MOTOROLA

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PowerPC™

Application Note

Flip-Chip PBGA Package Construction— Assembly and Board-Level Reliability

Motorola introduced the flip-chip plastic ball grid array (FC PBGA) packages as an alternative to, and in some cases a replacement package for, PowerPC™ microprocessors and related chips that are currently packaged predominately in ceramic BGA (CBGA). This application note is designed to assist both current CBGA and first time BGA users to reliably deploy Motorola's FC PBGA technology into their assembly processes and products from an interconnect perspective.

1.1 General Package Information

The FC PBGA has a similar general configuration to the CBGA, but there are several major differences in the packages. The two most significant differences are as follows:

- The FC PBGA is based on an epoxy/glass organic, as opposed to a ceramic substrate
- The FC PBGA uses 62Sn36Pb2Ag solder balls that melt in the solder reflow process, while the CBGA uses 90Pb10Sn solder balls.

A cross-section of each package type is shown in Figure 1 through Figure 4 and includes higher magnification cross-sections of the two solder-ball types. Additionally, because the PBGA package employs near-eutectic solder balls, there is no eutectic solder paste volume requirement for assembly, as compared with the CBGA package. For successful FC PBGA assembly, solder paste or flux must be successfully applied to each motherboard pad.

The CBGA is qualified to JEDEC moisture sensitivity level (MSL 1), meaning it is resistant to moisture-induced damage during reflow. The epoxy/glass substrate of the FC PBGA results in the package being moisture sensitive. The FC PBGA is currently qualified to MSL 3. FC PBGA devices are shipped dry-packed and after the drypack is opened, packages must either be stored at less than 20%RH or soldered within 168 hrs of exposure to 30°C/60%RH. Packages that are not soldered within 168 hrs must be baked for 24 hrs at 125°C prior to assembly. Table 1 outlines the major differences between the two package types.

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Table 1. Comparison of Motorola's FC PBGA and CBGA Packages

Package Attribute	Flip-Chip PBGA	CBGA
Substrate dielectric material	Epoxy/Glass	Ceramic (Alumina - Al_2O_3)
Substrate CTE (ppm/°C)	12 to 14	6.7
Solder ball composition (weight %)	62Sn36Pb2Ag	10Sn90Pb[1]
Solder ball diameter (mm)	0.76	0.86
Package solder pad diameter (mm)	0.64	0.86
Package solder pad type	Soldermask Defined (SMD)	Metallization Defined
Entire solder ball reflows during assembly	Yes	No
Solder ball liquidus (°C)	189	302
Solder ball solidus (°C)	179	275
Recommended motherboard solde pad solderable surface diameter (mm)	0.58 (or 23.0 mils)	0.72 (or 28.5 mils)
Optional motherboard solder pad solderable surface diameter (mm) Note: Use of this pad is acceptable, but may result in slightly reduced board-level reliability.	0.72	0.58
Solder paste volumes required for motherboard assembly (mm3)	No min. Must only apply flux or paste to each solder pad	Minimum of 0.079 Nominal of 0.115
JEDEC moisture sensitivity level (MSL)	MSL3 (Can be out of dry-pack for 168 hrs at 30°C/60%RH. Exceeding 168 hrs requires bake-out before reflow)	MSL1[2]
Allowable out of dry-pack storage conditions to avoid bake-out before reflow£20%RH for up to one year any condition since MSL1	≤20%RH for Up to One Year	Any condition because MSL1
Bake-out time before reflow (for parts violating out-of-drypack time)	24 hrs at 125°C	Not applicable because MSL1
Recommended assembly reflow profile	Solder-paste dependent	Solder-paste dependent
Qualified maximum reflow temperature (°C)	220-0/+5 (3 passes)	220-0/+5 (3 passes)
Specified maximum coplanarity (mm)	0.20	0.15
Body size for given pin counts	503 pin (33 mm) 360 pin (25 mm) 255 pin (21 mm)	503 pin (32.5 mm) 360 pin (25 mm) 255 pin (21 mm)

[1] Ball attached to package with 63Sn37Pb solder

[2] Not moisture sensitive—can be out of dry-pack indefinitely before reflow

Figure 1 through Figure 4 show a cross-section of each package type.

NOTE:

Figure 1 and Figure 3 do not show the die and are not approximately proportional. Solder joint pictures are only approximately proportional.

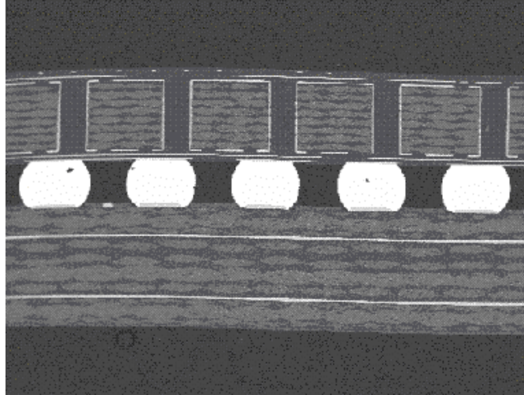


Figure 1. FC PBGA Package Mounted to a Board

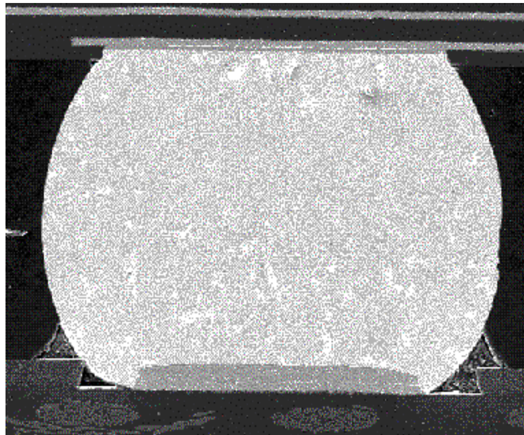


Figure 2. FC PBGA Solder Joint

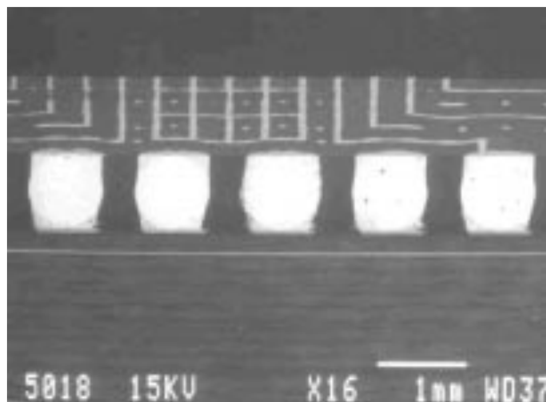


Figure 3. CBGA Package Mounted to a Board

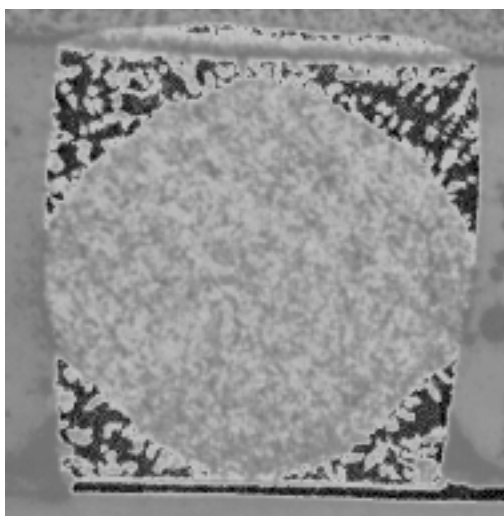


Figure 4. CBGA Solder Joint

1.2 Motherboard Solder Pad Geometries

Figure 5 and Figure 6 contain the recommended solder pad geometries for the FC PBGA and the CBGA, respectively. A pad with a 0.58 mm diameter solderable surface that is 0.05 mm smaller than the 0.635 mm package pad is recommended for the FC PBGA. The preferred CBGA pad is larger with a diameter of 0.72 mm. For maximum solder joint reliability, it is recommended to maintain the solder pad diameter within the range shown (0.72±0.037). However, board-mounted solder joint reliability data in 0 to 100°C thermal cycling on a CBGA using a PBGA-sized motherboard pad shows that reliability is not impacted greatly; see Section 1.3, “Surface Mount Assembly.” Even when the smaller motherboard pad is used for the CBGA, a minimum solder paste volume of 0.079 mm3 (see Table 1) must be applied to each pad during board assembly.

Note that the pads shown in both Figure 5 and Figure 6 are non-soldermask (NSMD) or etch defined. They have an annular soldermask clearance of 0.075 mm around the copper pad. This configuration is recommended for the best solderability, especially when a hot air solder leveled (HASL) surface finish is used. However, there are other factors that affect what motherboard pad type is chosen. The NSMD pad is best for solderability, but because it has a smaller copper diameter than an SMD pad and does not have the added strength provided by the soldermask overlap, it may be weaker. It may be more likely to fail during bending, severe ramp rate thermal cycling, component rework or site dress after rework. Failure can occur by the pad lifting out of the board or by the trace cracking where it enters the pad, especially if the trace has a width of less than 0.30 mm.

The via and via-pad diameters shown in Figure 5 and Figure 6, as well as soldermask clearances, can be adjusted as necessary to meet individual design rules. The interstitial plated through-hole diameter is shown as 0.30 mm for CBGA and greater than or equal to that for the FC PBGA. A via size increase may be possible due to the decreased solder pad diameter associated with the FC PBGA. Soldermask clearance around the solder pad should be specified such that soldermask does not encroach on the pad at the worst-case soldermask to artwork registrational tolerance of the printed circuit board fabricator. The surface finish for CBGA or FC PBGA may be any consistently solderable surface such as organic solderability protectant (OSP), HASL, electroless or electrolytic nickel/gold or immersion silver.

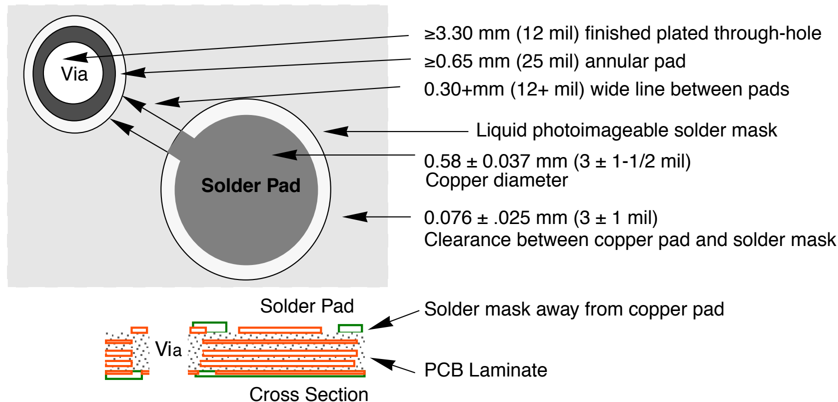


Figure 5. Recommended FC PBGA Motherboard Solder Pad Geometry

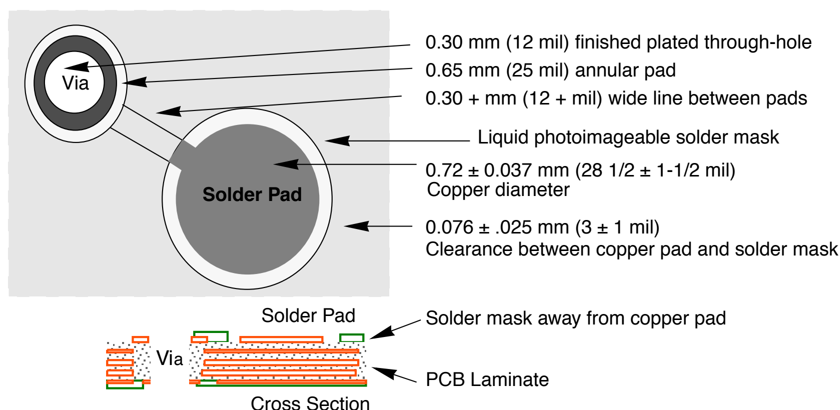


Figure 6. Recommended CBGA Motherboard Solder Pad Geometry.

1.3 Surface Mount Assembly

The board assembly process for FC PBGA is basically the same as for CBGA with a couple of exceptions. Due to its high-Pb content solder ball, the CBGA has very specific solder paste volume requirements while the FC PBGA has none. The CBGA's minimum volume of 0.079 mm^3 equates to a 0.15 mm thick stencil with 0.84 mm diameter apertures. Another difference may be in the profiling and zone settings of the reflow furnace. The CBGA has a much higher thermal mass than the PBGA; therefore, it may be the coolest part on a given assembly. Both part types should be profiled along with other suspected low and high temperature packages on the board. For the BGAs, this is accomplished by placing a thermocouple under the part, preferably within the solder joint, surrounded by thermally conductive grease or epoxy.

The reflow profile for both package types should follow the recommendations of the solder paste supplier. Neither package has a required reflow profile, and both packages are qualified to a maximum reflow temperature of 225°C. In general, it is recommended that the profile have a preheat sufficient to raise temperature of the joints to 100°C over a period of no less than 50 seconds. Too long of a rise time can cause the flux or solder paste to dry out and reduce its effectiveness. The peak temperature on any component should generally be between a minimum of 205°C and a maximum 220°C. It is recommended that the dwell time be less than two minutes above 183°C. The desirable dwell time above 183°C is greater than 50 seconds and less than 80 seconds.

With regard to component placement using automated pick and place equipment, the solder balls on the two BGA types are easily recognized by most vision systems. The solder ball diameter, grayness (due to the different Pb content), and package body colors are different for FC PBGA and CBGA, so adjustments may be necessary to certain vision parameters. Alignment can take place off of the solder balls or the package body for either package type. It should be noted that due to JEDEC registrational differences, the body size for a given pin count may be slightly different for FC PBGA versus CBGA. See the last line of Table 1 for specific information.

1.4 Board-Level Reliability

The two package types behave quite differently with regard to the solder joint's ability to withstand repeated board-mounted thermal cycles. The CBGA substrate, with a coefficient of thermal expansion (CTE) of 6.7 ppm/°C, is mismatched to most epoxy/glass motherboards which have a CTE of around 16 to 22 ppm/°C. This package to motherboard expansion difference causes the solder balls at the CBGA corners followed by the edge to fail first in repeated board-level thermal cycling.

The silicon die itself has a CTE of 2.6 ppm/°C that results in a mismatch with respect to the ceramic substrate. However, because the ceramic is relatively stiff, the die has minimal influence on the CBGA solder joints. The reliability of the interconnection between the die and ceramic substrate (in effect, the bumps) is excellent due to the presence of an underfill.

Figure 7 shows two-parameter Weibull plot of the board-level reliability of the Motorola XPC107 503-pin CBGA with a 32.5 mm body size cycled from 0 to 100°C while mounted to a 1.57 mm thick, four-layer test board. Data is supplied using both the CBGA and PBGA-sized pads. Both cases used a solder-paste volume of 0.079 mm^3.

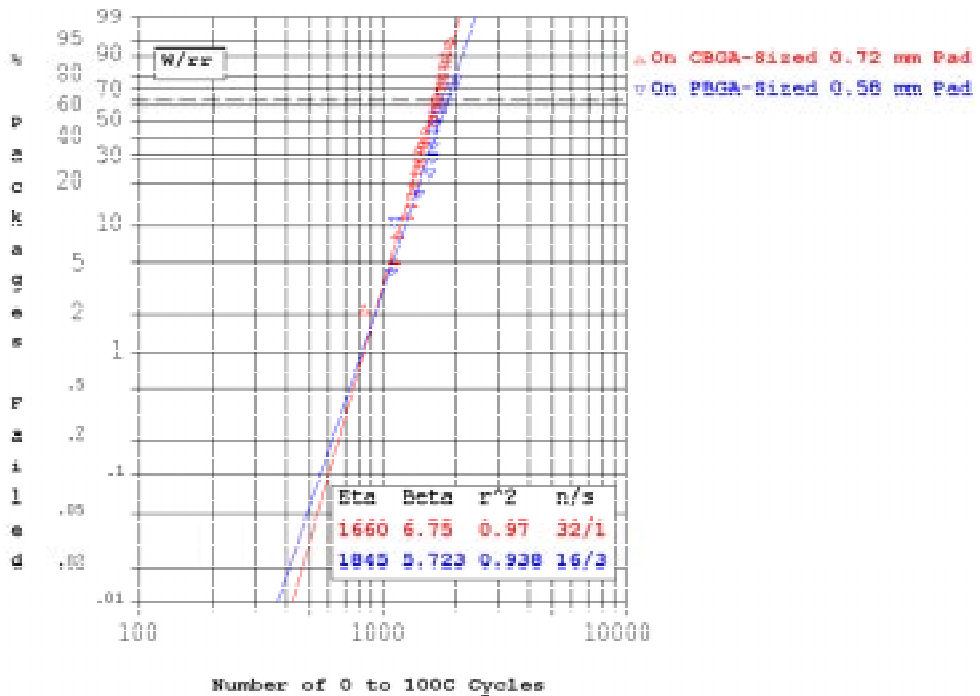


Figure 7. Two Parameter Weibull Plot of the Board-Level Reliability of the Motorola XPC107 503-pin CBGA

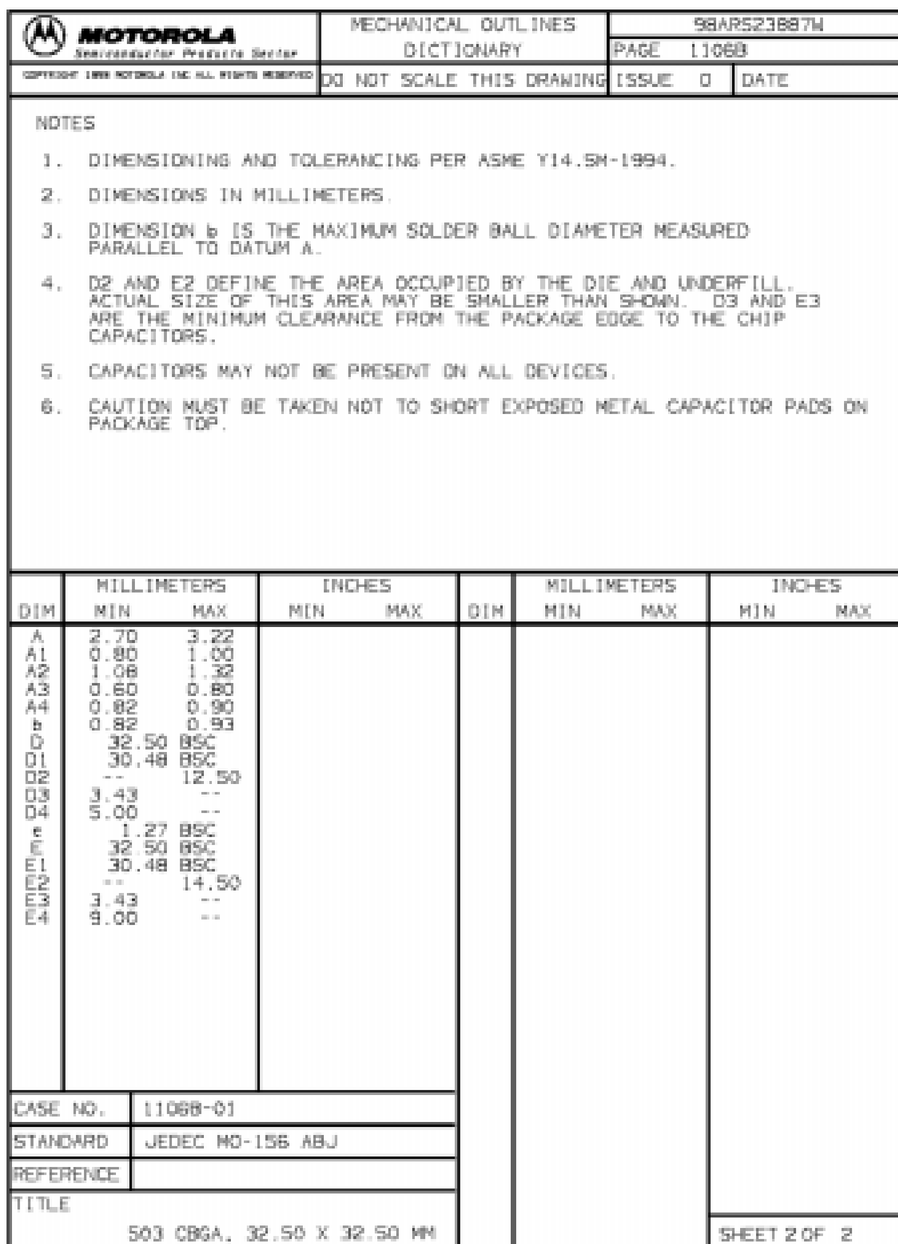
Board-Level Reliability

Motorola has extensive board-level reliability data on every CBGA body size used for products. Figure 7 contains solder-joint reliability data for the 503-pin, 32.5 mm body Motorola XPC107 mounted to a 1.57-mm thick, four-copper-layer FR-402 epoxy/glass test board that is thermally cycled from 0 to 100°C with five-minute ramps and ten-minute dwells. This is currently the largest CBGA body size offered by Motorola; see package drawing in Figure 8. This package contains seven perimeter rows of solder balls with an 11x11 array depopulated in the center. The board-level failure data in Figure 7 is plotted on two parameter Weibull axes, and data is presented for both the CBGA and PBGA preferred motherboard pad sizes of 0.72 and 0.58 mm, respectively. Each point on the lines represents a package failure which is defined as the series resistance through all the joints going over 300 Ohms during continuous in-situ monitoring. The PBGA recommended pad actually has a higher Eta or cycles to 63.2% failure, but due to the lower slope of the line (Beta) for the PBGA-sized pad, the cycles to failure for lower failure rates such as 0.1% and 0.01% are somewhat worse for this optional pad.

Conversely to the CBGA, the FC PBGA's epoxy/glass substrate is well matched in terms of expansion to most motherboards. The FC PBGA substrate has a CTE of approximately 12 to 14 ppm/°C. It also relies on underfill to provide adequate die-to-package interconnect reliability, but since the FC PBGA substrate is not as stiff as the CBGA's, the die can have some influence on the reliability of solder joints proximate to the die edge. The die's influence is mitigated by the use of 1.0-mm thick substrate on all Motorola FC PBGAs and by depopulating the solder balls under the die edge on some designs such as the 503-pin package.

The Motorola XPC107 in a 503-pin FC PBGA (see Figure 9) has passed 6,000 0°C to 100°C thermal cycles with no fails. This equates to an expected 6x increase in board-level reliability relative to the same size CBGA for which data was presented in Figure 7. Because the 503-pin is a perimeter package with no solder balls under the die edge, the board-level reliability for full-array FC PBGAs such as the 255- and 360-pin packages may not exhibit the same increase, but they will still provide a significant board-level reliability improvement over CBGA. Board-level cycling on the 360-pin, 25 mm FC PBGA is currently underway with no fails out to 3,000 cycles, which represents an approximate 3x increase in life relative to the equivalent CBGA. Cycling on this 360-pin FC PBGA is being carried out using both the FC PBGA and the CBGA-sized motherboard pads with no fails on either pad size.

Figure 8. Motorola 503-Pin CBGA Package Drawing



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2. DIMENSIONS IN MILLIMETERS.
3. DIMENSION b IS THE MAXIMUM SOLDER BALL DIAMETER MEASURED PARALLEL TO DATUM A.
4. D2 AND E2 DEFINE THE AREA OCCUPIED BY THE DIE AND UNDERFILL. ACTUAL SIZE OF THIS AREA MAY BE SMALLER THAN SHOWN. D3 AND E3 ARE THE MINIMUM CLEARANCE FROM THE PACKAGE EDGE TO THE CHIP CAPACITORS.
5. CAPACITORS MAY NOT BE PRESENT ON ALL DEVICES.
6. CAUTION MUST BE TAKEN NOT TO SHORT EXPOSED METAL CAPACITOR PADS ON PACKAGE TOP.

DIM	MILLIMETERS MIN	MILLIMETERS MAX	INCHES MIN	INCHES MAX	DIM	MILLIMETERS MIN	MILLIMETERS MAX	INCHES MIN	INCHES MAX
A	2.70	3.22							
A1	0.80	1.00							
A2	1.08	1.32							
A3	0.60	0.80							
A4	0.82	0.90							
b	0.82	0.93							
D	32.50 BSC								
D1	30.48 BSC								
D2	--	12.50							
D3	3.43	--							
D4	5.00	--							
e	1.27 BSC								
E	32.50 BSC								
E1	30.48 BSC								
E2	--	14.50							
E3	3.43	--							
E4	9.00	--							

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TITLE 503 CBGA, 32.50 X 32.50 MM

SHEET 2 OF 2

Figure 8. Motorola 503-Pin CBGA Package Drawing (Continued)

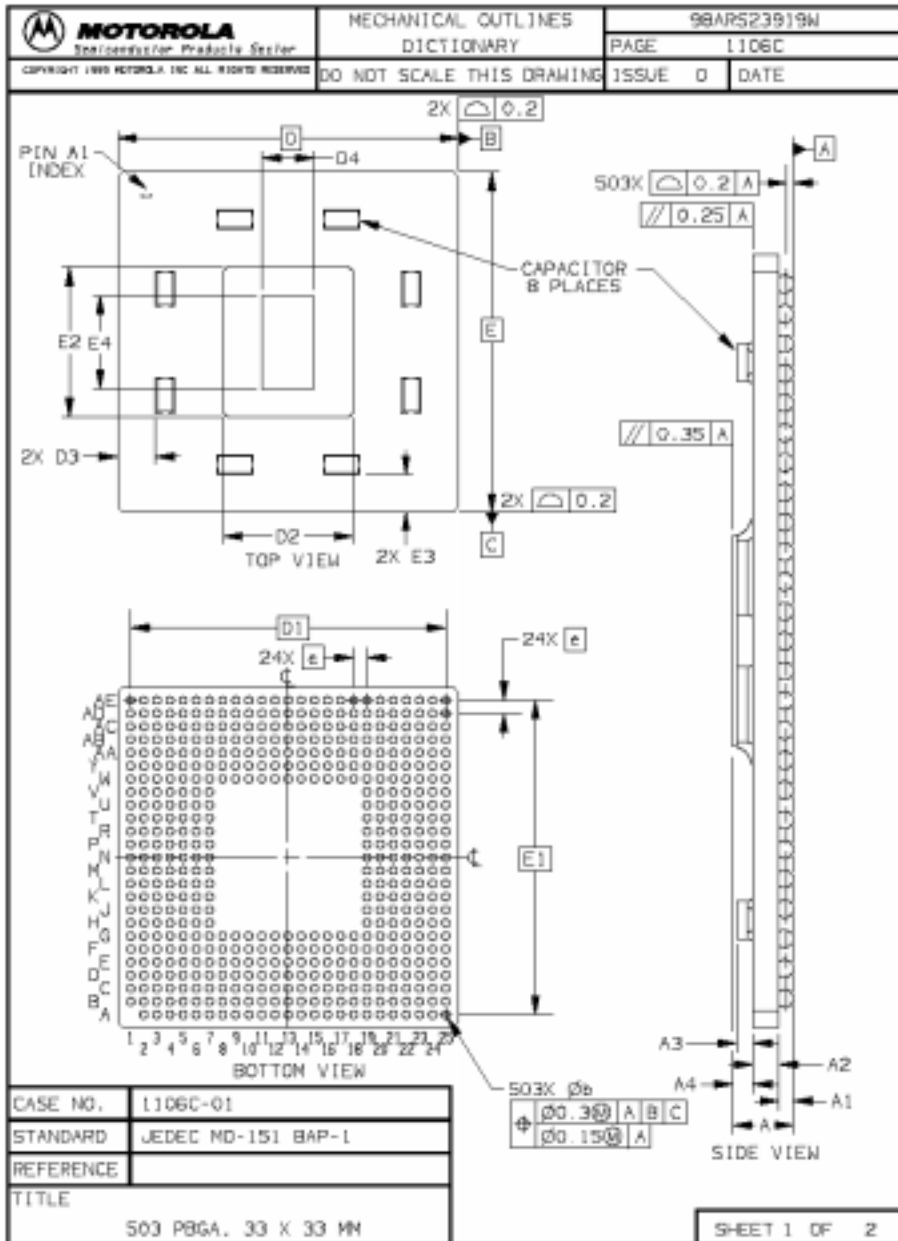
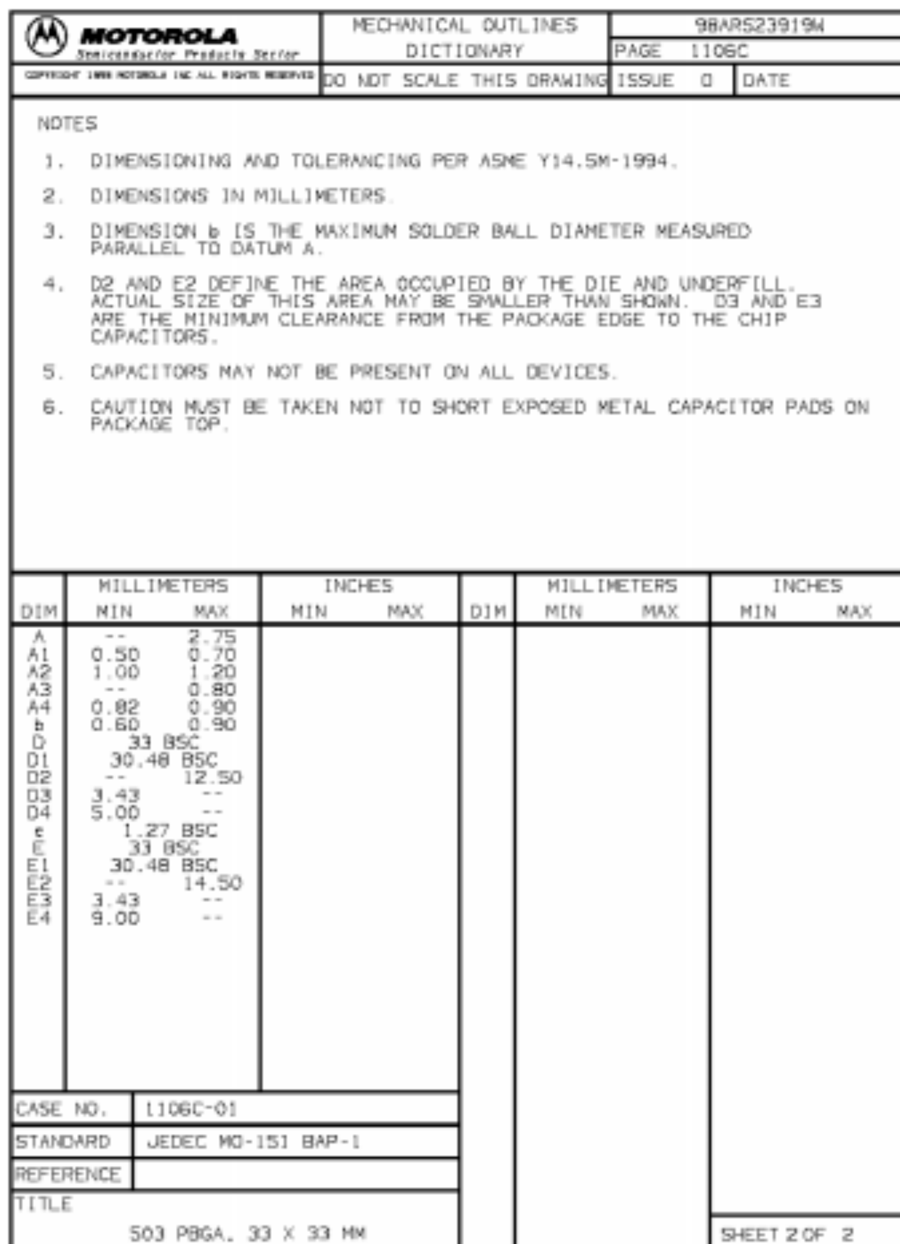


Figure 9. Motorola 503-Pin Flip-Chip PBGA Package Drawing



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5. CAPACITORS MAY NOT BE PRESENT ON ALL DEVICES.
6. CAUTION MUST BE TAKEN NOT TO SHORT EXPOSED METAL CAPACITOR PADS ON PACKAGE TOP.

DIM	MILLIMETERS		INCHES		DIM	MILLIMETERS		INCHES	
	MIN	MAX	MIN	MAX		MIN	MAX	MIN	MAX
A	--	2.75							
A1	0.50	0.70							
A2	1.00	1.20							
A3	--	0.80							
A4	0.82	0.90							
b	0.60	0.90							
D	33 BSC								
D1	30.48 BSC								
D2	--	12.50							
D3	3.43	--							
D4	5.00	--							
e	1.27 BSC								
E	33 BSC								
E1	30.48 BSC								
E2	--	14.50							
E3	3.43	--							
E4	9.00	--							

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TITLE 503 PBGA, 33 X 33 MM

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Figure 9. Motorola 503-Pin Flip-Chip PBGA Package Drawing (Continued)

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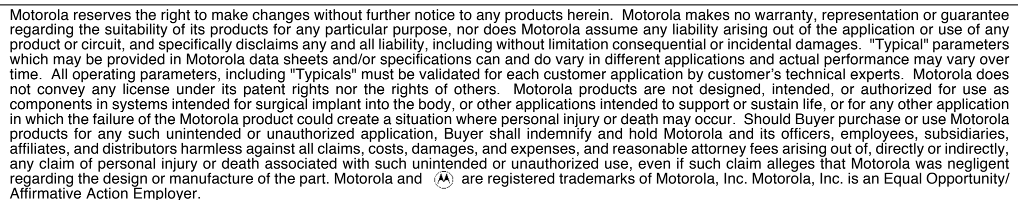

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