

Converting Ball Grid Array Components to Column Grid Array

Russell T. Winslow

Six Sigma
Milpitas, CA 95035

URL: www.sixsigmaservices.com

Email: russ@solderquik.com

*Military, Aerospace, Space, and Homeland Security: Packaging Issues & Applications Workshop
(MASH 2005)*

Abstract

Area array packaging technology has taken the electronics industry by storm. Ball Grid Array (BGA) components provide a huge increase in available interconnects without the troubles associated with bent leads. However, these wonderful new components bring with them serious issues related to board-level reliability at extreme temperatures as seen in industrial, military, and space environments. Column Grid Array (CGA) is the solution to this problem. This paper introduces a process for converting ball grid array components to column grid array. It specifically discusses the construction details of the reinforced solder column, provides background on its heritage, and presents reliability data.

The Need for Ruggedized Components

The availability of military-grade microelectronics components has been on a steady decline. This has forced high-reliability users to utilize Commercial-off-the-Shelf (COTS) components to fulfill their requirements. Commercial-grade components cannot always meet the reliability requirements of harsh environment applications. In order to meet this demand, techniques have been introduced for the ruggedization of these COTS components.

BGA Reliability Compromises

BGA is rapidly becoming the industry standard for high lead-count microelectronics packaging. As this revolution in packaging takes place, the industry is accepting a compromise in thermal cycling reliability. A perimeter-led device, such as a Plastic Quad Flat Package (PQFP), with flexible gull-wing leads, can be subjected to thermal cycles without encountering stresses due to the Coefficient of Thermal Expansion (CTE) mismatch between the component and the board. BGA packages, on the other hand, are connected with a rigid structure of solder spheres that provide very little compliance between the component and the board. When the device is powered-on, waste heat builds up and creates a temperature differential between the component and the board. This temperature differential, as well as the differences in CTE between the component and the

board will lead to stresses in the solder joints. For commercial temperature ranges (0°C to 100°C) and life cycle requirements (<2000 cycles), the stresses have been shown to be acceptable. However, applications that require broader temperature ranges (e.g., -40°C to +125°C), extended life cycles (>2000 cycles) and possibly the use of ceramic substrates (e.g., Motorola PowerPC™), BGA technology is a high risk.

Column Grid Array Solution

A successful solution to the BGA compromise is to utilize a flexible column in place of the solder spheres. Figure 1 shows the difference between a BGA component with solder spheres and a CGA component with solder columns.

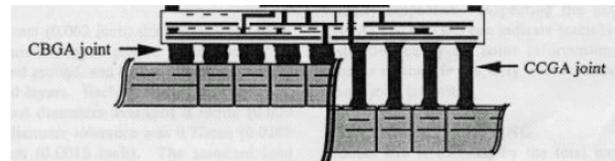


Figure 1. Ball Grid Array vs. Column Grid Array¹

CGA provides a more robust design for thermal cycling environments in two ways:

First, the leads are designed to have a lower stiffness than a solder sphere, and second, they have a higher standoff distance between the component and the board. These two features enable the leads to flex with less stress as the dimensional expansion between the component and the board varies. The taller standoff will reduce the stress in the solder joint by the square of the distance between the component and the board.²

Figure 2 shows a simplified equation for the maximum stresses in a solder column. This is a first order approximation and assumes that the column is in elastic bending only. The equation shows that the stress is proportional to the difference in temperatures (T_1 , T_2), difference in CTE (α_1 , α_2), distance to the neutral point (S), diameter of the column (d), and inversely proportional to the square of the column length (L). The size of the fillets will slightly reduce the “effective” value of (L).²

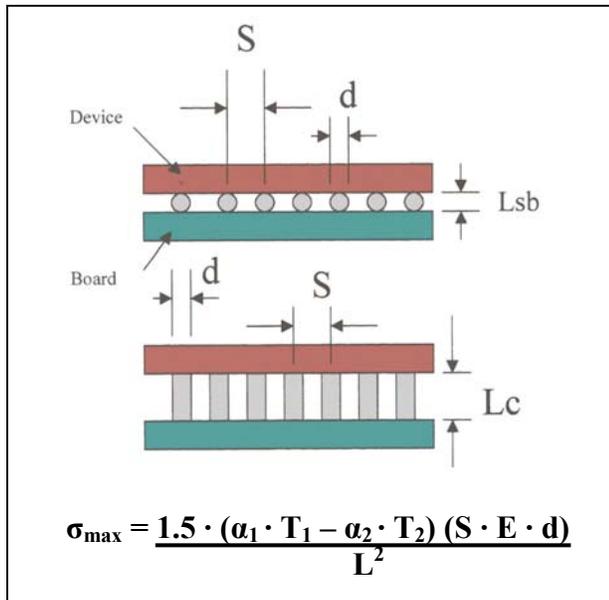


Figure 2. Stresses in Solder Joints

Where:

- T_1 = Temperature of Board
- T_2 = Temperature of Component
- α_1 = CTE of the Board
- α_2 = CTE of the Component
- S = Distance from Neutral Point (DNP)
- E = Modulus of Elasticity of Ball or Column
- d = Diameter of Ball or Column
- L = Standoff Height of Ball or Column

Typical solder columns have a standoff height of approximately 2.2 mm and typical solder spheres (eutectic) will have a standoff (after reflow) of approximately 0.64 mm. This change in standoff reduces the stresses by a factor of 4 to 16.³ Additional reductions are achieved because the solder columns are smaller in diameter and, therefore, have a lower overall stiffness.

Column grid array technology is not limited to use on ceramic components. Plastic ball grid array components have been successfully mounted on solder columns thereby providing significant improvements in second-level reliability.

Column Grid Array History

The technology for solder columns has been available for over 20 years. In 1984, Raychem Corporation (now a division of Tyco) developed a patented solution for mounting Leadless Chip Carriers (LCCs) to circuit boards using solder columns.² In this timeframe, the LCC had one of the same problems that we are faced with today - namely, the mismatch of CTE between the ceramic component and the board. Raychem's solution was a Chip Carrier Mounting Device

(CCMD). The CCMD product (figure 3) consists of solder columns held in place by a water-dispersible paper laminate that is washed away after the columns are attached to the component. The CCMD solution was quite successful and has been used in many military and space electronics applications such as the Singars radio, flight data recorders, and many satellites. Millions of military LCCs mounted on CCMD solder columns have performed successfully.

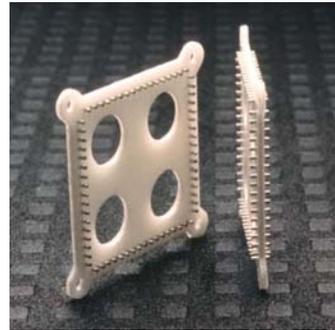


Figure 3. Raychem's Patented CCMD

In 1996, the Raychem Solderquiktm line, including exclusive rights to the patented CCMD technology, was purchased by Winslow Automation, Inc. The Column Grid Array version of CCMD (figure 4) was introduced in 1998 by Winslow Automation, Inc. dba Six Sigma. In 1999, the Motorola Power PC with reinforced solder columns was qualified for use in electronics upgrades for the FA-18 jet fighter.

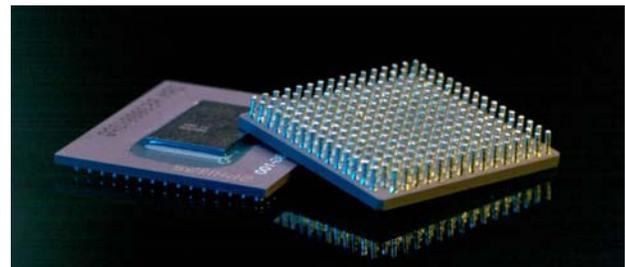


Figure 4. BGA Converted to Column Grid Array

There are three basic types of solder column technologies on the market today.

- 1) **The wire column.** This consists of a high-lead (Pb90-Sn10) solder wire mounted to the component and the circuit board with eutectic (Sn63-Pb37) solder. Hard tooling is typically used to attach these columns.
- 2) **The solder column interposer.** This consists of high-lead (Pb90-Sn10) solder held in an array with an additional ceramic substrate. The ceramic interposer remains in place beneath the component after board assembly. This additional substrate will induce its own stresses if its temperature differs from that of the component.

3) **The reinforced solder column.** This column design consists of a high-lead solid wire core spiral-wrapped with a copper ribbon (figure 5). The column material is encapsulated with eutectic (Sn63-Pb37) solder. The reinforced solder columns are held in a water-soluble laminate until attached to the component at which point the laminate is washed away or removed.

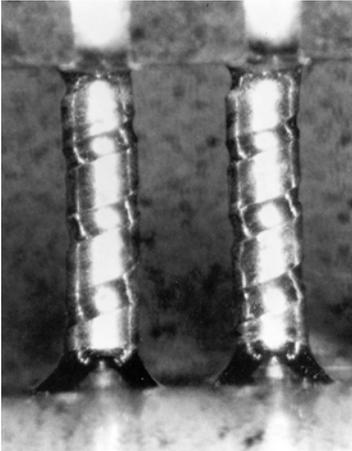


Figure 5. Reinforced Solder Column

Advantages of the Reinforced Solder Column

The spiral copper ribbon adds redundancy without a significant increase in stiffness. Typical solder column failures occur due to cracking at the taper of the eutectic (Sn63-Pb37) fillet.^{4,5,6} Figure 6 shows the location of maximum strain predicted by a finite element model developed by the Georgia Institute of Technology.⁷ Literature shows that this failure may occur towards either the board or component end of the solder column.^{4,6,8}

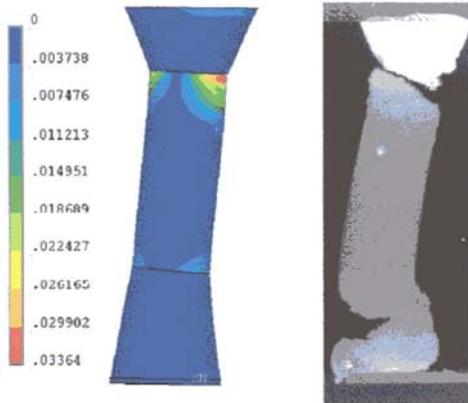


Figure 6. Non-Reinforced Column Failure^{7,8}

In the case of the reinforced solder column, this failure mechanism is abated by the copper reinforcement

allowing the component to continue functioning long past when the high-lead core has cracked. Figure 7 shows a cross-section of the copper-reinforced solder column.

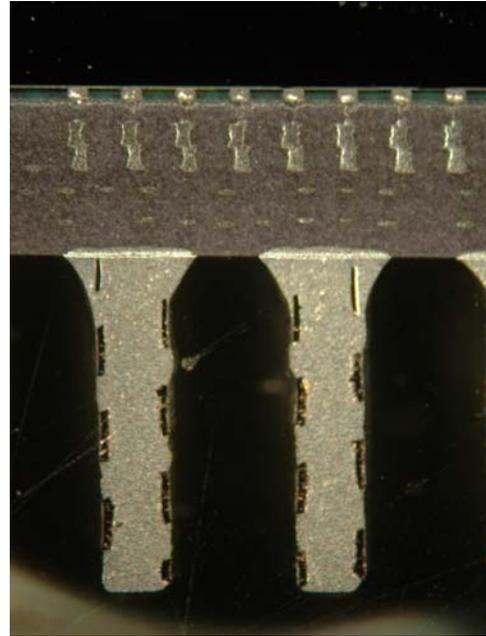


Figure 7. Cross-Section of Reinforced Solder Column

Construction Details

The reinforced column wire made by wrapping high-lead solder wire with a tin plated copper ribbon as shown in figure 8. The wire is then passed across a wave of eutectic (Sn63-Pb37) solder to encapsulate it (figure 9).



Figure 8. Solder Column Wrapping Process



Figure 9. Solder Column Wire after Wave Solder

Component Preparation

BGA, CGA, or virgin Land Grid Array (LGA) components, are prepared for column attach by passing them across a wave of eutectic (Sn63-Pb37) solder on a robotic solder dipping system. This removes any existing solder balls, columns, and/or gold metalization. If not removed, the residual gold could cause solder joint embrittlement due to the formation of Gold-Tin (Au-Sn) intermetallics.⁹

After this initial preparation step, the substrates are printed with solder paste or bumped with small spheres of solder to provide the correct amount of eutectic (Sn63-Pb37) solder for the fillet. After alignment of the solder column preform, the component is reflowed and then washed to remove the preform. The components are then inspected, baked, and dry packaged appropriately.

Test Results from Industry

A long-term temperature-cycle study by Lockheed Martin shows a significant performance improvement of the reinforced column over both the straight wire column and the solder column interposer.¹¹

Temperature Cycles were conducted at -10 to +125 °C

CBGA625 (U3): Ceramic Ball Grid Array. This is a 625-pin full array package with solder balls made from Pb90-Sn10 attached to the component with Sn63-Pb37 solder. Package Size 32mm square with a matrix of 25 x 25 balls on a pitch of 1.27mm.

CCGA625R (U4): Ceramic Column Grid Array. This is a 625-pin full array package with reinforced solder columns provided by Six Sigma. Package Size 32mm square with a matrix of 25 x 25 columns on a pitch of 1.27mm.

CCGA625 (U5): Ceramic Column Grid Array. This is a 625-pin full array package with straight wire solder columns made from Pb90-Sn10 attached to the component with Sn63-Pb37 solder. Package Size 32mm square with a matrix of 25 x 25 columns on a pitch of 1.27mm.

CI-CGA361 (U10): Ceramic Column Grid Array. This is a 361-pin full array package with a ceramic interposer with solder columns made from Pb90-Sn10 attached to the component with Sn63-Pb37 solder. Package Size 25mm square with a matrix of 19 x 19 columns on a pitch of 1.27mm.

Visual Crack Detection	F50	eta	
U3	CBGA625	240	259
U4	CCGA625R	1700	1830
U5	CCGA625	840	911
U10	CI-CGA361	840	896

Daisy Chain- Manual Bench Probe

		F50	eta
U3	CBGA625	95	112
U4	CCGA625R	3010	3291
U5	CCGA625	1500	1750
U10	CI-CGA361	1600	1927

Daisy Chain- Anatech Real-Time

		F50	eta
U3	CBGA625	50	76
U4	CCGA625R	3400	3793
U5	CCGA625	1650	1844

Another long-term reliability test was performed previously by an un-disclosed company. In this test, a total of (32) 360-Pin Ceramic Ball Grid Arrays and (32) Ceramic Column Grid Arrays with reinforced columns were temperature-cycle tested from 0 to 100 °C. The temperature-cycle conditions were 2 cycles per hour with a ramp time between temperatures of 10 minutes and a dwell time at each temperature of 5 minutes. The components were daisy-chain devices mounted on 1.57 mm thick FR-4 made up of 4 layers with two 1-ounce copper layers in the center to simulate power and ground planes. Half-ounce copper was used for the signal layers on top and bottom. The board pad was non-solder mask defined with a 28.5-mil solderable surface. The pad coating was an organic solderability protectant.

The results of this test are shown in figure 10.

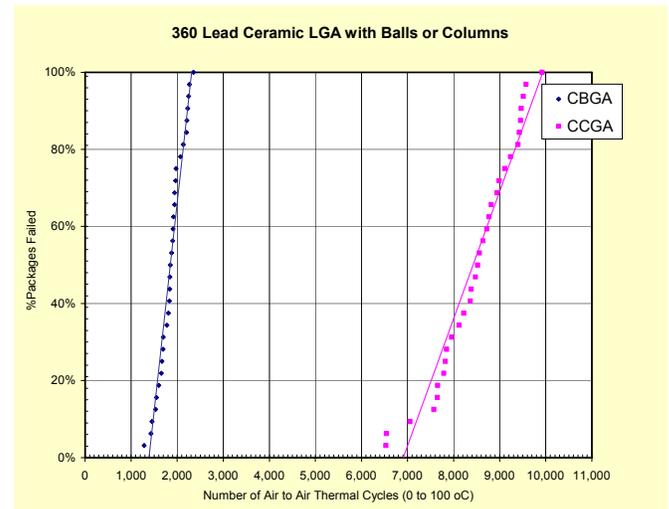


Figure 10. Temp-Cycle comparison of High-Lead CBGA vs. Reinforced Solder Columns.

Summary

CGA is an important technology that has many applications in future high reliability systems. The technology has been available and proven reliable for over 20 years. IBM has been using the technology for many years to provide its components with a CGA interconnect. Additionally, column attach has been commercially available for most land grid array (LGA) components as a value-added service through Six Sigma for over 7 years. It has been qualified as a reliable interconnect format by numerous OEMs. As the need for grid array packaging designs proliferates into the high reliability market, this technology is expected to become widely used for many commercial and military applications

Acknowledgments

The author would like to thank William Davis, Applied Material Technologies, for his valuable analysis, discussions, and helpful input.

References

- [1] Donald R. Banks, R. David Gerke, "Assembly and Reliability of Ceramic Column Grid Array" *Proceedings of SMI*, 1994, Vol. 2, pp. 271-276.
- [2] Gabe Cherian, "Use of discrete Solder Columns to Mount LCCCs on Glass/Epoxy Printed Circuit Cards", *Proceedings of International Electronics Packaging Conference*, 1984, pp. 701-710.
- [3] W. E. Davis, R. T. Winslow, "Column Grid Array: A Modified COTS Approach for Area Array Packaging of Military and Space Electronics" *Proceedings: Commercialization of Military and Space Electronics (CMSE)*, February, 2001, pp. 391-398.
- [4] A. Sinha, P. Issacs, T. Tofil, "Mechanical Reliability of CCGA Solder Joints", *Proceedings of SMTA International*, April 1997.
- [5] R. N. Master, "Ceramic Column Grid Array for Flip Chip Applications", 1995 Proceedings 45th Electronic Components and Technology Conference, pp. 925-929.
- [6] E. M. Ingalls, M. Cole, J. Jozwiak, C. Milkovich, J. Stack, "Improvement in Reliability with CCGA Column Density Increase to 1mm Pitch", 1998 *Proceedings 48th Electronics Components and Technology Conference*, pp.1298-1304.
- [7] Andy Perkins, Suresh K. Sitaraman, "Thermo-Mechanical Failure Comparison and Evaluation of CCGA and CBGA Electronic Packages", *Proceedings of Electronics Components and Technology Conference (ECTC)*, 2003, pp. 422-430.
- [8] M. Cole, I. DeSousa, M. Interrante, L. Jimarez, J. L. Jozwiak, M. S. June, G. B. Martin, C. Milkovich, J. Ross, M. J. Shannon, "The new Millenium for CCGA – Beyond 2000 I/O" *Proceedings of SMTA International*, September 2001.
- [9] H. H. Manko, "Solders and Soldering", 3rd Edition, McGraw-Hill, New York, 1992.
- [10] D.R. Banks, C. G. Heim, R. H. Lewis, A. Caron, and M. S. Cole, "Second Level Assembly of Column Grid Array Packages" *Journal of Surface Mount Technology*, 7 (2), 1994, pp. 3-9.
- [11] T. Clifford, "Final Report – Phase 1 T-Cycle Test", IP-Free version, *Lockheed Internal Document*, July 25, 2004.