

# AN1017

## Ultra Miniature Surface Mount Transistor Packages: Concerns for Design Engineers

Advances in technology are usually exponential. Surface mount transistors are no exception. Introduced in the mid-1960s, the SOT-23 was the industry's first miniature 3-lead surface mount transistor package. At 2.9 X 1.5 X 1.2 mm it was indeed tiny (*Figure 1*), but the constant demand for smaller, lighter products put pressure on transistor manufacturers to develop smaller, lighter surface mount devices.

The first major downsizing took over 25 years.

In 1992 the SOT-323 was introduced. At 2.0 X 1.25 X 1.0 mm it was approximately 40% smaller than its predecessor.

Hailed as a major advancement, especially for lightweight handheld products, the SOT-323's reign as the tiniest transistor lasted little more than a year.

The title now goes to NEC's Ultra Super Mini Mold "19" package.

At only 1.6 X 0.8 X 0.85 mm, the 19 package represents another 40% reduction in size (*Figure 2*) — and a 3-leaded package that's *one third* the size of the original SOT-23.

### Smaller size — improved performance

Some of the benefits of smaller transistor packages are obvious. They weigh less and require less real estate; important considerations in the design of new portable wireless products. But there are other benefits that aren't so obvious; performance benefits that could persuade a designer to choose one of these new miniature devices over a larger, more familiar package (*Figure 3*).

Noise Figure and Associated Gain both improve as package size decreases, primarily due to the reduced lead inductance and lower capacitance of the smaller package. A good example is NEC's NE685 series of plastic surface mount bipolar transistors. Figure 4 demonstrates how Noise Figure and Gain for a NE685 bipolar die improve as the package size grows smaller.

A small package can also improve a device's repeatability. As parts shrink, interconnections are smaller and closer, and the mechanical tolerances between leads and solder pads are reduced — all of which help to reduce circuit-to-circuit deviations.

Solder joint volume, often overlooked by designers, also plays an important role in the performance of high frequency circuits. Smaller parts mean smaller pads — and smaller solder volumes. When the variation

in solder volume as a percentage of wavelength decreases, parasitics are reduced even further.

Finally, from a mechanical standpoint, substrate choice is not as critical with smaller parts. With the small footprint, solder blocks are less inclined to break if the board should warp or flex.

### Power dissipation — a concern or not?

As transistors come down in size, power dissipation becomes a concern. A smaller package has less lead frame surface area to dissipate heat, and smaller collector leads make the RTH higher.

Fortunately, these parts' voltage and current demands are shrinking at about the same rate as their packages. The reduction in the ability to dissipate heat is probably offset by the lower amount of power consumed — especially in the battery powered circuits for which these ultraminiature parts are designed.

### Automated Assembly of Miniature Devices

A major concern of any engineer designing circuits for high volume consumer products is manufacturability. Is this trend toward smaller transistor packages outpacing advances in automated assembly technology? What good are ultra miniature transistors if the pick and place equipment required to handle them doesn't exist?

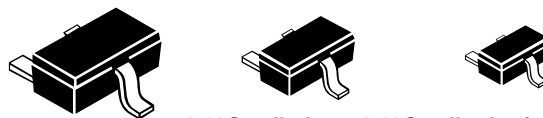
The truth is, the equipment does exist — and is actually a step ahead of transistor packages. Pick and place technology is driven by surface mount *capacitors* and *inductors*,

**Figure 1. History of the 3 Pin Surface Mount Transistor Package**

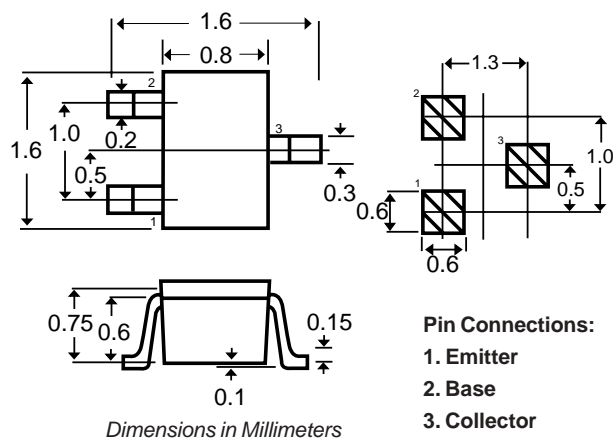
**Mid 1960s  
NEC "33"  
Package**

**1992  
NEC "30"  
Package**

**1993  
NEC "19"  
Package**



Dimensions (mm)	Mid 1960s NEC "33" Package	1992 NEC "30" Package	1993 NEC "19" Package
Length	2.9	2.0	1.6
Width	1.5	1.25	0.8
Height	1.2	1.0	0.85
Surface Area (mm <sup>2</sup> )	4.35	2.5	1.28
Weight (grams)	0.0125	0.0062	0.0030
U.S. Designation	SOT-23	SOT-323	—
Japanese Designation	SC-59	SC-70	—



**Figure 2.**  
**NEC "19" Package and Solder Pad Layout**

not transistors, and is currently at the "0402" level. This means state-of-the-art pick and place equipment can handle packages as small as 40 mils by 20 mils.

At 63 mils by 31.5 mils, NEC's new 19 package falls into the "0603" category — a size easily handled by the widely used 0603 pick and place assembly machines.

### Circuit Layout

While the equipment is readily available to pick and place these devices, there are some design considerations an engineer should be aware of when laying out a circuit that employs ultraminiature parts.

As mentioned above, solder volume is a concern because it can affect a circuit's parasitics. Solder volume is controlled by a device's pad size, the solder mask, the formulation of the solder paste, the solder stencil, and the stenciling process.

California Eastem Labs can provide you with recommended PC board layout geometries that specify the location and size of solder pads for the NEC devices you've chosen (Figure 3). Share them with your assembler, but remember, they're only recommendations. Your assembler's unique experience may lead to modifications.

Once pad geometry is determined, a *solder mask* is created on the PC board. Tiny apertures in this mask align with the pads in your circuit. When solder paste is laid into these apertures, the mask acts as a well, or dam, to keep the solder from spreading.

If the apertures are too small, there's a chance that not enough solder will be available. This can result in a solder joint that makes no contact with your device's lead, or worse, makes a mechanically weak contact that's unreliable and costly to trace.

If an aperture in the mask is too large, a lead can get too much solder. When heated, the surface tension of the extra solder can be significant enough to pull the part out of alignment, and out of contact with its pads.

While size and position of the apertures in the solder mask are critical, control of the volume of solder paste is just as important. Controlling solder volume is especially tricky when miniature devices are combined with large ones that require relatively massive amounts of solder. Too much solder can cause tiny parts to float out of alignment during the reflow process — and increase parasitic capacitance from the pad to the lead frame or die.

Solder paste is applied to the PC board by forcing it through tiny holes in a *solder stencil* that align with the apertures in the solder mask. Solder volume is determined by the size of the hole, the thickness of the stencil, and the formulation of the solder paste.

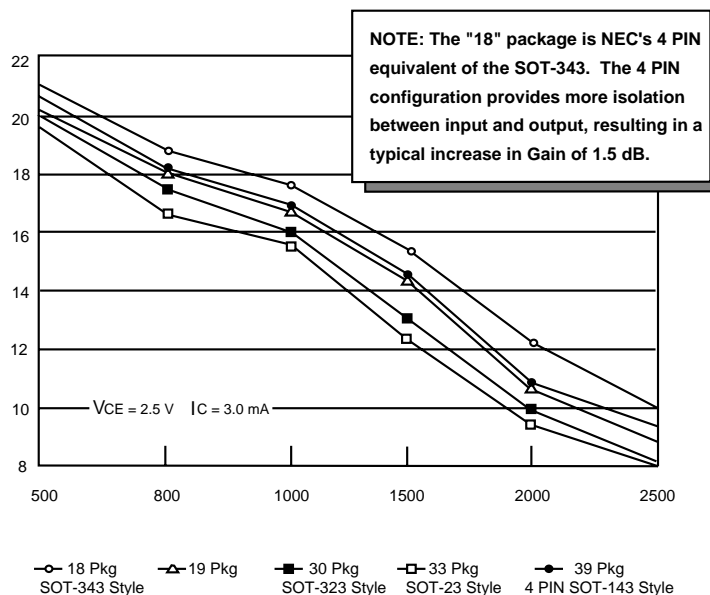
Experienced assemblers understand the nuances of solder paste formulation and the resulting reflow characteristics. Smaller parts mean smaller areas of paste, so a more viscous formula with high metals content is used to assure sufficient volume.

Once the solder formula is determined, the assembler can specify one of two different kinds of stencils to control its volume. The first is of uniform thickness with the holes sized to hold exactly the volume of solder required. The hole size is a function of the size of the pad, the thickness of the stencil, the solder formula, and a good deal of experience on the part of the assembler.

The alternative is a *step down* stencil (Figure 5). These stencils are thin in the area of your miniature devices, limiting the volume of solder that's laid down, and thicker — some times twice as thick — under your large parts, providing deeper holes for the larger volumes of solder paste these parts require.

While step down stencils provide more precise control of

**Figure 3.**  
**NE680 Series Bipolar — Performance in Different Packages**



solder volume, they do require the design engineer to isolate tiny devices in specific areas on the PC board, away from the larger components.

**Manufacturability**

The *manufacturability* of an assembly takes into account its “cost-of-design” and its “survivability”. Cost-of-design addresses the equipment and process required to produce the assembly. Survivability covers ESD, parts handling, moisture, and part placement.

ESD is always a concern with higher frequency devices. The enormous voltages generated can wreak havoc on the tiny geometries of high frequency transistors. FETs are especially susceptible, but with a few precautions, static problems can be avoided.

First, make it clear to your assembler — ahead of time — that they’ll be working with static-sensitive high frequency parts, and even though they may be bipolars, ESD precautions cannot be relaxed. CEL can provide you with specific guide lines, or you can refer to Military Standard such as DOD-HDBK-263 (*available through Naval Sea Systems Command, SEA 3112, Department of the Navy, Washington, DC 20362*).

Second, don’t give your assembler small parts in bulk bags. Their size makes them difficult to handle, and extra handling increases the potential for ESD problems. Whenever possible, see that parts are provided on tape and reel.

And handle those reels like eggs.

On NEC reels, parts sit firmly in perfectly proportioned pockets on the tape. But occasionally, a manufacturer’s pocket can be a bit loose. Pick at the end of the tape too much and those flea-sized parts can jump like fleas. Automated pick and place equipment depend on parts sitting in the correct position in their pockets. If they’ve jumped out of position, they’ll have to be literally tweezered back into their pockets — or hand-placed on the board. To avoid the problem, keep the end of the tape tucked in or taped down whenever the reel is transported or stored

Like movie projectors, automated pick and place machines require a certain amount of *leader* when threaded. A general rule of thumb is to provide 18 inches of cover tape -- the clear tape that holds the parts in their pockets -- as a leader. If extra leader is missing from your reel, you may have to sacrifice 18 inches’ worth of parts to provide it. With some machines you can avoid this by simply taping a spare piece of cover tape to your parts tape. Your assembler will provide you with the specific needs of his equipment.

**Figure 4.**  
NE685 Bipolar Die:  
Performance vs.  
Package Size

NE68533  
(In the NEC  
"33" Pkg)

NE68530  
(In the NEC  
"30" Pkg)

NE68519  
(In the NEC  
"19" Pkg)



f(MHz)	NF(dB)	Ga(dB)	NF(dB)	Ga(dB)	NF(dB)	Ga(dB)
500	1.17	16.7	1.08	17.6	1.05	19.3
800	1.30	13.4	1.15	14.1	1.12	15.8
1000	1.39	11.7	1.22	12.6	1.17	13.4
2000	2.00	6.3	1.68	7.4	1.50	7.5

$V_{CE} = 2.5V$   $I_C = 3mA$

**Moisture**

Moisture is a critical concern when working with plastic parts. In the reflow processes, parts are quickly blanketed with intense heat - 220° to 250°C. In the wave solder process temperatures rise even faster, and the part is encapsulated in molten solder. Both processes can cause any moisture trapped inside the part to boil and expand, cracking the plastic package. Typical failure points are the fissures and distortions found along the lead frame and the encapsulant interface. The damage may not effect the part immediately, but with its environmental seal lost, reliability is compromised.

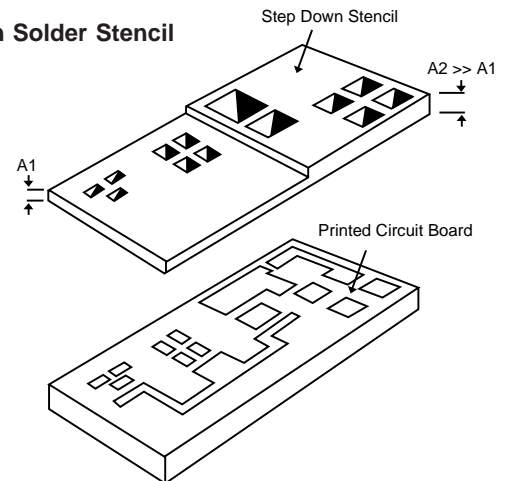
The solution is to *prebake* the parts before assembly. By slowly heating the part to a specified temperature, then holding it at that temperature for a specified period of time, the moisture inside is evaporated. Many manufacturers prebake their devices before packaging. If so, they’ll have specific storage, handling and “time-to-reflow” requirements that must be observed.

If the prebake is to be done by the assembly house, the manufacturer’s bakeout requirements must be followed to avoid damaging the part.

Interestingly, the NEC 19 package is so small, moisture concerns are minimized. While NEC recommends these parts be stored at 5 to 30° C, and at relative humidities less than 65%, prebaking is not required.

**Figure 5.**

**Step Down Solder Stencil**



For parts that do require prebake, their embossed tapes usually have a small hole under each part that allows moisture to escape. Since these tapes are not air tight, the reels should be stored in a moisture-minimized environment. This is especially true for reels that have been opened and partially used. Work with your device vendor and assembler to see that everyone understands, and follows, the manufacturer's instructions.

## Solder Reflow

Reflow specifications are also critical to the assembly process. A part's reaction to reflow is heavily dependent upon its size, shape, and composition. CEL will provide you with guidelines for specific devices (*See Figure 6*). These specifications profile reflow and peak temperature versus time, and should be followed closely by your assembler.

### The Assembly Process

Many machine-placed parts will *self-center* themselves on the PC board during the reflow process. The surface tension of the solder is actually strong enough to pull a part into position on its pads. With miniature parts, the tiny amounts of solder often don't produce enough surface tension to overcome the part's inertia. This is especially true if there is any flashing left on the package from the manufacturing process. While a tiny burr is insignificant on a large package, it can literally act as a parking brake on a small one.

As a result, placement accuracy is more critical with smaller parts. An assembly machine's jaws can mechanically center the parts to within  $\pm 4$  mils -- but it depends on clean and consistent parts for precision centering. Flashing can cause misalignment in the jaws and throw off the placement, or cause parts to get stuck in the jaws and jam.

The NEC 19 packages have little or no flashing. We were able to pick and place them easily with a Zevatech FS710 assembler by handling them as thick 0603 type packages. This FS710 required no elaborate set-up; we had the NEC 19 packages loaded and the machine placing them on a PC board in under 15 minutes.

For standard SOT packages, special alignment jaws are available that are designed to fit the SOT's leads. For non-SOT packages, the part handling capability of pick and place equipment varies. Generally an assembly machine designed to handle 0603 packages can be made to handle other miniature devices by using a four-jaw chuck and a low gripping force.

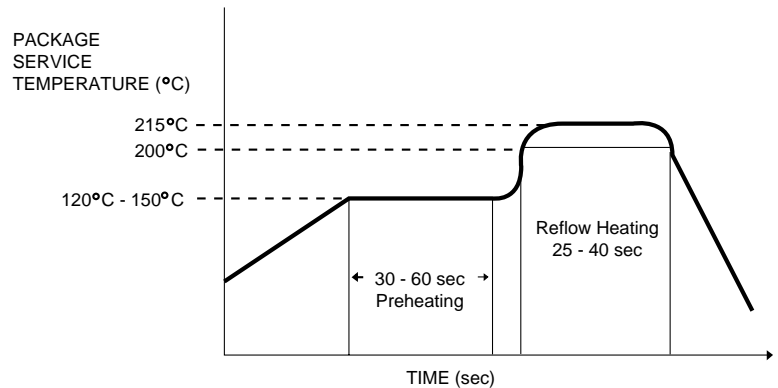


Figure 6. Solder Reflow Temperature Profile

Part centering accuracy can be greatly improved with *optical centering* placement equipment. Optical centering is an expensive add-on to low-volume mechanical-centering assembly equipment, but its typically standard on high-volume high-speed machines. Optical centering makes placement more precise ( $\pm 2$  mils), and it can help speed the set-up process and the throughput of mechanically inconsistent devices, or those with excessive flashing.

### Miniature surface mount devices, are they right for you?

In summary, the benefits of ultra miniature packages are clear: smaller size, reduced weight, and better electrical performance. Any concern about power dissipation is probably offset by the reduced power they consume. And packages even as tiny as the NEC 19 can be manipulated with everyday pick and place equipment — which makes automated assembly simple and straight forward if the design engineer is aware of the potential pitfalls, plans for them accordingly, and chooses an assembler with the experience to handle small parts.

Should design engineers take a closer look at these ultra-miniature devices? The answer is an emphatic yes, especially if the application is a wireless, handheld, battery operated product.

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