

**INTRODUCTION:**

The following paper is intended to inform on the subject at hand and is based on years of laboratory observations.

What does Galvanic Corrosion mean regarding my connector system/contact interface and can it be prevented or at least reduced?

This paper will address the phenomena that we call galvanic corrosion which in most cases is actually a combination of galvanic and electrolytic action. We will look at this from the electrical contact perspective. **GENERALIZED RULE NUMBER ONE: DO NOT MIX METALLURGIES**

**WHAT IS GALVANIC CORROSION?**

A Galvanic reaction is actually the creation of electrical current via chemical reaction. The result is the transfer/combining/corrosion of materials via the same reaction as in a battery. During this process, ions of metal move from “metal A” (anode) to “metal C” (cathode) while electrons move from “metal C” to “metal A” balancing the system/circuit. So in order to have a galvanic reaction, you need two dissimilar metals, an electrolyte and a common electrical connection (a path for the ions and electrons to flow).

**For Electrical Contacts, the typical scenario is:**

1. Dissimilar metals are mated (tin plug mated to a gold receptacle or vice versa).

Waiting for a reactive environment:

2. An electrolyte is introduced (moisture, salt spray, flux, etc.)

A tiny electrical current begins to flow through the unpowered contacts:

3. Galvanic reaction begins in the contact interface (and electrolytic reaction once power is applied).

The materials corrode forming resistive compounds:

4. Contact resistance increases as the materials corrode eventually leading to contact failure.

**NOTE:** Although the main thrust of this paper is a discussion of the galvanic/electrolytic reaction in electrical contacts, the same principles hold true for fasteners, guide hardware, cable conductors and wherever dissimilar metals are in close proximity.

## What is a galvanic cell?

A galvanic cell is similar to a battery and a plating cell containing an anode, cathode and electrolyte. The definition of a galvanic cell is a chemical reaction that produces electricity, like in a battery, while an electrolytic cell is a chemical reaction resulting from electrical stimulation like electroplating. One material is giving up electrons, while the other material is giving up ions.

So in an electrical circuit where there is current supplied, both reactions are taking place, both resulting in similar damage. Also called Metal to Metal corrosion or Dissimilar Metal corrosion, galvanic corrosion can also be compared to plating whereby one metal is transferred onto the surface of another (dissimilar) metal.

## Examples from history:

Back in the 1970s, an automotive manufacturer began using an aluminum bracket against a steel component. It wasn't long before we learned about putting steel against aluminum and then not being able to get them apart because they had galvanically corroded, and thus bonded together. We now use "anti-seize type of goop" between the aluminum and steel. Mixing metallurgies was found to be unacceptable in that environment.

The aluminum wire implementation in houses during the 1960s and 1970s caused a number of house fires and was eventually done away with until the 1990s when we finally got a suitable process for aluminum wire application. Aluminum and copper do not mix well without taking the appropriate steps to mitigate the galvanic reaction.

## GENERAL SUSCEPTIBILITY RULES:

The accepted limits as called out by NASA (NASA-STD-6012 and NASA-STD-6016) and the DoD (MIL-STD-889) have been established for many years and are repeated in many other documents.

In Table 1, some materials that are typically not encountered in the life of a connector system have been removed since this paper is written with that industry in mind. The full NASA table is at the end of this document.

If you are considering mating dissimilar metals, then the following classifications can be used in conjunction with the table to assess the system susceptibility to galvanic corrosion for various applications.

The numbers next to the environments represent the maximum "safe" difference between the voltages of the two materials being considered. We are using the Anodic Index (AI) convention where gold's AI is zero volts. The NASA table is based on the AI of +0.15V for gold in seawater.

**Example:** Gold (0V) when mated to Tin (0.65V), the AI Voltage difference is 0.65ΔV.

As you can see when comparing this Gold - Tin delta voltage to the application specific limits, this combination would not be recommended for any applications according to the accepted standard criteria.

**APPLICATION SUSCEPTIBILITY CLASSIFICATIONS (Maximum delta AI voltage)**

1. Harsh Environments (Outdoor, Military, etc.): 0.15ΔV
2. Normal Environments (Typical consumer products, uncontrolled indoor use): 0.25ΔV
3. Controlled Environments (Indoor, temperature and humidity controlled): 0.50ΔV

GALVANIC SERIES OF METALS COMMONLY FOUND IN ELECTRICAL CONNECTORS		
	METAL	Anodic Index (V)
1	Gold and gold-platinum alloys	0.00
2	Silver and high silver alloys	-0.15
3	Nickel and high nickel-copper alloys, Monel	-0.30
4	Copper, low brass and bronze, silver solder, high copper-nickel alloys	-0.35
5	Commercial, yellow Brass and Bronze	-0.40
6	High Brass and Bronze	-0.45
7	Tin plate and Tin-Lead solder	-0.65
8	Lead and high lead alloys	-0.70
9	Aluminum (2000 series, wrought)	-0.75
10	Carbon steel, wrought iron	-0.85
11	Aluminum (other than 2000 series, wrought)	-0.95
12	Hot dip Zinc plate (galvanize)	-1.20
13	Zinc, wrought	-1.25
14	Magnesium	-1.75

Table 1

**NOTE:** Some of the metals listed above may not be used directly as electrical contact material, but may be encountered during processing or during the life of the product.

**CONCLUSION:**

How can we stop it?

The stock answer that has been used for years is “**DO NOT MIX METALLURGIES**”.

**Use an anti-seize compound:**

While the anti-seize compounds are an effective way of preventing galvanic corrosion, many of the substances used may interfere with the electrical performance of the contact system and as such, this method of mitigation is not viable in some cases. Also due to the wet nature of some of these substances, they may have the propensity to hold particulate contaminants such as dust, wear debris, etc.

**Test your system!**

If you must mix metallurgies, then you should perform a proper testing protocol (aligned with your application) consisting of Temperature/Humidity Cycling, Steady State Humidity with polarizing voltage or possibly other environments that will exacerbate this reaction such as Salt Fog or even Mixed Flowing Gas. The testing will depend on your application.

**NASA and MILITARY REFERENCES**

**NASA-STD-6012**

**Table 2—Compatible Couples in Seawater**

GROUP NUMBER	METALLURGICAL CATEGORY	EMF (V)	ANODIC INDEX (0.01 V)	COMPATIBLE COUPLES (see note)
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 silvery 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	-0.45	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 2000 series	-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 2000 series 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 member of the series, ● indicates an anodic member. Arrows indicate the anodic direction.

Table 2

## NASA-STD-4003A

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**5.3 Galvanic Corrosion of Dissimilar Materials**

*Direct contact of dissimilar materials in the presence of moisture may result in corrosion, which impairs the effectiveness of any electrical bond and weakens the structure in which it occurs. When choosing materials for a given electrical bonding application, major factors that contribute to corrosion are the degree of separation of metals in the galvanic series and the amount of moisture present.*

a. Corrosion control of galvanic couples shall be in accordance with NASA-STD-6012 and NASA-STD-6016.

*Refer to Appendix A.3.7 for more information.*

**A.3.7 Galvanic Corrosion of Dissimilar Materials**

See paragraph 5.3 for applicable requirements. NASA-STD-6012 and NASA-STD-6016 contain considerably more information on this subject.

Two materials may be placed in direct contact if the electromotive force (EMF) difference between their groups is not more than 0.25 volts. Where other dissimilar materials are placed in contact, galvanic reaction may cause corrosion of the material that is higher (more anodic) in the galvanic series. Corrosion impedes current flow and damages materials. When two materials form a couple that is incompatible, the materials should be plated, coated, or otherwise protected with a conductive finish compatible with each; or a material compatible with each should be inserted between the two materials.

If the mating of dissimilar materials cannot be avoided, the most active of the materials should be replaceable in reusable vehicles. In all applications the electrolyte contact area of the most anodic materials, higher in series, should be larger than that of the cathodic materials. The larger the anodic area the lower the current density will be on more cathodic-materials. An approved sealant should be used to seal all edges from moisture.