

The QFN: Smaller, Faster and Less Expensive

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This leadless package is gaining wide industry acceptance and represents a significant technology breakthrough. This article discusses the two principal methods of producing the plastic QFN and examines the pros and cons of each process.

For the past twenty years the objective of the semiconductor assembly industry has been to make plastic packages smaller, thinner, cooler, cheaper and at a faster production rate.

The PDIP (plastic dual inline package), once the dominant package, represents less than 10 percent of the packages used today.¹ It has been replaced primarily by the gull-wing SO (small outline) format, which represents about 60 percent of total worldwide volume.

We are seeing a phenomenal growth of a new leadless plastic package family, classified by JEDEC² as the QFN (quad flat non-leadless), shown in Figure 1. Many people believe this package family will eventually replace the SO format and some of the QFPs (quad flat packages).

Specifications

Plastic QFN body sizes generally range from 1x2 mm with 3 leads, to 10x10 mm with 68 leads.³ There are currently two package outline versions registered with the JEDEC JC-11 Committee: the MO220 for packages with leads on all four sides, and the MO229, with leads on only two sides.

Compared to the standard leaded package with similar body sizes and lead count, the QFN is significantly smaller and thin-



This is the singulation station of an in-line CM-MS system. The system measures 19 meters (62 feet) in length.

ner. (Figure 2 compares some typical packages.) For example, when mounted to a PC board, a 48-lead 7x7 mm QFN consumes 40 percent less area than a comparable TQFP (thin quad flat package). The QFN is typically 0.80 to 1.0 mm thick compared to the TQFP, which is 1.0 to 1.2 mm thick.

Removal of Heat Essential

New generations of ICs are adding more functions; they operate at higher speeds and often produce higher device temperatures.

Naturally, the efficient and cost-effective removal of heat is essential. Compared to leaded packages with similar body sizes and lead counts, the QFN offers far superior thermal performance because the leadframe is on the bottom of the package.

As a result, the die attach pad is exposed, allowing it to be easily soldered directly

to the board.⁴ In general, the θ_{Ja} for the QFN is about half of its leaded counterpart. (Figure 2 compares some typical θ_{Ja} values, measured per JESD-51).

A device using a 48-lead, 7x7 mm QFN package, operating at an ambient temperature of 70°C, can dissipate about 2.5W. The equivalent TQFP package is limited to about 1.5W.

At higher operating speeds, the combined inductance of the gold wire and long lead-frame traces will affect device speed performance. The QFN provides excellent electrical characteristics because it eliminates gullwing leads and shortens wire lengths. In general the self-inductance for the QFN is approximately half its leaded counterpart.

Clearly, reducing cost is the biggest challenge. This factor will determine whether the QFN becomes a package for special applications or whether it replaces some of the gullwing packages.

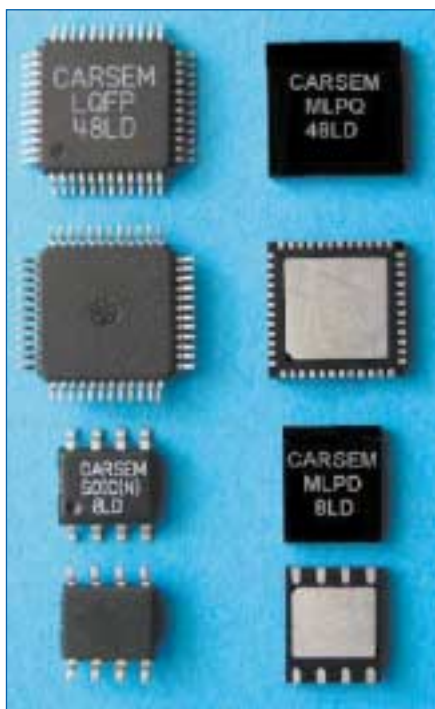


Figure 1. Top and bottom view of a typical QFN package compared to similar QFP and SOIC packages

From an end-product standpoint, cheaper also includes the QFN's ability to pack more circuit functions into a smaller area of the PC board.

Major Assembly Process Methods

There are two major assembly process methods used to manufacture the QFN package. One is an array-molded, saw-singulated (AM-SS) process. The alternate method employs a cavity-molded, mechanically-singulated (CM-MS) process. Figure 3 illustrates both AM-SS and CM-MS leadframe strips post-mold.

Determining what "cheaper" means from an assembly standpoint, requires evaluating the pros and cons of each process.

Both processes use an etched leadframe concept. However, as shown in Figure 3, the design of the leadframe varies, depending on which process is selected. Figure 4 shows the process flows.

The AM-SS Process

The first process step that differs from the assembly of standard plastic packages is the attachment of a polyimide tape to the backside of the leadframe strip.

The polyimide tape prevents resins in the mold compound from bleeding onto the back of the package. The tape can either be attached by the leadframe supplier or by the assembler, prior to die attach or after wire bond. Since the tape's adhesive will deteriorate over time, care must be taken in determining when to attach the tape.

Inspection

If there is an inspection after wirebond (3rd optical), then consideration must be given to how rejects are marked and identified at the final pick-and-place process.

The older method of removing a lead using a punch tool is unsuitable, since this method will cause severe peripheral damage. Unit mapping techniques must be implemented, with the ability to transfer data to the laser mark operation. This will allow the auto inspection cam-

eras used at pick-and-place to find the rejects and leave them behind.

Molding

The AM-SS version is generally produced by overmolding three to four sections of a leadframe strip.

Due to technical limitations related to transfer molding, the AM-SS process is typically restricted to overmolding an area of about 50x50 mm. Considering that a single mold shot could involve up to 8,000 units, any power failure would be costly; therefore, a backup power supply is worth considering.

Additionally, each mold shot will almost certainly involve molding different products and lots simultaneously. Each leadframe strip should be bar-coded to assure lot integrity.

Lead Plating and Laser Mark

After molding, the polyimide tape is removed and the strips are plated with PbSn, matte Sn or other lead finishes. This step also enables cleaning any polyimide tape residue that remains on the frame. The long-term cost objective is to use pre-plated leadframes and a tape that leaves no residue. Devices are laser marked while still in the array-molded format.

The leadframe strip is singulated into individual devices by sawing, with a process that is similar to dicing wafers. Singulation is achieved by sawing through the leadframe channels that separate the array's rows and columns. This is the most

Package Type	Body Size (mm)	Leads	Height (mm)	Max Die Size	PCB Area	θ Ja	L11	C11
QFN	7 x 7	48	1.00 max	203 x 203 mils	49 mm ²	27	0.9	0.2
TQFP	7 x 7	48	1.20 max	190 x 190 mils	81 mm ²	55	1.7	0.2
QFN	5 x 7	38	1.00 max	124 x 202 mils	35 mm ²	34	0.8	0.2
TSSOP	4.4 x 9.7	38	1.10 max	108 x 207 mils	62 mm ²	73	2.1	0.5
QFN	5 x 5	16	1.00 max	124 x 124 mils	25 mm ²	37	0.7	0.2
QSOP	3.9 x 4.9	16	1.75 max	86 x 120 mils	31 mm ²	112	1.7	0.3

L11 = self inductance, C11 = self capacitance

Figure 2. This chart compares QFN body dimensions, maximum die size, PC board area and thermal and electrical data with a similar gullwing package.

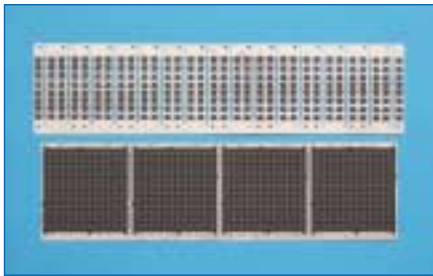


Figure 3. Molded strip processed with the CM-MS method (top) and one processed with the AM-SS method

challenging process in meeting both quality and cost targets.

Quality Risks

The main quality risks at saw are package chipping, lead burrs and plating smears. These risks increase with faster feed rates during saw.

Quality can be achieved at feed rates of 15 mm/sec. To be cost effective, however, feed rates must be in excess of 60 mm/sec. While both the sawing process and the blade construction are important, we have found that the leadframe design is paramount in determining saw feed rates.

Additional throughput solutions include the use of a spindle with two blades. While singulation equipment using “gang sawing” is available, its effectiveness is limited to the strength of the weakest blade.

Saw equipment is expensive. It dominates the overall cost of this process option, and there are still many challenges to overcome to make this process more cost effective. A secondary concern is that this technology does not lend itself well to performing final electrical test in strip form.

Pick-and-Place

After the saw process is completed, the individual devices are placed in tubes, trays or bulk canisters using pick-and-place equipment. This equipment is expensive and relatively slow.

Now, let’s look at the alternate method for QFN assembly, the CM-MS process.

The CM-MS Process

The front-of-line processing for the CM-MS method is identical to the AM-SS process except that the leadframe taping operation is eliminated. The end-of-line processing for CM-MS differs greatly, however, and the cost and flexibility trade-offs between CM-MS and AM-SS are quite significant.

The CM-MS package is produced by molding individual die sites on a leadframe strip.

In the CM-MS version, each package is individually molded. Consequently, there will be a dedicated mold for each package body size.

Other Considerations

When using pre-plated leadframes, a company can develop an entire in-line process from mold through singulation into tubes, trays or bulk canisters.

The lead photo shows an in-line system that accommodates processing three different body sizes at the same time. Changeover to a different body size can be done on the fly. In addition, the CM-MS lends itself to strip testing relatively easily.

The lead plating and laser marking steps are similar to the AM-SS process, except that there is no need to remove the polyimide tape.

The QFN is likely to replace many existing plastic packages with lead counts from 2 to 68.

Although tooling investments are high for the CM-MS process, the cost benefits are equally high. There are very complex considerations in the design of the mold and singulation tooling.

For example, Carsem developed a method called a “high density leadframe,” which utilizes a mold and leadframe strip that is denser than the AM-SS version. (Figure 5 illustrates a leadframe designed to maximize the number of units per strip for a 5x5 mm body.)

The singulation tooling must be specially designed to handle leadframes placed on the bottom surface of the package. Tolerances are very tight to allow for an optimized die size and a maximum number of die sites per leadframe strip.

After the lead plating process, the devices are mechanically singulated and then put directly into tubes, trays or bulk canisters. (Figure 6 shows a CM-MS strip being processed through a five-stage singulation system.)

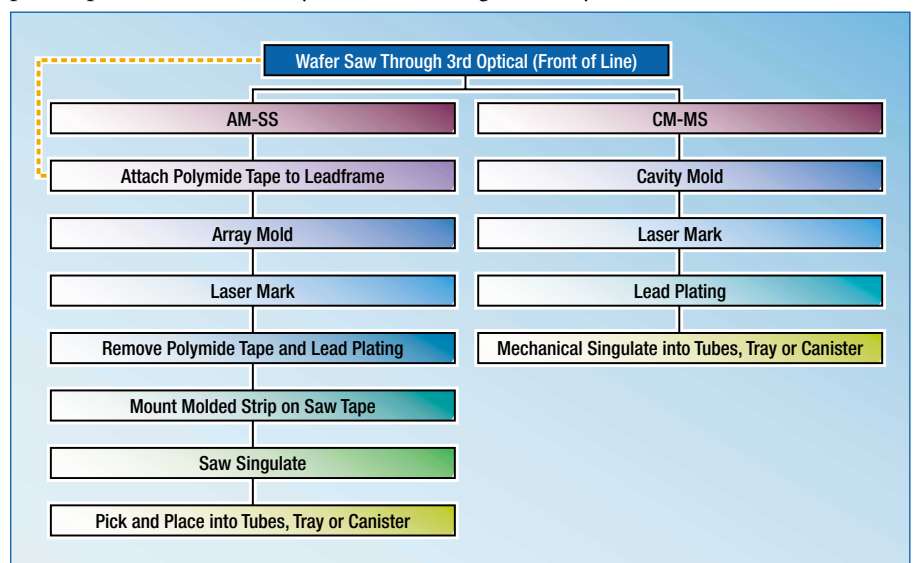


Figure 4. Process flows for AM-SS and CM-MS methods.

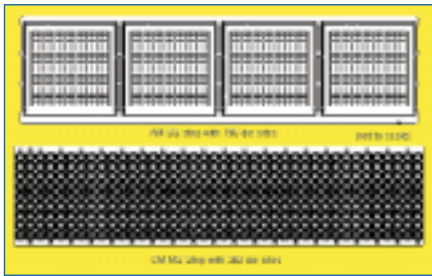


Figure 5. Illustration shows leadframe strips for 5x5 mm AM-SS and high density CM-MS. Use of the CM-MS process results in 360 units per strip compared to 196 for the AM-SS version. (Not to scale)



Figure 6. Photo of a CM-MS five-stage singulation system with a leadframe strip

Which Process Is Best?

Both processes, as noted, offer advantages and disadvantages in cost, throughput, mold utilization and cycle times.

AM-SS Advantages

- One mold design covers all body sizes, lead counts and various lead pitches, resulting in high mold equipment utilization.
- This technology can easily accommodate new and oddball body sizes without any capital expenditure.
- A new body size can go from design concept to first article samples in two to three weeks.

AM-SS Disadvantages

- Saw and pick-and-place operations are expensive and slow.
- Polyimide taping is expensive and subject to residue removal problems.
- Saw operation is subject to very tight process controls to assure good quality.
- The technology does not lend itself

easily to performing final electrical test in strip form.

CM-MS Advantages

- Manufacturing costs are lower.
- The technology offers high throughput and short process times
- It is relatively easy to perform final electrical testing in strip form.

CM-MS Disadvantages

- Tooling is expensive.
- Longer lead times are needed to tool new package body sizes.

Both processes offer advantages and disadvantages in cost, throughput, mold utilization and cycle times.

- There is a 5-10 mil decrease in maximum die size when compared to the AM-SS process.

Because the processes differ, the package outline dimensions will vary enough to cause concern over the contactors employed in handlers during final test. While both packages fully comply to JEDEC outline requirements, the AM-SS package has square vertical edges, while the CM-MS format displays a slight draft angle.


Conclusion

The QFN is gaining wide acceptance in the industry and is a significant breakthrough in IC packaging technology. It will certainly become one of the dominant packages, and is likely to replace many existing plastic formats with lead counts between 2-68.

We believe that both QFN assembly processes will co-exist. The AM-SS is ideal for small-to-medium volumes, and, with a minimum investment, also lends itself to produce packages suitable for optical sensing and imaging.

For high volumes, the CM-MS process is clearly more cost-effective. For example, using an optimized CM-MS process,

the cost to produce a 24-lead, 5x5 mm QFN can be as low as \$0.001/lead.

Alternatively, an optimized AM-SS process will not decline much below \$0.0025/lead. Moreover, these costs exclude the advantage that the CM-MS can be strip tested at final electrical test. 

References

1. *Advanced IC Packaging Markets and Trends 2002*, 5th Edition, Electronic Trend Publications, San Jose, Calif.
2. The JEDEC Solid State Technology Association of the Electronic Industries Alliance (EIA) was

formerly known as the Joint Electron Device Engineering Council [jedec.org].

3. The proper term is “lands” for leadless packages, such as the QFN, but “leads” is used for simplicity.
4. There are QFNs available without the exposed die attach pad for use with flip-chip-on-leadframe and chip-on-leadframe.

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