

# How to Use the Right Flux for the Selective Soldering Application

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## Abstract

The selective soldering application requires a combination of performance attributes that traditional liquid fluxes designed for wave soldering applications cannot fulfill. First, the flux deposition on the board needs to be carefully controlled. Proper fine tuning of the flux physicochemical characteristics combined with a process optimization are mandatory to strike the right balance between solderability and reliability. However, localization of the flux residue through the drop jet process is not enough to guarantee the expected performance level. The flux needs to be designed to minimize the impact of unavoidable spreading and splashing events. From this perspective a fundamental understanding of the relationships between formulation and reliability is critical. In this application, thermal history of the flux residues (from room temperature to solder liquidus) is a key performance driver. Finally, it is necessary to conduct statistically designed experiments on industrial selective soldering machines in order to map the relationships between flux characteristics and selective process friendliness. In this area, multiple performance attributes will be considered: compatibility with drop jet dispensing (clogging effects, cleaning frequency, and satellite formation), spreading (in actual processing conditions, with multiple solder resist types) and soldering performance as measured by barrel filling and defect production in challenging thermal conditions. Therefore, a strong partnership between the flux designer and the equipment manufacturer is a key component of a robust flux design for selective soldering.

## Introduction

The design of fluxes for a selective soldering applications pose unique problems due to the localization of the soldering process. Both the heat treatment and the scrubbing action of the flux residue by the solder wave are confined in the soldered area. In order to address this specific issue, the flux formulator follows two complementary strategies.

First, the physical characteristics of the flux are optimized in synergy with the application process to minimize its footprint on the board. The flux must work in concert with the drop jet dispensing head to flow seamlessly (e.g. no clogging) during the entire operation, localize the deposit, and finally stay in place. The dispensing process parameters (open time, frequency, robot speed) and the board preheat temperature are critical parameters [1], and their optimal settings depend upon the characteristics of the flux (viscosity, surface tension, solid content, solvent). Assembly materials also play an important part, as the optimal surface energy of the solder mask is typically lower than that for the conventional wave soldering process (35 mN/m vs. >50 mN/m) in order to prevent excessive bleeding of the flux on the board after deposition. Hence, the design of a selective soldering flux is a good illustration of the mandatory collaboration between the formulators, equipment, and assembly materials manufacturers from the very beginning of the design process. We have partnered with tier-1 selective wave soldering equipment manufacturers to design a process friendly flux adapted to industry representative printed circuit board materials and layouts.

Second, the flux chemical package is formulated to minimize the impact of unavoidable spreading and splashing events. These will result in partially heated flux residues which won't be removed by the washing action of the solder. As such, they pose a serious threat to the reliability of the assembly, as ionic residues can induce electrochemical migration, corrosion, and resistance losses, which will invariably result in the in-field failure of the assembly when exposed to a moist environment [2, 3]. It is therefore of paramount importance to establish a correlation of the thermal history of the flux with the reliability of the residues. From this perspective, a series of activator packages has been designed specifically to guarantee an optimal reliability when partially heated [4]. The reliability of the fluxes designed for the selective soldering application was assessed using well known industry standards, where the flux was subjected to various thermal conditioning conditions (Table 1).

**Table 1 – Flux Reliability Testing Methods**

Reliability Test	Method	Condition	
Copper Mirror	IPC 2.3.32D	23C; 50%RH	
Copper Corrosion	IPC 2.6.15	40C; 93%RH	
SIR	IPC 2.6.3.7	40C; 90%RH	Pattern Up & Down
			80°C Preheat only
	IPC 2.6.3.3	85C; 85%RH	Room Temp
			Pattern Up & Down
ECM	IPC 2.6.14.1	65C; 88.5%RH	80°C Preheat
			Room Temp

A statistically significant experimental protocol was conducted on a manufacturer's industrial selective soldering equipment in order to evaluate the impact of materials and process parameters on the following response factors: dispensing performance (clogging and satellites), flux spread, and soldering performance. The learnings from these experiments are reported in the following paragraphs.

### Flux Spread

The spread is influenced by the surface tension of the flux as well as its temperature. Alcohol based fluxes will have a much lower surface tension than VOC-free fluxes, which are water based (22mN/m at 25C versus 72mN/m). Also, the dispensing temperature will tend to favor spreading by lowering the flux viscosity. On the other hand, the impact of the board preheat will depend on the nature of the flux: VOC-free fluxes tend to spread more on warmer boards, while alcohol based fluxes will show an opposite trend, as the temperature thinning effect competes with the high drying rate of the flux. Finally, the surface energy of the solder mask is another critical parameter: lower surface energies are favored for selective soldering fluxes compared to conventional wave soldering fluxes (35mN/m vs >50mN/m) to increase the contact angle of the flux on the substrate. This is easily understood when looking at the balance of surface tensions modeled in Young's equation:  $\gamma_{SG} = \gamma_{SL} + \gamma_{LG} \cos \theta$ . It should be noted that the preheating of the board may impact the surface energy of the solder mask.

We estimate the intrinsic spreading of our fluxes by deposition on a representative set of printed circuit boards with various solder masks types. In contrast, in-process optimizations of the flux spread are conducted by directing the drop jet on the shiny side of an aluminum foil which presents a comparable surface energy, and measuring the dried deposits after preheat as illustrated in Figure 1.

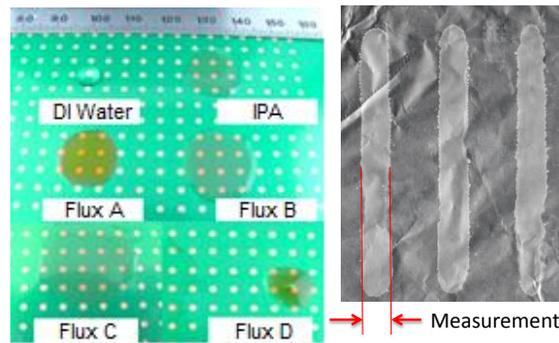


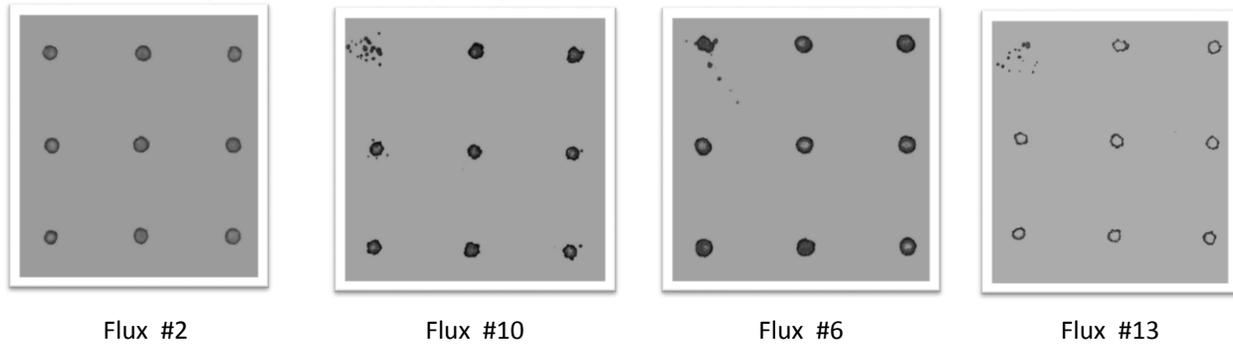
Figure 1 – Flux Spread measurement (Left: PCB, Right: Al foil)

### Drop jet dispense: clogging and satellites

The high-frequency drop jet technology has been developed to narrow the spray pattern compared to atomizing-type aerosol spray heads or ultrasonic spray fluxers. The deflection of the flux droplets is minimized but occurrence of satellites is always a possibility; these very small flux droplets varying in sizes appear in random directions outside of the flux direct deposition corona. Their formation depends on the flux physicochemical characteristics (viscoelastic properties, surface tension), hence its formulation, coupled with the jetting process itself. It is critical to mitigate the formation of satellites, as these side deposits won't be exposed to the same heat cycle and solder scrubbing mechanism as the non-deflected droplets, and will therefore pose a serious threat of electrochemical migration under bias in a moist environment. Another processing issue frequently encountered during dispense is the clogging of the drop-jet fluxer, due to the narrow channels of the spray head (typically 130 $\mu$ m) combined with the high-volatility of alcohol-based selective soldering fluxes.

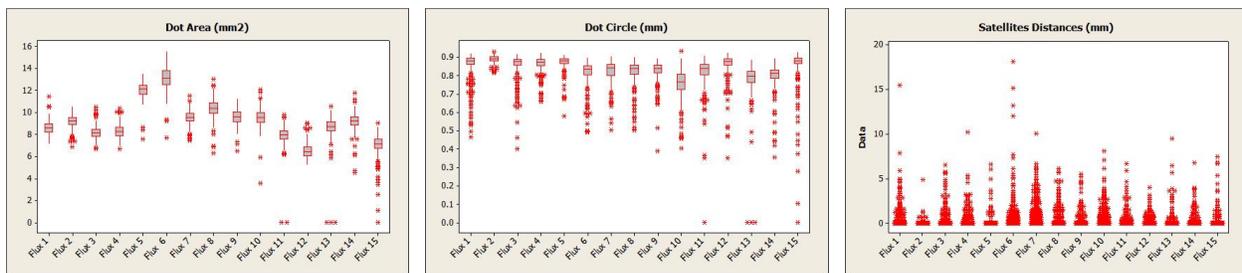
Both clogging and satellite formation are assessed during the same set of experiments, which enable us to screen our flux formulation efficiently on industrial selective soldering equipment. Fax paper is used to identify the location and geometry of droplet deposits. It should be noted that we typically avoid the use of fax paper for in-process spread measurement as the absorption of flux into the fabric of the substrate will result in an inaccurate representation of the flux spread data. The tests consist of successive deposition cycles executed at increasing time intervals. Twenty dots are printed at 2 s intervals in one cycle. This sequence is repeated 4 times, with 30 s breaks between each cycle. The whole procedure is then repeated 4 times, this time with 15 min breaks in between. The dot geometries and satellite positions are computed for the 500 dots deposited in total using an image analysis software. The successive breaks during the sequence make the procedure particularly aggressive. In our experience, a continuous flow of flux through the drop jet unit self-regenerates the head. The breaks give time for the deposits to accumulate, ripen, and create solid deposits on the side, which are more difficult to remove when the sequence is restarted. In consequence, fluxes can be efficiently discriminated through this experimental protocol. Figure 2 shows a representative set of deposition patterns obtained with various fluxes. The flux #2 deposition conditions were near

perfect, while #10, #6, and #13 show multiple defects. One can observe that satellites and variations in surface area of the deposit often happen at the beginning of the sequence where deposit concentration is at its maximum, which demonstrates that this effect is the major root cause for dispensing failures.



**Figure 2 – Typical deposition patterns for the drop jet dispensing test**

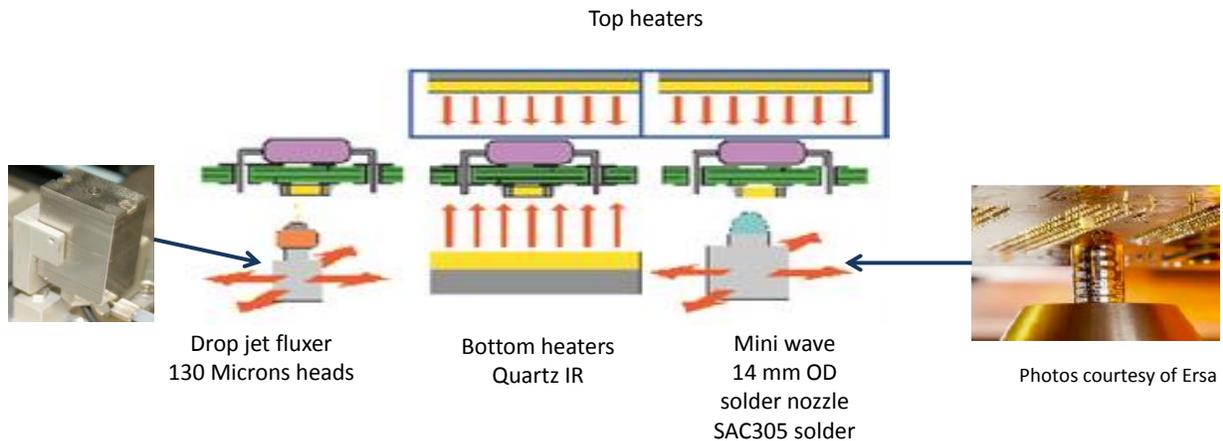
Overall, 15 formulas were screened using the statistically significant set of data generated during these complex deposition sequences. Results of the deposition pattern analysis are reported in Figure 3. The efficiency of this screening method is confirmed, as large differences are observed between fluxes in terms of uniformity of the deposits across the whole deposition sequence (dot area and dot circle), as well as the occurrence and spatial distribution of the satellites. Fluxes #1, 2, 3, and 4 present the best dispensing performance and were selected for the final soldering performance assessment.



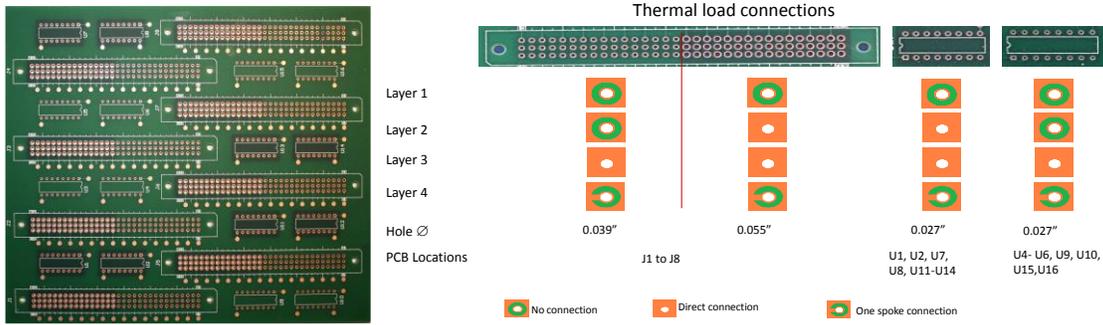
**Figure 3 – Dispensing tests results for 15 experimental formulas.  
Statistical analysis of 500 data points per formula, collected through an image analysis software**

**Soldering Performance**

A performance evaluation was completed on an industrial selective wave soldering machine (Figure 4), using 93 mils FR-4 boards made of 4 Copper layers (1/2/2/1 oz), solder mask over bare copper and an OSP finish (Figure 5). These boards were populated with 16 pins dual in-line packages (DIP) containing IC chips, and 96 pins Eurocard connectors.



**Figure 4 – Selective soldering equipment configuration**



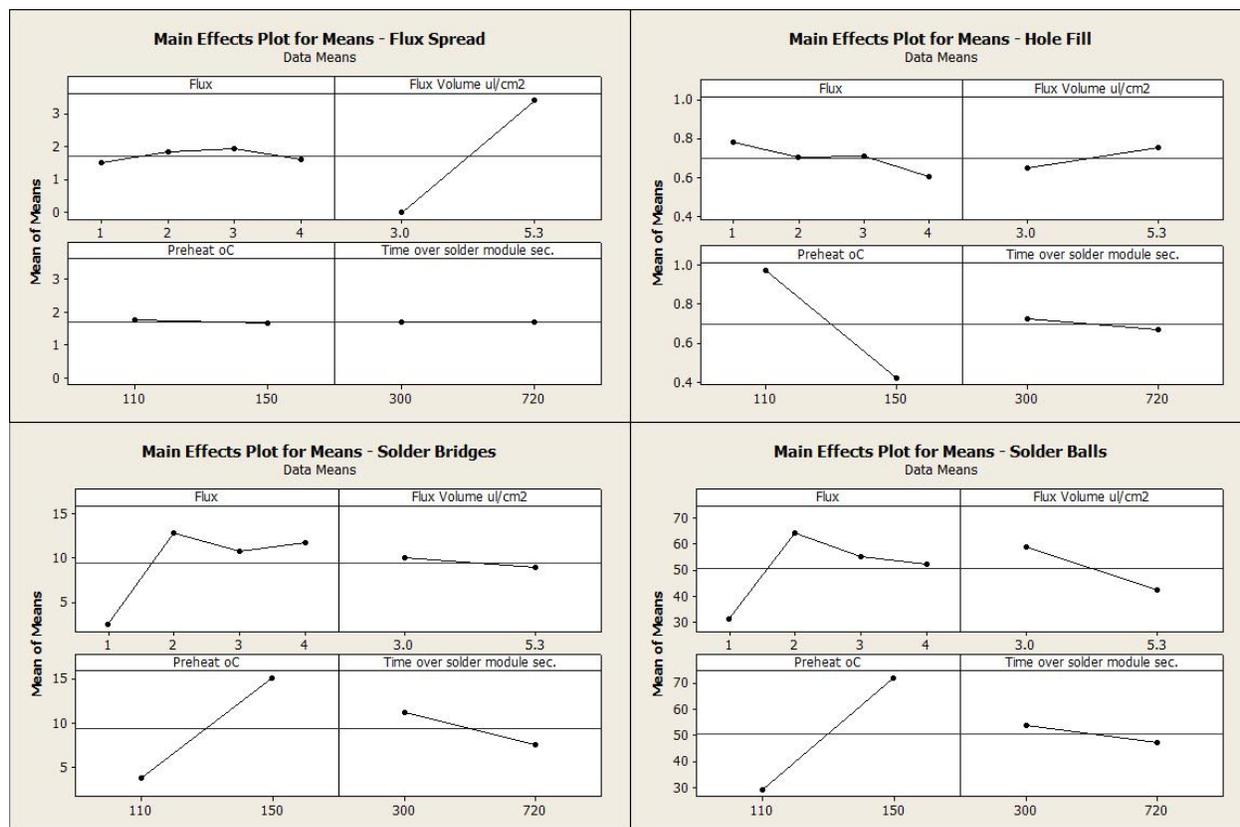
**Figure 5 – Selective soldering testing board**

To determine the soldering performances of the fluxes, the L16 Taguchi design of experiment reported in Table 2 was used.

**Table 2 – Soldering Performance DOE parameters**  
**Fixed Parameters: Solder bath: 290°C, Solder alloy: SAC305, Solder Nozzle: 10ID/14OD, wetted**

Parameter	Level 1	Level 2	Level 3	Level 4
Flux Chemistries	Flux #1 10% solids	Flux #2 6% Solids	Flux #3 8% Solids	Flux #4 10% Solids
Flux Volume $\mu\text{m}^2$	3	5.3		
Board Preheat Temperature	110°C	150°C		
Board Temperature Over the Solder Module	110°C	125°C		
Time In the Solder Module	300 sec.	720 sec.		

The response factors were flux spread (measured area), % hole fill (evaluated by X-Ray Diffraction), and the number of solder bridges and solder balls (visual count). The statistical analysis of the results is reported in figure 6: main effects are represented here, as second-order interactions were found to be statistically insignificant. All fluxes presented similar spreading results, the only impactful process parameter being the dispensed volume. Hole fill performance was found to be comparable between fluxes, while particular attention needs to be given to the board preheat temperature. This result is in good agreement with our background knowledge. Preheat times are relatively long in point-to-point selective soldering applications, which poses a challenge to the thermal stability of the activator packages. In this context, very satisfactory performance is found with all fluxes for a preheat temperature of 110C. More flux discrimination was found when considering soldering defects. Flux #1 clearly stands out compared to the 3 other fluxes, with minimal defect rates observed in all conditions. The strong impact of board preheat temperature on defects confirms our initial interpretation on the activators thermal stability envelope.



**Figure 6 – Soldering Performance DOE results**

## Conclusions

The design of high-performance fluxes for selective soldering applications require a combination of formulation, application, and equipment expertise which mandates a strong partnership between the flux designer and the equipment manufacturer. Multiple performance aspects have to be taken into account. The flux itself must have proven reliability (corrosion, electrochemical migration) under various heat exposure conditions, in particular when only partially activated. Having down selected a series of fluxes filling this requirement, it is necessary to conduct statistically designed experiments on industrial wave soldering machines in order to map the relationships between flux characteristics and selective process friendliness. In this area, multiple performance attributes will be considered: compatibility with drop jet dispensing (clogging effects, cleaning frequency, and satellite formation), spreading on the board (in actual processing conditions, with multiple solder resist types), and soldering performance (fluxing activity, thermal stability) as measured by barrel filling and defect production.

## References

- [1] G. Diepstraten, Achieving repeatable, consistent control over the selective production process, SMTA International, Sep. 27-Oct 1, 2015, Rosemont, IL, USA
- [2] B. Tolla, Y. Shi, X. Wei, H. Bhavsar, Chemical Influences on the reliability of complex assemblies Proc. SMTA SE Asia, April 14-16 (2015), Penang, Malaysia
- [3] B. Tolla, D. Jean, H. Bhavsar, Y. Shi, X. Wei, Reactivity of no-clean flux residues in electronic assemblies: A systematic study, Proc. SMTA International, Sept27-Oct 1 (2015), Rosemont, IL, USA
- [4] X. Wei, K. Loomis, J. Allen, B. Tolla, Partially-Activated Flux Residue Influence on surface insulation resistance of electronic assemblies, SMTA International, Sept27-Oct 1 (2015), Rosemont, IL, USA

## Acknowledgements

The authors would also like to acknowledge Kyle Loomis and Jennifer Allen from the company, for their applied knowledge of reliability testing for the Electronic Assembly industry.

# How to Choose the Right Flux for the Selective Soldering Application

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Bruno Tolla, Ph.D.

Kester

# Outline

- Goal
- Potential Reliability Issues
- Flux Spread
- Flux Satellites
- Soldering Performance
- Conclusion

# Goal

- Reduce flux contamination to a non-detrimental level
- Maintain selective soldering benefits
  - Reduce flux spread (migration)
  - Satellite-free flux (drop jet fluxer head)
  - Sustain high preheat temperature – high thermal mass board
  - Extended soldering time under preheat condition
  - Higher solid content to increase the activity per square inch
  - Non-clogging of the drop jet fluxer head

# Potential Reliability Issues

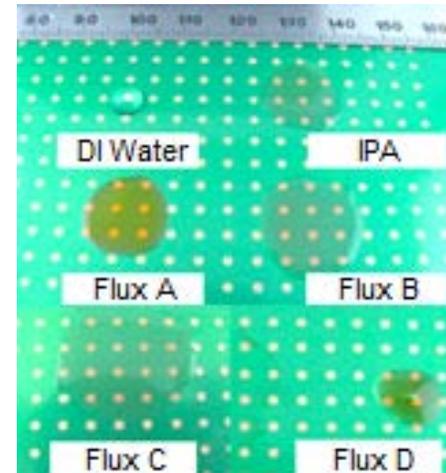
- Flux creates a unique problem for selective soldering application
- Selective soldering or single point to point soldering localizes the heat to a specific area
- Applied flux can spread beyond the soldering area
  - No solder washing action to remove it
  - Insufficient heat to encapsulate itself
  - Flux that migrates beyond the soldering area could leave significant ionic residues and produce latent defects

# IPC Classification and Reliability Tests

Reliability Test	Method	Condition	
Copper Mirror	IPC 2.3.32D	23C; 50%RH	
Copper Corrosion	IPC 2.6.15	40C; 93%RH	
SIR	IPC 2.6.3.7	40C; 90%RH	Pattern Up & Down
			80°C Preheat only
			Room Temp
	IPC 2.6.3.3	85C; 85%RH	Pattern Up & Down
			80°C Preheat
			Room Temp
ECM	IPC 2.6.14.1	65C; 88.5%RH	

# Flux Spread

- Factors that influence the flux spread:
  - Flux surface tension
    - Surfactant
    - Solvent
      - IPA: 22mN/m at 25°C
      - Water: 72mN/m
  - Temperature of the flux



# Flux Spread

## –Temperature of the board

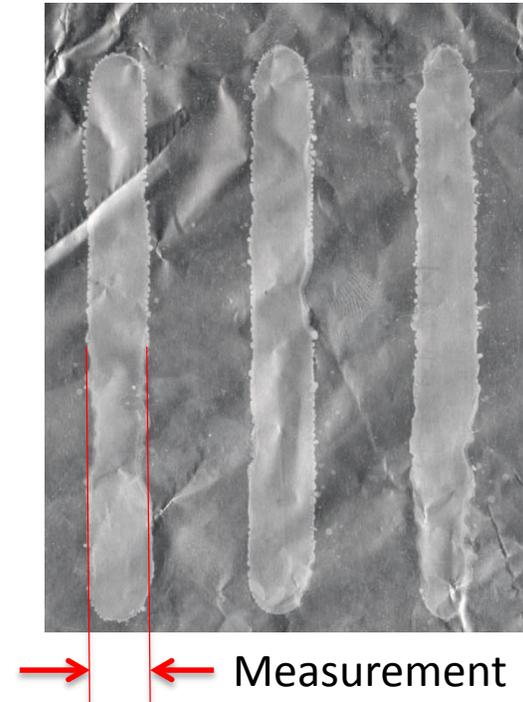
- Alcohol-based flux will spread less when the board is preheated
- A VOC-free base flux will spread more when the board is preheated

## –Surface energy of the solder mask

- Wave soldering: Glossy solder mask is preferred
- Selective soldering : Matte solder mask is preferred
- Preheating the board before flux application may have an impact on the surface energy of the solder mask

# Flux Spread Measurement

- The flux absorption by pH or thermal fax paper will result in inaccurate representation of the flux spread area
- Flux sprayed on the shiny side of an aluminum foil and the dry flux area measured after the preheat step



# Flux Satellites

- Satellites are very small droplets
- Satellites are formed during drop jet fluxing process
- Satellites sizes and direction are not controllable
- Satellites are a function of the flux formulation and the jetting techniques
- Potential reliability risk

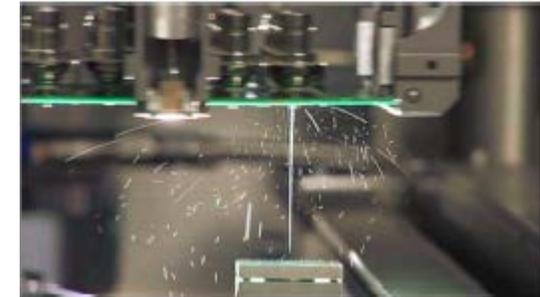
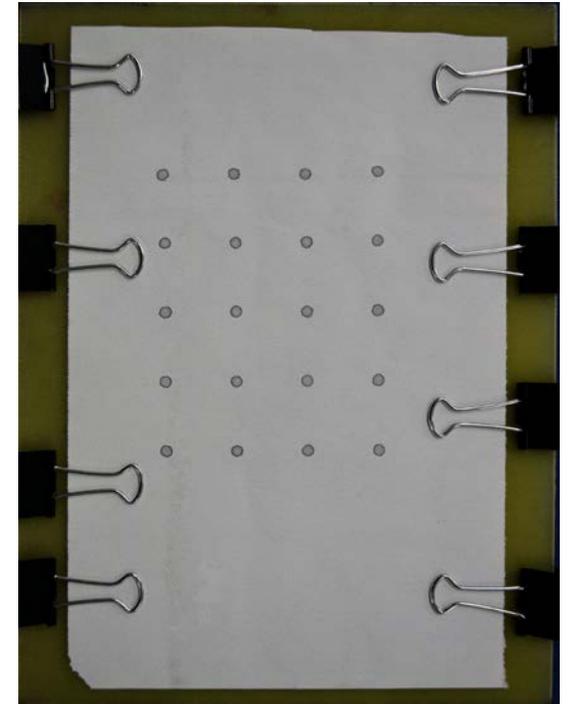


Photo courtesy of Vitronics Soltec

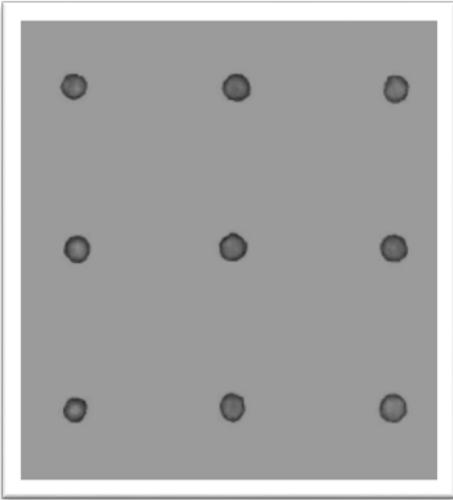
# Flux Clogging and Satellites Experiment

## Test

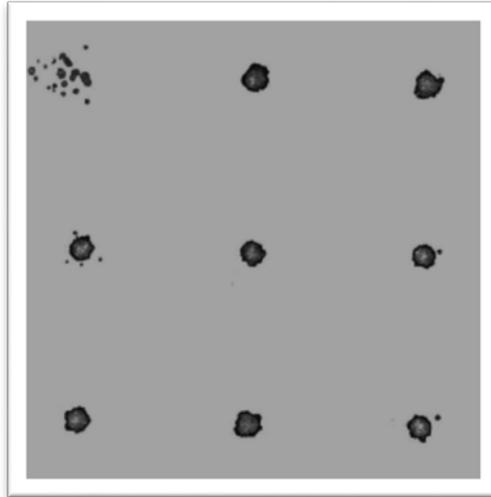
1. Sprays  $\approx$  1 droplet on fax paper followed with a 2 second pause, 20 times
2. Pause 30 seconds and repeat step 1, 4 times
3. Pause 15 minutes and repeat step 1 and 2, 4 times
4. Measure the dot diameter and the overspray between dots
5. 15 flux formulations were tested



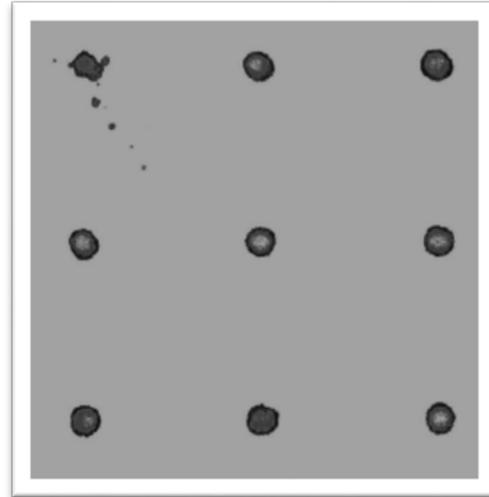
# Flux Dots and Satellites Results



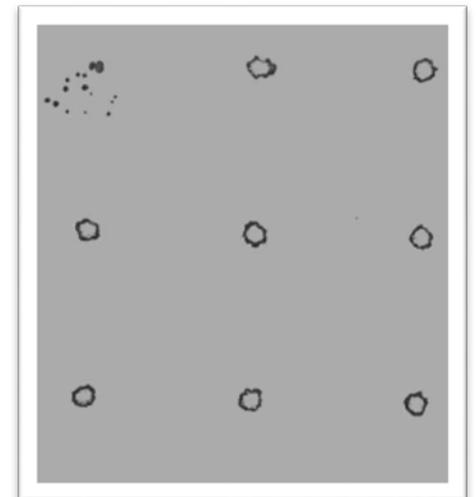
Flux #2



Flux #10



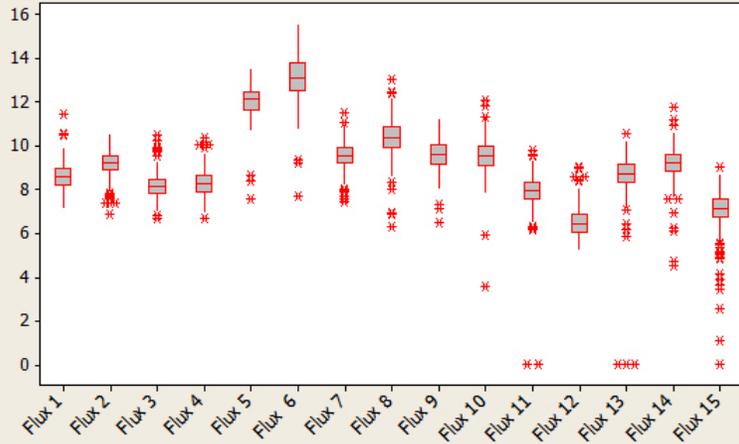
Flux #6



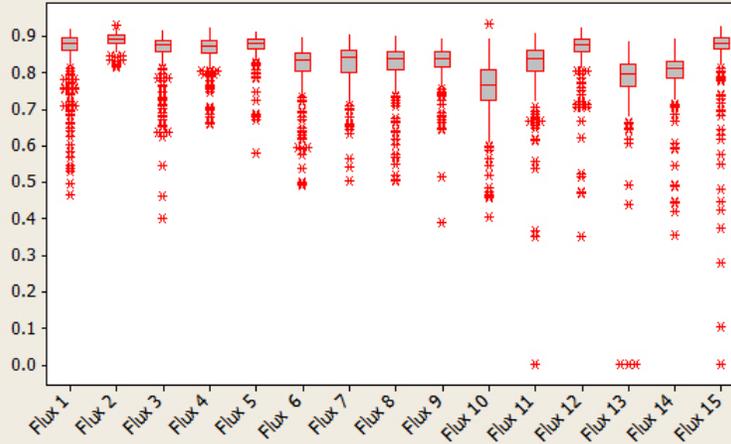
Flux #13

# Flux Dots and Satellites Results

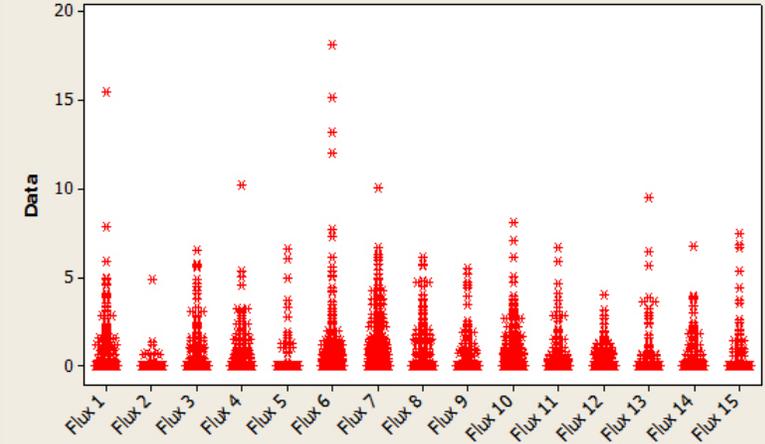
**Dot Area (mm<sup>2</sup>)**



**Dot Circle (mm)**

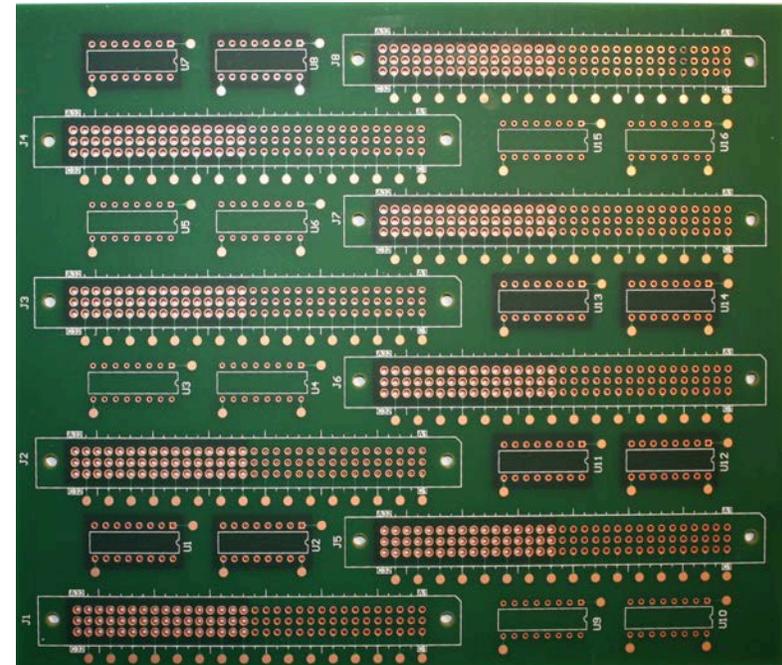


**Satellites Distances (mm)**



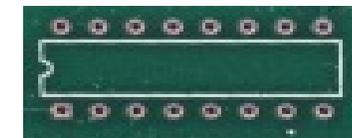
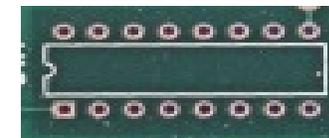
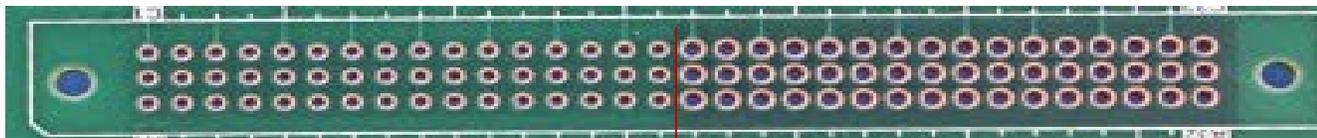
# Soldering Performance – Test Board

- Test Board
  - 0.093” FR4 PCB
  - 4 layers
    - 2oz copper for the inner layers
    - 1oz copper for the outer layers
  - OSP surface finish
  - Solder mask over bare copper
  - Components
    - 16 pins DIP ICs
    - 96 pins Eurocard connectors



# Soldering Performance – Test Board

## Thermal load connections



Layer 1



Layer 2



Layer 3



Layer 4



Hole  $\varnothing$

0.039"

0.055"

0.027"

0.027"

PCB Locations

J1 to J8

U1, U2, U7,  
U8, U11-U14

U4- U6, U9, U10,  
U15,U16



No connection



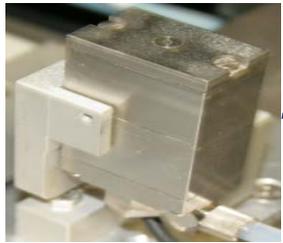
Direct connection



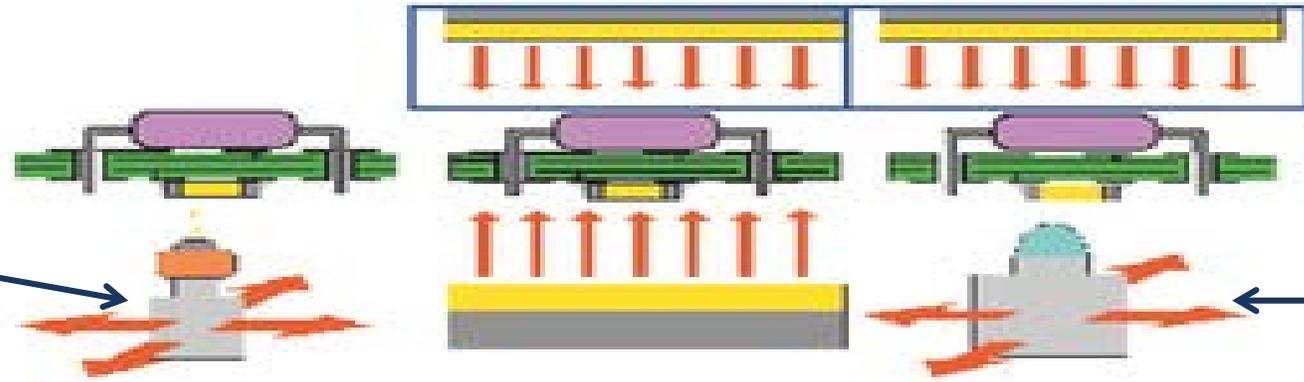
One spoke connection

# Selective Soldering Equipment Configuration

Top heaters



Drop jet fluxer  
130 Microns heads



Bottom heaters  
Quartz IR

Mini wave  
14 mm OD  
solder nozzle  
SAC305 solder



Photos courtesy of Ersu

# Soldering Performance – DoE

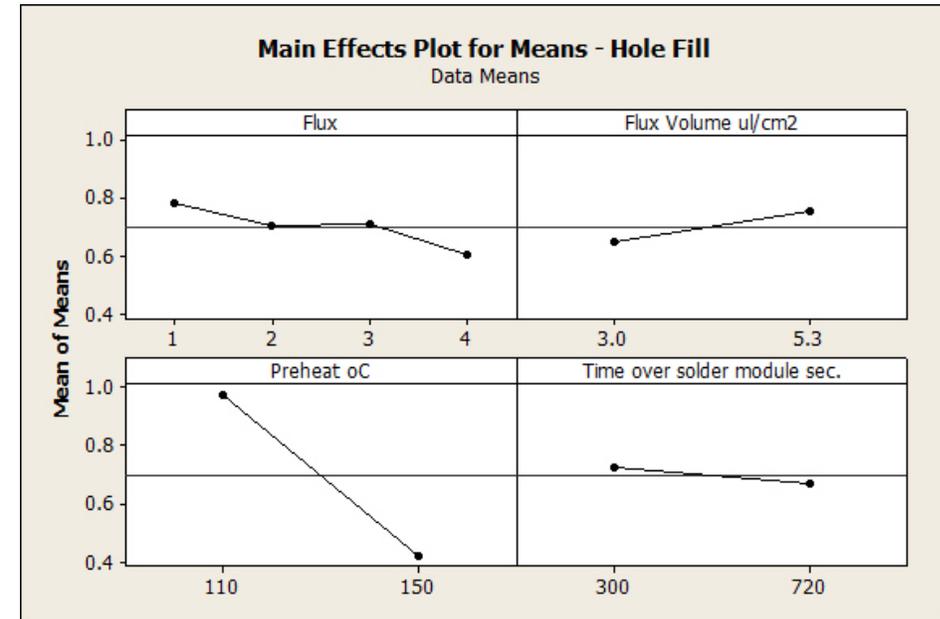
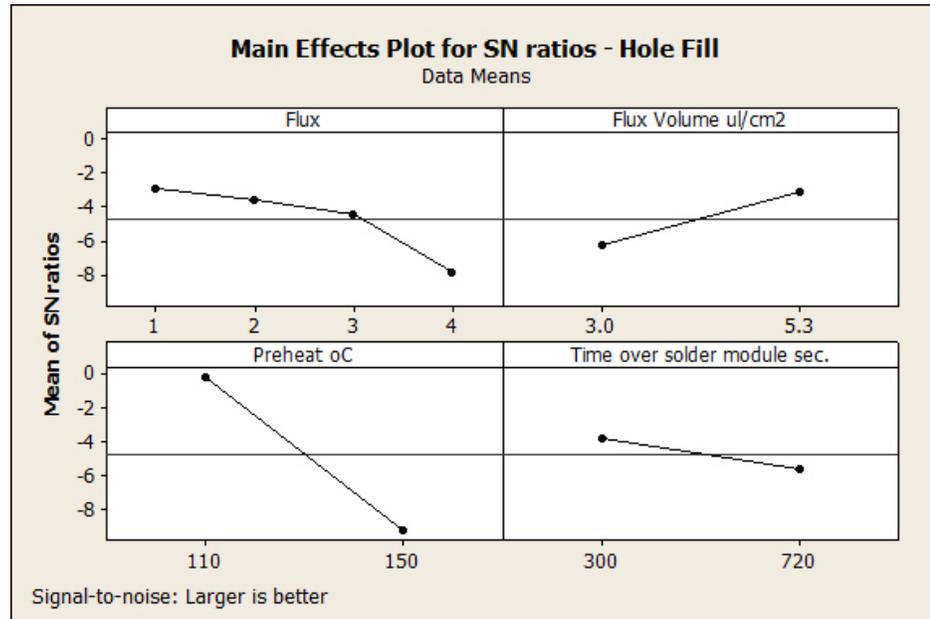
To determine the soldering performances of the fluxes a L16 Taguchi Design of Experiment was used.

Parameter	Level 1	Level 2	Level 3	Level 4
Flux Chemistries	Flux #1 10% solids	Flux #2 6% Solids	Flux #3 8% Solids	Flux #4 10% Solids
Flux Volume $\mu\text{l}/\text{cm}^2$	3	5.3		
Board Preheat Temperature	110°C	150°C		
Board Temperature Over the Solder Module	110°C	125°C		
Time In the Solder Module	300 sec.	720 sec.		

## Fix Parameters:

- Solder bath: 290°C
- Solder alloy: SAC305
- Solder Nozzle: 10ID/14OD, wetted

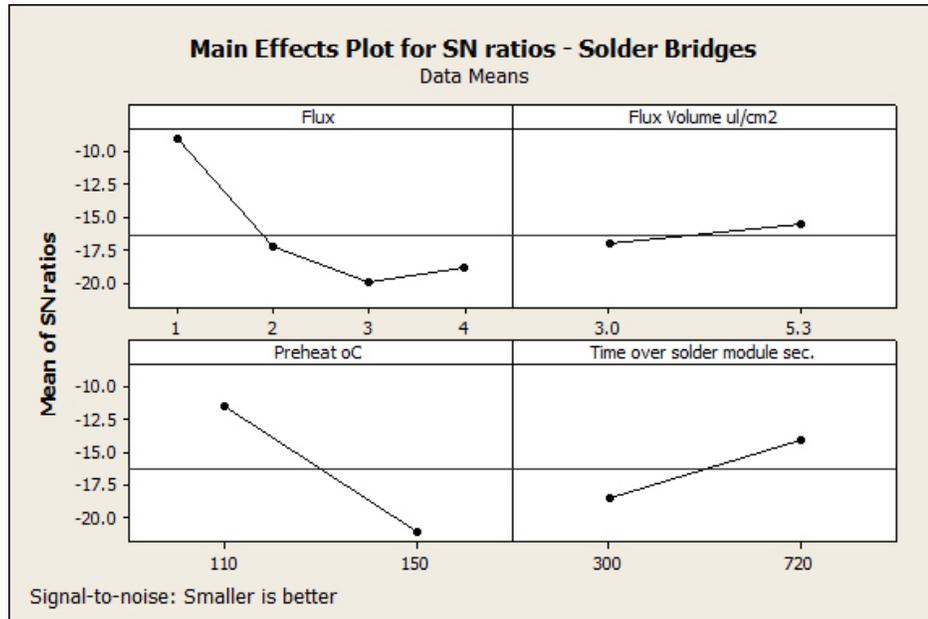
# DoE Analysis – Hole Fill



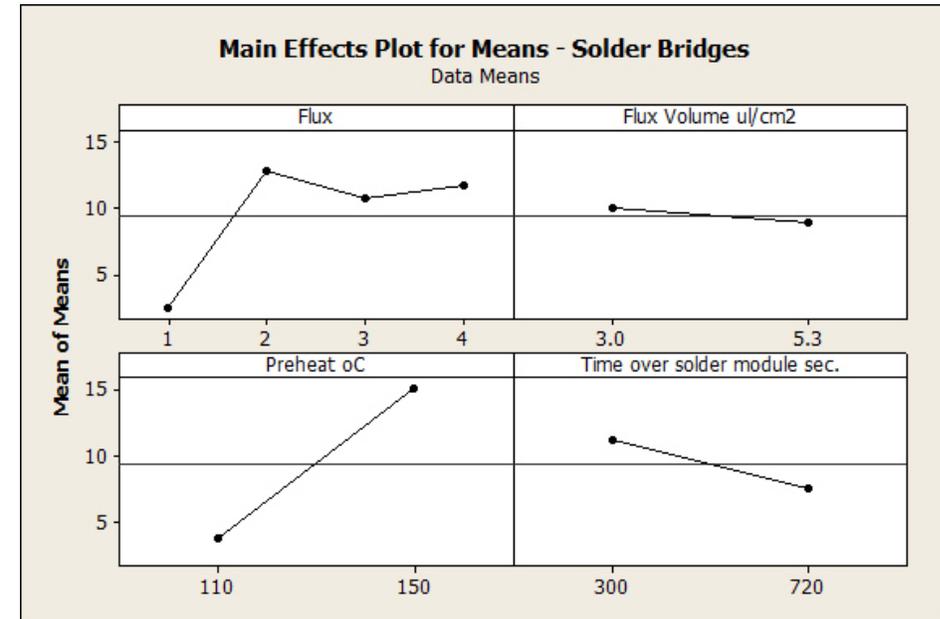
Level	Flux	Flux Volume ul/cm2	Preheat oC	Time over solder module sec.
1	-2.9219	-6.2636	-0.1839	-3.8189
2	-3.5878	-3.1480	-9.2278	-5.5927
3	-4.4178			
4	-7.8958			
Delta	4.9739	3.1156	9.0439	1.7738
Rank	2	3	1	4

Level	Flux	Flux Volume ul/cm2	Preheat oC	Time over solder module sec.
1	0.7813	0.6462	0.9800	0.7281
2	0.7050	0.7544	0.4206	0.6725
3	0.7112			
4	0.6038			
Delta	0.1775	0.1081	0.5594	0.0556
Rank	2	3	1	4

# DoE Analysis – Solder Bridges

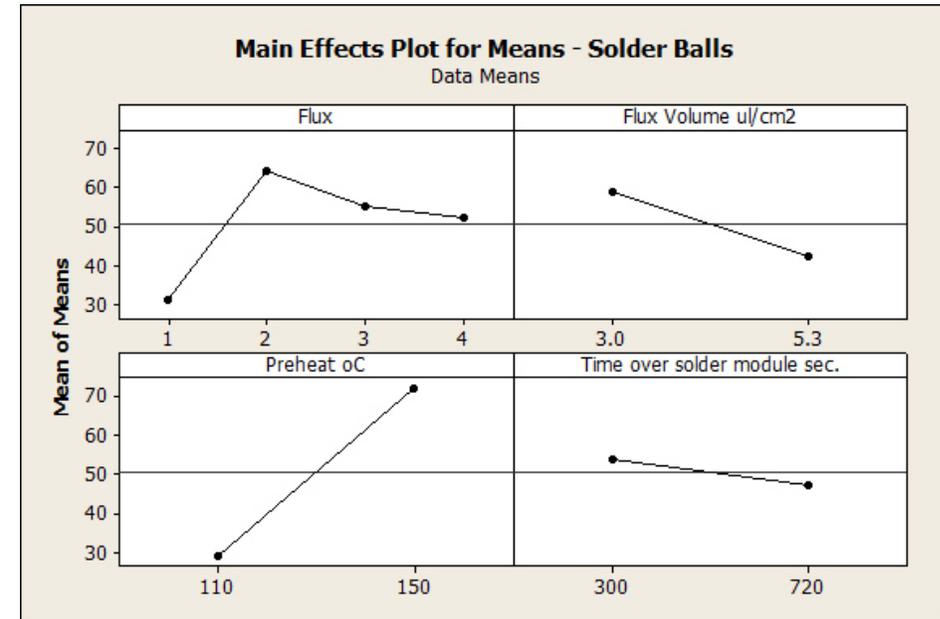
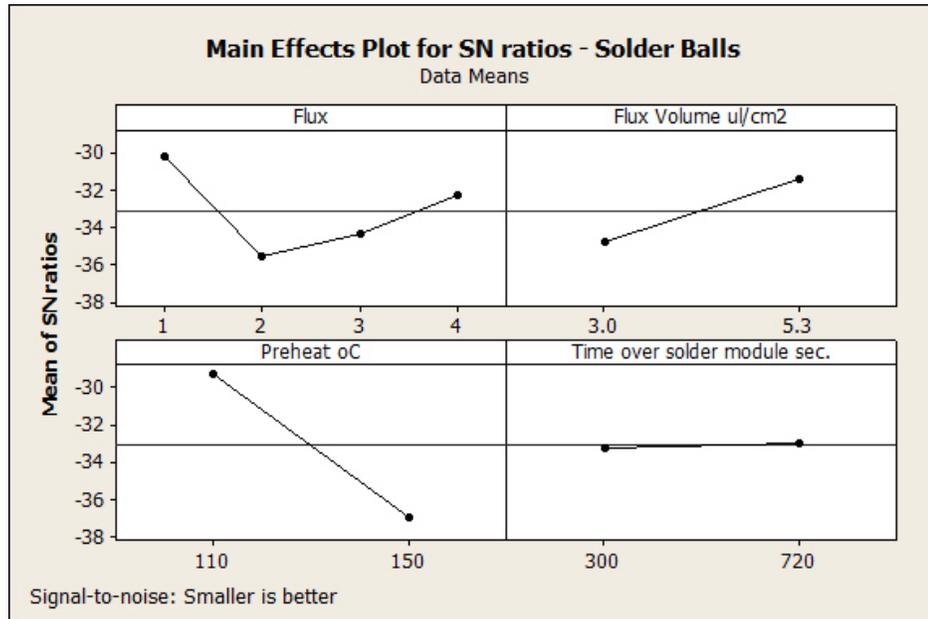


Level	Flux	Flux Volume ul/cm2	Preheat oC	Time over solder module sec.
1	-9.065	-17.017	-11.507	-18.522
2	-17.253	-15.601	-21.111	-14.095
3	-20.052			
4	-18.865			
Delta	10.987	1.416	9.604	4.427
Rank	1	4	2	3



Level	Flux	Flux Volume ul/cm2	Preheat oC	Time over solder module sec.
1	2.500	10.000	3.750	11.250
2	12.750	8.875	15.125	7.625
3	10.750			
4	11.750			
Delta	10.250	1.125	11.375	3.625
Rank	2	4	1	3

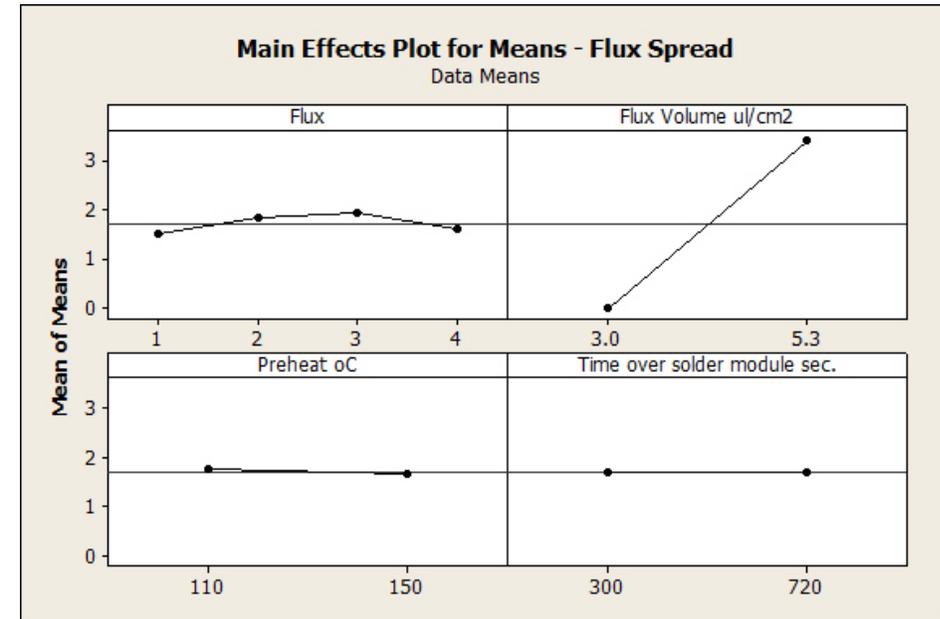
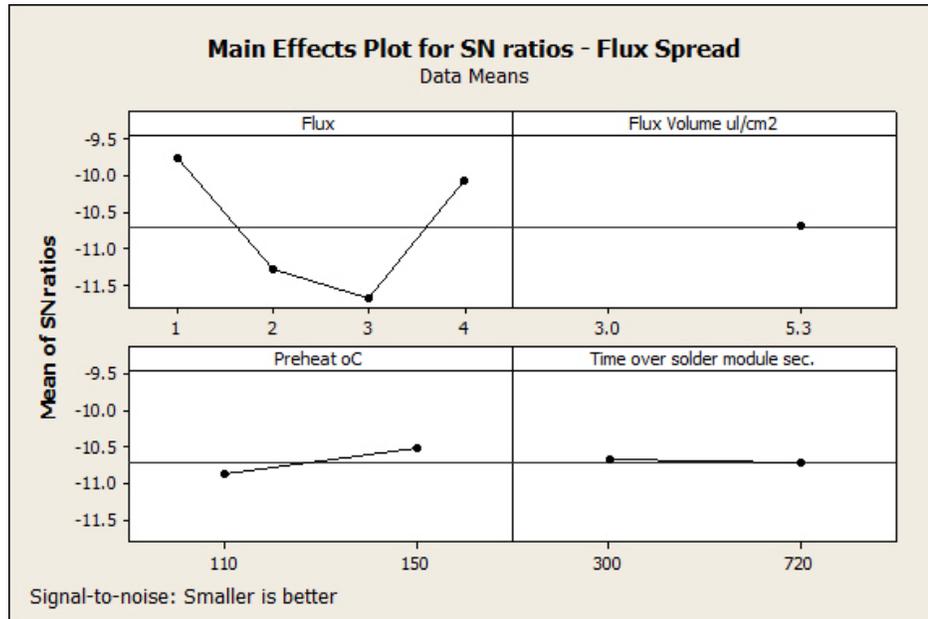
# DoE Analysis – Solder Balls



Level	Flux	Flux Volume ul/cm2	Preheat oC	Time over solder module sec.
1	-30.21	-34.81	-29.27	-33.23
2	-35.59	-31.40	-36.94	-32.98
3	-34.35			
4	-32.29			
Delta	5.38	3.41	7.67	0.25
Rank	2	3	1	4

Level	Flux	Flux Volume ul/cm2	Preheat oC	Time over solder module sec.
1	31.00	58.75	29.13	53.88
2	64.00	42.38	72.00	47.25
3	55.00			
4	52.25			
Delta	33.00	16.38	42.88	6.63
Rank	2	3	1	4

# DoE Analysis – Flux Spread



Level	Flux	Flux Volume ul/cm2	Preheat oC	Time over solder module sec.
1	-9.769	*	-10.886	-10.685
2	-11.288	-10.707	-10.529	-10.729
3	-11.690			
4	-10.082			
Delta	1.920	0.000	0.357	0.044
Rank	1	4	2	3

Level	Flux	Flux Volume ul/cm2	Preheat oC	Time over solder module sec.
1	1.48750	0.00000	1.75500	1.70875
2	1.82750	3.41250	1.65750	1.70375
3	1.92000			
4	1.59000			
Delta	0.43250	3.41250	0.09750	0.00500
Rank	2	1	3	4

# Conclusions

- Choose the right formulation for the selective soldering application. The formula should:
  - Not clog the drop jet head while providing a low cleaning frequency requirement
  - Have a satellite-free process
  - Have a higher surface tension to control the spread area
  - Have a good SIR/ECM reliability under different temperature exposure conditions
  - Have enough flux activity per square centimeter

# Thank You

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