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Higher Reliability "Oriented" Plastic Packages

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Abstract

Plastic IC Packages are generally considered to be <u>not</u> as reliable as their ceramic counterparts. One of the major reasons is the question of hermeticity. Plastic materials generally allow moisture/ humidity to penetrate through the body of the package. When moisture reaches the chip, the chip gets damaged and fails. With ceramic packages, moisture is kept out and the chips last much longer.

However, if we analyze the problem more closely, we would find that the penetration of the moisture into the package is accelerated by "Micro-Cracks" that occur at the interface between the metal leads and the plastic encapsulation, where the plastic material hugs and wraps around the leads. The tiny cracks, in essence, separate the plastic material from the lead metal. The cracks start at the edge of the plastic body and then propagate gradually inwards. Moisture gets into the cracks and follows them until it reaches the chip and damages it.

Moisture penetration via the cracks is much faster than through the solid plastic body. So, if we reduce or eliminate the chance of the occurrence of these micro cracks, then we would prolong the life of the plastic packages.

The author believes that the present design of plastic packages contributes largely to the creation of the micro-cracks, especially in the presence of thermal cycling and similar environmental conditions.

The author has arrived at a solution that would reduce the occurrence of such cracks, thus improving the reliability of plastic packages. This paper will describe the proposed solution.

Keywords

Assembly, Ceramic packages, Hermeticity, Micro-Cracks, Moisture, Moisture penetration, Humidity penetration, IC Packages, Plastic IC Packages, Prolong life, Propagation, Reduce occurrence of cracks, Reliability, TCE Mismatch, Thermal Coefficient of Expansion (TCE), Thermal cycling.

Executive Summary or End Goal

Figure 1 shows the general principle and the suggested way to orient the leads of leaded plastic packages. The leads are oriented such that the wide face of each and every lead would be looking to the "thermal center" of the device or the assembly. The result is that the leads would behave as soft springs, and would flex easily under thermal cycling. This in turn would exert minimum stresses at the bases of the leads, hence minimum chance of cracking the plastic housing of the device. Consequently, less moisture would penetrate to the chip cavity and the device would last longer.

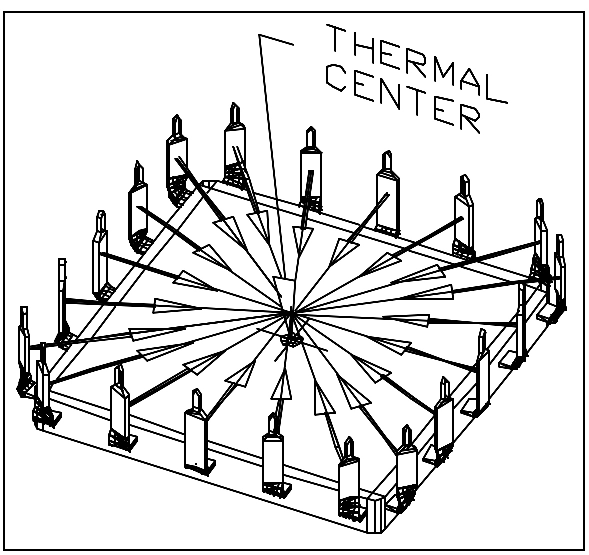

Figure 1 – Package with Oriented Leads

Background and Introduction
The proposed designs and solutions address the problems resulting from exposing electronic assemblies, including plastic packages, to varying temperatures, such as thermal cycling or power cycling, or resulting simply from being exposed to harsh environment, including hot and cold temperatures.

It has been know that plastic packages are <u>not</u> as reliable as ceramic packages. Plastic packages do <u>not</u> last as long as Ceramic packages. The Military, the Airline Industry and the Telecommunication Industry require that component last some ten to twenty years without failure. These industries specify ceramic leaded components most of the time, because their experience leads them to believe that ceramic components can satisfy these long operating life requirements, better than plastic components.

It has been stated that one of the reasons why plastic leaded components fail prematurely, as compared to ceramic, is the occurrence of <u>micro-cracks</u> between the plastic material and the leads or rather the legs. The legs are made of metal, most of the time out of Alloy 22, which has a TCE that closely matches the TCE of the Silicon chip. Sometimes other similar metals are used. Regardless of the material, the legs are usually relatively stiff. And this creates one of the main problems. After a component is assembled and soldered to its board, it has been noticed that some micro-cracks develop between the legs and the surrounding plastic material, which is the body of the package. The cracks start at the outside edges of the plastic, right next to the metal legs. The cracks migrate gradually inwards and become larger, until they allow moisture and outside atmospheric gases to migrate inwards towards the chip inside the package. This migration of undesirable materials can damage the chip or at least can make the chip "age" faster. The end result is the failure of the package.

Of course, the plastic material of the body itself allows some moisture to pass through, but the moisture penetration through the micro-cracks, once they have developed, is much faster, and that is the reason why it is always desirable to prevent such cracks from occurring. It is also believed that thermal cycling accelerates such micro-cracks.

The proposed designs and solutions are believed to be able to improve this situation. These solutions will be described here below.

Definitions
I would like to use the following terms and expressions in the paper. The following definitions will ensure that the reader will get the correct meaning as we proceed. See Figure 2.

<u>Lead or Leg</u>: A connecting element that is provided on an electronic device, to mount the device or to attach it to another electronic device or a printed circuit board or substrate.

Lead Nomenclature. See Figure 2, which gives the designations of all the terms used in this paper, e.g. <u>Lead Base</u>, <u>Foot</u>, <u>Heel</u>, <u>Twist</u>, <u>Stem</u>, <u>Taper</u>, <u>Pin</u> and <u>End</u>.

Bending or Flexing of the Leads: <u>Across Flats</u>, <u>Across Face</u>, <u>Across Edge</u>:

Figure 3 shows two leads at a corner of a leaded package. Usually the leads of leaded electronic devices are made out of flat sheet metal, with a relatively small thickness compared to the width of the lead. The lead on the right hand side of the figure is being bent "<u>across the flats</u>" or "<u>across the face</u>", where the tip is moving from point C to D and back. This implies that the flat wide face/ section of the lead is facing the bending direction. In contrast, the lead on the left-hand side of the figure is being bent "<u>across the edge</u>", where the tip is moving from point A to B and back. This implies that the bending direction is against the edge of the lead.

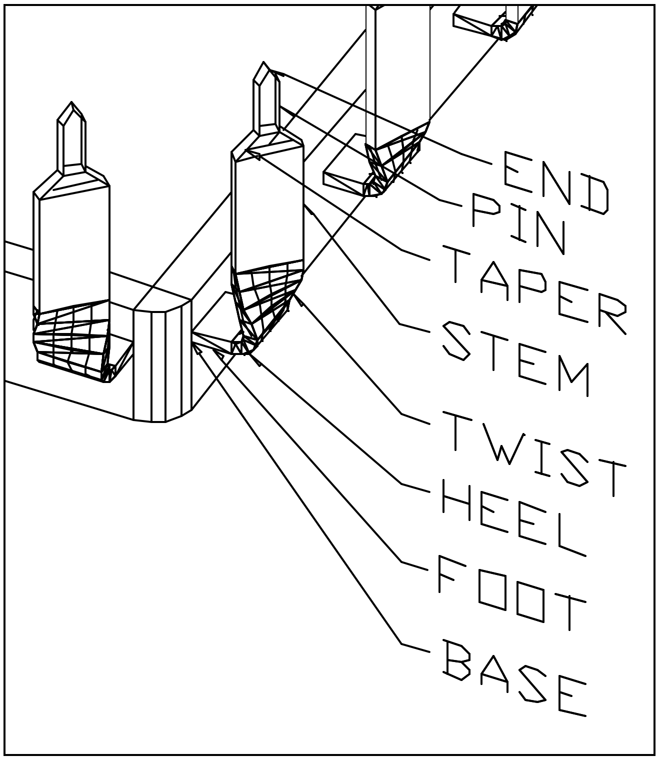

Figure 2 – Definition of Terms Used in the Paper

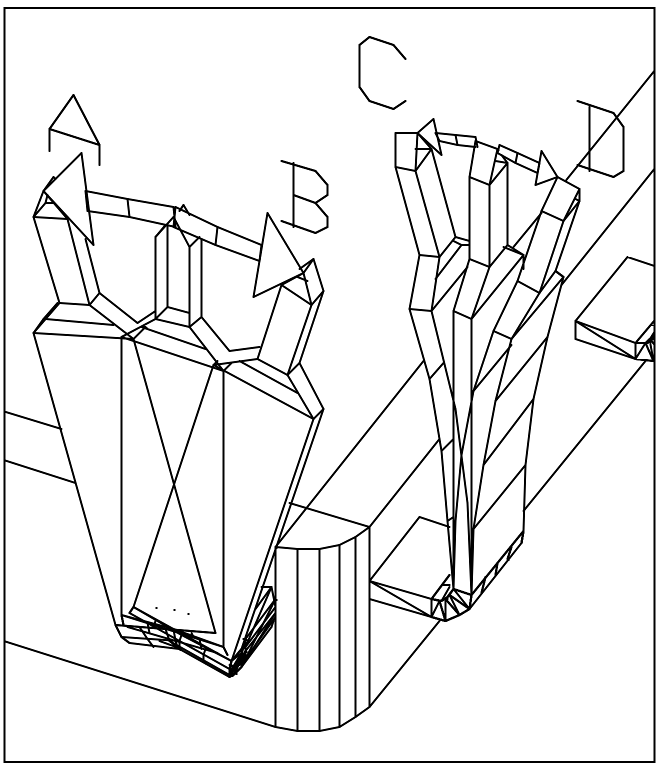

Figure 3 – Bending the Leads "On Edge" (A-B) or "Across the flat" (C-D)

Basic Principle

Any physical body that is heated or cooled expands or shrinks in a three-dimensional fashion, in a spherical pattern. It behaves as if there is a point somewhere in its center that is the "origin" of all the dimensional changes. I will refer to such a point as the "thermal center" of that body.

Electronic packages are no different. When a package is heated or cooled, it expands and contracts in a similar fashion. All elements of the package move along some imaginary radii, emanating from the thermal center. For assemblies that are relatively flat and thin, the expansion and contractions could look as if they happen in a flat plane or slab, as if the motion is circular, not spherical.

So, the legs or leads of a leaded electronic component get pushed or pulled in similar fashion, i.e. along those imaginary radii. Let me explain that action and explain the effect of such action.

If a leaded package were mounted to a PCB that has a different TCE than that of the package, and if the assembly were exposed to thermal cycling, then the package would expand and contract at a different rate than the PCB. This is called the Effect of the TCE Mismatch. The dimensional differences would have to be absorbed by the leads connecting the package to the board. The leads would deflect, bend and/or flex to take up the dimensional differences.

Now, let us study how the leads behave.

Figure 3 shows two leads at a corner of a leaded package. Usually the leads of leaded electronic devices are made out of flat sheet metal, with a relatively small thickness compared to the width of the lead. The lead on the right hand side of the figure is being bent “across the flats” or “across the face”. See my definitions at the beginning of the paper. This implies that the flat wide surface of the lead is facing the bending direction. In contrast, the lead on the left-hand side of the figure is being bent “across the edge”. This definition implies that the bending direction is against the edge of the lead.

From general experience and common sense, we know that such a lead would bend easier across the flat and would behave as a soft spring, compared to the case where we try to bend it across the edge, where the lead would behave as a much stiffer spring. It can also be demonstrated analytically that this is true.

Now let us study the effect of such bending on the stresses at the base of the lead. First, let us study the bending <u>across the flats</u>. Let’s say we need to bend the lead, so that we get a certain amount of deflection at its tip. Since the lead will flex (the technical term would be “deflect”) easily, then for that amount of deflection, we will get a relatively small level of stress at the base of the lead.

Now, let us compare that with the other case, and bend the lead <u>across the edge</u>. We will try to bend the lead, so that we get the <u>same amount of deflection</u> at the tip of the lead, as we did in the first case. Since the lead is much stiffer in bending across the edge, the base of the lead will exert a much higher level of stress on the plastic body of the package.

Such higher level of stress can be enough to crack or break the plastic surrounding the base of the lead.

Let me explain further.

If we try to use a crow bar to open the lid of a crate, we would be more successful if we use a bending motion in the same direction as with the lead on the left-hand side of Figure 3, i.e. bending the crow bar on edge. The crow bar will be stiffer, i.e. stronger, and will not flex, and will help us open the crate. The force required to bend the crow bar will be high, but we will create a big gap or opening in the crate. If, on the other hand, we use the crow bar in a way similar to the bending effect on the lead at the right hand side of the figure, i.e. bending it across its flats, the crow bar handle may flex and may not open the crate.

The same crow bar action and its effect will apply to the package, as explained here below.

In conventional leaded packages, which are either square or rectangular in shape, the leads are usually in an orthogonal position, such that the leads are parallel to the sides or the central axes of the package and the leads are either parallel or at 90 degrees to each other.

The leads that are along the central axes are usually bent across their flats, i.e. the bending direction on these leads is usually perpendicular to the face of the leads. But the bending direction on all the other leads is usually diagonal to the face of the leads. This means that, on those leads, there are two bending components acting on each lead. One component can be considered to be acting perpendicular to the face of the lead, while the second components would be acting on the edge of the lead.

This second component, the edge bending component, is the most detrimental one. It is the one that would have the undesirable “crow bar” effect on the plastic package, actually on any kind of leaded package. It is more likely to “open” or “crack” the plastic housing/body of the package. This is the bending component that I am trying to eliminate by my proposed designs.

This edge-bending component is a major contributor that causes the micro-cracks in the plastic body of plastic packages, and causes moisture to migrate to the insides of the package, ultimately causing the premature failure of the package.

So, in order to minimize this detrimental effect, we should try to minimize the crow bar effect. We can do that by trying to bend the leads across their flats, and not across their edge. And we can accomplish that, simply by arranging the leads to face the thermal center.

I would like to refer to this arrangement as “orienting” the leads to face the thermal center of the particular package that is being considered.

We can do that by orienting the leads, as described here in this paper**.**

How to Make the Twisted Leads
Figures 4 through 7 show one of the proposed methods. In Figures 1, 2, 4 and 5, the leads of the package are oriented, such that each lead is facing the thermal center, regardless of where the lead is. In this case, each lead is giving the least resistance against the bending action. Hence, the least stresses are applied to the base of the leads and transferred to the base of the leads, or to the plastic housing of the package.

Of course, one other way to help along the same goal would be to make the lead thinner and/or longer, thus softer. This could be done by using a thin material to start with, or by spanking or forming the lead to be thinner at that point and/or along its flexing length, so as to make it more flexible.

But if this option is not selected, then the rest of this paper will show what else can be done, i.e. the orientation of the leads.

There is ONLY ONE EXTRA STEP, to achieve the desired goal.

Figure 6 shows the only extra manufacturing step that is required to accomplish the proposed end goal. Figure 6 shows the leadframe, as stamped out or etched out of a flat sheet of metal, to create the leads out of that flat sheet metal. In the conventional manufacturing methods, the chip is attached to this flat leadframe, then encapsulated, then the molding dams are trimmed off, then the leads are “folded” down, ad then finally the package is separated from the carrier strip.

If we want to use this same leadframe to make packages with oriented leads, then the only extra step would be to “twist” the leads while the leadframe is still flat and is still being manufactured. Ideally, this should be done at some time, before the encapsulation, so that the twisting action would not stress or disturb the plastic encapsulation.

Please note that the amount of twisting will increase from zero at the central leads, and will increase as we go farther away from there, to a maximum at the corner leads.

If we compare the manufacturing method required to accomplish the end goal against the methods used to make conventional packages, we will see that there is only one additional step in the method described above, over the conventional methods. It is the step of twisting the external portion of the leads, shown in Figure 6.

This twisting step can be done at either one of two different instances during the manufacturing process.

One possibility is to do the “twist” when the leadframe is being manufactured on its own. When the leadframe is being stamped out of flat sheet metal strip, the external portions of the leads can be formed as well, to become twisted as required. The leadframe strip will then be reeled up on take-up spools for the subsequent operations. It would be advisable, in this case, to put a layer of protective material between the layers of metal leadframe, so as to protect the twisted leads from getting deformed or damaged.

The other opportunity would be during the molding/encapsulation process. The leadframe gets unwound and threaded into the molding machine or the molding boot (form). Before the encapsulation step, the external portions of the leads could be twisted as required and then the subsequent operations would take place as normal.

Figure 7 shows the package, after the twisted leads have been “folded” down, and just before separating the package from the carrier strip.

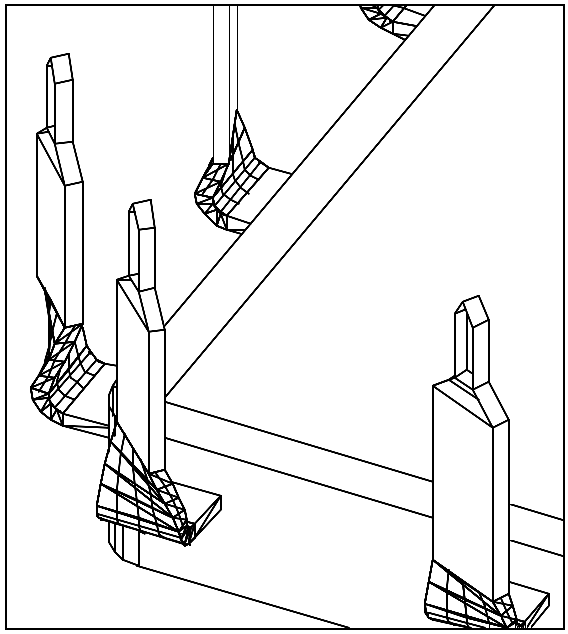

Figure 4 – Corner Leads, Twisted Right after their Heels, to be Oriented as Needed

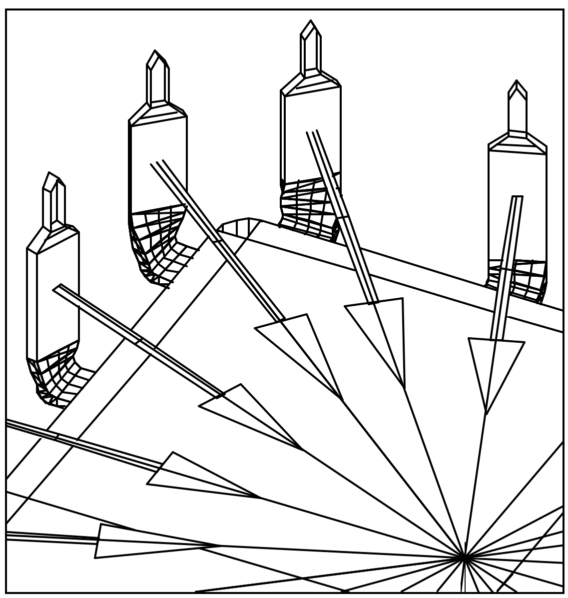

Figure 5 – Each and Every Lead is "Oriented" to have its "Flat" Facing the Thermal Center"

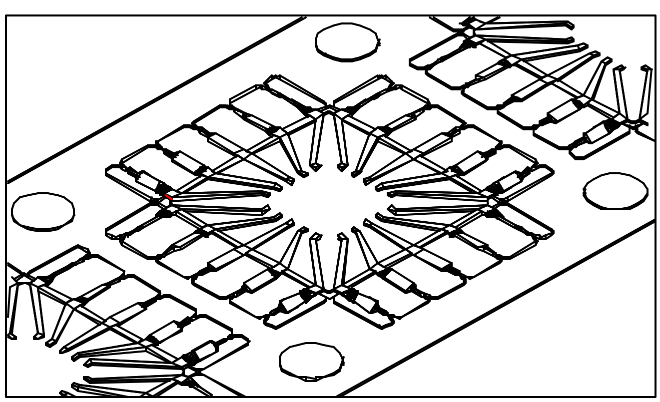

Figure 6 – Leads are "Twisted" near their Bases, while they are still on the "Flat" Leadframe – Each lead to an Appropriate Angle

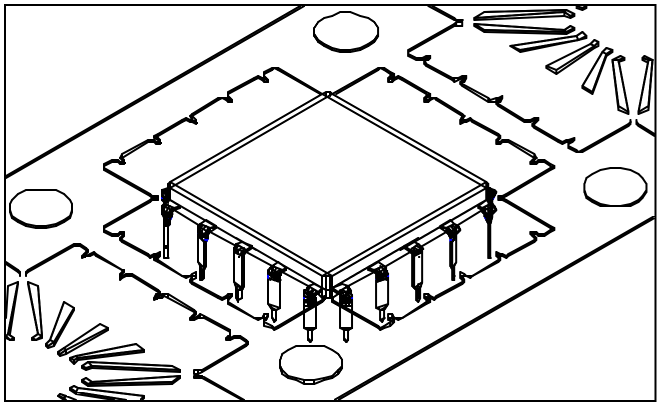

Figure 7 – When Leads are “Folded” at their Heels, they will Automatically be “Oriented” Properly

“Oriented Leadframe”
In all the above, we have assumed that the leadframe is made to have the leads come out of the body of the package, in an ORTHOGONAL direction. For this reason, we had to “twist” the leads, so that they would face the thermal center after they get folded down.

This has two disadvantages. First, it requires an additional step; the step of twisting that portion of the lead. Second, it makes it that we loose some height. The twisted portion of the lead would be ABOVE the generally more flexible portion of the lead.

I propose a second, easier method to accomplish the same end goal. There will be no need to “twist” the lead. A simple “fold-down” would accomplish the goal. Figures 8, 9 and 10 show the idea.

Figure 8 shows a leadframe of a package, where the leads protrude from its body in a “RADIAL” direction. The body of the package is represented by its square outline only. A portion of the leads that is embedded inside the body of the package is shown in solid lines, as if the plastic body is transparent, just for clarification. The drawing shows the rays, emanating from the “thermal center” and giving the direction for the leads protruding out from the body.

Figure 9 shows the top left portion of the flat leadframe and Figure 10 shows a 3-D view of that corner of the leadframe. We first see, at the left side of the two figures, the flat leadframe, as stamped say, and after the encapsulation step. The leads have not been folded yet. Then, in the middle/right side of Figure 10, we see the leads folded up, because here we are looking at the package up side down.

In this case, the fold-down steps, shown in Figure 10 would automatically produce leads facing the “thermal center”, without the need for any “twist” in the lead.

The result is that the flexible portion of the lead will be longer than the twisted leads, for the same package height.

This is more desirable and would be the preferred way to go. However, this means more changes in the way the portions of the leadframe that are embedded inside the body of the package would be designed and routed.

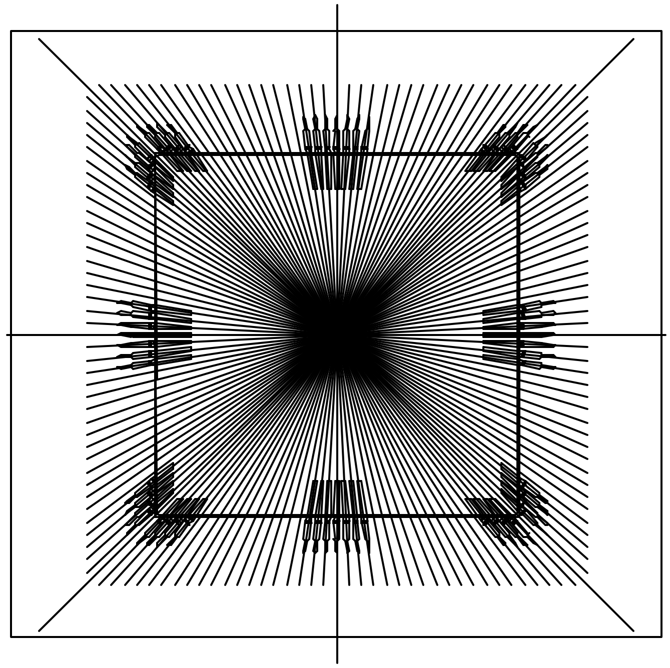

Figure 8 - Leads are "Blanked" "Radially" on their Respective Angles, so that when they are "Folded", they would end up being "Oriented" Properly No "Twisting" would be Necessary

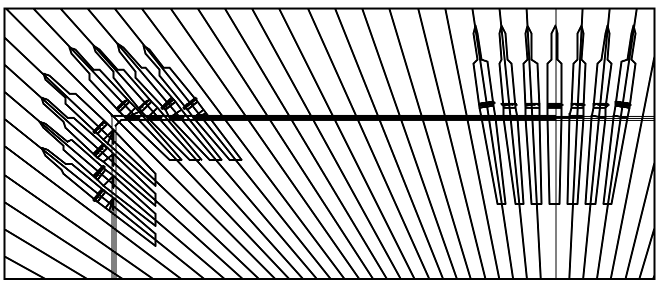

Figure 9 – Radial Lead blanks at a Corner and at the Center Edge of a Leadframe, showing "Fold Lines"

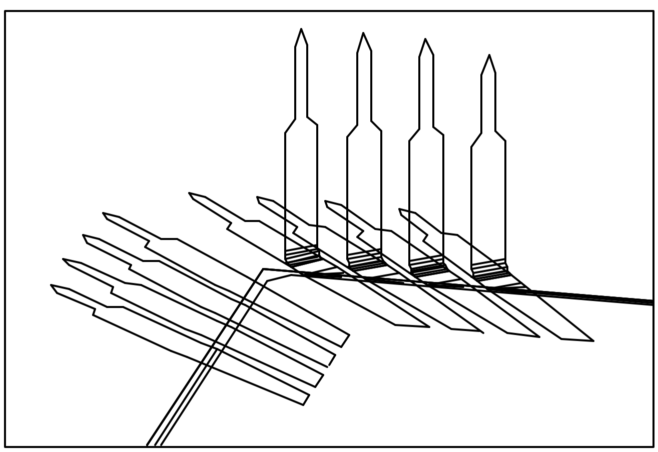

Figure 10 – Folded Leads at a Corner of a Package

All Types of Leaded Packages

Figures 11 and 12 show two leaded packages. The package in Figure 11 has gull-wing leads, while the one in Figure 12 has Jay-leads. In both cases, the leads are oriented as suggested designs, so as to face the thermal center of the package, so as to provide maximum flexibility and minimum resistance to deflection.

Basically, the concept applies to any leaded package, that have leads with varying stiffness depending on the orientation of the leads, and to packages that would undergo expansion and contraction problems due to TCE mismatch with their environment.

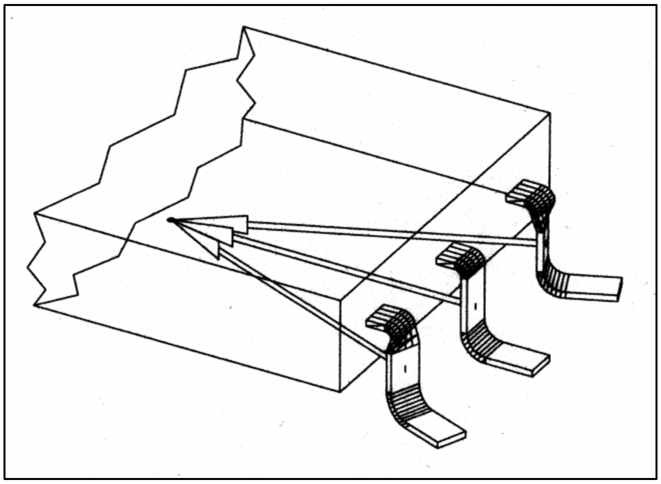

Figure 11 – Gull Wing Leads, Oriented Properly

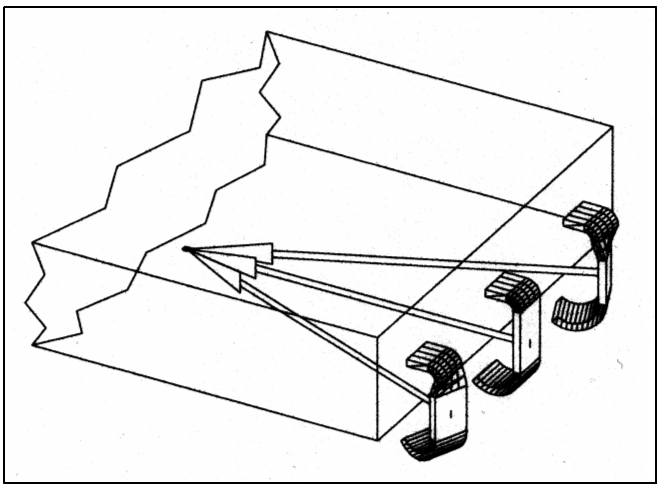

Figure 12 – Jay-Leads, Oriented Properly

Solder Pads

If the package, with oriented leads gets mounted on a PCB, with "through holes", i.e. the package leads get inserted in holes in the PCB, and then get soldered, then there is really no problem. Whether the "solder tails" of the package leads are "oriented" or not, in the majority of cases, this should make hardly any difference. The solder will simply fill the space between the hole and the lead tail, regardless of how the lead is oriented. The tools of the insertion machine may need to be adjusted to grab the leads properly. But this is not the object of this invention.

However, if the package get "Surface Mounted" onto the Board, then the solder pads could be modified to accept either the oriented leads only, or better yet, to be universal, so as to accept both conventional as well as oriented leads.

Intellectual Property

All the above is "Patent Pending".

Conclusion and Future Plans

Plastic packages with oriented leads are expected to perform better than conventional packages. It is expected that would compare favorably with ceramic packages and could be considered as a viable substitute for them.

The plan for the future is to make actual prototypes and test them side by side with conventional packages and assemblies, to prove that the proposed method does indeed accomplish the goals of improving the reliability of such packages.

The author is seeking partners to do the above and to prove the validity of the theory.

References

1. “Evaluating the Moisture Barrier” by J. J. Licari, Ph.D., Advanced Packaging Magazine, July-Aug 1997.
2. “How Plasma-Enhanced Surface Modification Improves the Production of Microelectronics and Optoelectronics”, by Dr. James D. Getty, March Plasma Systems, Concord, Calif., in CHIP SCALE REVIEW Magazine, January-February 2002, pp. 72 through 75.
3. "Bonding Strengths at Plastic Encapsulant-Gold-Plated Copper Leadframe Interface," by S. Yi, J. Kim et al., Microelectronics Reliability, January 2000, p. 1212.