RELIABLE SELECTIVE SOLDERING FOR HIGH VOLUME ASSEMBLIES

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ABSTRACT

The number of through hole connections on a circuit assembly are decreasing with the drive toward miniaturization. When these assemblies are manufactured in high volumes the most convenient method is selective soldering. Although selective soldering is very well introduced in automotive and industrial applications it can also be a very efficient method to solder high volume consumer products.

The number of pin through holes varies per assembly. On a mobile phone there are very few with examples being the micro-USB cable connector. On a Philips shaver the number is higher with approx. 10 – 15 including the battery. Selective dip soldering is a robot controlled soldering process that could solder 32 shavers in one dip. In other words 300 solder connections in a cycle time of 30 seconds; equals 10 solder connections per second 24 hours a day; being 30 times faster than hand soldering.

Selective soldering is identical to other soldering techniques - three ingredients are required to make a good solder joint: solder, non-oxidized metal surfaces to connect, and heat. All three have an influence on the final result. The solder properties define not only the hole filling, but have an impact on the appearance as well the shininess of the solder joint.

Heat is required to activate the flux and make the solder flow into the barrels. If there is not enough thermal energy in the assembly the solder will solidify in the barrel during the process and there may not be a sufficient hole fill (defined in the IPC-A-610E chapter 7.3.5).

To improve the hole filling properties and to clean the metal surfaces a flux is applied before the soldering. Critical for the process is that the flux is supporting the solder to penetrate into the barrels and also that the flux is activated. For activation of the flux a specified temperature must be achieved for a certain time period. This activation temperature and time are flux specific and should be defined by the flux supplier since they are tied into the flux chemistry.

Key words: selective soldering, flux, reliability

FLUX RESIDUES AND POTENTIAL RELIABILITY ISSUES

Although the flux has a similar function as observed in a wave soldering process; selective soldering requires different properties for a flux to be successful. Important are:

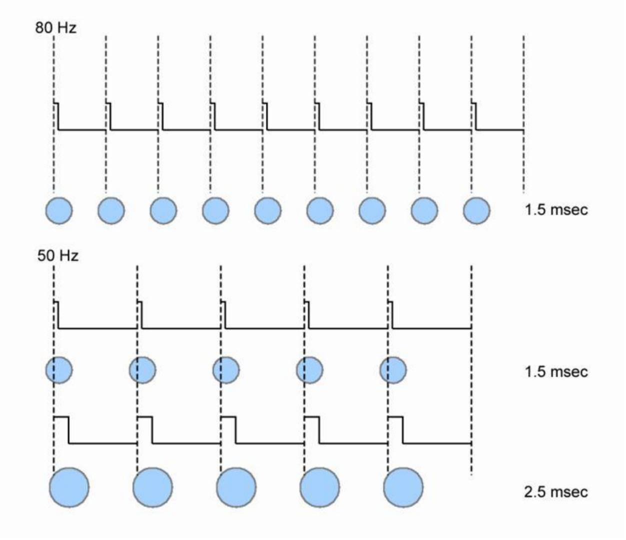
1. Spreading. In selective soldering the flux should not spread too far. Flux is only required in the soldering area and should not impinge outside of this area.
2. Inert after soldering. Non-activated flux residues are a potential risk for electro-migration.

Since spreading should be limited it is essential that the mechanism of spreading is well understood. Spreading is not only depending on the flux properties, but also influenced by the board material and more.

CONTROL FLUX AMOUNT

Selective soldering machines use a dropjet device to apply flux on the bottom (solder) side of the PCB. This device is mounted on a x,y controlled robot. The PCB is held during fluxing at a fixed position enabling the robot to apply flux on the areas where the solder is in contact during the process. How much flux is applied depends on three factors that can be programmed:

1. The robot speed during jetting (mm/s)
2. The open time of the dropjet (ms)
3. The frequency of the dropjet (Hz)



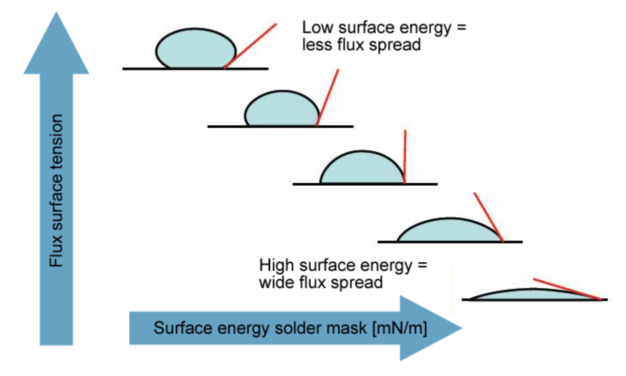
Principle flux parameters.

Figure 1. The number of droplets is defined by the frequency [Hz] (drops per second). The open time [ms] defines the amount per droplet. Longer open time gives larger droplets.

The amount of flux required for soldering is defined by the flux supplier in the flux datasheet. The amount depends on several properties of the flux and is unique for every flux. These properties include solid content, acid number, density, activation system, etc. The flux supplier defines the amount of dry flux per square inch. How much flux this will be for the assembly is defined by the spreading of the flux on that specific assembly.

The flux spread depends on several factors including:

- Flux surface tension (flux type)
- Surface energy of the board (solder mask)
- Temperature of the flux
- Temperature of the board
- Number and dimensions of the through holes



Surface energy of board and surface tension of the flux define the flux spreading.

Figure 2. The impact of the solder mask can be visualized. For wave soldering a board with a high surface energy (>50 mN/m) is preferred. This makes the flux spread to all areas and thus eliminates the risk for open solder joints, bridging, spikes or webbing. Due to the good spreading the residues will also be less visible; which is a cosmetic advantage.

For selective soldering applications a lower surface energy of the board is required. A typical value for a good spreading would be ~35 mN/m. Be aware that heating processes before selective soldering (similar to reflow soldering) may have an effect on the surface energy of the solder mask.

BOX-BEHNKEN DEFINING FLUX AMOUNT

The flux amount that is jetted to the PCB by the dropjet should be defined before the required flux amount per square unit can be calculated. For this a Design of Experiment is carried out. A Box-Behnken design is selected for the three parameters which are open time, frequency and robot speed.

Experimental layout:

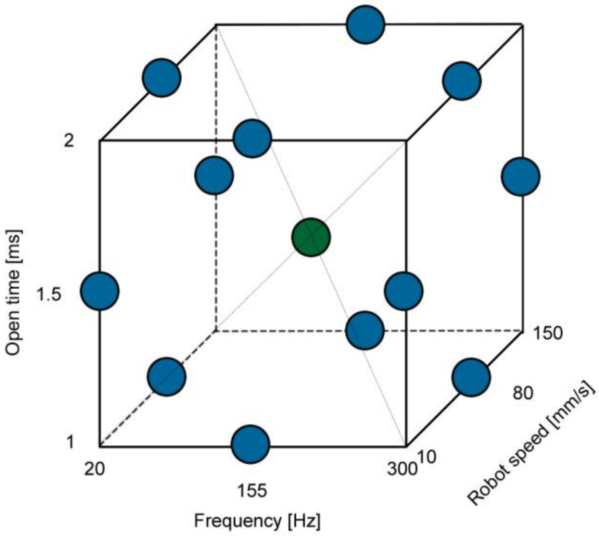
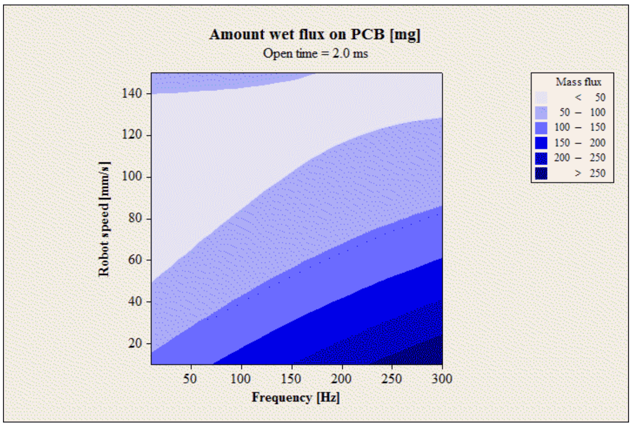


Figure 3. The experiments were made with the settings of the blue dots. The middle setting is repeated three times to verify repeatability.

After runs the amount of wet flux on the PCB is measured. The Minitab® software defines a formula for the flux amount [mg] applied as being:

Flux amount = 59 * Open time + 0.7 * Frequency – 2.2 * Robot speed + 0.02 * Robot speed^2 – 0.005 * Frequency * Robot speed + 6.9



For an open time of 2.0ms the wet amount of flux is monitored in the graph.

Figure 4. The robot speed (p = 0.027) and the frequency of the dropjet (p = 0.034) have statistically a significant impact on the flux amount. The open time (p = 0.187) has a minor impact.

The experiment returns a formula which enables us to define the values for the three parameters needed for the flux amount given by the flux supplier.

The flux amount that is required for a robust solder process is defined in micro grams per square inch of dry flux. In the experiment the amount of wet flux is measured. The assembly is then preheated. During the preheating the solvent (alcohol) will be evaporated and the solids in the flux will remain on the board.

The flux solid content is defined in the flux datasheet. The moment the spreading of the flux is known the amount of dry flux per inch can then also be calculated.

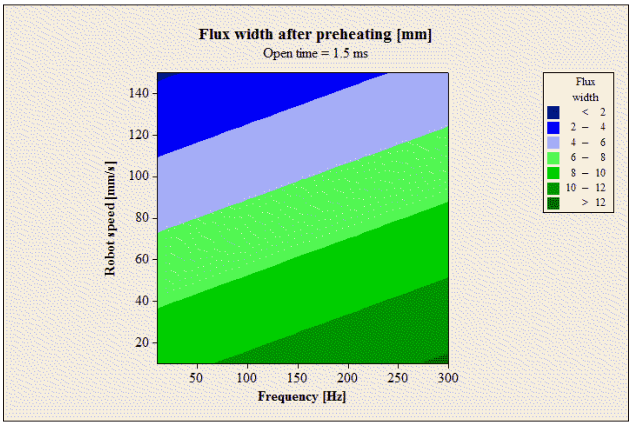
In the experiment a flux drag line was spread on the assembly for 8 different through hole connectors and pad designs. By selecting different connectors and pad dimensions the impact of the pins and metal lands on the flux spreading can be investigated. The next table shows the amount of wet flux and the average spreading width of the dry flux after preheating of the PCB.

Open time	**Frequency**	**Robot speed**	**Flux width**	**Mass flux**
[ms]	[Hz]	[mm/s]	[mm]	[mg]
1.5	155	80	9	32
1	155	10	12	132
1.5	300	10	12	485
1.5	10	150	2	4
1.5	155	80	5	36
1	155	150	5	12
1.5	300	150	6	38
1	10	80	4	19
2	300	80	5	84
2	10	80	5	38
1.5	10	10	11	26
1	300	80	10	29
1.5	155	80	5	40
2	155	10	12	272
2	155	150	9	34

Table 1: Data of the Box-Behnken experiment

The experiment concluded that the robot speed was affecting the width the most. A general formula for these conditions was:

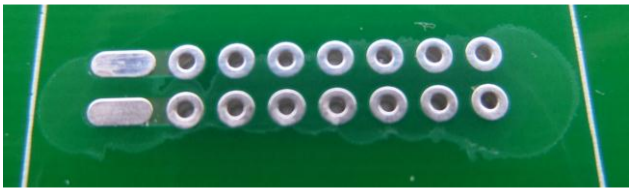
Flux width = 12.5 – 1.7 * Open time + 0.0097 * Frequency – 0.055 * Robot speed [mm]



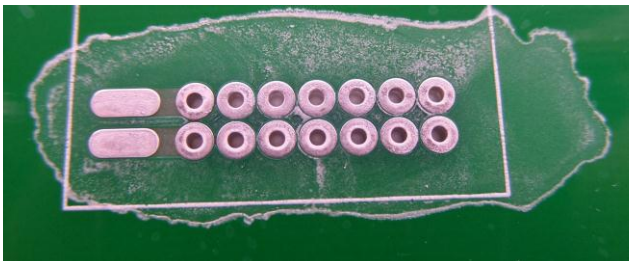
The higher the robot speed the smaller flux width.

Figure 5. Increasing the frequency give more droplets which in turn make the flux spread more.

Interesting was the remaining amount of flux on the print after preheating. There were significant differences between the settings in the experiment. Visual inspection of the boards showed clear evidence that the flux left different concentrations of solids on the board.



Flux for open time = 2 ms, frequency = 10 Hz and robot speed = 80 mm/s



Flux for open time = 1.5 ms, frequency = 300 Hz and robot speed = 10 mm/s

Figure 6a and 6b. Showing the wider spreading and more solid content for the run with a higher frequency and lower robot speed.

The flux used in this experiment was the IF2005C, which had a solid content of 3.3%. The solids left were 622 µg/in² on board 6a and 2645 µg/in² on board 6b.

Typically between 500 and 2000 µg/in² are required for a stable soldering process.

Open time	**Frequency**	**Robot speed**	**Fluxed area**	**Solids per in^2**
[ms]	[Hz]	[mm/s]	[in^2]	[µg]
1.5	155	80	0.4388	241
1	155	10	0.6326	689
1.5	300	10	0.6051	2645
1.5	10	150	0.0775	170
1.5	155	80	0.2015	590
1	155	150	0.2286	173
1.5	300	150	0.2519	498
1	10	80	0.1612	389
2	300	80	0.2220	1248
2	10	80	0.2015	622
1.5	10	10	0.5365	160
1	300	80	0.5065	189
1.5	155	80	0.2263	583
2	155	10	0.6539	1373
2	155	150	0.4524	248

Table 1: Data of the Box-Behnken experiment

The table shows that some of the settings have less than 500 µg/in² solids. For these settings the amount of flux in the solder area could be too small to have good soldering result. The surface energy of this test board was too high for selective soldering and this resulted in a too wide of a spreading causing a potential risk for non-activated flux after the soldering.

Conclusion of this experiment is that boards designed for wave soldering with a higher surface energy are not suitable for a selective soldering application.

SATELLITE FREE DROPJET

Dropjet fluxing is the application method to apply very small amounts of flux very on a very accurate way. Like in inkjet technology during the jetting satellites are formed by nature of the liquid and jetting method. These satellites are very small droplets at the start of the spraying (called head satellites) and at the end when the plunger closes (called tail satellites). Many studies are done using high speed cameras to understand the formation and behaviour of these flux satellites. Since the size and direction are out of control these flux particles may end up in unwanted SMD areas and are a potential reliability risk.

Satellite drops, which often follow each fast-moving main drop ejected from the nozzle, are undesirable because they are far more readily misdirected by aerodynamic and electrostatic forces. To eliminate the satellites a new HF (High Frequency) dropjet has been introduced. This device has a sapphire orifice and incorporates an internal pressure compensation bladder. The droplets will retain their integrity longer and travel further.

A way to visualize the flux patterns is fluxing on fax (heat sensitive) paper. To illustrate the satellites and the difference between a HF satellite-free and a common dropjet a series of flux drops were sprayed on fax paper using the same settings:

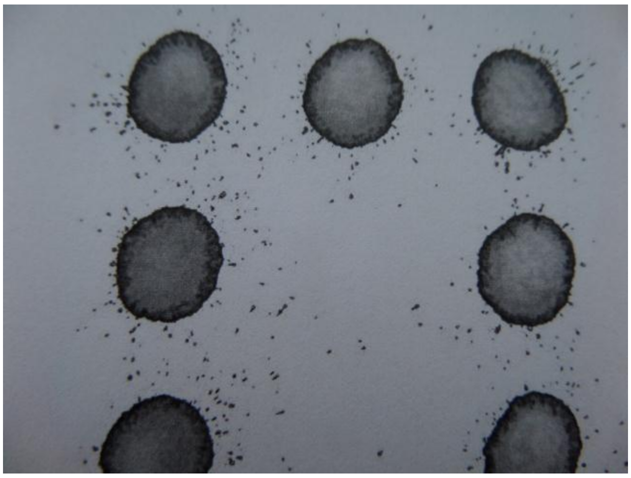


Figure 7a: Flux sprayed on fax paper showing the satellites.

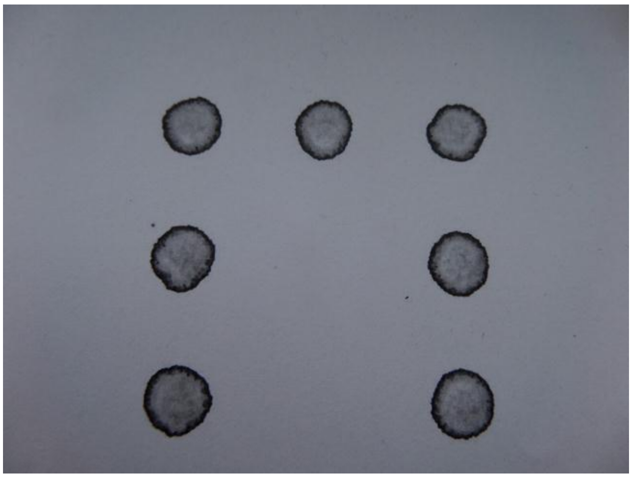


Figure 7b: Modified dropjet – no visual contamination from satellites after spraying.

PREHEAT BOARD BEFORE FLUXING

Another method to minimize flux spreading is preheating the assembly before applying the flux. A small experiment was performed to see the impact of the flux to a hot surface to see the spread of flux. The flux spreading would be tested on bare copper material. Three fluxes were used in the test. The three flux types were a typical alcohol based flux, a low VOC and a VOC-Free water based flux. The first table shows the spreading area and the second the amount of dry flux per square cm:

Spread [in²]	**Alcohol**	**Low VOC**	**VOC Free**
Ambient	0.561	0.257	0.068
50 ºC	0.299	0.226	0.081
80 ºC	0.198	0.225	0.082

Table 3. Spreading of flux on preheated copper coupons.

Dry flux [µg/ in²]	**Alcohol**	**Low VOC**	**VOC Free**
Ambient	323	1032	3548
50 ºC	581	1161	3032
80 ºC	903	1161	2968

Table 4. The amount of dry solids per square cm.

The amount of flux that was deposited on the copper coupons was 10 µl. This was repeated at ambient temperature, and then with the coupons preheated to 50 ºC and 80 ºC. Note the differences:

- The alcohol based flux spread less when the board was preheated, where VOC-Free water based flux spread more when the surface was hot.
- Due to the minor spreading the solid content left per in² was much more for a VOC-Free flux and less for the alcohol based flux.

Since alcohol fluxes are safe the trend for selective soldering fluxes would tend to be in the direction of alcohol based fluxes which have a higher solid content giving an improved activity per square inch. [1)]

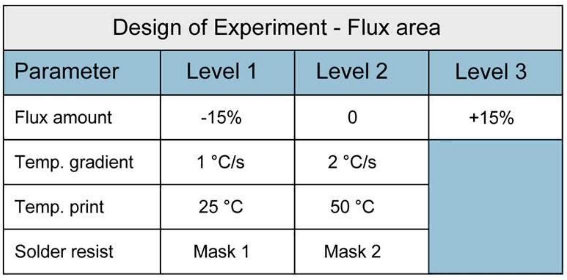
NITROGEN/INERT SOLDER AREA

As temperatures rise, the flux materials undergo changes in their physical and chemical properties such as the evaporation of volatile fractions, their surface activity, and their melt viscosity. The consequence for the solder flux is early displacement by the scrubbing action of the solder, and ultimately the thermal breakdown of the material. This results in loss of its functionality as a protective blanket, and the loss of an insulating film over the liquid solder when it wicks up the barrel of the via or through-hole. 2)

To make selective soldering with a small flux amount successful it is essential that during the soldering the environment is inert. Nitrogen coverage of the solder enables good penetration even with reduced flux activation. The lack of oxides reduces the bridging and also the solder joints become shinier when there is a good nitrogen blanket.

DOE TO DEFINE SOLDERING PERFORMANCE WITH MINIMUM OF FLUX

The objective of this experiment was to apply a small amount of flux and still have a consistent and robust selective dip soldering process for high volume assembly. The product that was soldered was a printed circuit board of a car radio. The flux amount in today‘s manufacturing line is set at level 2. The other levels have 15% more and 15% less flux.



Design of Experiment - Flux area			
Parameter	Level 1	Level 2	Level 3
Flux amount	-15%	0	+15%
Temp. gradient	1 °C/s	2 °C/s	
Temp. print	25 °C	50 °C	
Solder resist	Mask 1	Mask 2	

Figure 8. The full factorial design of the flux spreading experiment.

The focus was to apply a small amount of flux but with enough to solder with a minimum of spreading to minimize the electro-migration risk.

The parameters that were selected included the solder mask, print temperature during fluxing, and preheating gradient. As shown before the print temperature influences the spreading of the applied flux. In this experiment the customer used a low VOC flux that contained 20% water in combination with alcohol.

The flux was applied to the board using the above settings. After preheating the board was taken out of the selective solder machine and the components were removed. The board was scanned and the spreading could be defined using a software program to measure the fluxed area on the scan.

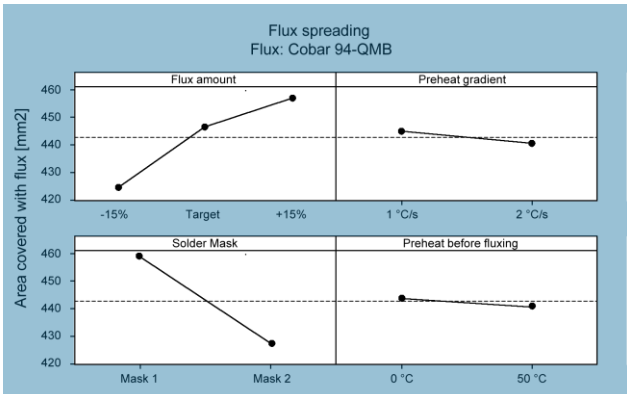


Figure 9. Showing the impact of the different settings on the spreading (lower scores are better).

The experiment showed that the flux amount and the solder mask have a major impact on the spreading of the flux. Although both solder masks are optimized for selective soldering and have a low surface energy (35 mN/mm); there is a significant difference in the spreading of the flux between the two brands.

For the same conditions boards were soldered to verify the solder quality at given settings. The target was to achieve good solder performance with the lowest amount of flux. As figure 10 shows more flux gives better soldering. The solder mask had significant impact where a faster preheating was preferred and fluxing on a hot (preheated) board didn’t return an acceptable soldering result.

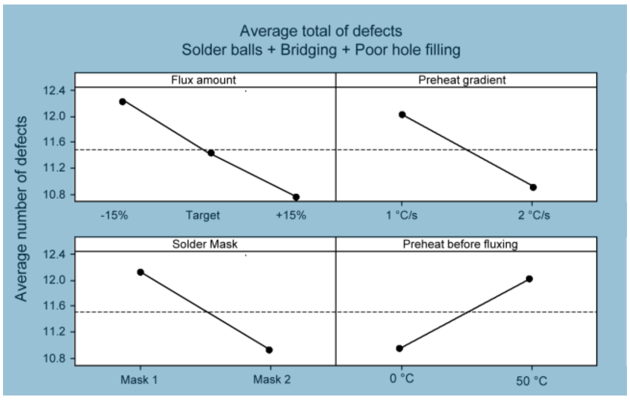


Figure 10. The solder defects counted together for each parameter (lower score is better).

MAINTAIN AN INERT SOLDER ENVIRONMENT

The data from this experiment (using solder mask 2, fast preheat and flux at ambient temperature) was successfully implemented across a three shift production of this product. Essential for a robust soldering process with a DPMO level of < 100 PPM was the nitrogen environment. At the spot where the solder joints are made the remaining oxygen level should be less than 200 PPM.

In order to achieve these low oxygen concentrations dedicated nozzle covers were made for each specific assembly.

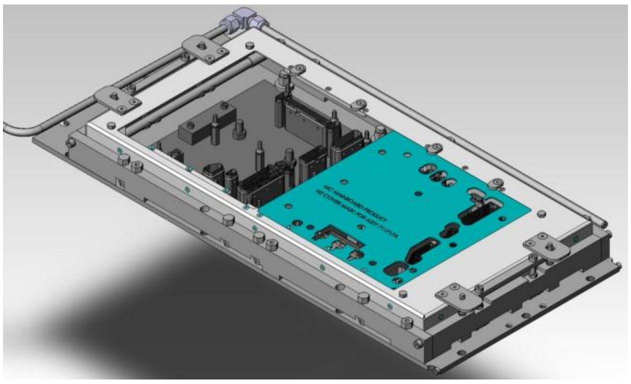


Figure 11. A dedicated nitrogen blanket system enables very low oxygen levels in the soldering area even for high volume products with short cycle times.

In case of a high volume dip solder process the remaining oxygen level is very much depending on the amount of nitrogen supplied. In this process 70 litres of nitrogen per minute was giving satisfactory results.

SUMMARY:

A selective soldering process can be reliable if an inert flux system is used and the spreading of the flux is controlled. The nitrogen environment during soldering improves the solder performance, and additionally supports the flux system. Because of the absence of solder oxides in inert environment a milder flux can be used which reduces the potential risk for electro-migration of non-activated flux residues in the field.

REFERENCES:

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