Salt fog exposure and nitric acid dips are used as a test for gold porosity. Long term field tests after initial wear of gold surface are needed to provide long term corrosion and contact resistance data. Quality control to assure nickel underplating and pore-free gold plating usually assures reliable connection.

2.4.3 Joining, Soldering, Bonding

Joining, soldering and bonding are used in various assembly processes in the following categories:

2.4.3.1 Insulated wires, point-to-point

Current technology of miniaturization has diminished the use of such wiring. In large Command, Control Centers (CCC) systems, these are applied with wire wrap, which is tool applied without soldering. Hand soldering usually has process control problems and may vary in quality as described below.

2.4.3.2 Thermobondings

Thermobondings are usually applied in hermetically sealed miniaturized packages and may involve excessive galvanic couples and/or thermal stresses. The designer depends on the clean hermetically sealed container to keep out moisture and electrolytic contaminants. Depending on the quality of assembly, degree of cleanliness and effectiveness of seal, corrosion and debonding of the joint can occur with failures. Controlling quality per MIL-C-38510 and with ESS screening, faulty or poor quality bonds can be screened.

2.4.3.3 Soldering

All quality soldering requires clean surfaces to be soldered, the proper heat applied and cleaning after to remove residual fluxes. For printed wiring assemblies, contaminants can be added during etching and flow or wave soldering. Since it is expensive to clean assemblies, or to use gold plating, many manufacturers may resort to using activated fluxes, which are controlled by MIL-F-14256, which does not permit use of type RA fluxes in CECOM equipments. Even with type RMA fluxes, cleaning after soldering must be rigorous. A cleanliness test for PWAs is required in MIL-P-28809. Finally, a protective conformal coating per MIL-I-46058 must be applied to shield the cleaned printed circuit board assembly from industrial and natural contaminants. Without the cleaning and coating protection, experience has shown that corrosion of the copper land areas, printed conductor lines and part leads can corrode and cause shorts and/or open circuits. For parts with poorly cleaned surfaces and use of a nonactivated flux, solder joints can be defective with poor process control. With each contract, and contractor, the soldering process must be controlled to assure good soldering joints while at the same time preventing corrosion which can occur eventually. Once established, this process must be continuously monitored to assure quality joints with no possibilities of corrosion failures occurring at later periods. The Institute of

Printed Circuits has published many handbooks on Assembly and Joining Techniques to provide guidelines of such processes. See Reference Number 14.

2.4.4 Antennas

Because of their exposure, and the need to use light weight metals such as high strength aluminums, antennas can be subject to extensive corrosion. In some cases, magnesium was used with resulting higher corrosion rates and failures. Figure 2.4.4 shows excessive corrosion of plated aluminum dipoles. Any dissimilar metal attached to a magnesium or aluminum structure can cause severe galvanic corrosion if surfaces and junctions are not adequately prepared and protected. Some very severe corrosion failures for the MPQ-4, 5, Firefinder, PPS-5 and PRC-77 have shown that the antenna designs needed improvement. Corroded structures are inefficient dipoles and will destruct in severe weather. All couples should be minimized and all surfaces adequately painted. Whip antennas for portable and/or manpack radios must be lightweight, flexible, but also rugged to avoid breakage. Applied finishes receive severe abrasion with resulting corrosion and breakage. It is best to use inherently resistant aluminum alloys which are surface treated to avoid reflective surfaces.

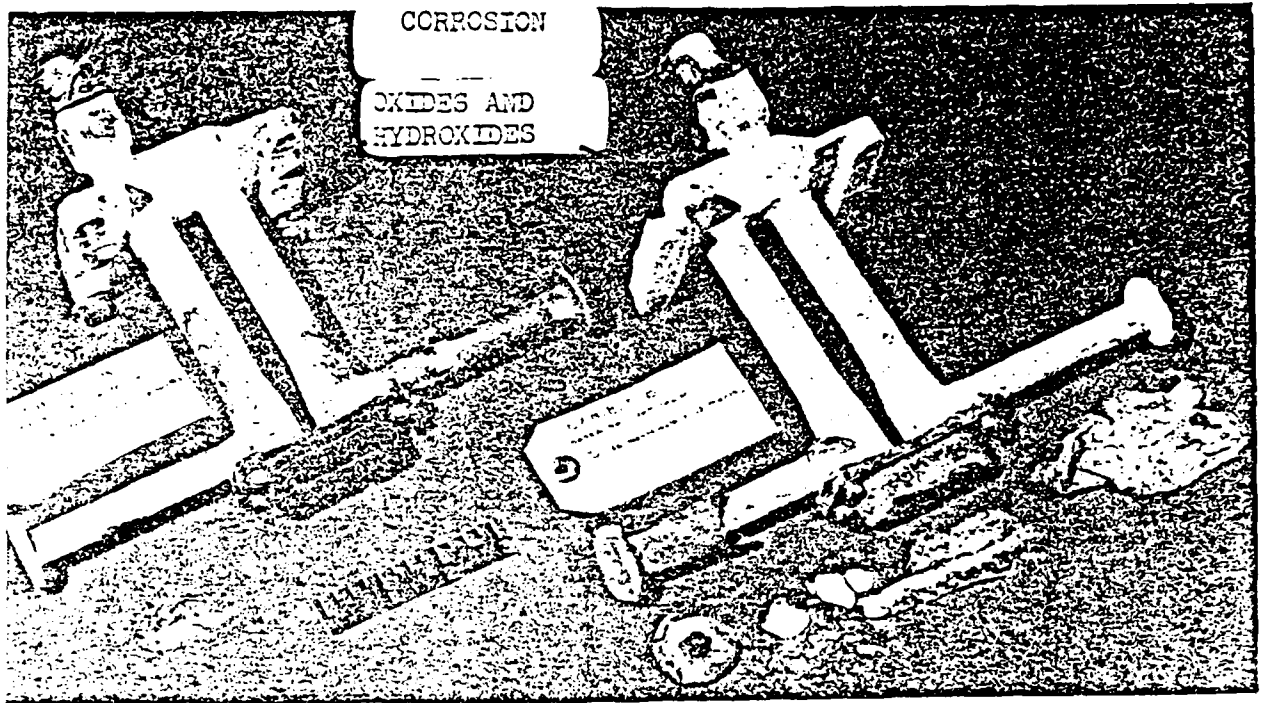


FIGURE 2.4.4 RADAR ANTENNA SHOWING CORROSION OF PLATED ALUMINUM DIPOLES

2.4.5 Connectors

These are especially prone to corrosion because of the same porous gold plating on copper alloy pins mentioned in para 2.4.2 "Contacts" above and the fact the connector can be in an exposed use situation. The constant plugging and unplugging of connectors, especially multipin types causes high wear and loss of gold plating with copper corrosion occurring. Again, it is necessary to assure that a .05 mil electroless nickel plating is applied as an underplating to gold in order to prevent pinhole corrosion, migration of copper and yet provide good wear properties. The corrosion of the connectors shells can cause corrosion products to migrate over the insulator insert and cause shorts. The use of attached protective boots and covers, with constant cleaning will prolong the useful life of connectors.

2.4.6 Waveguides

These are subject to corrosion and failure due to high humidities and contamination present inside the waveguide interiors. Flanges are welded to straight or curved sections, and without adequate cleaning, welding or brazing flux remains as a contaminant. For good waveguide alignment, a flexible section is usually located next

to the klystron tube. Strain in the convoluted flex section can incur stress-strain corrosion. Figures 2.4.6.1 and 2.4.6.2 show such failure samples. If there is arcing in the waveguide, nitrous gases are released which, in solution with humidity, form nitric acid. In the field, waveguides in antenna structures can collect salt air. Many waveguides are made of brasses, which are heavy and can dezincify. For light weight, magnesium/aluminum alloys are used which can corrode rapidly. Prevention is achieved by sealing the waveguide system, cleaning of subassemblies, circulation of dry air within the waveguide system, and prevention of arcing or overpower stresses by the klystron.

2.4.7 Case Designs, Seals, Gaskets

The greatest cause of field failures of Army equipments including CECOM equipments is entry and entrapment of water into a case or container designed to protect the internal hardware. When moisture enters a sealed enclosure, the moisture is evaporated into the enclosed air, absorbed by the materials i.e., plastics, coatings, metals, insulation, etc. When these materials are saturated (depending upon the vapor partial-pressures of each material), if any excess moisture is left, it will condense on the walls and the relative humidity of the enclosure rises to 100%. If any enclosed plastics, coatings, treatments are not fully cured, there would be outgassing, which usually is an electrolyte and goes into solution

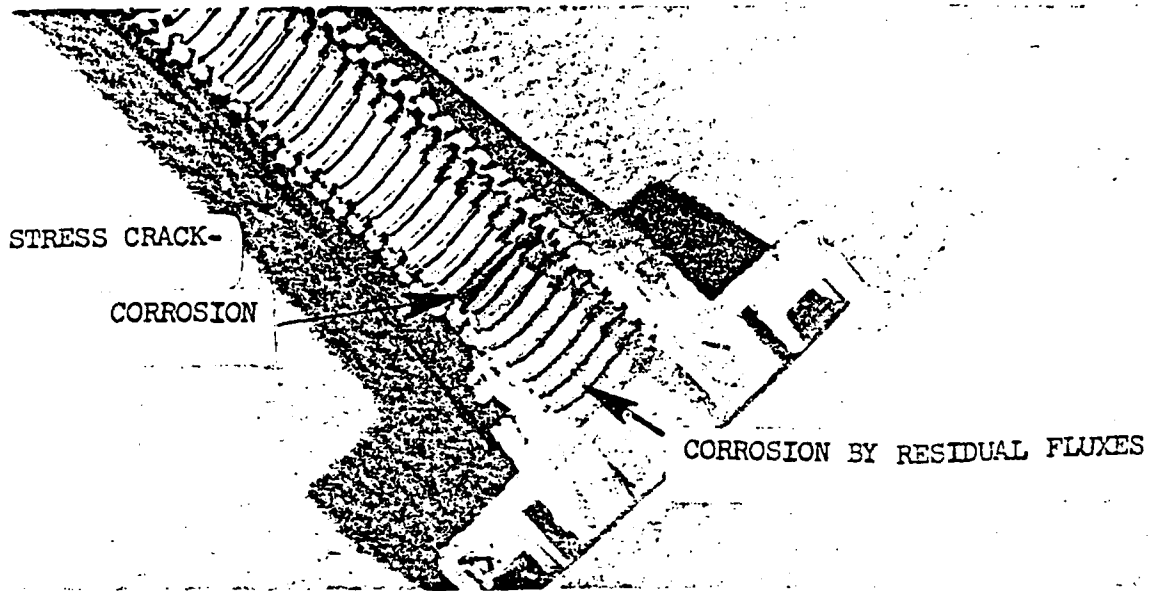


FIGURE 2.4.6.1 CORRODED FLEXIBLE WAVEGUIDE

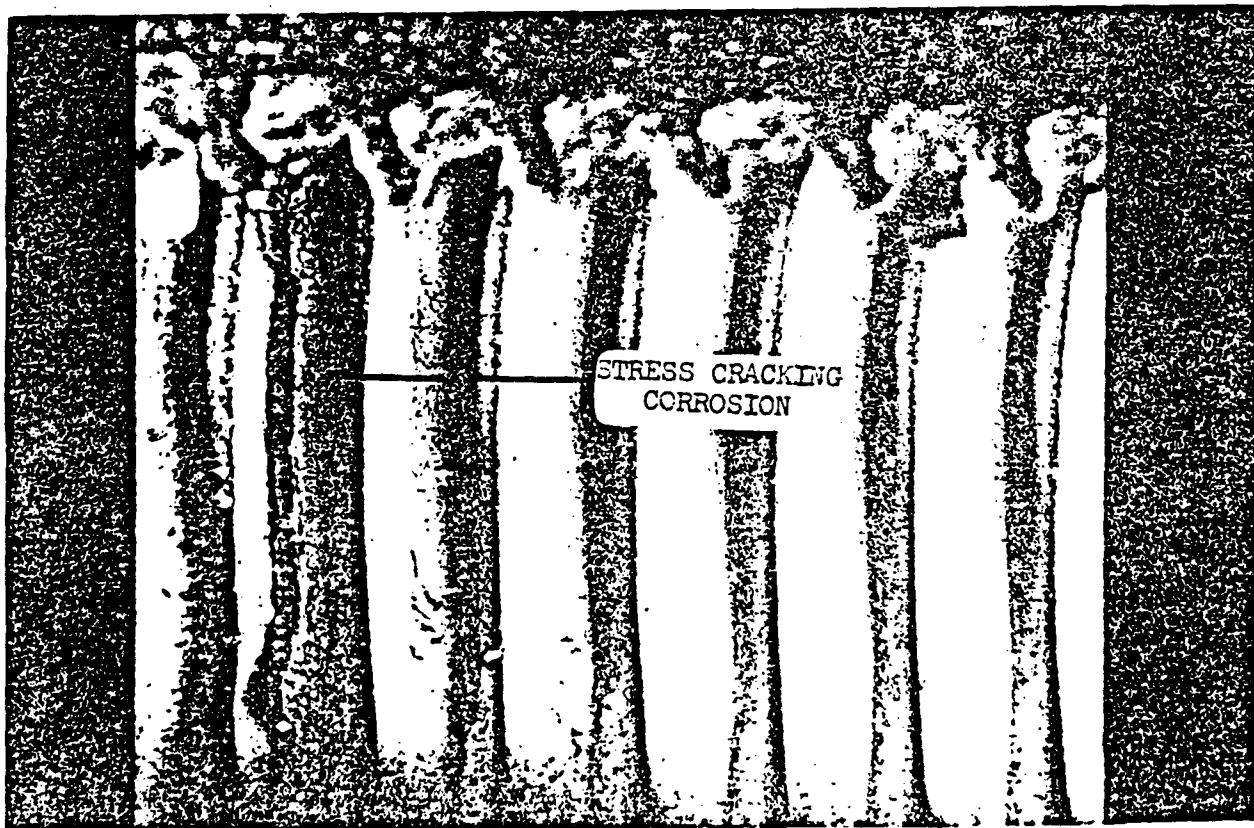


FIGURE 2.4.6.2 STRESS CRACKED WAVEGUIDE

with excess moisture. Thus, a classical situation for corrosive action has been created; especially if galvanic couples and poor quality finishes are present. If the equipment is powered and internal temperatures rise, corrosion rates are accelerated.

Case designs fall into three general categories as follows: Open, gasket sealed and hermetically sealed. For maintenance purposes, gasket seals are used; since dry interiors perform better than wet or exposed interiors; especially for manpack, portable, mobile, and river fordable types of systems. Gasket enclosures allow the operator and maintainer to open the case and do maintenance and repair. Figure 2.4.7 illustrates a gasket sealed antenna base AS-1729, showing corrosion as a result of water ingress and entrapment. In open designs, every little module should be self-protected, i.e, canned or potted, and all interior finishes should be the same as exterior finishes. All open designs should not have any areas that do not drain and which will entrap moisture.

Effective hermetic seals are usually not achievable with larger enclosures. In practice, gaskets have proven not to be reliable in providing an effective seal for a long enough period in the field. The cycling humidity test, Method 507.2, Procedure II of MIL-STD-810 imposes tests on the case design for its ability to prevent breathing types of humidity ingress. For part of the test, when applicable and specified, all gasket sealed enclosures are opened

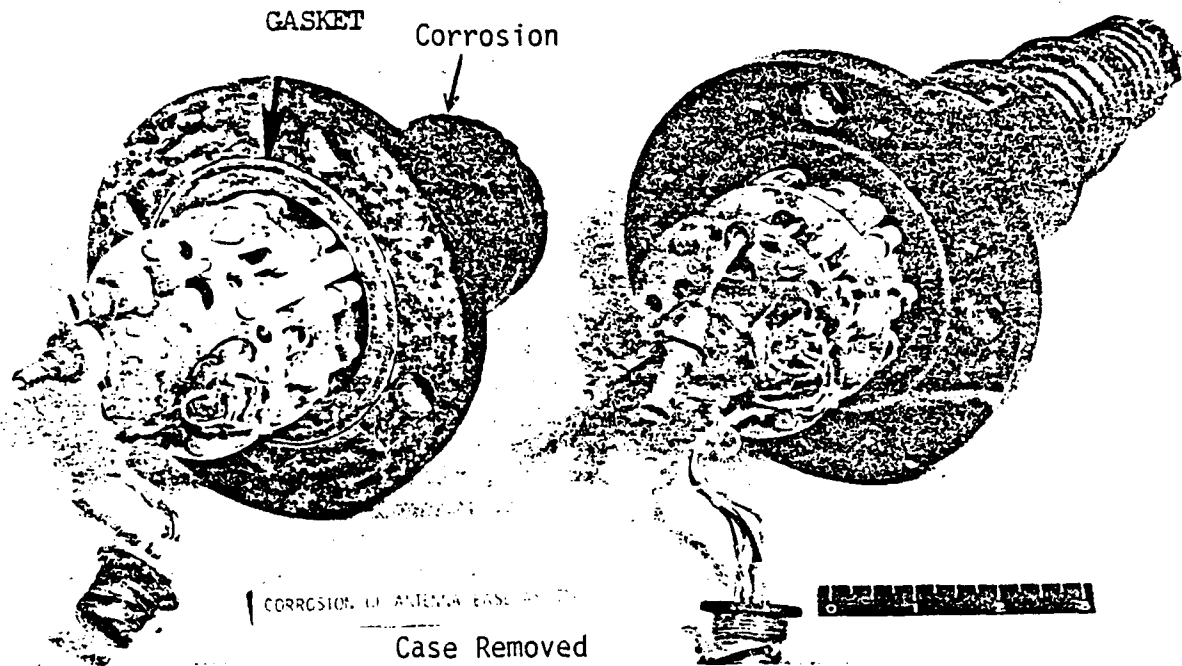


FIGURE 2.4.7 CORROSION DUE TO MOISTURE ENTRY IN GASKET SEALED ENCLOSURE
CORROSION OF ANTENNA BASE MOUNT DUE TO MOISTURE ENTRY INTO
GASKET SEALED ENCLOSURE

and the interior is exposed to full humidity cycling. Method 512.2 Leakage (Immersion) tests for leakage through all shafts, switch and gasket seals. With continued use, gaskets lose their effectiveness unless replaced periodically. The larger the gasket, the less the effective life. In effect, gasket sealed interiors cannot be relied upon to provide a dry interior unless critical portions of the interior circuitry are self-protected and the interior are periodically opened, cleaned, dried and the gasket replaced if defective. EMI gaskets because of their composition, i.e., filled with metallic meshes, usually have a shorter life and may be subject to corrosion.

2.4.8 Case Hardware

Handles, clamps, case materials, mounting hardware, etc. receive severe mechanical wear and damage. Special abrasion resistant epoxy enamels should be used per MIL-F-14072 "Finishes For Ground Electronic Equipment".

2.5 Manufacturing Processes

During production, control of assembly and material processes play a major role in the equipment quality. Most of these are described in MIL-P-11268, "Parts, Materials & Processes Used in Electronic

Equipment", MIL-STD-454 "Standard General Requirements For Electronic Equipment" and MIL-Q-9858, "Quality Program Requirements". The number and types of processes that apply are numerous, but the following highlights are those which have a considerable impact on corrosion resistance directly.

2.5.1 Cleanliness

Industrial contaminants can provide the electrolyte needed to complete the corrosion cell or cause direct chemical corrosion action. Periodic cleaning, covered transport boxes to transport items from station to station, clean tools, air venting of contaminated areas, minimum human handling, etc. all must be controlled to assure a minimum of contamination. For critical portions of circuitry, i.e., printed circuit board assembly, contacts, etc., semi-clean room handling and air-conditioned parts storage would be necessary. Figure 2.5.1 illustrates an automatic production line cleanliness tester. The cleanliness tester automatically, cleans and tests the cleanliness of the cleaning solution. If the solution gets too dirty or unclean, as required, the line stops and adjustments must be made.

2.5.2 Soldering Fluxes

The use of fluxes is controlled by MIL-F-14256 "Flux, Soldering, Liquid (Rosin Base) and Requirement 5 of MIL-STD-454. The use of

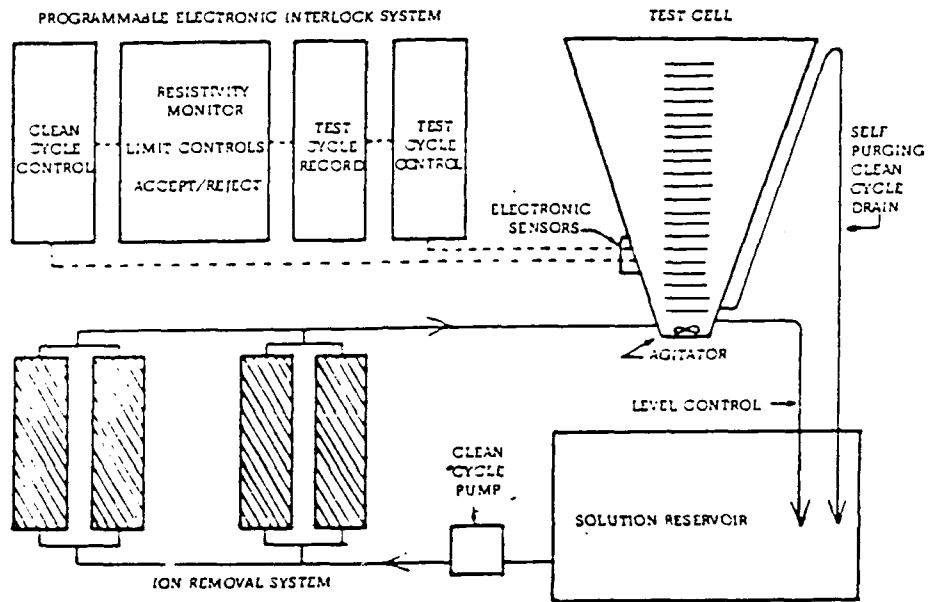


FIGURE 2.5.1 PRODUCTION LINE CLEANLINESS TESTER

activated fluxes is not permitted and even the use of RMA flux requires through cleaning after soldering.

2.5.3 Finishes, Platings, Coatings

There is a tendency by contractors to provide military hardware with commercial grade finishes. Careful incoming inspections should establish and assure acceptable military grade finishes as needed per MIL-F-14072. During assembly and processing, finishes may be scratched or damaged by sharp tools, machine handling, etc. These breaks in the finish coating can initiate corrosion which can spread in time. Epoxy type coatings per MIL-F-14072 have optimum scratch resistance. Platings should also comply with MIL-F-14072. Before production, samples of platings and coatings should be inspected and salt fog tested to establish quality acceptance criteria. Periodic sampling of fabricated and plated or coated parts should be sampled per MIL-STD-105 and tested again to assure quality. Good quality finishes play a major role in preventing direct chemical corrosion.

2.5.4 Repair/Fixes

During production certain repairs and fixes are processed. Such repairs require removal of coatings, resoldering touch-ups or all types of reworking. Many times the quality of repair is so poor or haphazard that a potential corrosion failure is incurred. Such examples are:

An open circuit is found on a printed circuit board assembly and a repair is made by scraping off the conformal coating and hand soldering a repair; possibly with activated flux. To avoid a refailure, the soldering should be done with an RMA flux, which is thoroughly cleaned to remove residual flux and the repair recoated with an approved conformal coat.

A deep scratch on the case is repaired by touch-up. To avoid failure, the scratch should be sanded, cleaned, dried, and recoated with an undercoat and a final epoxy coat, or the same finishes should be reapplied as originally applied.

In many cases, after repair, a reinspection is not performed. Actually, a reinspection should establish that the fix has not degraded the quality of the finish.

2.6 Corrosion Resistance Testing

2.6.1 Panel Testing

The testing of a plated or coated flat panel is usually done to evaluate the effectivity of a paint, coating or plating system (surface treatment and two coats or platings). Test panels of metal are coated and exposed to a Salt Fog Test per Method 509.2, MIL-STD-810 for 48 hours or more to establish the quality of

protection. A flat smooth panel is an ideal basis metal for evaluating and comparing various types of paintings or platings. Such results may be misleading as they would not be applicable to a complex electronic item. Shapes and sizes with varying smoothness of surface will affect results profoundly. In most cases, it is necessary to coat and expose the actual complex parts assembly to obtain a good test of the effectivity of the coating process quality.

2.6.2 Corrosion Resistance Testing of Electronic Systems

For electronic systems/equipments, MIL-STD-810 lists five tests that can be used to measure corrosion resistance effectivity. These are as follows:

- Method 506.2 Rain
- Method 507.2 Humidity
- Method 508.2 Fungus
- Method 509.2 Salt Fog
- Method 512.2 Leakage (Immersion)

Each of the above tests are usually included in Section 4 of any equipment specification and are scheduled to be conducted in First Article Test (FAT), preproduction, or initial production and

repeated periodically on a Group C lot-by-lot sampling. For purposes of testing corrosion resistance, the following should be used as a guide:

2.6.2.1 Rain Test

One of the purposes of the rain test is to determine if rain is collected or is entrapped in any complete system enclosure. Such entrapment would provide conditions for eventual initiation of corrosion. Because of the short test duration, no corrosion would be evident after the tests. If rain is entrapped or collected; this shall be considered as a failure of the design and must be classed as a deficiency requiring design improvement; even if only for the purposes of corrosion prevention. Rain tests are usually only conducted on field exposed stand-alone equipments. LRUs and equipments that are used in a shelterized facility should not be rain tested.

2.6.2.2 Humidity

Humidity can initiate some corrosion mechanisms but usually not enough to cause any failure of electronic functions. If the paints, coatings, or platings have not been applied properly, high humidity and temperatures will cause them to peel, blister or scrape off easily. Such corrosion will also not immediately affect the

operation and performance of the equipment. If a contaminant was present, then corrosion will initiate sooner and progress rapidly. Moving parts, even with initial corrosion, might bind. Contacts may experience higher resistances. The equipment may still perform even within specified levels. The important criteria is that initial corrosion will always increase and not reverse. Consequently, any initial corrosion should be cause for concern and failure of the equipment under test. In these instances, failure analysis should be thorough. The test can be extended for longer periods for diagnostic purposes. No initial type of corrosion should ever be dismissed as not significant.

2.6.2.3 Fungus

The main purpose of the Fungus Test is to determine if any organic materials were used or any contaminants were present which will support the growth of fungus. Fungus can affect the properties of organic materials by changing their molecular structure. The by-products of enzymatic actions can provide an electrolyte which can initiate and accelerate corrosion. A 28-day test as is specified in Method 508.2, is not long enough to provide extensive breakdown of material properties. Usually, longer periods of exposure such as 90 days of exposure are required to effect damage. Any initial or incipient corrosion noted by visual means after the Fungus Test should also be cause for concern and failure of the

equipment under test. Fungus growth may appear as a corrosion by-product. Usually, fungus growth will occur wherever organic materials are present, whereas corrosion will occur only where metals are present. Microscopic examination and chemical analysis may be necessary to determine the difference.

2.6.2.4 Salt Fog

This test is currently used by commercial and industrial companies to test for the protective effectiveness of applied finishes and coatings on metal surfaces and also to compare effectiveness of various types of finishes. Testing is usually accomplished on panel specimens. It is the most corrosive of all the so-called environmental tests. Applied to a C/E equipment, it will accelerate corrosion rates more than any other environmental test listed. It is a destructive test, rendering the C/E equipment under test not eligible for repair or rehabilitation if extensive corrosion does occur. While being the prime and most effective corrosion test, this test does have many shortcomings; which tend to make interpretation of results and application of failure criteria difficult because of the following:

Because of the high concentration of salt 5 + 1 percent solution which is used which is considerably higher than the natural sea mist at marine areas. Corrosion rates can be less than that occurring in the field.

There is a general misconception that the Salt Fog test simulates marine type conditions. No such correlation has ever been successfully established or reported.

Because of clogging, poorly mixed salt/water concentrations, uneven distributions, salt impurities, and water impurities, the test is not too reproducible.

Failure criteria for this test are mainly visual except for binding of shafts and switches. Encrustation of salt deposits makes this difficult. Washing to remove salt deposits will also remove water soluble corrosion deposits.

Most corrosive deposits can be identified visually by the naked eye. A four power amplification would help identify incipient corrosion; especially at structures with metallic couples. Any blistering, peeling or lifting of paints, coatings and/or platings shall be noted as failures. All mechanical devices such as: switches, contacts, adjustments, latches, hinges, should be checked for binding, high contact resistance or corrosion products. No electrical performance of the equipment; even after thorough washing, should be required as meaningful or applicable.

2.6.2.5 Leakage Immersion

This test is conducted to detect gross leaks for the purpose of determining the effectiveness of enclosed cases, either with gaskets or hermetically sealed to protect the enclosed system hardware. It is essential for manpack and portable equipments; especially units that are forded through rivers or lakes or stored in marine or tropical areas. When sufficient moisture leaks or enters such an enclosure, 100% Relative Humidity is attained when all of the enclosed mass is saturated with absorbed moisture; thus subjecting the electronic hardware to a constant high humidity condition. Moisture is continually leaked in but exits only under select conditions. Gasketed enclosures are notorious leakers; especially after the unit is opened and closed several times or the gasket material becomes stiff and/or breaks with age.

The best pass/fail criteria is one that weighs the assembly before and after immersion. Any excess moisture (+ x grams) weighed or noted inside the enclosure after immersion; indicates the possibility of leakage and moisture saturation inside the case. After immersion, the enclosed case or container should be allowed to dry for 24 hours, without opening the case, and then weighed. This weight should be compared to a dry case or container before immersion. Any gain in weight should be a basis for failure of the equipment under test.

3. Lessons Learned

The following are examples of corrosion problems which caused a delay in programs, which were resolved by determining the failure mechanisms and resulted in a fix. These are only typical examples selected to show the pattern of corrosion occurrence, failure analysis and get-well recommendations. In most instances, initial failure reporting did not mention corrosion but only failure types were reported, i.e., open circuit, failed part, etc. Only after extensive failure analyses of the part, its application, and several field trips was corrosion discovered as the root cause of failure and an effective fix applied.

3.1 Waveguide Corrosion

TPQ-37: Extensive failures of the waveguide sections of the mortar locator radar was being experienced with high replacements. The flexible waveguide section next to the klystron tube was made of accordion shaped brass alloy guides. The shaping of these guides caused high stresses to exist at the outside loop of the guide. Arcing from the klystron would deposit nitrous oxide in the air and in solution with the moisture which entered the waveguide, it created a nitric acid solution. This acid provided an electrolyte to cause stress corrosion of the waveguide convolutions. In addition, there was extensive corrosion on the brass flanges due to

residual brazing fluxes. See Figures 2.4.6.1, 2.4.6.2. The problem was cured by circulating dry air in the waveguide sections, thoroughly cleaning the waveguide sections before assembly to remove brazing fluxes and other contaminants, and annealing the flexible waveguides after forming. The lesson learned was to remove all welding and brazing fluxes during production and to circulate dry air in the waveguide system during operation.

3.2 Antenna Corrosion

ASN-128 Doppler Navigator: The antenna section of the ASN-128 was installed in the belly of the Blackhawk helicopter, which meant it collected all the cleaning water during cleaning operations with unknown detergent cleaning ingredients. This all collected in the belly and seeped into the antenna section. Extensive corrosion occurred to the magnesium waveguides and magnetic components. This also occurred whenever the helicopter occasionally landed on water. The cure was to force the contractor to improve all seals and pass a severe immersion test with no gain in weight allowed. The use of unknown cleaning compounds was controlled by specifying one without corrosive ingredients. Also a drain plug was added to the bottom part of the aircraft belly.

3.3 Connector Pin Corrosion

A complete lot of thermal batteries used in the Hawk Missile operations were delivered to the prime missile contractor with blackened connector pins. The complete lot was rejected. This halted delivery of the missiles. Analysis of the pins revealed that the black substance was copper oxide which is an insulator. The copper alloy pins had been gold plated, but with less than 50 microinches of gold. Microscopic examination revealed porous gold plating. The copper oxide had migrated through the pinholes and caused high resistance contacts. A fix was applied which polished the pin surfaces, applied a 50 microinches electroless nickel undercoat and a final 50 microinches gold plate. No failures due to poor contacts were experienced thereafter. The lesson learned was never gold plate over copper without a nickel undercoat.

3.4 Printed Circuit Board Connectors

The high number of instances that this type of failure precludes any attempt to list all the particular systems' in which failures occurred. Both the edge type and the pin and socket type connectors have been subject to the same type of failure. Copper lands and copper alloy pins are gold plated to prevent tarnishing and avoid costly cleaning. Because of the cost of gold, only a very thin gold plating was applied (less than 50 microinches). The result was

pinholes in the gold which also results in copper oxide film formation and open circuits. Fixes include smoother copper alloy surfaces and an undercoat of nickel. Lesson learned included not using less than 50 microinches of gold over copper alloy pins and to always include a 50 microinches of nickel undercoat. See Figures 3.4.1 and 3.4.2 and Figures 2.3.11.2a and 2.3.11.2b.

3.5 Kovar-Glass Seals

Kovar glass seals are used because the glass and Kovar metal have the same coefficient of expansion. To get the glass to adhere to the Kovar, it is necessary to etch the Kovar with acid solutions. The etchant must then be cleaned off to avoid subsequent corrosion of the leads. Cleaning, however, is very difficult at the base of the Kovar wire where it enters the glass bushing. When wet, the Kovar lead will corrode and the lead will break off causing an open circuit. Lesson learned is to never create an uncleanable area. Glass bushings should be applied with a generous glass to Kovar fillet. Thorough cleaning with cleanliness tests should be applied. Subsequent protective platings should be inspected to assure coverage at the base of the pins or leads. See Figure 3.5.

3.6 Plastic Encapsulated ICs

Integrated Circuits have normally been enclosed (hermetically sealed) in a tin metal can. In order to effect savings in cost and

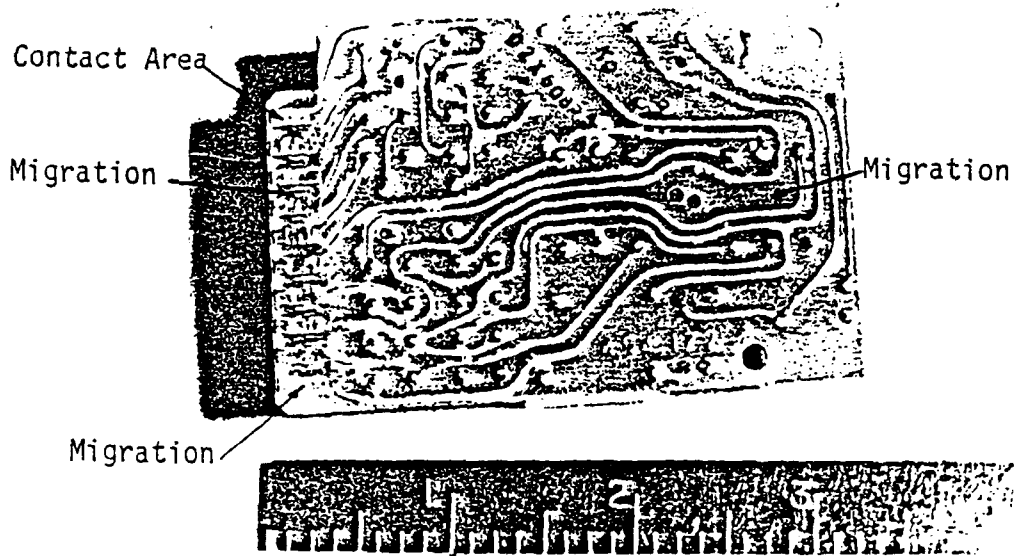


FIGURE 3.4.1 PRINTED CONTACT CORROSION



FIGURE 3.4.2 GOLD PLATED PIN CONTACT

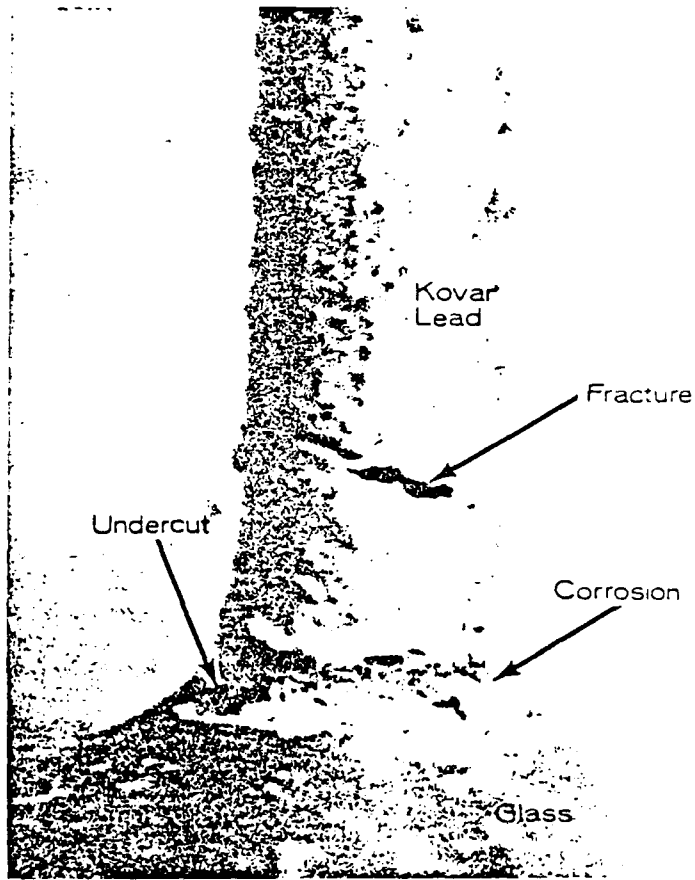


FIGURE 3.5 CORRODED H.S. PIN

gains in weight and volume, ICs were plastic encapsulated for commercial use. See Figure 3.6.1. These were adapted for military use initially in the ARC-115 Radio-Transmitter. High failure of the ICs and subsequent failure analysis revealed that corrosion of the IC aluminum lands was caused by uncured ingredients in the plastics being used, and the bonding of gold leads on aluminum lands. See Figure 3.6.4, 3.6.5. The cure required that only certain plastics, with no harmful ingredients, capable of being thoroughly cured (no residual uncured ingredients) and relatively impervious to moisture could be used. Figure 3.6.2 shows the polarity schematic of a type IC, and Figure 3.6.3 shows the analysis necessary to explain demetallization shown in Figures 3.6.4 and 3.6.5.

3.7 Lead Wire, Tabs

Lead wires used with parts which are bent and inserted into PWA soldered holes under strain are also subject to vibration and shock stresses and to corrosion by residual fluxes. Tabs used with flat packs and DIPs and hybrid microcircuits are also subject to the same conditions. Corrosion can take place at the body-to-lead wire interface or at the lead wire to PWA interface. Corrosion can take place, and if strain cracks are present, failure can occur. First of all, thorough cleaning and conformal coating plus mounting and cushioning when assembled onto PWAs to prevent vibration damage are all preventive measures. See Figures 2.3.11.3, 2.3.11.4 and 2.3.11.5. Sharp small angle bends in the copper lead wire should also be avoided.

EPOXY
NPN



I

EPOXY
NPN PNP



II

SILICONE
NPN



III

EPOXY
NPN

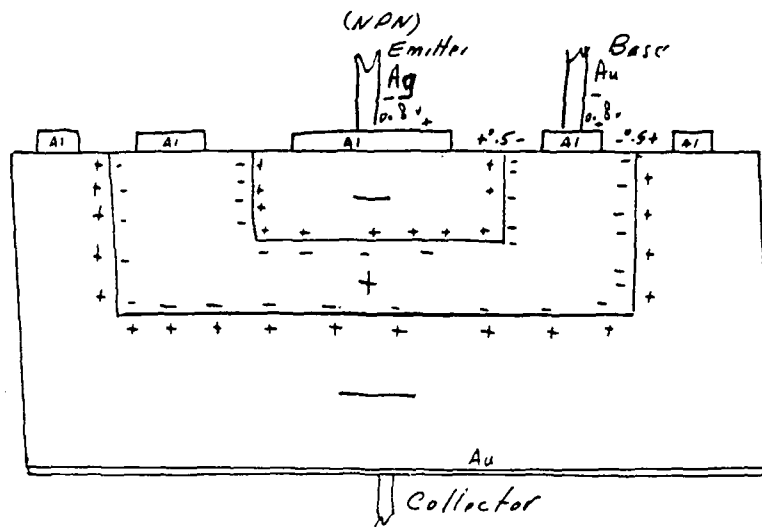


IV

SILICONE
NPN



FIGURE 3.6.1 TYPICAL PLASTIC DEVICES



Al = 1.66 (KE) volts oxidation potential
 Gold to aluminum galvanic cell = 0.8 volts

FIGURE 3.6.2 POLARITY SCHEMATIC OF IC CROSS SECTION

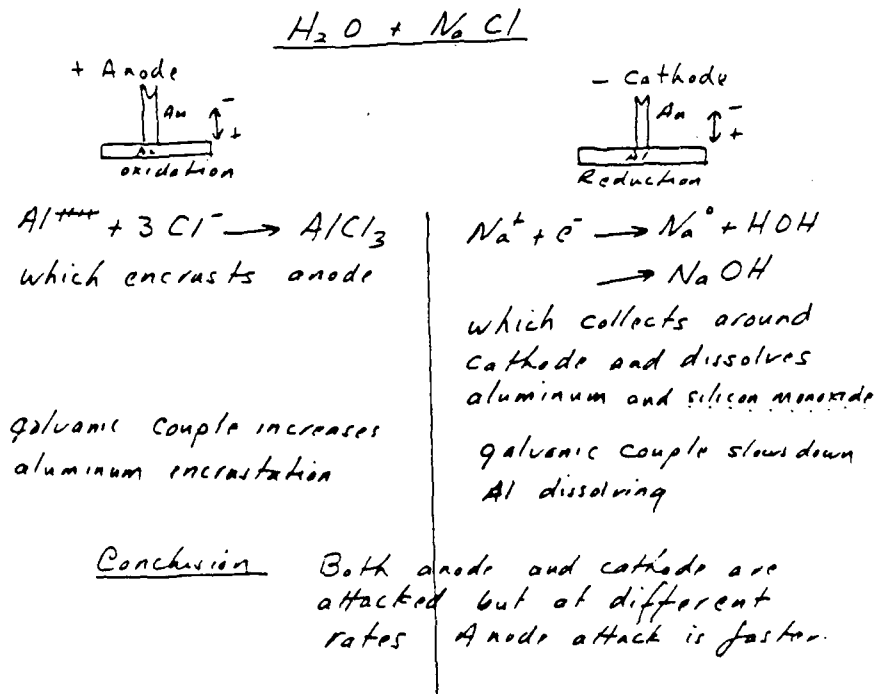


FIGURE 3.6.3 ZERO BIAS WITH DISTILLED WATER AND SALT

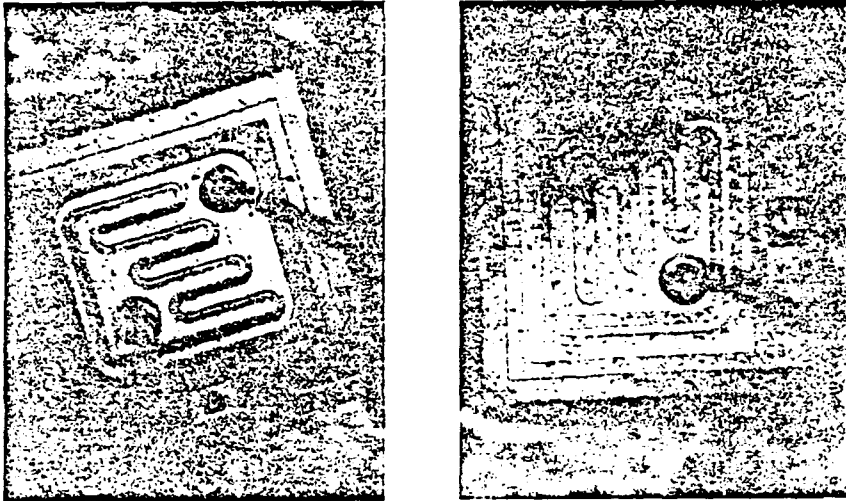


FIGURE 3.6.4 DEMETALLIZATION OF BASE ALUMINUM (DW)

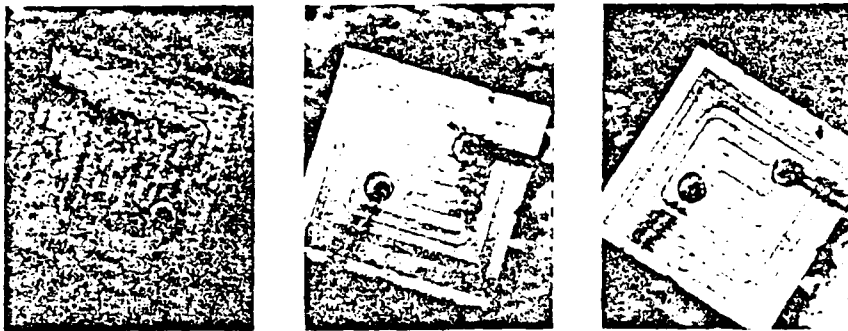


FIGURE 3.6.5 DEMETALLIZATION OF BASE ALUMINUM (HCl)

4. Corrosion Prevention Measures

4.1 General

In the corrosion tutorial presented in preceding paragraphs, many preventive techniques were mentioned. It would be appropriate to summarize prevention in an organized fashion with "Do's and Don'ts". It must be emphasized that there are many design decisions and trade-off studies which will impact upon corrosion prevention and control. Specification requirements leave room for trade-off decisions on a wide range of objectives and engineering practices to meet not only performance, cost and milestone schedules, but also reliability and maintainability requirements; of which corrosion prevention and control are a part. Consequently, in every material selection and design decision to be made, the question to be answered is: How will the decision affect corrosion resistance and field service life? During the acquisition of C/E equipments, many factors need to be considered and reviewed for corrosion impact. Each of these will be listed for each acquisition phase.

In addition, to impact upon performance reliability and maintenance, the cosmetic appearance of corroded equipment will also impact upon the confidence the soldier operator will have on using and maintaining his equipment in the field. Noncorroded clean equipment will receive more confidence and use than dirty corroded equipment and also last longer.

4.2 Corrosion Prevention Measures During Acquisition

The following paragraphs will delineate factors to be considered for Corrosion Prevention Advisory Board (CPAB) review during contractual phases of acquisition, Material Use and Selection, Design decisions, and "Do's and Don'ts".

4.2.1 Concept Exploration Phase

The following tasks should be reviewed by CPAB and monitored by PM/PCB throughout the acquisition cycle to define Corrosion Control & Prevention goals specifically tailored to fit the particular system being acquired:

- Review ROC, Mission Profile and Operated Modes
- Determine Platform Usage, Per Para 4.2 MIL-STD-810D
- Estimate Field Service Life (i.e.: 10 years, 20 years)
- Develop Environmental Design Criteria & Test Plan in the Test & Evaluation Master Plan (TEMP)
- Review Development & Validation Phase Specification plus TDP to assure CPC requirements are included in the D&V Phase

4.2.2 Demonstration & Validation Phase

During D&V Phase, many design decisions are achieved as a result of trade-off studies. Each decision should be evaluated to determine impact on CPC by participating in the following program phases:

- Review RAM Plan for Environmental Test Plan
- Prepare Draft CPC Plan, Scope of Objectives
- Participate in Design Reviews, Trade-off Study Decisions
- Provide Inputs to DT/OT-I Plans
- Review TEMP to assure adequate Environmental Tests and that Corrosion Critical Failure Criteria definitions are included.

4.2.3 Full Scale Development (FSD)

In many cases, corrosion occurs because a bad design, an unsuitable materials have been chosen or a production process has not been suitably controlled. Adequate specifications (MIL-P-11268 and MIL-STD-454) are applicable which, if enforced, will result in high material corrosion resistance. The CPAB should review the following plans to assure CPC objectives and requirements will be adequately planned and budgeted for and that adequate testing and evaluation are conducted:

- Review Contractors Reliability Program Plan
- Update TEMP
- Update CPC Plan
- Review Parts Control (Non-Std. Parts Approvals) Plan
- Review Effects of Functional Testing, Storage, Handling, Packaging, Transportation, Maintenance Requirements
- Review Reliability Test Plan Procedures

- Failure Modes, Effects & Criticality Analysis (FMECA) FRACAS Plans
- Participate in Failure Review Board
- Review Environmental Test Reports (DT-I)
- Provide Input to DT-II Scoring Conference
- Provide Warranty Input (Insist on plans for corrosion failure analysis of items returned for repair under warranty.)

In Full Scale Development, all design and material selection and use decisions must be reviewed to consider their effect on corrosion resistance and deterioration control as planned and implemented in the above listed plans and procedures usually accomplished during FSD. During this acquisition phase, many decisions on design, material selection and processing control are made by the contractor to meet performance and form-fit-functions. Corrosion prevention and control objectives must be maintained within these design, cost, and performance constraints. Achievement of corrosion control objectives need not be diminished and must always be realized by developing corrosion solutions without loss of design objectives.

4.2.4 Production

Quality inspection and control must be adequately applied to assure conformance to specified quality under MIL-P-11268, MIL-STD-454 and close attention to any corrosion occurring as a result of the

environmental tests applied with insistence that any corrosion defects be corrected. This can be accomplished by monitoring the following production activities:

- Review FAT results for corrosion results
- Review ECPs for effect on corrosion resistance
- Attend Materiel Review Board and PCB board for decisions affecting CPC
- Review Group C Test Reports for corrosion failures
- Review Warranty Plan to assure Corrosion Failure Analysis and fix resolution
- Review Storage Serviceability Standard Plan for packaging, storage conditions, periodic inspection test plans, RH indicator in package.
- Review Packaging and Storage Requirements

4.3 Deployment

All corrosion deficiencies occurring in the field should be considered and processed under Warranty and, if necessary, PIP.

- Attend, Participate with Warranty Review Group
- Review SSS with Depot on storage, packaging
- Review QDRs, SDRs
- Participate in Fielded System Reviews

- Follow-up on Corrosion deficiencies reported
- Monitor Corrosion PIPs
- Monitor Quality Levels of spare parts, modules for maintenance
- Visit Depot Maintenance Shops periodically to obtain corrosion field data.
- Monitor Overhaul Procedures
- Review DMWRs

4.4. Material Selection and Use

4.4.1 General

In design decisions involving the selection and use of materials, it is important to consider not only the electrical characteristics, but also factors such as basic resistance to corrosion, compatibility between metals, stability of organic materials and maintainability. Material applications recommendations include:

4.4.2 Galvanic Couples

Minimize dissimilar metals (galvanic) couples. The joining of dissimilar metals should be limited to those applications where similar metals cannot be used due to peculiar design requirements. If absolutely required, however, select the dissimilar mating metals to minimize the electrochemical potential of the joint. Design the

couple so that the anode area of contact is as large as possible so that corrosion occurs over a larger area at a slower rate. In all cases involving dissimilar metals, it is essential that the junction area be cleaned and sealed to minimize the presence of an electrolyte at the bimetallic interface. This sealing may be performed by the conformal coating on a PWB, or by application of sealant for couples located exterior to a LRU. Other couples within a LRU can be sealed using a non-acetic acid cure RTV (Room Temperature Vulcanizing), per MIL-A-46146. Where a dissimilar metals junction is designed for disassembly, such as a grounding or bonding connection, an easily replaceable anodic (consumable) part, such as an aluminum washer, should be included in the assembly.

Graphite is a material that is both a good conductor and a good lubricant. However, this material acts electrochemically like a noble metal and is cathodic (corrosive) to all structural metals. It is especially destructive when in contact with aluminum. Because of its extreme corrosiveness, graphite lubricants in any form should not be used on CECOM equipment. When graphite is unavoidably present, as in graphite composite structural parts, ensure that insulation is applied to electrically isolate any component from contact with the graphite composite. Lubricants used shall be IAW Requirement 43 MIL-STD-454.

4.4.3 Surface Treatments

All working of aluminum, e.g., cutting, drilling, grinding, forming, etc. should be completed before surface treatment is applied. Of the common surface treatments used on aluminum, anodizing provides the best protection, followed by Chemical Conversion Coating, MIL-C-5541, Class 1A, and lastly by MIL-C-5541, Class 3. All of the foregoing coatings have insulative properties, decreasing in degree from anodize to Class 3. In most applications where electrical conductivity is required, the MIL-C-5541, Class 3, will provide adequate continuity and offer some environmental protection. Since even this coating provides some resistance to ground or attenuates weak signals, areas of this type should be kept to a minimum. For generally adequate electrical conductivity, per MIL-B-5087, all contamination and coatings except MIL-C-5541, Class 3, must be removed to bare aluminum at the point of contact. Treat cleaned area with MIL-C-5541, Class 3, if some other type of coating has been removed. Assemble electrical connection and seal entire junction area. The slight impedance due to the MIL-C-5541, Class 3, film is the compromise to achieve some corrosion protection and enhanced coating or sealant adhesion.

4.4.4 Electrical Connectors

Boots (rubber, plastic, elastomeric) have been used over ends of wire bundles, harnesses, connector backshells and similar

applications to seal out moisture, provide strain relief and abrasion resistance for connectors used in exposed locations. In applications where the harness breathes, boots can be used only for strain relief and abrasion resistance. Such boots must contain provisions for good drainage to prevent the boot from becoming a "bathtub" area. Boots intended to seal out moisture must be installed with the prescribed adhesives at both the cable and connector ends, and can be used only with harnesses that are already jacketed up to the junction with the boot. Requirement 11 MIL-STD-454 specifies good practice usage for connectors. Corrosion failure can occur on the pins causing shorting paths on the insulators surface. Caps should be used for unmated connectors to keep out moisture and contaminants.

4.4.5 Metals Selection & Use

In the case of metallic materials, the most corrosion resistant configuration (passivated) should be used with the minimum possible residual stressing. An experienced Materials Engineer (Metallurgist), who is also aware of the characteristics and effects of the possible field environments, should participate in the selection of metals that are resistant to the adverse features of that environment.

4.4.5.1 Magnesium

Generally, the use of magnesium for any applications in a marine environment runs a very high risk of failure. If the use of magnesium is attempted, first priority in all design decisions must be toward maximizing protection from corrosive conditions. No metal more cathodic than aluminum should be mated to magnesium. If at all possible, do not use magnesium.

Low Pressure Laminates: For structural applications, low pressure laminates, polyester impregnated glass laminates is a corrosion resistant substitute for metals and should be considered for many applications, especially for magnesium use.²⁶

4.4.5.2 Plating Systems

Utilize metal plating, where applicable, to provide sacrificial protection, barrier protection, as a third metal (such as tin) interposed between two otherwise incompatible metals, or as a substitute surface presenting a reduced galvanic voltage differential to a contacting metal. Use a nickel strike (thin plate) under gold. Because it promotes solderability and has outstanding corrosion resistance, gold is widely used as a thin plating over silver or copper. However, silver diffuses through gold, as does copper. Gold over either silver or copper accelerates

corrosion of the less noble metal at the pores or pinholes in the gold.¹⁸ To avoid diffusion and corrosion, and still retain the strength of the base metal and the corrosion resistance of the gold, a plating of nickel should be placed on the copper, (instead of silver) under the gold. Use a nickel strike of at least 50 microinches under a gold plate of no less than 50 microinches. A continuous, nonporous gold plate is critical to preventing corrosion of the base metal. Platings of better quality can be achieved over smoother basis metallic surfaces that have been polished. An experienced Materials Engineer (Metallurgist) should participate in the identification of metal applications to avoid problems such as red plague (a silver-copper intermetallic compound), purple plague (a gold-aluminum intermetallic compound), metallic whiskers, silver migration and other potential metallic problems.

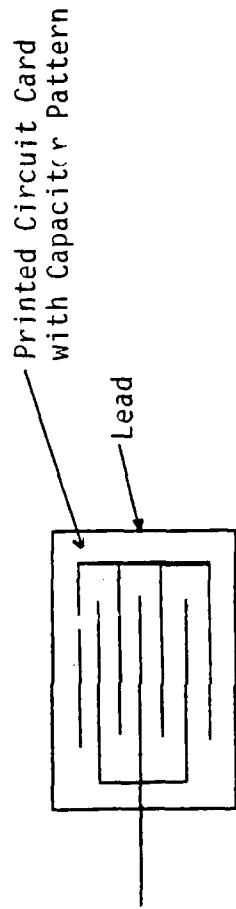
4.4.5.3 Organic Coatings

The preferred organic coating system for external surface protection of the structural metals used in the fabrication of electronic equipment is an Epoxy Topcoat, MIL-C-2270, over an Inhibited Epoxy primer, MIL-P-23377. When aluminum is the base metal, the surface should be anodized or conversion coated prior to priming. While Polyurethane Topcoat, MIL-C-83286, also provides a tough, yet flexible coating, the health hazards involved in the application of this paint makes it generally difficult for use in plant paint facilities.

4.4.5.4 Conformal Coatings

Because of the protection against moisture and corrosion, primarily, and enhanced resistance of mounted components to shock and vibration, secondarily, all PWAs for CECOM equipment should have a MIL-I-46058 conformal coating. Figure 2.3.10.2a shows the results of corrosion on a PWB that was not protected by a conformal coating. Figure 4.4.5.4 shows that at least a 3 mil coating is needed to protect the printed lines on a PWA. More than 3 mils, however, may change distributed capacitance between lines and affect performance. As a production applied conformal coating, paraxylene currently provides the best sealing. Other MIL-I-46058 materials have characteristics that may make the selection of a coating material other than paraxylene valid under special circumstances. Of the conformal coatings that can be applied in a repair action at field maintenance levels, epoxy has been reported by as the preferred coating. Polyurethane is a close second. Acrylic, RTV and varnish types of coating have performance deficiencies that render them a poor design choice. All PWAs must be thoroughly cleaned prior to coating sufficient enough to pass the cleanliness test per paras 3.6.10 and 4.8.2 of MIL-P-28809, Printed Wiring Assemblies.

CORROSION PROTECTION VS. CONFORMAL COATING THICKNESS



CORROSION VERSUS COATING THICKNESS

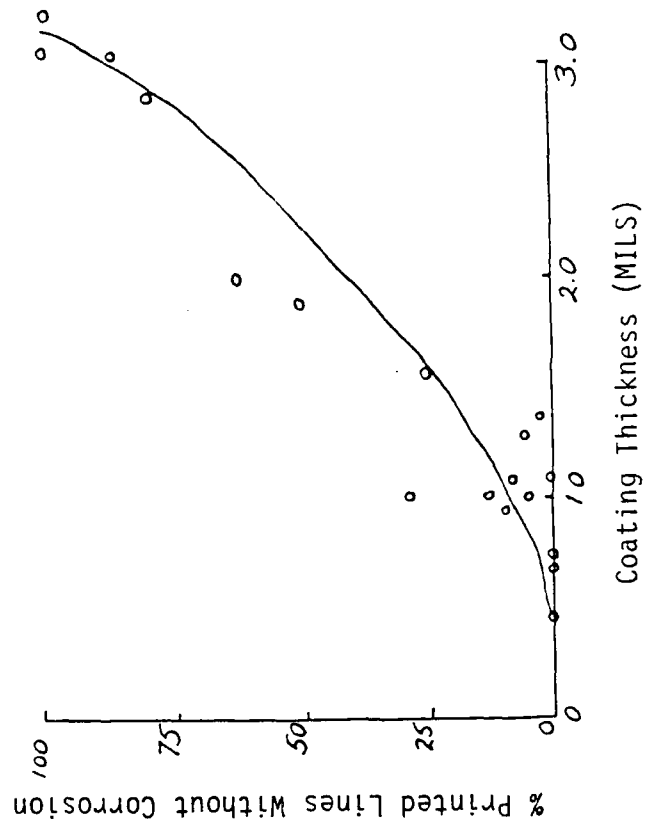


FIGURE 4.4.5.4

4.4.6 Solder Flux

Use the lowest acid content flux possible for soldering per Requirement MIL-STD-454. The term "no acid or acid salts should be used" is applied to solder, and Military Specifications permit only noncorrosive and nonconductive fluxes per MIL-F-14256.²⁷ However, even "neutral" fluxes must have some acidity in order to remove metal oxides and provide a reducing atmosphere to prevent oxide formation, and "nonactivated" fluxes can corrode metals.²⁸ Thus, any flux residue must be completely removed by cleaning per MIL-P-28809 and Requirement 9, MIL-STD-454. Welding and brazing also use fluxes which, if not removed, will provide an electrolyte to initiate corrosion failures.

4.4.7 Organic Materials

Avoid those materials that outgas corrosive contaminants, support fungi, absorb moisture, and, in the case of seals, can be degraded in performance by the presence of fuels and cleaning fluids. All proposed organic materials should be reviewed by an experienced materials specialist. Selection of approved organic materials should be per MIL-P-11268 and Requirement 4 of MIL-STD-454.

4.4.8 Gaskets, "O" Rings and Seals

The initial costs of most gaskets, "O" rings or seals are very small compared to the reliability and maintainability penalties associated with failure and replacements of these items. Fluorocarbon and fluorosilicone type materials are most resistant to weathering effects and cleaning fluids.

4.4.9 Conductive Gaskets

A thin conductive gasket of silver, copper or graphite impregnated material is sometimes used in an attempt to enhance conductivity between a blade antenna aluminum base and the equipment aluminum skin. This extreme galvanic couple results in nonconductive products of aluminum corrosion that greatly degrade system performance. A clean aluminum antenna base mounted against a clean case (each treated with Chemical Conversion Coating, MIL-C-5541, Class 3) and secured with metal screws provides the best long term mounting. Seal around coaxial exit from the case and around the periphery of the antenna base, with Sealant, Polysulfide, MIL-S-8802 should be used.

4.4.10 EMI Gaskets

Like the conductive gasket, the design of an EMI gasket normally involves the use of highly cathodic materials (silver, copper, graphite) mounted against the very anodic aluminum skin. This is fundamentally a metallurgically unsound condition. The survivability of such a design depends upon the effectiveness of a sealing system that precludes "breathing" of ambient air or any other method of moisture intrusion into the vicinity of the galvanic couple at the skin/gasket interface. Design ingenuity must also take into account the problem of restoring this super-sealed condition following field maintenance or equipment replacement.

4.5 Design Case Configurations to Minimize Corrosion

4.5.1 General

Serious consideration should be given to the design to be used to protect the interior of equipment housings; especially manpack or ground portable. The only effective seal that is completely protective is a hermetic seal design. While this is a very effective means of minimizing moisture intrusion, the additional weight, necessary housing rigidity, pressure tight sealing, and the need to maintain and service equipment interiors periodically, preclude such configurations. The decision on how to protect the

interior should be made early in development, since applique methods such as sealing with caulks or gun sealants are not effective. Since gaskets allow the housing to be opened in the field, every item inside should be protected with the assumption that moisture will eventually get into the equipment.

4.5.2 Case Designs

The available choices are limited to repairable or throwaway items. For repairable items, gasketed enclosures are necessary. A durable, rugged design should be used; sufficient to be effective after a predicted number of maintenance cycles. A renewable device, which will indicate the RH of the interior mounted and viewable on the front panel should be used where practicable and cost effective. Throw away items can be hermetically sealed, canned or potted. The other option for case design would be an open case design without water traps and easy drainage at the low point of the case. Critical portions of the circuit functions should be well-packaged or hermetically sealed. The following design features can help to minimize fluid intrusion:

- a. Use "O" rings for sealing around all control shafts that must penetrate into the enclosure.

- b. Avoid the use of knurled wheels that intrude into the enclosure. Effective sealing around such wheels is extremely difficult.
- c. Access plates utilizing a gasket for sealing are less subject to leakage when mounted on a vertical surface.
- d. It is preferred to mount electrical connectors horizontally (on the vertical sides/walls). If it is essential to mount a connector on the top of a housing, provide a slightly (at least 3/16") raised base for the connector mounting relative to the surrounding horizontal area. Never put a mating half of a vertical connector in a well-cup located on top of the case. The cup will collect standing water.
- e. Use an "L" type connector so the wiring enters horizontally into the upper portion of a vertically mounted connector.
- f. For all multicontact connectors, wiring should lead upward toward the connector to prevent water from running along wire into the connector. Strain relief is essential to ensure no side loads exist on wires entering backshell grommets or potting.

The PWBs, motherboards and feed-through connectors should all be

located so they are well above the bottom of a housing (at least 1/2" clearance). In addition, mount PWBs vertically to prevent condensation and debris from collecting on the board. The edge connectors should be either on the vertical edges or mounted on the back of the PWB.

When access to equipment is through the top, use a "shoe box" type of lid with no penetrations through the top of the lid.

Specifically, avoid countersunk or dimpled fastener holes.

Fasteners through the skirt of the shoe box lid can provide security without collecting moisture. If fasteners through the top of the lid are unavoidable, ensure the area over each fastener is covered with a sealant.

All case designs should allow for easy cleaning or decontaminating procedures; which are described in maintenance manuals including the noncorrosive cleaning compound to be used.

4.5.3 Printed Wiring Assemblies, Microcircuits

In most cases, PWAs and microcircuits are the critical functions of the equipment and must be protected with quality packaging. A corrosion failure in most situations will usually result in catastrophic failure. Prevention of corrosion is paramount. Printed wiring assemblies should conform to MIL-P-28809 and all

sections of para 3.10.32 of MIL-P-11268. Microcircuits (integrated circuits) shall conform to para 3.10.26, Requirements of MIL-STD-454 and MIL-M-38510. For purposes of corrosion prevention, the following guidelines would be applicable:

4.5.3.1 Materials

Avoid organics, especially those which have residual active ingredients or impurities. All materials should be completely cured without residuals, active ingredients and strains. Avoid magnesium compound metals and higher than necessary high strength aluminums.

4.5.3.2 Designs

Avoid galvanic couples with higher EMF couples than recommended by Table 2.4.1.1 unless hermetically sealed in accordance with fine and gross leak test per MIL-STD-883, Test Method 1014. All copper contact areas should be as smooth as possible with 50 microinches of nickel undercoat plus 50 microinches of gold plate per MIL-G-45204. Avoid edge type connectors, and use only pin and socket type connectors instead.

4.5.3.3 Processes

During processing repairs and assembly, after printing etching, soldering and assembly, the uncoated PWA should be thoroughly

cleaned and tested for cleanliness per para 4.8.2. "Cleanliness and Resistivity of Solvent Extract," of MIL-P-28809. All PWAs should be conformally coated per MIL-I-46058. At each intermediate step in processing and assembly, the PWA shall be protected from industrial contaminants by specially clean containers with covers and processed with a minimum of handling. All assembly processes should be accomplished in a semi-clean room facility.

4.5.3.4 Testing Inspection

After conducting the environmental tests listed in paras 2.6.2 above, the PWA should be thoroughly inspected for gross and minute corrosion occurrence using microscopic visual inspection. All instances of the slightest occurrence of corrosion should be corrected before approvals.

5. Field Usage

The main effort in the field to minimize corrosion would be to keep the equipment clean and as dry as possible. At times, this may be difficult, but preventive maintenance should include periodic cleaning and drying. TMs should include cleaning procedures with safe cleaning solutions and drying procedures at the operational level. There should be no field repairs of PWAs unless these repairs can be accomplished with clean room facilities and all repairs are cleaned and recoated.

6. Storage

The Storage Serviceability Standard (SSS) should specify the necessary storage conditions, i.e., air conditioned, sheltered, periodic inspection, packaging, etc. An enclosed desiccant indicator but visible from outside the packaging should indicate the relative humidity (RH) inside the packaging. With a high RH indication, the package should be opened and the equipment dried and a new replacement of the RH indicator inserted. The cause for the high RH should be determined and corrected. If corrosion has occurred, the SSS should state overhaul procedures.

7. Do's & Don'ts of Design, Materials, Processes

For equipment designers, the following "Do's" and "Don'ts" lists can serve as general checklists: Do's and Don'ts are general guidelines which should be used without compromising other important equipment design factors. A trade-off study should always decide which design factor is paramount and alternate solutions should be used to avoid corrosion.

7.1 The "Do's" of Equipment Design

- o Design on the assumption that moisture and fluid will be present in the airframe and equipment.
- o Seal all dissimilar metal (galvanic) couples.
- o Use a conformal coating on printed wiring boards in accordance with MIL-1-46058.
- o Use an easily replaceable anodic (consumable) part in assembling grounding or bonding connections.
- o Electrically isolate graphite composite materials from electronic equipment.

- o Use only electrical connector boots that can be sealed with adhesives.

- o Carefully select a protective system for use on magnesium; whenever the use of magnesium cannot be avoided.

- o Complete the working of aluminum (drilling, cutting, grinding) prior to surface treatment.

- o Use surface treatments (anodize and conversion coatings) on aluminum.

- o Carefully select the metal plating used to provide sacrificial protection, barrier protection, as a third metal between two otherwise incompatible metals, or as a substitute surface.

- o Use a nickel strike under gold plating.

- o Use solder flux with lowest possible acid content.

- o Use metallic materials with the most corrosion resistant configuration (passivated) with minimum possible residual stressing.

- o Use fluorocarbon or fluorosilicone type materials for gaskets, "O" rings and seals.

- o Seal conductive and EMI gaskets against moisture/fluid intrusion.
- o Use low point drains
- o Mount equipment and components at least 1/2 inch above potential standing water level.
- o Use hermetic sealing where possible. Use only potting compounds without uncured residuals and without corrosive ingredients.
- o Use transparent (clear) conformal coating.
- o Place ambient pressure sensing components outside equipment housings.
- o Design for maintainability and cleanliness.
- o Mount PWBs vertically with the edge connectors on vertical edge of back of board.
- o Mount electrical connectors horizontally.
- o Use drip loops on electrical cables.
- o Use desiccant systems with outside visual indicators.

- o Use cooling systems that remove moisture and particulate matter.
- o Use "O" rings to seal around control shafts that must penetrate an enclosure.
- o Be aware of various interior and exterior fluids used near electronics.
- o Protect against insulative films on contacts, grounds.
- o Recognize the operational environment.
- o Recognize the maintenance environment.
- o Be aware of maintenance procedures and materials.
- o Get the maintenance technician's input during fielded surveys.
- o Listen to feedback and lessons-learned.

7.2 The "Don'ts" of Equipment Design

- o Don't use dissimilar metal (galvanic) couples if it can be avoided.

- o Don't use RTV that contains acetic acid.

- o Don't place graphite in contact with aluminum or any structural metal.

- o Don't use heat shrink (non-sealed) electrical connector boots to stop moisture fluid intrusion.

- o Don't mate magnesium to a metal more cathodic than aluminum.

- o Don't use gold over silver or copper.

- o Don't use organic materials that outgas, support fungi, absorb moisture or are degraded by maintenance and operational fluids.

- o Don't use silver, copper or graphite impregnated material for conductive or EMI gaskets.

- o Don't use top mounted lid fasteners.

- o Don't mount PWBs horizontally.

- o Don't mount electrical connectors (multicontact or coaxial) vertically.

- o Don't place connectors on the bottom edge of a vertically mounted PWA.

- o Don't create side loads or cable tension on the rear seal of electrical connectors.

- o Don't use direct air cooling on active electronic components.

- o Don't mount LRUs less than 1/2 inch above the compartment floor.

- o Don't use hygroscopic materials.

- o Don't use nickel plated electrical connector shells.

- o Don't use foam cushioning materials that can deteriorate (revert).

- o Don't permit the presence of water in trap areas.

8. Glossary

8.1 Terms, Definitions

ACTIVE METAL - A metal that is in a condition in which it tends to corrode.

ADDITIVE - A compound added for a particular purpose - in the case of fuel and lubricants for such purposes as to prevent corrosion gum formation, varnishes, sludge formations, knocking, etc.

AERATION CELL - An electrolytic cell in which the driving force to cause corrosion results from a difference in the amount of oxygen in solution at one point as compared to another. Corrosion is accelerated where the oxygen concentration is least, for example, in a stuffing box or under packing, etc.

ALLOY - A combination of two or more metals.

ANAEROBIC - Free of air or uncombined oxygen.

ANION - An ion that carries a negative charge. The chloride ion in sea water is an anion.

ANODE - The electrode of a galvanic cell at which oxidation occurs. In corrosion, the electrode which is being attacked. The less noble electrode of an electrolytic cell at which corrosion occurs. This may be a small area on the surface of a metal or alloy, such as where a pit develops, or it may be the more active metal in a cell composed of two dissimilar metals, i.e. the one with the greater tendency to go into solution. The corrosion process involves the change of metal atoms into ions with a liberation of electrons that migrate through the metal to the cathode of the cell.

ANODIC PROTECTION - The reduction or elimination of corrosion of a metal that can sometimes be achieved by making current flow from it to the solution as by connecting it to the positive pole of a source of current. Under most conditions, as the potential of an initially active metal is gradually shifted in a more noble direction, as by potentiostatic means, the corrosion current gradually increases. However, with suitable combinations of metal and solution, a critical potential is soon reached. At somewhat higher values of the potential the current drops to a very low value, and the metal becomes passive. The potential of metal has to be regulated by a potentiostat.

ANODIZING - A process for thickening the layer of oxide on the surface of metal, especially aluminum. The article is made by dipping the anode in a bath of chromic or sulfuric acid. It provides protection from corrosion and is a good base for paint.

AUSTENITIC - A term applied to that condition of iron associated with a change in crystal structure that makes it nonmagnetic. This occurs with ordinary iron at an elevated temperature. When sufficient chromium and nickel are present, iron becomes austenitic (nonmagnetic) at atmospheric temperature. This is the case with the many stainless steels that contain about 18% chromium and 8% or more nickel.

BASIS METAL - The underlying metal which is plated or coated.

CATHODE - The more noble electrode of a corrosion cell where the action of the corrosion current reduces or eliminates corrosion.

CATHODIC PROTECTION - The reduction or elimination of corrosion of a metal that is achieved by making current flow to it from a solution, as by connecting it to the negative pole of some source current. The source of the protective current may be sacrificial metal, such as magnesium, zinc or aluminum. The current may also be derived from a rectifier, generator or battery applied through an appropriate anode which may be consumed by the applied current, as in the case of steel, or remain substantially unaffected by the current, as in the case of graphite or platinum. Cathode protection may become complete when anodic reactions are completely suppressed and only cathodic reactions occur on the metal surface.

CATION - A positively charged ion of an electrolyte. Metallic ions, such as iron and copper, are cations.

CELL - In corrosion processes, a cell is a source of electrical current that is responsible for corrosion. It consists of an anode and a cathode immersed in an electrolyte and electrically bonded together. The anode and cathode may be separate metals or dissimilar areas on the same metal.

CHALKING - Deterioration of an organic coating upon exposure that results in a powdery, chalky residue on the painted surface.

CHEMICAL CONVERSION COATING - A film that is deliberately produced on a metal by immersing it in, brushing it, or spraying it with a selected chemical solution for the purpose of providing improved corrosion resistance to the metal or increasing the adhesion of organic coatings to be applied later. Coatings covered by MIL-C-5541 are examples.

CLEAR WATER - Is defined for use in this manual as color free water containing no visible suspended particles.

CONCENTRATION CELL - An electrolytic cell consisting of an electrolyte and two electrodes of the same metal or alloy that develops a difference in potential as a result of a difference in concentration of ions (most often metal ions) or oxygen at different points in a solution.

CORROSION - The deterioration of a material, usually a metal through reaction with its environment.

CORROSION FATIGUE - A reduction by corrosion of the ability of a metal to withstand cyclic or repeated stresses.

CORROSION RATE - The speed at which a metal or alloy is wasted away because of corrosion. This may be experienced in terms of loss in weight or loss of thickness in a given period of time.

COUPLE - Two or more dissimilar metals or alloys in electrical contact with each other so that they can act as the electrodes of a cell if they are immersed in an electrolyte.

CRACKING - (a) Localized breaking of a paint film to expose the underlying material.

(b) Breaking of a metal or alloy in a brittle fashion along a narrow path or network.

CREVICE CORROSIONS - Corrosion that occurs within or adjacent to a crevice formed by contact with another piece of the same or another metal or with a nonmetallic material. When this occurs, the intensity of attack is usually more severe than on surrounding areas of the same surface.

CRITICAL HUMIDITY - Under controlled conditions, a metal or alloy will not corrode if relative humidity is kept below a certain value. In the presence of hygroscopic (moisture absorptive) solids or corrosion products the critical humidity will be lowered. Steel will not corrode if the relative humidity is under about 30% in a marine atmosphere.

DEPOSIT ATTACK - The excessive corrosion that may be deposited on a metal surface and thus shield it from ready access to oxygen or ions in solution. This is a form of concentration cell corrosion.

ELASTOMER - Substance having some of the physical properties of rubber. MIL-S-8802 sealants are examples of an elastomer.

ELECTRODE - A metal or alloy that is in contact with an electrolyte and serves as the site where electricity passes in either direction between the electrolyte and metal. The current in the electrode itself is a flow of electrons, whereas, in the electrolyte, ions carry electric charges and their orderly movement in solution constitutes a flow of current in the electrolyte.

ELECTROLYTE - Any substance which, in solution or fused, exists as a electrically charged ion that renders the liquid capable of conducting a current. Soluble acids, bases and salts, such as sea water, are electrolytes.

ELECTROMOTIVE FORCE SERIES (EMF) - The elements can be listed according to their standard electrode potentials. The more negative the potential the greater the tendency of the metals to corrode but not necessarily at high rates. This series is useful in studies of the thermodynamic properties but does not indicate the rates of corrosion. A hydrogen gas electrode is the standard reference and is placed equal to zero. All potentials are positive or negative with respect to the hydrogen electrode. In this country, the potentials of zinc and iron are written as negative and those of copper and platinum positive.

EMBRITTLMENT - Severe loss of ductility of a metal alloy that results in a brittle fashion.

EROSION - Destruction of a metal by the combined action of corrosion and abrasion or attrition by a liquid or gas with or without suspended matter.

EXFOLIATION - Breaking away from a surface in flakes or layers.

FATIGUE - The tendency for a metal to crack and fracture in a brittle manner under conditions of cyclic stresses at stress level below its breaking strength.

FAYING SURFACE - The common surface formed by matting parts.

FILIFORM CORROSION - Corrosion that develops under coatings on metals as fine ragged hairlines, usually wavy or curved and randomly distributed.

FILM - A thin layer of material that may or may not be visible.

FRETTING CORROSION - Corrosion at the interface of two contacting surfaces usually under high pressure and subject to very minute slippage due to relative vibration of surfaces that ordinarily are not supposed to move relative to each other as a shrink fits.

GALVANIC - In this manual, the flow of direct current between dissimilar metals.

GALVANIC CORROSION - The increased corrosion above normal corrosion of a metal that is associated with the flow of current to a less active metal in the same solution and in contact with the more active metal.

GALVANIC SERIES - A list of metals and alloys arranged in order of their relative potentials in a given environment. The order of their arrangement in this list may be different in other environments.

HYDROGEN EMBRITTLEMENT - Loss of ductility of a metal caused by the entrance of absorption of hydrogen into the metal as in the pickling of steel.

IMPINGEMENT ATTACK - Corrosion that is associated with turbulent flow of a liquid as at the entrance of a condenser tube or around bends in a pipe line.

INHIBITOR (AS APPLIED TO CORROSION) - A chemical substance or mixture which when added in small amounts to a solution markedly decreases corrosion.

INORGANIC COATINGS - Electroplates, conversion coatings, anodic coatings, phosphates, and oxide coatings.

INTERGRANULAR CORROSION - Corrosion along grain boundaries

ION - An electrically charged atom or group of atoms. The sign of the charge is positive in the case of cations and negative in the case of anions.

LOCAL CELL - A cell in which the driving force is due to difference in potential between areas on a metal or alloy surface immersed in an electrolyte. The potential difference may be due to inclusions, lack of homogeneity, varying concentration of the solution with respect to oxygen or metal ions, etc.

MATTE SURFACE - A metal with a low specular, or mirror-like, reflectivity as in the case of an etched or sandblasted surface.

METAL ION CONCENTRATION CELL - A cell established on a metal surface due to different concentrations of its ions in the electrolyte where it is in contact with the metal surface. These variations in concentration result in local differences in potential thus allowing the establishment of local cell.

MILL SCALE - The heavy oxide layer formed during hot fabrication or heat treatment of metals. The term is most frequently applied to the scale of mixed iron oxides on iron and steel.

MINOR CORROSION - An existing corrosion discrepancy which, by the dictates of good maintenance practice, should be corrected on a noninterference basis of other activities.

NOBLE METAL - An metal that is so inert that it is usually found as uncombined metal in nature. Unattackable or more resistant to corrosion. Platinum, gold and silver are noble metals.

ORGANIC COATINGS - Paint, lacquer, plastics, greases, etc.

OXIDATION - Generally speaking, in chemical terms, any change involving the loss of electrons by an atom constitutes oxidation, hence any anode or corrosion process involves oxidation of the metal in a true chemical sense. More specifically, it also may imply the destruction of a metal or alloy as a result of the direct action of oxygen on the metal, e.g., the scaling of steel at a high temperature.

PASSIVATION - The process or processes by means of which a metal becomes inert to a given corrosive environment.

PASSIVATOR - An inhibitor that causes a shift in the potential of a metal in the inhibited solution to a more cathodic or electropositive value and thereby makes the metal more resistant to corrosion by the solution. Chromates inhibit corrosion of steel by water in this manner.

PASSIVE-ACTIVE CELL - A cell involving conditions in which the EMF is due to the potential difference between a metal in an active state and the same metal where the one surface is in an active state and the other surface a passive state. The pitting of stainless steel in sea water is due to a cell set up between an active surface within a pit and the passive surface surrounding it.

PASSIVE - State of a metal that is active in the EMF Series, or an alloy composed of such metals, when it exhibits an appreciably greater resistance to corrosion and behaves more like a less active or noble metal in resisting corrosion and by exhibiting a relatively noble potential in a galvanic series.

PATINA - A green or greenish-blue coating which forms on copper or copper alloys exposed to the atmosphere.

pH - The acidity of a solution is determined by the concentration of hydrogen ions in it. The pH of a solution is a term used to express the effective hydrogen ions in it. In terms of the effective hydrogen ion concentration. It ranges from pH-1 to pH-14. A value of pH-7 indicates a neutral solution. Values lower than 7 indicate an acid condition. The stronger the acidity, the lower the pH. Conversely, values of pH above 7 indicate an alkaline condition, the higher the pH, the more alkaline the solution. Fresh water usually exhibits a pH of about 6 to 7. Sea water ranges from pH 7.8 to 8.4 with an average of about 8.2.

PITTING - A form of corrosion that develops in highly localized areas on a metal surface that is not attacked elsewhere to any great extent. This results in the development of cavities which are termed pits. They may vary from deep cavities of small diameter to relatively shallow depressions.

POTENTIAL CORROSION - A condition which if left unchanged can create a corrosion problem.

PRIMER COAT - The first coat of a protective paint, etc. Originally applied to improve adherence of the succeeding coat, but now usually containing an inhibitor pigment such as zinc chromate or red lead.

RELATIVE HUMIDITY - The ratio, expressed as percentage, of the concentration of water vapor in the air to the water vapor concentration that it would have if saturated at the same temperature.

RUSTING - Corrosion of iron or iron-base alloys resulting in the formation of corrosion products on the surface that consists mainly of hydrated ferric oxide with a color from red to yellow hues.

SCALING - The formation at high temperatures of partially adherent layers of corrosion products on a metal surface.

SEVERE CORROSION - An existing corrosion condition that has progressed to the point where the structure integrity of the unit is questionable. It should be corrected prior to the units next operating cycle.

SLUSHING COMPOUND - A nondrying oil, grease, or similar organic compound which when applied to a metal protects against corrosion.

SPALLING - The chipping, fragmenting, or separation of particles from a surface; such as a paint or coating.

STRESS CORROSION - Corrosion that is accelerated by stress, either residual internal stress in the metal or externally applied stress.

STRESS CORROSION CRACKING - Cracking that results from the combined effects of corrosion and stress.

TARNISH - Surface discoloration caused by formation of a thin film of corrosion product or oxide film.

8.2 Acronyms

CCC	Command Control Center
CECOM	Communications-Electronics Command
C/F/M	Corrosion/Fungus/Moisture
CPC	Corrosion Prevention & Control
DMWR	Depot Maintenance Work Requirements
DT/OT-1	Development Tests/Operational Tests
D&V	Demonstration & Validation
ECP	Engineering Change Proposal
EMF	Electro-Motive Force
EMI	Electro-Motive Interference
ESS	Environmental Stress Screening

FAT	First Article Test	
FMECA	Failure Modes, Effects & Critical Analysis	
FRACAS	Failure Reporting and Corrective Action	
FSD	Full Scale Development	
IAW	In Accordance With	
LRU	Line Replaceable Unit	
LSI	Large Scale Integration	
MFP	Moisture and Fungus Proofing	
pH	Measure of Acidity of a Solution	
PIP	Product Improvement Plan	
PVC	Polyvinyl Chloride	
PWA	Printed Wiring Assembly	
PWB	Printed Wiring Board	
RAM	Reliability, Availability, Maintenance	
ROC	Required Operational Capability	
RTV	Room Temperature Vulcanizing	
SSS	Storage Serviceability Standard	
TDP	Technical Data Package	
TEMP	Test and Evaluation Master Plan	
Type A	Activated	- Liquid Flux
Type R	Nonactivated Flux	- Rosin Core Fluxes
Type RA	Activated Flux	- Rosin Core Fluxes
Type RMA	Mildly Activated Flux	- Rosin Core Fluxes
Type W	Nonactivated Flux	- Liquid Flux
VHSIC	Very High Scale Integration Circuit	
WPAB	Wright Patterson Air Force Base	

8.3 Related Specifications and Standards

Specification

Number

Item

H50	Evaluation of a Contractor's Quality Program
H51	Evaluation of a Contractor's Inspection System
H-B-178	Brush, Wire, Scratch
TT-R-248	Remover, Paint and Lacquer, Solvent Type
TT-T-266	Thinner, Dope and Lacquer, Cellulose-Nitrate
O-C-303	Chromium Trioxide, Technical Chromic Acid
TT-T-306	Thinner, Synthetic Resin Enamel
O-D-406	Disinfectant, Germicidal and Fungicidal Concentrate
TT-E-489	Enamel, Alkyd, Gloss, for Exterior and Interior Surfaces

TO-1-2	Aircraft Weapon System Corrosion Prevention and Control
TT-E-527	Enamel, Alkyd, Lustreless
TT-E-529	Enamel, Alkyd, Semi-Gloss
QQ-S-571	Solder, Tin Alloy, Lead-Tin Alloy and Lead Alloy
O-S-595	Sodium Dichromate
H-B-643	Brush, Acid Swabbing
P-D-680	Solvent, Dry Cleaning
TT-E-751	Ethyl, Acetate, Technical, Organic Coating Use
O-S-801	Sulfuric Acid, Electrolyte, for Storage Batteries
SS-P-821	Pumice, Ground, Abrasive
MIL-STD-109B	Quality Assurance Terms & Definitions
MIL-P-116	Preservation, Methods of

MIL-V-173	Varnish, Moisture-and-Fungus-Resistant for the Treatment of Communication, Electronic, and Associated Electrical Equipment
MIL-STD-210A	Climatic Extremes for Military Equipment
MIL-STD-202	Test Methods for Electronic and Electrical Component Parts
MIL-STD-275	Printed Wiring for Electronics Equipment
MIL-STD-965	Parts Control Program
MIL-STD-252	Classification of Visual and Mechanical Defects for Equipment, Electronic, Wired and other Devices
MIL-STD-454	Standard General Requirements for Electronic Requirements
MIL-STD-810	Environmental Test Methods
MIL-STD-889	Dissimilar Metals
MIL-STD-1250	Corrosion Prevention and Deterioration. Control in Electronic Components and Assemblies (MICOM)

MIL-M-3171 Magnesium Alloy, Processes for Pretreatment and
Prevention of Corrosion on

MIL-E-5400 Electronic Equipment, Airborne, General
Specification for

MIL-T-5422 Testing, Environmental, Airborne Electronic &
Associate Equipment

MIL-C-5541 Chemical Films and Chemical Film Material for
Aluminum and Aluminum Alloys

MIL-S-7124 Sealing Compound, Elastomeric, Accelerator
Required, Aircraft Structure

MIL-E-7729 Enamel, Gloss

MIL-R-7751 Remover, Paint and Varnish Silicate Type

MIL-C-8514 Coating Compound, Metal Pretreatment, Resin-Acid
ASG

MIL-P-8585 Primer Coating, Zinc Chromate, Low-Moisture
Sensitivity

MIL-A-8625	Anodic Coatings, for Aluminum and Aluminum Alloys
MIL-M-10578	Metal Conditioner and Rust Remover Phosphoric Acid Base
MIL-P-11268	Parts, Materials, and Processes Used in Electronics Equipment
MIL-F-14072	Finishes For Ground Electronic Equipment
MIL-F-14256	Flux, Soldering, Liquid Resin Base
MIL-C-14460	Corrosion Removing Compound, Sodium Hydroxide Base, for Electrolytic or Immersion Application
MIL-C-15074	Corrosion Preventive, Fingerprint Remover
MIL-S-15847	Spray Gun and Accessories, Paint and Dope, Aircraft Use Validated September, 1965
MIL-P-15930	Primer Coating, Shipboard, Vinyl-Zinc Chromate Formula No. 120--for Hot Spray
MIL-P-15932	Enamel, Outside, Gloss Black, Vinyl-Alkyd Formula No. 122-1

MIL-P-15933	Enamel, Outside, Dull Black, Vinyl-Alkyd Formula No. 122-3
MIL-P-15934	Enamel, Exterior, Gray, No. 7 Vinyl-Alkyd Formula No. 122-7
MIL-P-15935	Paint, Outside, Gray, No. 11 Vinyl-Alkyd Formula No. 122-11
MIL-P-15936	Enamel, Exterior, Gray No. 27 Vinyl-Alkyd Formula No. 122-27
MIL-S-19500	Semiconductor Devices
MIL-R-25134	Remover, Paint and Lacquer, Solvent Type
MIL-C-25769	Cleaning Compound, Aircraft Surface, Alkaline Waterbase
MIL-T-27602	Trichloroethylene, Oxygen Propellant Compatible
MIL-P-28809A	Printed Wiring Assemblies
MIL-C-38334	Corrosion Removing Compound, Prepaint, for Aluminum Surfaces

MIL-M-38510	General Specification for Microcircuits
MIL-G-45204	Gold Plating Electro Deposited
MIL-I-45208A	Inspection System Requirements
MIL-I-46058	Insulative Compound Electrical (Printed Circuit) Assemblies
MIL-S-46860	Soldering of Metallic Ribbon Lead Materials to Solder Coated Conductors, Process for Reflow
MIL-S-46844	Solder Bath Soldering of Printed Wiring Assemblies
MIL-P-52192	Primer Coating, Epoxy
MIL-P-468438	Printed Wiring Assemblies
MIL-STD-210	Climatic Extremes for Military Equipment
MIL-STD-454	Standard, General Requirements for Electronic Equipment
MIL-STD-810	Environmental Test Methods

References

1. Keynote Address, Gen. Bryce Poe II, Commander, AF Logistics Command, Wright Patterson, AFB, Ohio - Proceeding of the 1980 Tri-Service Conference on Corrosion.
2. "Corrosion Control of Army Electronics Equipment" by Charles P. Lascaro, US Army Electronics Command, Ft. Monmouth, Presented at 1976 Tri-Service Conference on Corrosion, MCIC-77-33, Published by Metals & Ceramics Information Center, Battelle Columbus Laboratories.
3. Navy Maintenance Support Office Instruction 4790.1, Catalog of Aviation 3M Information Reports, NAMS0, Mechanicsburg, PA 17055.
4. Chief of Naval Operations Instruction 4790.2, Naval Aviation Maintenance Program, Chief of Naval Operations, Washington, D.C. 20350.
5. Naval Air Systems Command Instruction 5400.15, Master List of Engineering Cognizance Assignments, Naval Air Systems Command, Washington, D.C., 20361.
6. NAVAIR 16-1-540, Avionics Cleaning and Corrosion Prevention/Control, September 1981.

7. Anon., Test Report on Avionics Corrosion Control Program - Evaluation of Equipment for Cleaning of Avionics, Resource Management Systems Report, R79-01, May 1979.
8. Schmidt, R.D., RT-591/APN-130 and RT-908/APN-182 Radar Receiver-Transmitter Corrosion Problems, NARF North Island Engineering Report No. 10-74 of September 1974.
9. DeLong, G.E.; Myrben, L. C.; Carrato, A. F.; and Shaffer, I. S.; Aircraft Antenna and Electrical Bonding Corrosion Control, Report No. NADC-8009-60, Naval Air Development Center, Warminster, PA., April 1980.
10. Carrato, A. F.; Shaffer, I.S.; and Richwine, R. H.; Corrosion in Naval Aircraft Electronic Systems, National Association of Corrosion Engineers Conference, New Orleans, LA, October 1978.
11. Anon, Money, Manpower Called Keys to Progress, Aviation Week & Space Technology, October 6, 1980.
12. Reboul, M. C., Galvanic Corrosion of Aluminum, National Association of Corrosion Engineers, Corrosion, V. 35#9, September 1979.

13. "The Role of Quality Control in Preventing Corrosion in Electrical Circuitry" by C. H. Hutcherson, Materials Protection, Vol. 7, No. 6, June 1968.
14. Printed Circuits, "Assembly & Joining Techniques", published by IPC, 1717 Howard St., Evanston, Illinois, 60202.

8.5 Pamphlets, Handbooks

15. NAVMAT P-4855-2 Design Guidelines for Prevention and Control of Avionics Corrosion, June 1983.
16. Carrato, A.F.; Shaffer, I.S.; and Richwine, R.H.; Corrosion in Naval Aircraft Electronic Systems, National Association of Corrosion Engineers Conference, New Orleans, LA, October 1978.
17. Anon, Money, Manpower Called Keys to Progress, Aviation Week & Space Technology, October 6, 1980.
18. Navy Maintenance Support Office Instruction 4790.1, Catalog of Aviation 3M Information Reports, NAMS0, Mechanicsburg, PA 17055.
19. Chief of Naval Operations Instruction 4790.2, Naval Aviation Maintenance Program, Chief of Naval Operations, Washington, D.C. 20350.

20. Naval Air Systems Command Instruction 5400.15, Master List of Engineering Cognizance Assignments, Naval Air Systems Command, Washington, D.C., 20361.
21. NAVAIR 16-1-540, Avionics Cleaning and Corrosion Prevention/Control, September 1981.
22. Anon., Test Report on Avionics Corrosion Control Program - Evaluation of Equipment for Cleaning of Avionics, Resource Management Systems Report, R79-01, May 1979.
23. Schmidt, R.D., RT-591/APN-130 and RT-908/APN-182 Radar Receiver-Transmitter Corrosion Problems, NARF North Island Engineering Report No. 10-74 of September 1974.
24. DeLong, G.E.; Myrben, L.C.; Carrato, A.F.; and Shaffer, I.S.; Aircraft Antenna and Electrical Bonding Corrosion Control, Report No. NADC-8009-60, Naval Air Development Center, Warminster, PA, April 1980.
25. Reboul, M.C., Galvanic Corrosion of Aluminum, National Association of Corrosion Engineers, Corrosion, V. 35#9, September 1979.

26. Gilbert, L.O., Prevention of Material Deterioration: Corrosion Control Course, U.S. Army Rock Island Arsenal, 1966.
27. Anon., Reliable Electrical Connections, NASA SP-5002, Technology Handbook, December 1963.
28. Sparling, R.H., Corrosion Prevention/Deterioration Control Electronic Components and Assemblies, Engineering Report CR6-347-958-001, U.S. Army Missile Command, Redstone Arsenal, Alabama, undated.
29. "Corrosion of Army Electronic Equipment" by Charles P. Lascaro, 1972 Tri-Service Conference on Corrosion MCIC-71-19, Metals and Ceramics Center, Battelle, Columbus Ohio Laboratories.
30. Corrosion & Anti-Corrosives M. G. Fontana, R. V. Stachle, NY Plenum Press, 1974, Hex. Libr. No. 620.11
31. Corrosion Prevention for Practicing Engineers, 1970, Barnes & Noble, Busich, Joseph F.
32. Corrosion Resistance of Metals & Alloys, F. L. LaQue and H. R. Copson (Edited), First Edition by R. J. McKay & R. Worthington, Hex. Libr. No. 620.11.

33. NACE, Bibliographic Survey of Corrosion, 1950-51, Publication 55-4.
34. NACE Basic Corrosion Course, Houston Texas, 1970, Hex. Libr. No. N277NBCC, 620.11
35. Fundamentals of Corrosion, Scully J. C. Oxford, NY, Pergmon Press, 1966, Hex. Libr. No. 620.112.
36. Plastics for Corrosion Resistant Applications by Raymond B. Seymour, Robert H. Steiner, Reinhold, 1955, Hex Libr. No. 6685
37. Corrosion, Causes and Prevention, Speller, Frank Newman, 1951, McGraw Hill, Hex Libr. No. 62.11S.
38. Symposium on the State of the Art of Corrosion Testing, Toronto, 1970, Handbook on Corrosion Testing and Evaluation, Edited by W. H. Ailor, NY, J. Wiley, 1971, Hex. Libr. No. 620.1125.
39. Corrosion & Corrosion Control, Uhlig, Herbert Henry, NY, Wiley, 1963, Hex. Libr. No. 620.11V.
40. "Corrosion Handbook", Uhlig, Herbert Henry, Electro Chemical Society, 1948, NY, Wiley, Hex. Libr. No. 620.11.

41. Corrosion Resistance Tables, Metals, Plastics, Non-metallics, Rubbers, Schweitzer, Phillip A., 1976, Hex. Libr. No. 620-1122 S413.
42. Corrosion Engineering, Fontana, Marselio Guido, McGraw Hill, 1967, Hex. Libr. No. 620.112F.
43. Corrosion Resistant Materials Handbook, Mellan, Ibert, 1976, Hex. Libr. No. 620-112, M524.
44. IEEE Annual Reliability & Maintainability Symposium Proceedings, Hex. Libr. No. 620.00.45
45. Symposium of the Physics of Failure in Electronics, Chicago, 1963, RADC Series in Reliability, Hex. Libr. No. 653.55.
46. Reliability Physics Symposium, Annual Proceedings", sponsored by the IEEE Electron Device Group and the IEEE Reliability Group, 1970-1984, Hex. Libr. No. 620R.
47. Reliable Electrical Connections, EIA Conferences, NY Engineering Publication C1958, Hex. Libr. No. 621-37R.
48. Reliable Electrical Connections, Proceedings of Second RETMA Conferences, University of Pennsylvania, Philadelphia, 1956, 1957, Hex. Libr. No. 621.37.

49. IEEE Transactions on Components, Hybrids and Manufacturing Technology.
50. IEEE Transactions on Electron Devices.
51. IEEE Transactions on Parts Materials & Processes.
52. Corrosion, Volume 1: "Corrosion of Metals & Alloys," Edited by L. I. Shreir, 1963, John Wiley & Sons.
53. "Handbook of Corrosion, Testing & Evaluation," Edited by W. H. Ailor, Reynolds Metal Co., Sponsored by the Electrotechnical Company, John Wiley & Sons.
54. "Deterioration of Materials, Causes & Prevention Techniques," by Glenn A. Greathouse and Carl J. Weisel, Reinhold Publishing Co., 1954.
55. "The Fundamentals of Corrosion," J. C. Sculley, Pergamon Press, 1966.

9. Contractual Clauses Applicable to Acquisition Clauses

In order to achieve the stated objectives of a CPC plan, planning should be organized and implemented during all four stages of system acquisition. An outline of the recommended SOWs for each acquisition phase is as follows:

9.1 Concept Exploration

Determine from the ROC, mission profile and operational mode summary, the equipments planned platform use and field exposure in certain geographic areas during use, transportation and storage in accordance with paras 4.2.2, 4.5.9 and 4.6 of MIL-STD-810D, the contractor shall provide the following:

- a. The level and need for environmental protection and the level of corrosion protection needed in designs shall be predicted based upon the ROC mission profile and operational mode summary.
- b. The contractor's organizational element and individual with corrosion prevention background and experience, who will be responsible for management for a MADPAC program.

9.2 Demonstration & Validation (D&V)

The Contractor shall prepare a Corrosion Control Plan which will assure that corrosion and deterioration of protective finishes, coatings and paints will not occur when the completed design is exposed to the environmental conditions derived from paras 4.2.2 and 4.6 of MIL-STD-810D, AR-70-38 and MIL-STD-210. The planned design should meet design criteria and process controls listed in Appendix B of DARCOM R-702-24 and CECOM Supplement 1. The Reliability Program Plan per MIL-STD-785 shall list plans for subjecting the Full Scale Development equipments to corrosion stress testing which will establish the ability of the equipment to withstand the following environmental tests included in MIL-STD-810:

<u>Method No.</u>	<u>Title</u>
506.2	Rain
507.2	Humidity
508.3	Fungus
509.2	Salt Fog
512.2	Leakage (Immersion)

The CPC Plan shall include the following plan details as described in Appendix A and CECOM Supplement 1 of DARCOM-R-702-24.

- 9.2.1 Deterioration Prevention Discipline
- 9.2.2 Deterioration Prevention Program Plan and Progress Reports
- 9.2.3 Management
- 9.2.4 Quality Control Measures, Inspections
- 9.2.5 Design Considerations and Prediction of Effectivity During Storage, Field Use and Transportation
- 9.2.6 Degree of Protection Required for Each Functional Area and Package. Include Use of Transit Cases, Trailers, Vans, Platforms.
- 9.2.7 Finishes, Surface Treatments, Conformal, Coatings, Pottings, Internal, External
- 9.2.8 Materials Used, Metals, Plastics, Fungus and/or Corrosion Susceptibility, Galvanic Couples, Organics, Outgassings, Contaminants, Fasteners, Hardware with Stresses Susceptible to Corrosion, Minimum Strength Levels, Solders, Fluxes, High Strength Aluminums, High Zinc Brasses, Welding or Brazing Fluxes, Surface Quality of Contacts, Thickness of Gold Platings, Thickness of Nickel Underplate, Gold-Aluminum Intermetallics, Lubricants, Antiseize Materials, Complete Process Breakdown of Printed Circuit Assemblies and their Cleaning and Conformal Coating, Moisture Susceptibility of Honeycomb and/or Foam in Place Foams, Resistance to Moisture Ingress of all Cases; Containers; Especially Gasketed Including EMI RTV sealants.

9.2.9 Environmental Testing Schedule for DT/OT-II and Production

9.2.10 Plans for Preparing an SSS

9.2.11 Failure Analysis Plans which covers corrosion events

The contractors shall prepare a draft proposal for warranties against corrosion failures in the field including a list and definition of failure types that can occur and a rating of their criticality to equipment function and performance.

9.3 Full Scale Development (FSD)

The contractor shall update the CPC Plan to include design changes to indicate corrosion prevention has been considered and will be effective. Environmental test plans for corrosion during Production Phase shall be prepared and include samples of all painted, plated, coated or treated subassemblies or piece part hardware to be tested per MIL-STD-810D, Method 509.2 Salt Fog to determine quality of corrosion protection. All sealed containers should be planned to be tested for leakage per MIL-STD-810D Method 512.2 Immersion.

The contractor shall propose a final Warranty Program which includes a statement of liability for the contractor to prevent corrosion and a liability to correct corrosion deficiencies.

9.3.1 Suggested Warranty Clause Definition of Corrosion Failures

Prior to any contractual agreement on Warranty, a list of potential type of corrosion failures, functional or cosmetic, shall be proposed by the Government; including a definition of environmental limits of extremes, and a life cycle environmental profile, the equipment may be exposed to during usage, storage and transportation, IAW para 4.2.2.2, MIL-STD-810D.

The above list of definitions shall form the basis for remedies under the conditions of warranty. During the warranty period, equipments that have failed in the field shall be returned to the contractor and conduct failure analysis, sufficient to establish the root cause of failure and such results shall be reviewed by the CECOM CPC Management Office (PA&T).

10. Conclusions

- 10.1 The Mission Profile, Mode of Operation and projected field climatic extreme exposures should be used to specify the severity of the environmental testing to be required in FAT and Group C tests.
- 10.2 The control and prevention of corrosion in CECOM equipments is achievable by requiring and enforcing compliance with currently available specifications and standards. Due to the effect of rapidly changing techniques, however, it is essential that the applicable specifications and standards be continually updated accordingly.
- 10.3 In every acquisition plan, the CPC plan should be generated in the Advanced Development phase and updated in ongoing acquisition phases with periodic progress reports.
- 10.4 During the development phases, all material selection and design decisions should be reviewed for impact on corrosion resistance. During production, all ECPs should also be reviewed for corrosion impact. During storage, SSSs should require protective storage and periodic inspections for corrosion. During fielding, field manuals should describe corrosion inspections and QDRs should be studied for TNPs. It should be the responsibility of the CPC DPAO to monitor the above actions.

10.5 The seven essential guidelines for CPC are as follows:

- Good design, material selection and quality finishes.
 - Cleaning during all phases; especially production fielding and overhaul.
 - Drying interiors (open cover, dry, close cover)
 - Protective dry storage.
 - Any sign of corrosion after test should be cause for failure.
- All environmental tests should be rigorously required and performed.
- All electrical and mechanical failures should be subject to failure analysis to determine root cause of failure.
 - Warranties should insure against corrosion failures.

10.6 CPC key words are:

CPC Plan

Material Selection

Design Decisions

Process Controls:

MIL-P-11268

MIL-STD-454

MIL-F-14076

MIL-P-28809

Cleanliness

Dry Containers, Cases

Environmental Testing

Failure Analysis

SSS

QDR/Technical Need Proposals

Warranty