



Effects of Hand Soldering MIL-PRF-55365 Tantalum Capacitors

***Erik K. Reed**
Jet Propulsion Laboratory
Pasadena, California

Penelope L. Spence
Jet Propulsion Laboratory
Pasadena, California

Douglas Sheldon
Jet Propulsion Laboratory
Pasadena, California

Jet Propulsion Laboratory
California Institute of Technology
Pasadena, California

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***Erik K. Reed**
Jet Propulsion Laboratory
Pasadena, California

Penelope L. Spence
Jet Propulsion Laboratory
Pasadena, California

Douglas Sheldon
Jet Propulsion Laboratory
Pasadena, California

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Jet Propulsion Laboratory
4800 Oak Grove Drive
Pasadena, CA 91109

<http://nepp.nasa.gov>

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Abstract

Different values of MIL-PRF-55365 tantalum capacitors were subjected to three different types of soldering conditions—Convection Reflow, JPL Standard Hand Soldering, and Optimized Hand Soldering. The electrical parameters for a large number of capacitors of each value were measured before and after thermal soldering stress. The results indicate that tantalum capacitors subjected to convection reflow conditions experience detectable changes in electrical parameters; capacitors subjected to hand solder conditions show reduced changes in electrical parameters when compared to the reflow samples. Optimized hand solder conditions are shown to have a minimal effect on electrical parameters.

Introduction

The thermal stress of soldering has long been recognized as an area of concern for the assembly of all surface mount devices, including, of course, tantalum capacitors [1-2]. MIL-PRF-55365 is used to specify the requirements for high reliability electrolytic (tantalum) capacitors, and provides specific guidance for the stability of electrical parameters of tantalum capacitors under thermal solder stress.

A standard resistance-to-soldering heat test is defined in method 210 of MIL-STD-202. The standard covers a wide range of test conditions in order to provide coverage for a variety of different device types. Test conditions exist for soldering irons, solder dip, wave solder, Vapor Phase Reflow, and infrared reflow. These various test conditions from MIL-STD-202 are shown in Table 1.

MIL-PRF-55365 defines the parameters, shown in Table 2, to be tested before and after a resistance-to-soldering heat test.

The set of experimental conditions that will be reported in this paper are designed to augment the tests defined in the MIL-STD and the MIL-PRF documents. These experimental conditions include two types of hand soldering conditions as well as a standard convection reflow condition. This convection reflow is very similar to condition J in Table 1 with slightly less time above 183°C.

Hand soldering techniques are often used on boards for spacecraft applications. This includes re-work as well as custom, single-unit board prototyping. Because of this continued use of hand soldering, it is important to vary the hand soldering conditions and determine quantitatively if any damage is being done to the capacitors.

Table 1. Method 210 in MIL-STD-202 for Resistance to Soldering Heat Test

Solder Technique Simulation	Test Condition	Temperature (°C)	Time (s)	Temperature Ramp / Immersion and Emersion Rate	Number of Heat Cycles
Solder iron	A	350 ± 10 (solder iron temp)	4-5		1
Dip	B	260 ± 5 (solder temp)	10 ± 1	25 mm/s ± 6 mm/s	1
Wave: Topside board-mount product	C	260 ± 5 (solder temp)	20 ± 1		1
Wave: Bottomside board-mount product	D	260 ± 5 (solder temp)	10 ± 1	Preheat 1°C/s-4°C/s to within 100°C of solder temp. 25 mm/s ± 6 mm/s	1
	E	CANCELLED			
	F	CANCELLED			
	G	CANCELLED			
Vapor phase reflow	H	215 ± 5 (vapor temp)	60 ± 5	1°C /s-4°C /s; time above 183°C, 90 s-120 s	1
IR/convection reflow	I	215 ± 5 (component temp)	30 ± 5	1°C /s-4°C /s; time above 183° C, 90 s-120 s	3
	J	235 ± 5 (component temp)	30 ± 5	1°C /s-4°C /s; time above 183°c, 90 s-120 s	3
	K	250 ± 5 (component temp)	30 ± 5	1°C /s-4°C /s; time above 183°C, 90 s-120 s	3

SOURCE: MIL-STD-202 [3]

KEY: Test condition E is cancelled; use test condition C.
 Test condition F is cancelled; use test condition B.
 Test condition G is cancelled.

Table 2. MIL-PRF-55365 Resistance to Soldering Heat Requirements

Parameter	Pass/Fail Criteria
DC Leakage	As specified in slash sheet
Capacitance	< ±5% change from initial value
Dissipation Factor	As specified in slash sheet

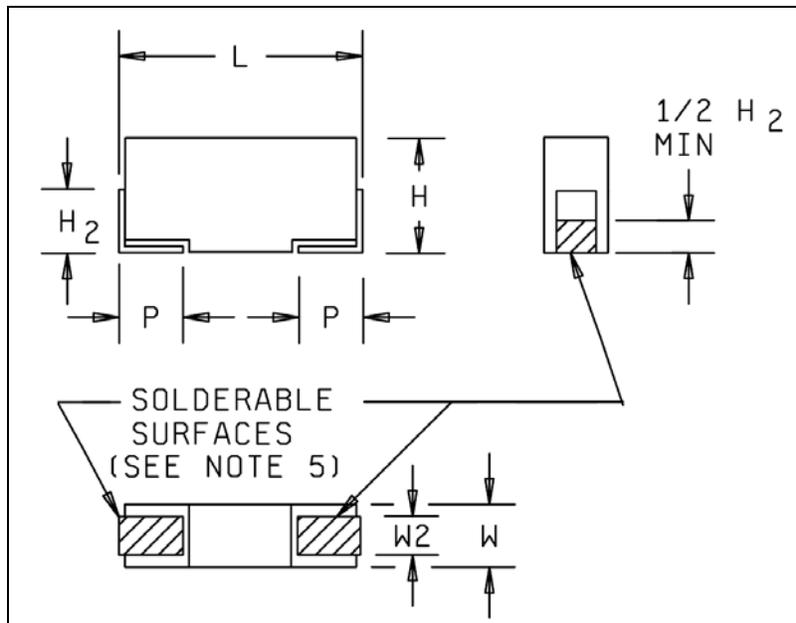
SOURCE: MIL-PRF-55365 [4]

Experimental Setup

Four different values of MIL-PRF-55365 tantalum capacitors were used in this study. Table 3 summarizes the types of capacitors used. The capacitors are listed in increasing volume (case size A is the smallest; case size D is the largest). The dimensions of each case size can be found in Figure 1 and Table 4.

Table 3. Tantalum Capacitors Used in This Report

Style	Case Size	Capacitance (μF)	Voltage Rating (V)
CWR11	A	0.47	25
CWR11	B	2.2	20
CWR11	C	4.7	25
CWR11	D	10	25



SOURCE: MIL-PRF-55365/8 [5]

Figure 1. MIL-PRF-55365 Slash Sheet 8: Dimensions of Case Sizes

Table 4. MIL-PRF-55365 Slash Sheet 8: Dimensions of Case Sizes

Case Code	Dimensions					
	H (mm)	L (mm)	W (mm)	H (in)	L (in)	W (in)
A	1.6 ±0.2	3.2 ±0.2	1.6 ±0.2	0.063 ±0.008	0.126 ±0.008	0.063 ±0.008
B	1.9 ±0.2	3.5 ±0.2	2.8 ±0.2	0.075 ±0.008	0.138 ±0.008	0.110 ±0.008
C	2.5 ±0.3	6.0 ±0.3	3.2 ±0.3	0.098 ±0.012	0.236 ±0.012	0.126 ±0.012
D	2.8 ±0.3	7.3 ±0.3	4.3 ±0.3	0.110 ±0.012	0.287 ±0.012	0.169 ±0.012

SOURCE: MIL-PRF-55365/8 [5]

Three different types of solder profiles were chosen:

1. Convection Reflow
2. JPL Standard Hand Soldering
3. Optimized Hand Soldering

Convection Reflow involves exposing capacitors to various temperatures in an oven. As the capacitors pass through the oven, the temperature is slowly raised in phases to the point that the solder reflows and attaches the capacitor to the board. The idea is that less damage is done to the capacitor by slowly increasing temperature.

JPL Standard Hand Soldering is a process of attaching surface mount devices to a circuit board quickly using a low temperature soldering iron. An overview of this process can be found in Appendix A.

Optimized Hand Soldering is similar to JPL Standard Hand Soldering, but is intended to introduce less heat. Heat is applied only long enough to form acceptable solder joints. Details of this process can be found in Appendix B.

In order to measure the exact temperature profile seen during the two hand soldering processes, small thermocouples were inserted into representative capacitors from each style by drilling small holes into the bodies and then exposing the capacitors to the different thermal profiles. A capacitor of case size D is shown in Figure 2 with the thermal couples inserted.

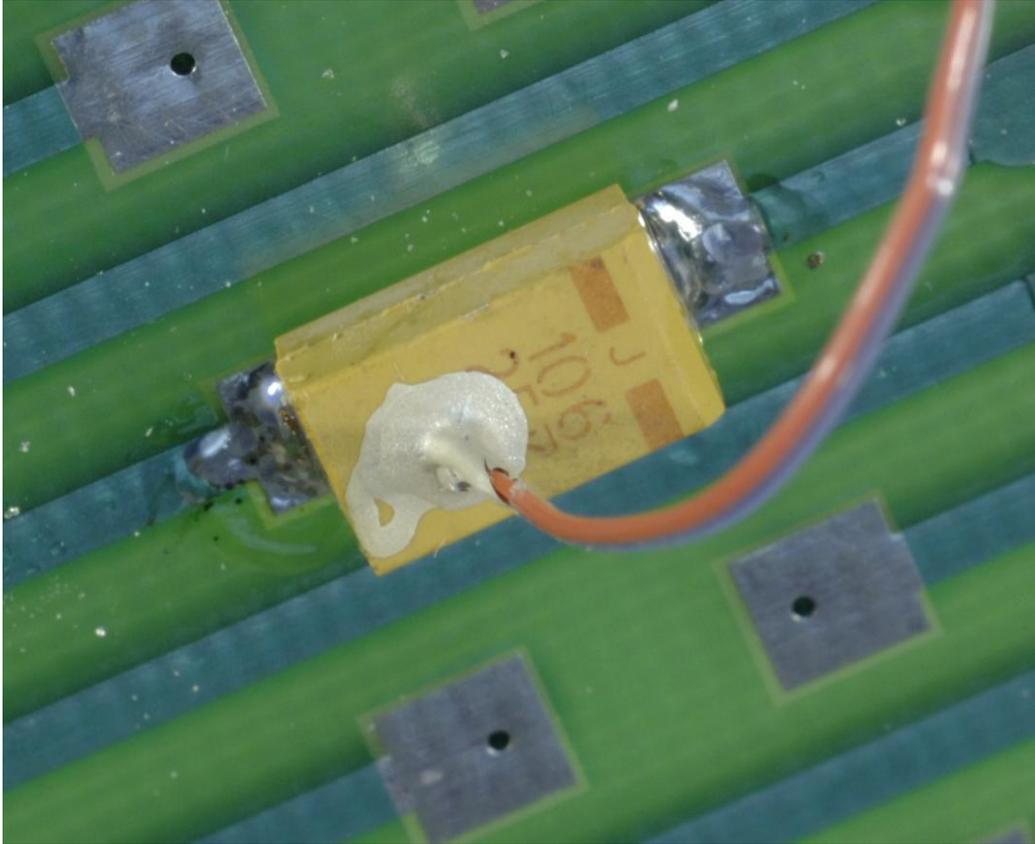


Figure 2. Thermocouples Inserted into Case Size D

Figure 3 shows the internal temperature for the JPL Standard Hand Soldering process. The results of Figure 3 show that case sizes A and B are similar in profile. There are two distinct peaks in temperature, one around 100°C and the other near 125°C. The separation time between the first and second peak of each curve is the time taken between soldering the first and second terminals.

Case sizes C and D in Figure 3 have lower temperature profiles. This is because the capacitor sizes are larger than case sizes A and B and they have higher thermal mass. The larger the mass of the capacitor, the less temperature rise occurs for a given solder iron contact duration, and the contact duration is relatively constant. For case sizes C and D, the first peak occurs near 60°C and the second peak occurs between 75°C and 95°C.

The general profile trends seen in Figure 3 for the JPL Standard Hand Soldering also occur in Figure 4 for the Optimized Hand Solder. Case sizes A and B share a similar profile, with higher temperatures than the profiles of case sizes C and D.

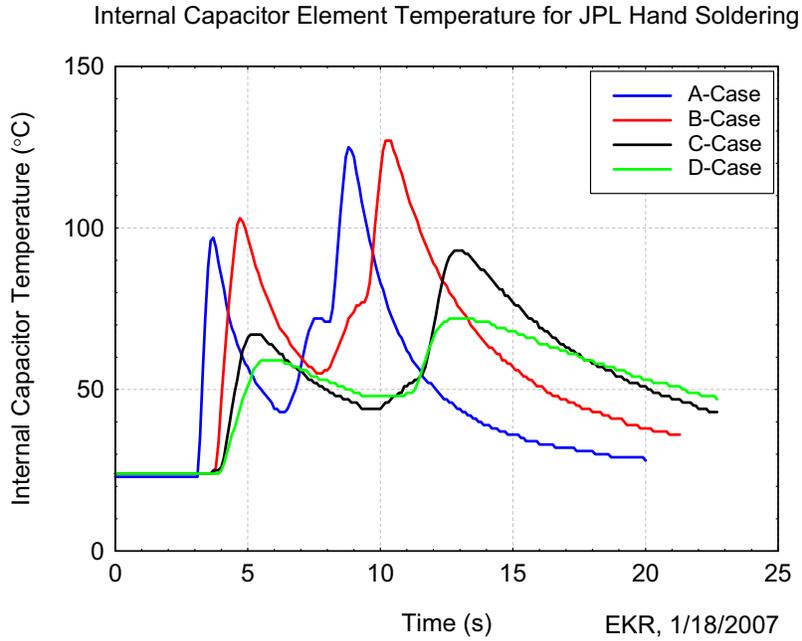


Figure 3. Internal Temperature for JPL Standard Hand Soldering Profile

Figure 4 shows the internal temperature for the Optimized Hand Solder process.

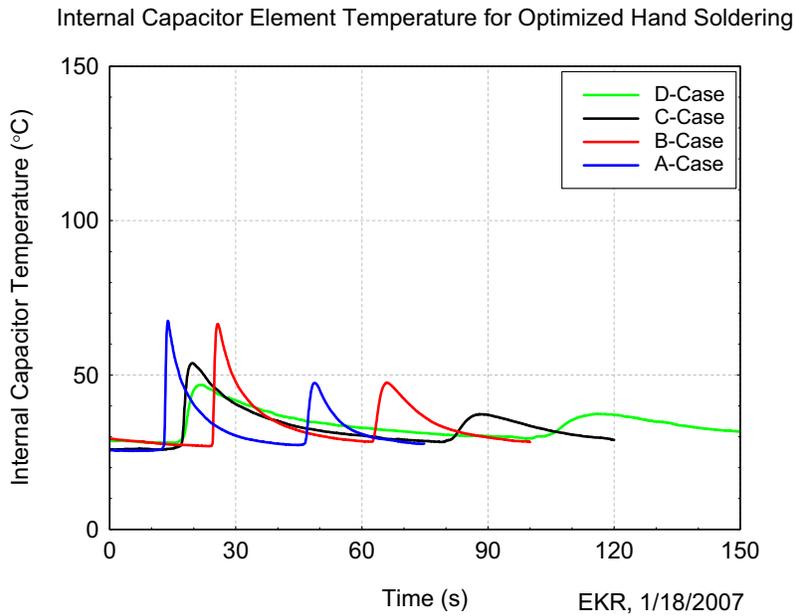


Figure 4. Internal Temperature for Optimized Hand Soldering Profile

The main differences between the Optimized Hand Soldering and the JPL Standard Hand Soldering profile are maximum temperature and overall time. The Optimized Hand Soldering profile is almost exclusively below 50°C with only case size A and case size B having brief temperature spikes to approximately 65°C. In contrast, the Standard JPL Hand Soldering profile is almost never below 50°C. The Optimized Hand Soldering process sequence takes almost 120 seconds to complete while the JPL Standard Hand Soldering flow is complete within 20 seconds. Optimized Hand Soldering takes longer because the capacitor is allowed to cool to room temperature before introducing the next soldering step, thus preventing heat from accumulating in the capacitor.

The goal of Optimized Hand Soldering is to apply heat for the shortest time necessary to form acceptable solder joints. Tantalum capacitors can be damaged by prolonged exposure to solder reflow temperatures. This is in contrast with ceramic chip capacitors which withstand prolonged high temperature exposure well, but can be very sensitive to rapid changes in temperature.

Figure 5 shows the thermal profile for convection reflow solder. The profile is very similar to the J requirement for Method 210 shown in Table 1. This profile involves slightly less time above 183°C (70.43 seconds instead of the minimum value of 90 seconds). The shorter time is not unusual in commercial mounting processes where it is well known that reducing thermal exposure minimizes damage to sensitive electronic components.

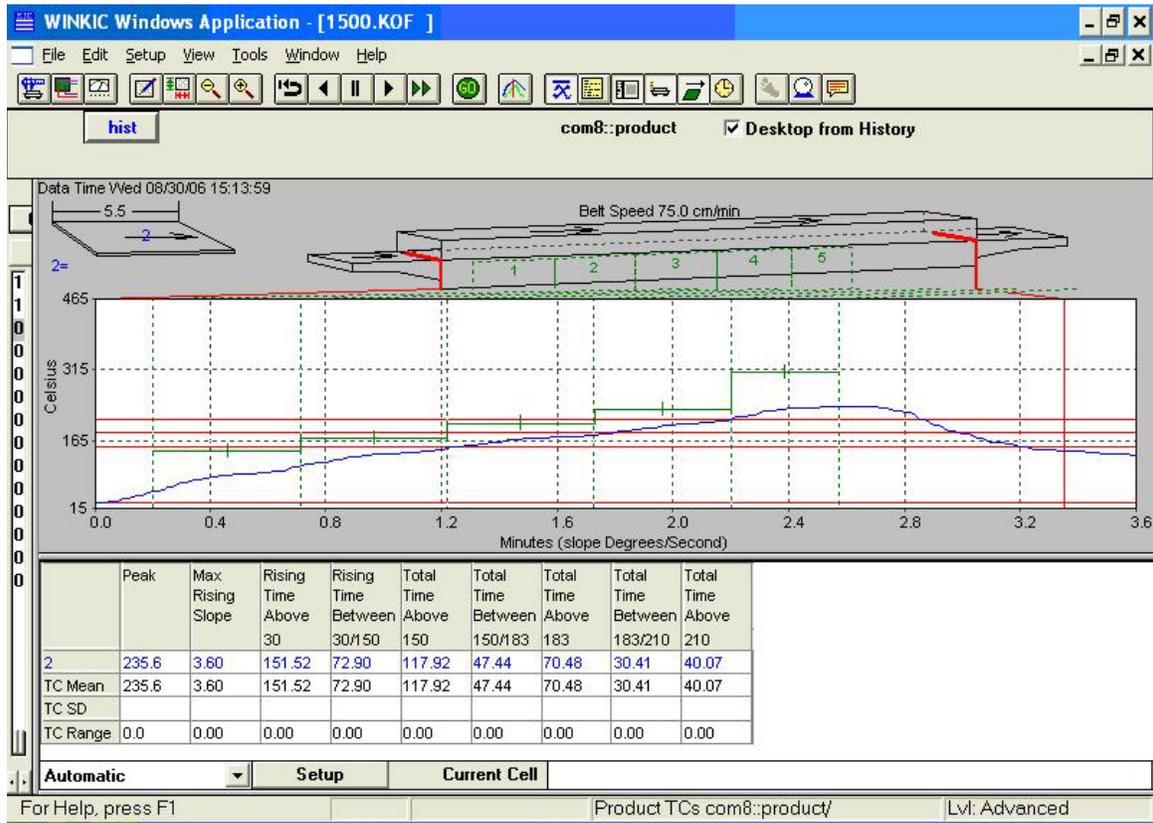


Figure 5. Convection Reflow Profile

The blue line in Figure 5 is the temperature measured in the solder joint of a component of comparable size to the capacitors used in this experiment as it passed through the convection reflow oven. The temperatures for each zone of the reflow oven are shown in Table 5. The reflow oven was a Heller 1500SX with KIC profile software.

Table 5. Convection Reflow Oven Settings

Zone	1	2	3	4	5
Temperature (°C)	140	170	200	230	315

Results and Analysis

The four different capacitor values were subjected to four different measurements, before and after each of the soldering processes:

1. Capacitance at 120Hz
2. Dissipation Factor at 120Hz
3. Equivalent Series Resistance (ESR) at 100kHz
4. DC Leakage (DCL) at rated voltage, 90 second charge through 1000Ω

One hundred (100) samples of each capacitor were measured.

Table 6 shows the results for capacitance measurement for each soldering process.

Table 6. Capacitance (before and after) Solder Processing

Case Size	Convection Reflow			JPL Standard Hand Soldering			Optimized Hand Soldering		
	Pre-Capacitance (uF)	Post-Capacitance (uF)	% Gain or Loss	Pre-Capacitance (uF)	Post-Capacitance (uF)	% Gain or Loss	Pre-Capacitance (uF)	Post-Capacitance (uF)	% Gain or Loss
A	0.46346	0.45816	-1.144%	0.46409	0.46115	-0.633%	0.46348	0.46316	-0.069%
B	2.205	2.196	-0.408%	2.226	2.206	-0.898%	2.222	2.225	0.135%
C	4.748	4.724	-0.505%	4.735	4.719	-0.338%	4.750	4.754	0.084%
D	10.114	10.031	-0.821%	10.129	10.071	-0.573%	10.114	10.121	0.069%

The values shown in Table 6 are the mean value for each type of capacitor. Sigma values for these data are approximately 1% of the mean; therefore, it is a well controlled distribution without much spread. The data in Table 6 indicate that all capacitors in the Convection Reflow and JPL Standard Hand Soldering groups showed a reduction in capacitance as a result of being exposed to these processes. This reduction in capacitance was between 0.3% and 1.1%. Three out of the four samples in the Optimized Hand Soldering parts showed a very small ($\leq 0.135\%$) increase in capacitance between pre- and post-soldering.

The data in Table 6 are graphed in Figure 6, which shows a slight positive slope for the Optimized Hand Soldering process. This could be a result of applying heat, but not too much heat. For tantalum capacitors, an increase in ambient temperature causes an increase in capacitance.

Another cause for an increase in capacitance is moisture. Moisture diffuses in through the plastic case, increasing the capacitance. At higher soldering temperatures (both JPL Standard Hand Soldering and Convection Reflow applied more heat to the capacitors than Optimized Hand Soldering), some moisture is driven out of the capacitor element, which lowers the capacitance.

All the shifts seen in capacitance in Table 6 are consistent with heat and moisture and do not indicate damage from the soldering process. See Appendix C for all capacitance probability plots.

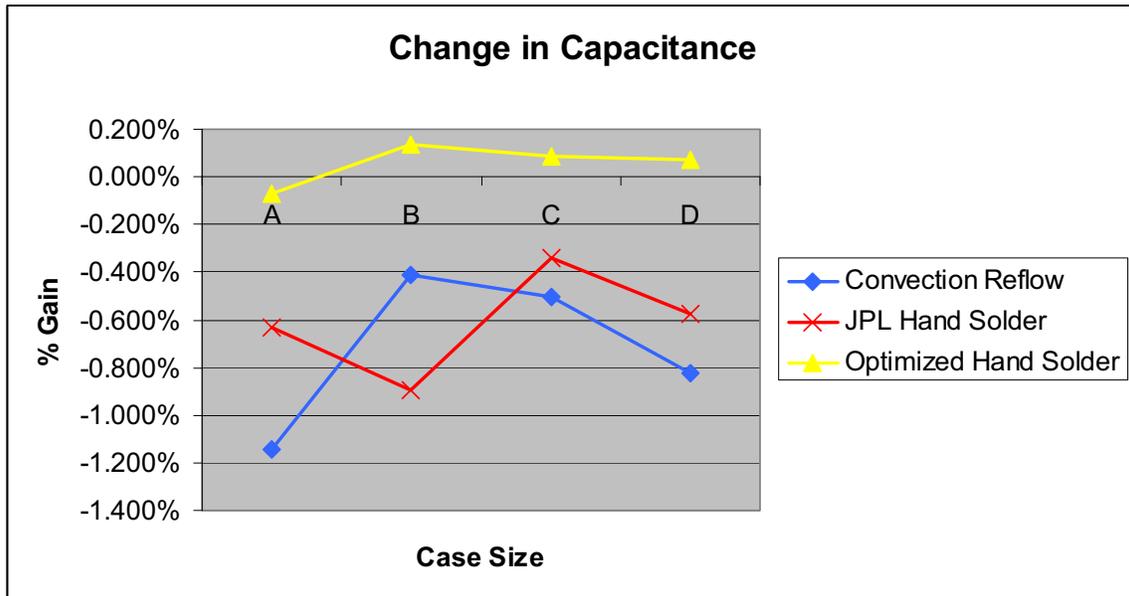


Figure 6. Percent Capacitance Gain vs. Case Size

Table 7 shows the results for the Dissipation Factor (DF) measurement.

Table 7. Dissipation Measurements (before and after) Solder Processing

Case Size	Convection Reflow			JPL Standard Hand Soldering			Optimized Hand Soldering		
	Pre-DF (%DF)	Post-DF (%DF)	$\Delta\%DF$ (%DF)	Pre-DF (%DF)	Post-DF (%DF)	$\Delta\%DF$ (%DF)	Pre-DF (%DF)	Post-DF (%DF)	$\Delta\%DF$ (%DF)
A	1.39	1.24	-0.150	1.42	1.4	-0.020	1.41	1.4	-0.010
B	1.89	1.78	-0.110	1.91	1.88	-0.030	1.91	1.99	0.080
C	1.27	1.24	-0.030	1.26	1.25	-0.010	1.28	1.36	0.080
D	1.37	1.59	0.220	1.39	1.47	0.080	1.37	1.45	0.080

Almost all of the changes in dissipation factor were smaller than the accuracy requirement of DF measurements in MIL-PRF-55365. The only significant shifts in DF occurred during Convection Reflow, but all parts remained comfortably within limits. The largest effect was seen for Convection Reflow indicating some sensitivity to the high reflow temperatures, but there is no evidence of significant damage.

Figure 7 shows the resulting shifts in the DF. See Appendix D for all DF probability plots.

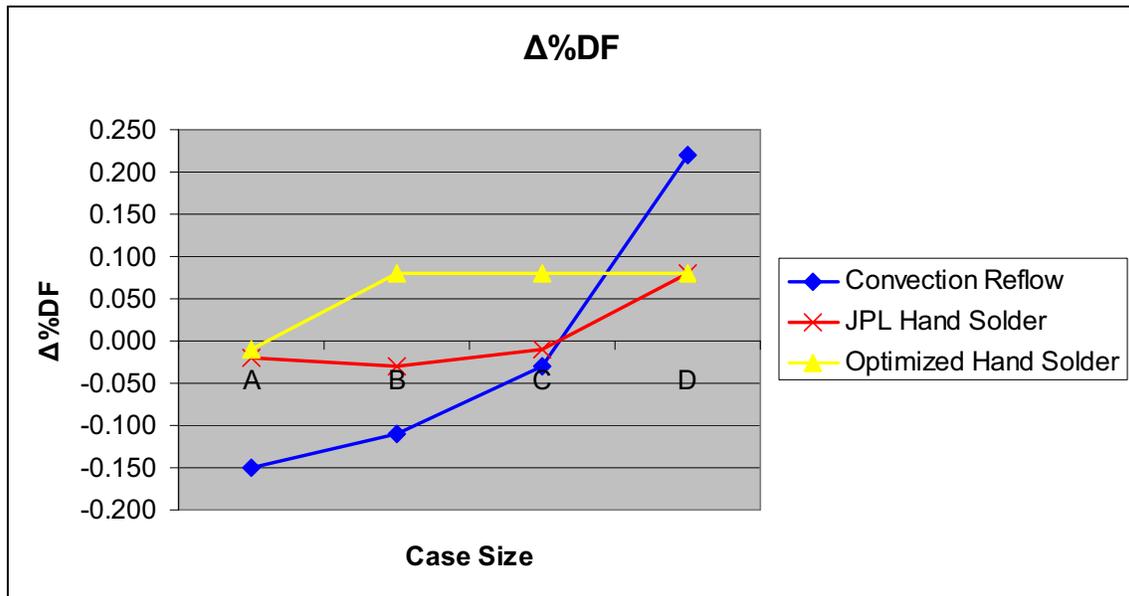


Figure 7. Change in Dissipation Factor vs. Case Size

Table 8 lists the results for ESR.

Table 8. Equivalent Series Resistance Measurement (before and after) Solder Processing

Case Size	Convection Reflow			JPL Standard Hand Soldering			Optimized Hand Soldering		
	Pre-ESR (mΩ)	Post-ESR (mΩ)	% Gain or Loss	Pre-ESR (mΩ)	Post-ESR (mΩ)	% Gain or Loss	Pre-ESR (mΩ)	Post-ESR (mΩ)	% Gain or Loss
A	2,749	2,411	-12.295%	2,824	2,827	0.106%	2,882	2,901	0.659%
B	814	750	-7.862%	823	840	2.066%	814	806	-0.983%
C	460	416	-9.565%	469	458	-2.345%	461	449	-2.603%
D	251	221	-11.952%	248	235	-5.242%	251	238	-5.179%

Table 8 shows a significant reduction in ESR for all case sizes after Convection Reflow. The reduction in ESR is always greater than 7%. These Convection Reflow data are significantly different from those of both hand soldering processes. The reduction in ESR during convection reflow is probably the result of a one-time slight case shrinkage, which can improve the contact between the cathode layers of the capacitor. This improved contact drives the ESR down. However, sustained high temperatures can also raise ESR by damaging the cathode layers.

There was no large downward shift in ESR for parts mounted by hand soldering. This is because the peak temperatures were much lower for hand soldering than for Convection Reflow, and no significant case shrinkage was possible.

The data for the JPL Standard Hand Soldering and Optimized Hand Soldering processes are similar for three of the four capacitor sizes as seen in Figure 8. The downward slope is probably caused by taking the measurements before the capacitors had completely cooled, since ESR decreases with device temperature, and devices with larger case sizes cool off more slowly.

For the JPL Standard Hand Soldering curve, case size B failed to follow this trend. Figure 3 shows that the case size B parts were exposed to higher temperatures than the case size A parts. As mentioned earlier, excess heat can cause slight damage to capacitors, which can raise the ESR level. This appears to have occurred in this case. See Appendix E for all ESR probability plots.

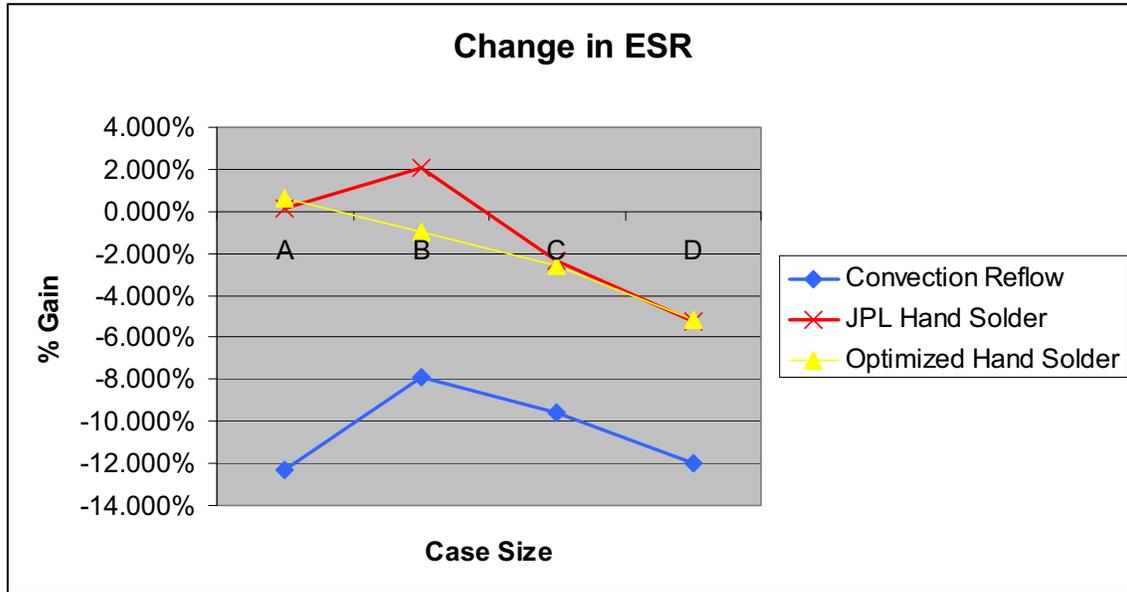


Figure 8. ESR Gain vs. Case Size

Table 9 shows the data for DCL.

Table 9. DC Leakage (before and after) Solder Processing

Case Size	Convection Reflow			JPL Standard Hand Soldering			Optimized Hand Soldering		
	Pre-DCL (nA)	Post-DCL (nA)	% Gain or Loss	Pre-DCL (nA)	Post-DCL (nA)	% Gain or Loss	Pre-DCL (nA)	Post-DCL (nA)	% Gain or Loss
A	2.05	1.90	-7.317%	1.80	1.80	0.000%	2.00	2.10	5.000%
B	9.45	9.40	-0.529%	9.00	9.40	4.444%	9.40	9.15	-2.660%
C	27.10	29.10	7.380%	28.20	29.80	5.674%	30.50	29.35	-3.770%
D	50.35	50.15	-0.397%	50.45	50.20	-0.496%	51.00	48.00	-5.882%

DCL is the most sensitive parameter with regard to heat. Thermo-mechanical stress causes the DCL to increase by cracking the dielectric in vulnerable locations. Lower peak temperatures cause much less stress and are not likely to cause much increase in DCL.

The change in DCL for each soldering profile is shown in Figure 9. The four most positive shifts (Optimized Hand Soldering: case size A, JPL Standard Hand Soldering: case sizes B and C, and Convection Reflow: case size C) are strongly correlated with the relatively higher temperatures of their respective reflow conditions. Generally, the Optimized Hand Soldering parts (Optimized Hand Soldering: case sizes B, C, and D) had the lowest DCL levels, which is consistent with their exposure to the lowest soldering temperatures. The effects on all capacitors with respect to DCL are very subtle, which

shows that none of the soldering profiles were particularly harmful to the capacitors. See Appendix F for all DCL probability plots.

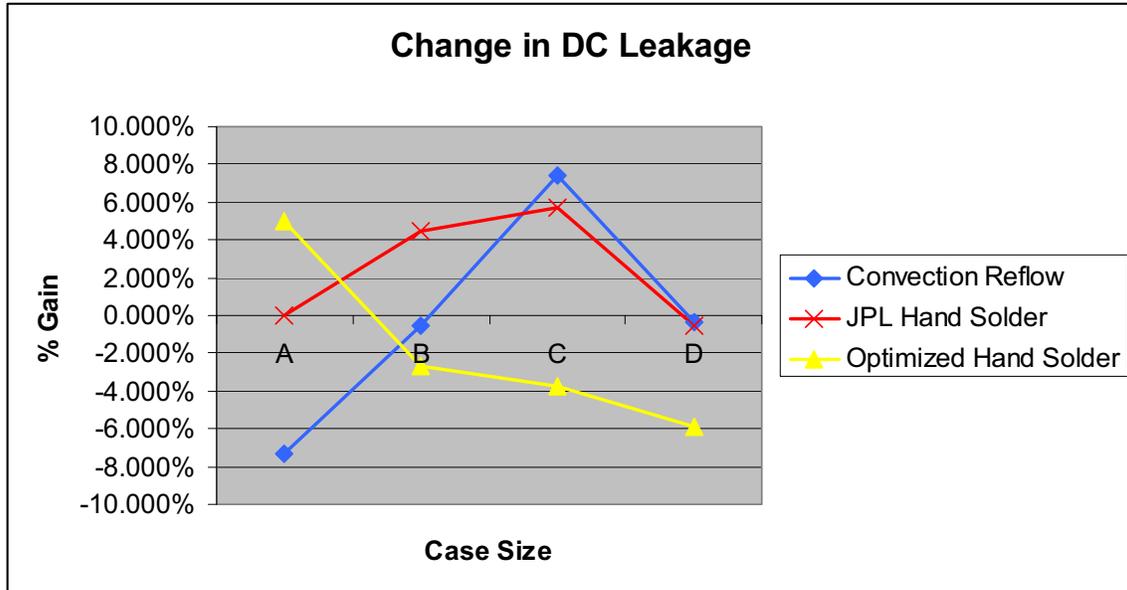


Figure 9. DCL Gain vs. Case Size

Conclusions

An Optimized Hand Soldering process has been developed and tested on a variety of MIL-PRF-55365 tantalum capacitors. The process has been optimized for reduced temperature at the expense of increased process time. The impact of this optimized process on capacitor parameters was compared to the impact of JPL Standard Hand Soldering and Convection Reflow.

Although hand soldering is widely believed to be potentially harmful, the parametric shift data indicate that the two hand soldering techniques were generally more benign than the Convection Reflow technique. Moreover, the Optimized Hand Soldering process appears slightly superior to the JPL Standard Hand Soldering process.

However, it must be mentioned that the hand soldering processes tend to be subject to more human-introduced variability than do convection reflow processes. Therefore, it is essential for the operators to be properly trained. To maximize the potential benefits of hand soldering, operators must understand that the goal is to minimize the contact time and, thus, the temperature rise of the soldered device.

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Appendix A

JPL Standard Hand Soldering

The full details of this process can be found in JPL Rules! (DocID 35514). The following is a shortened version of the process and does not contain all of the details or warnings.

- (1) Apply a light film of fresh rosin mildly activated (RMA) flux to the intended solder pad using an artist's brush.
- (2) Place the component on solder pads, and hold in place during tacking using a vacuum-operated gripper with the appropriate sized probe tip. Apply a slight downward pressure during tacking to increase thermal transfer.
- (3) Tack solder one end of the component. Apply soldering iron tip to the corner of the printed wiring board (PWB) solder pad for a maximum of 3 seconds. Do not apply soldering iron to component.
- (4) Solder the other end of the component using the same technique as used in tacking, except do not hold the component down with the vacuum gripper; add solder as required. Re-solder the tacked end of the component. The soldering iron should not be in contact with the PWB for more than 5 seconds [6].

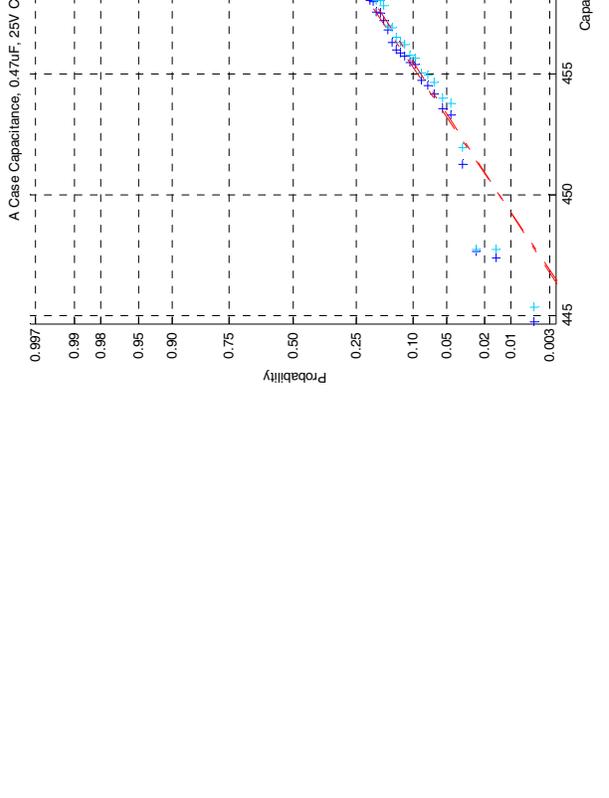
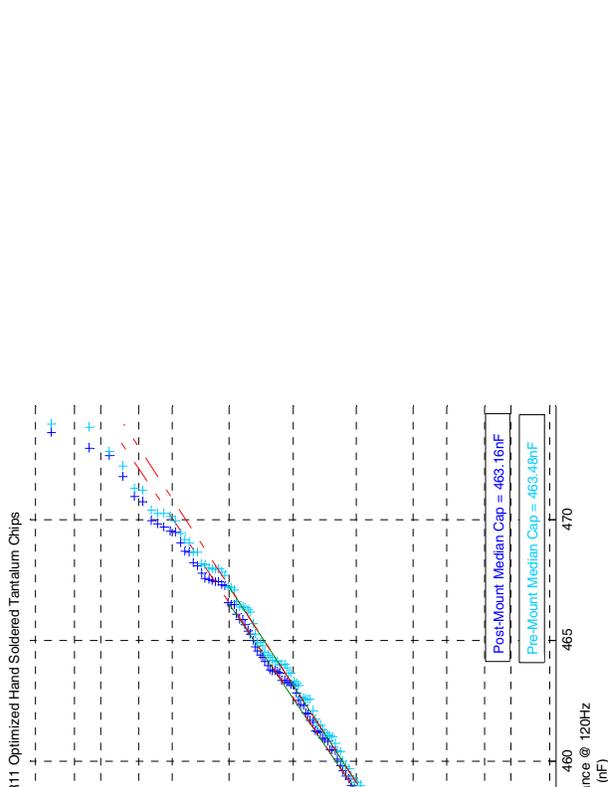
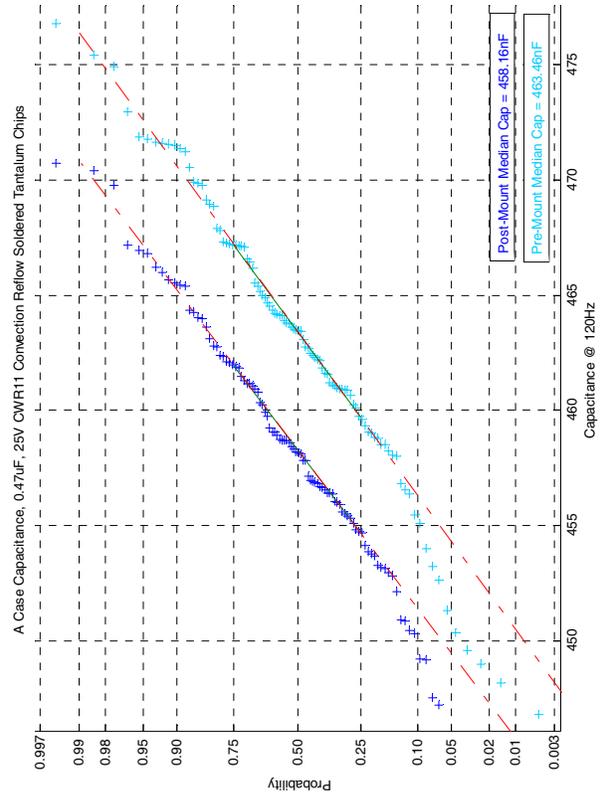
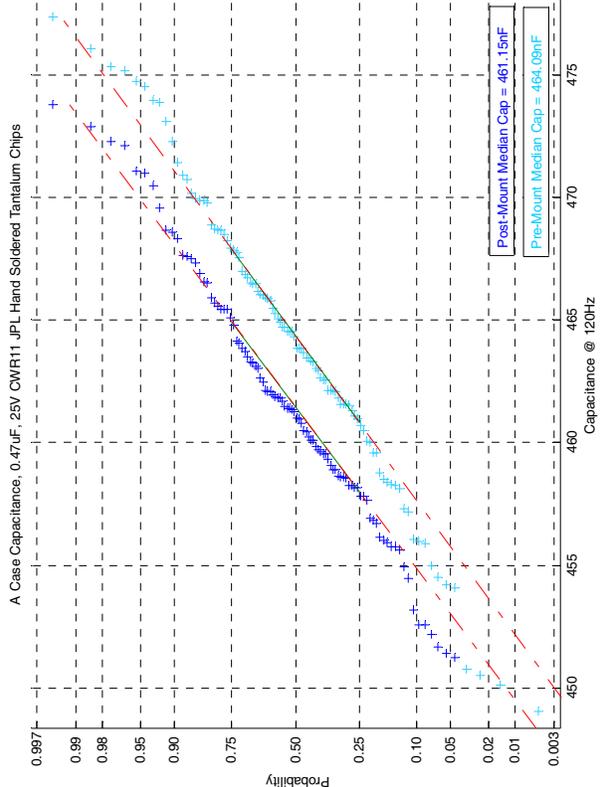
Appendix B

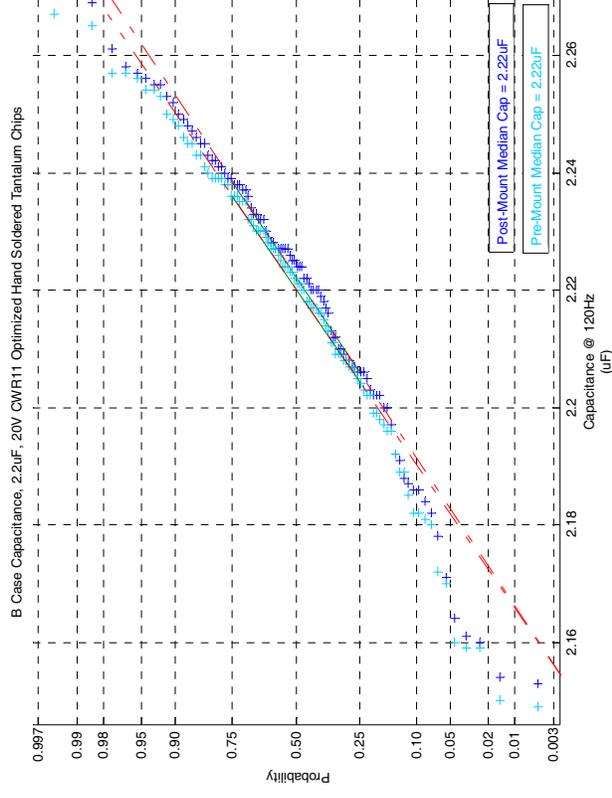
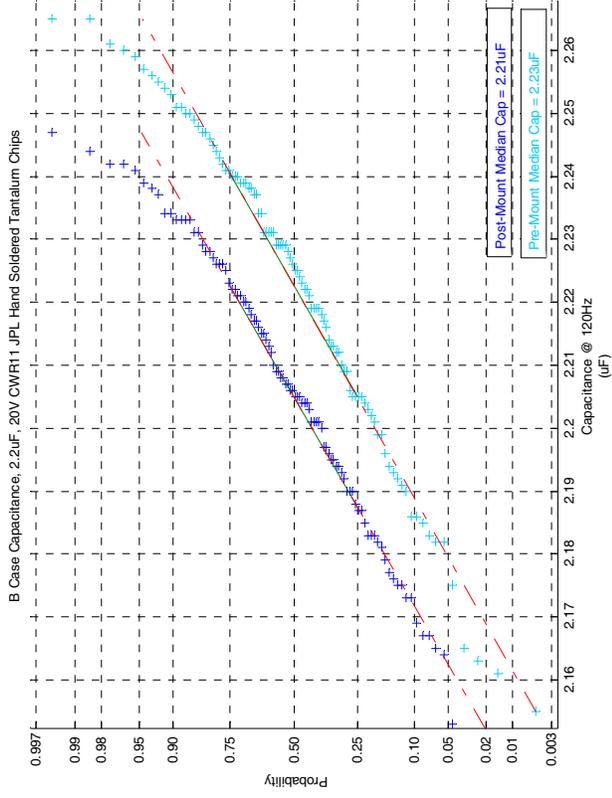
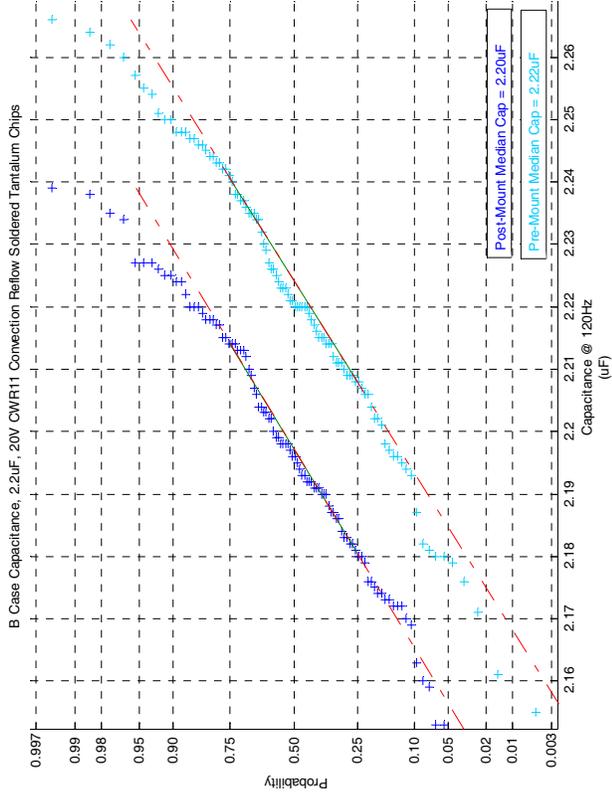
Optimized Hand Soldering

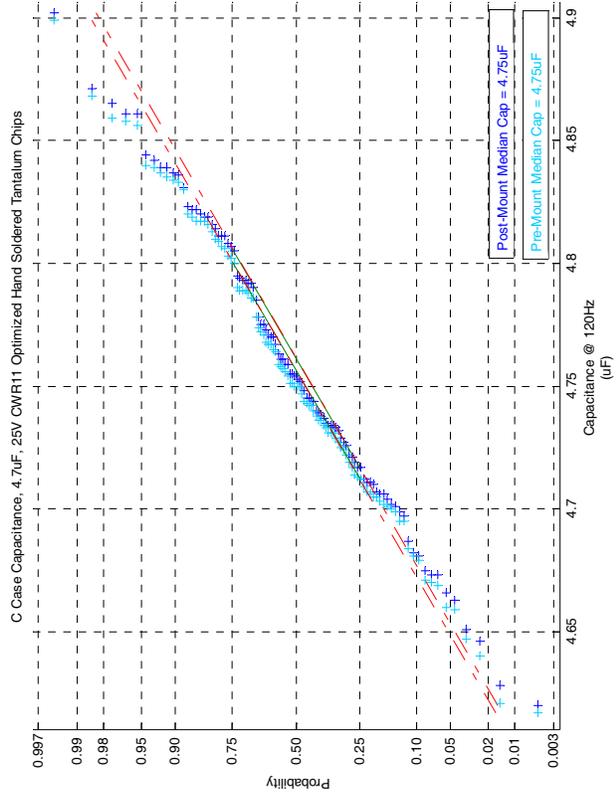
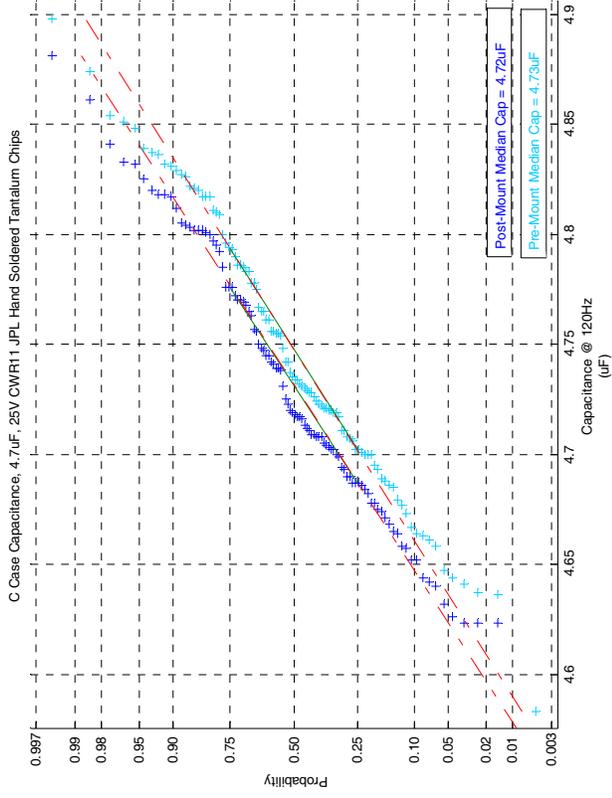
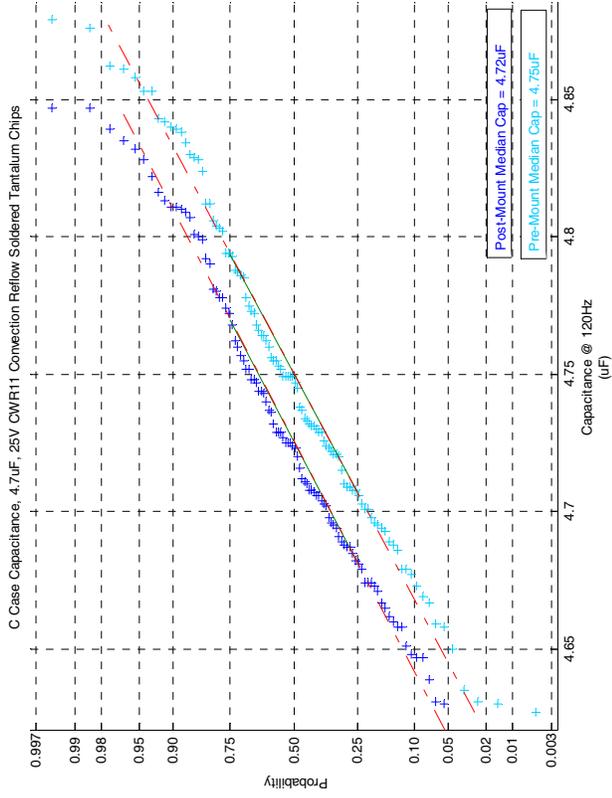
The goal of Optimized Hand Soldering is to apply heat for the shortest time necessary to form acceptable solder joints. Tantalum capacitors can be damaged by prolonged exposure to solder reflow temperatures. This is in contrast with ceramic chip capacitors, which withstand prolonged high temperature exposure well, but can be very sensitive to rapid changes in temperature.

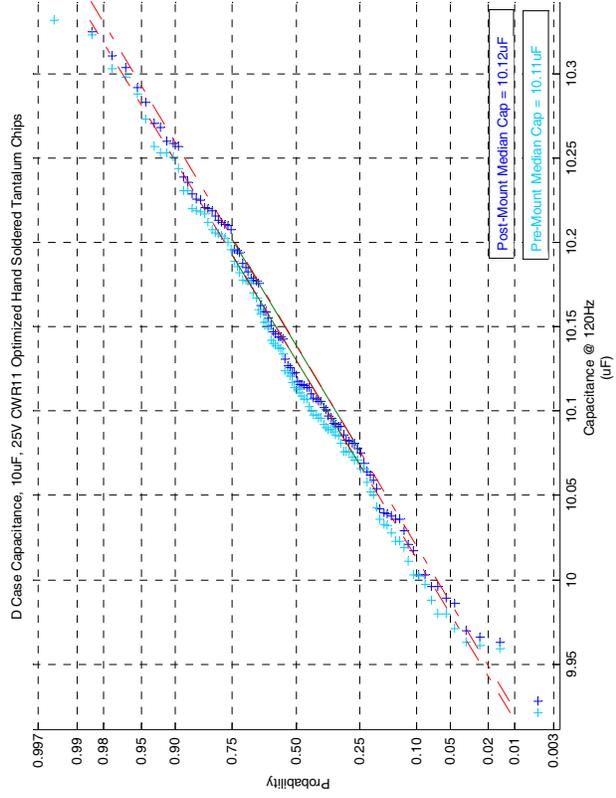
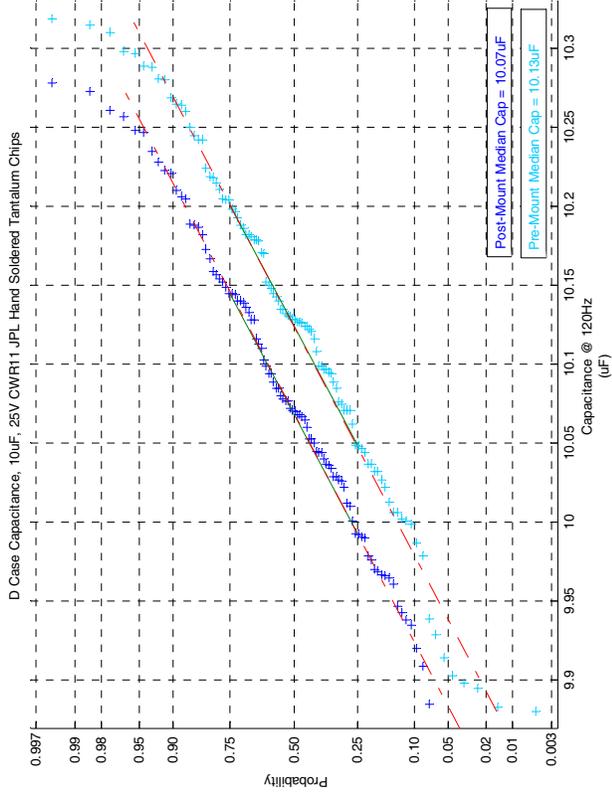
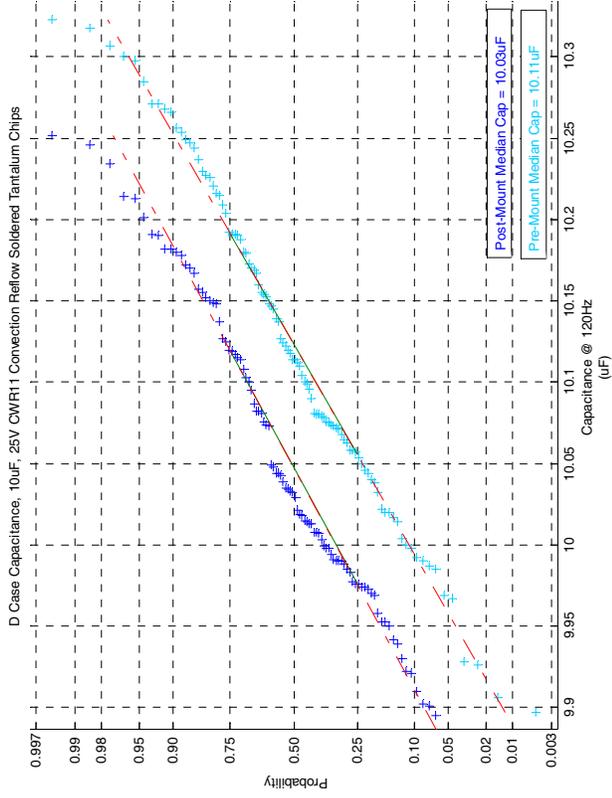
- (1) Pre-tin the positive pad on the circuit board with a small amount of flux-bearing solder. Do not remove the excess flux residue at this time as it will aid the reflow process in step 3.
- (2) With tweezers or equivalent tool, position the capacitor so that its positive terminal is lightly pressing on the pre-tinned positive pad.
- (3) Touch the junction of the capacitor's positive terminal and the pre-tinned positive pad with a freshly cleaned/tinned solder iron tip. As soon as the solder on the pre-tinned pad reflows and wets to the capacitor's positive terminal, remove the solder iron tip. Apply heat just long enough to create an acceptable solder joint. Now the capacitor is physically secured to the board and the tweezers are no longer necessary.
- (4) Apply a freshly cleaned/tinned solder iron tip and additional flux-bearing solder simultaneously to the junction of the capacitor's negative terminal and the negative pad. Apply heat just long enough to form an acceptable solder joint. Good solder joints can be created with very little added solder.

Appendix C

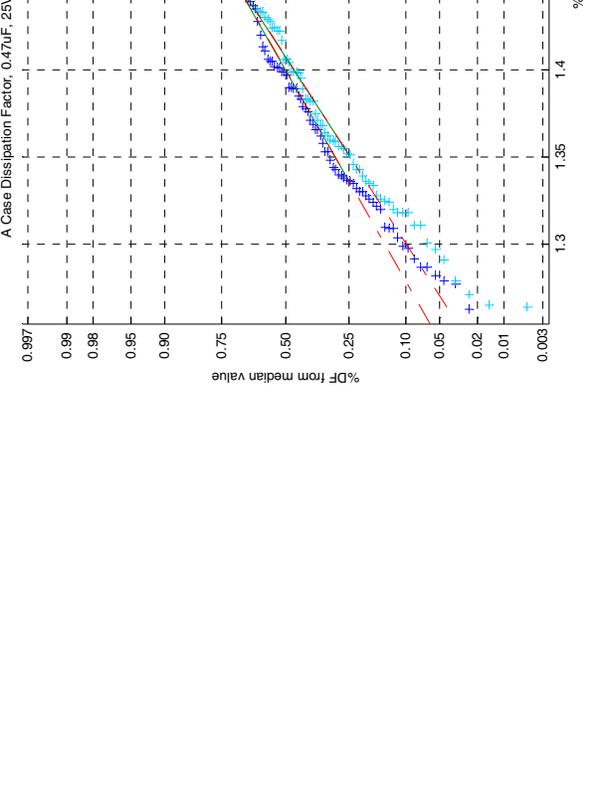
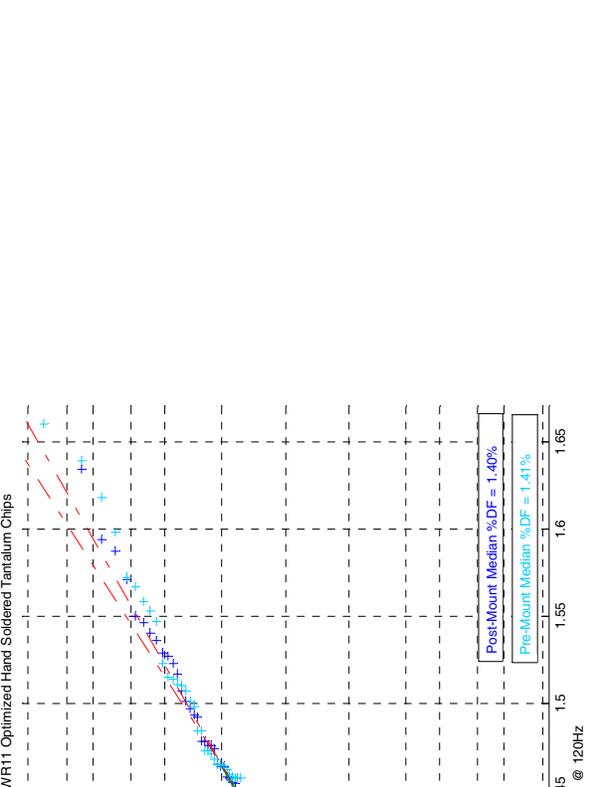
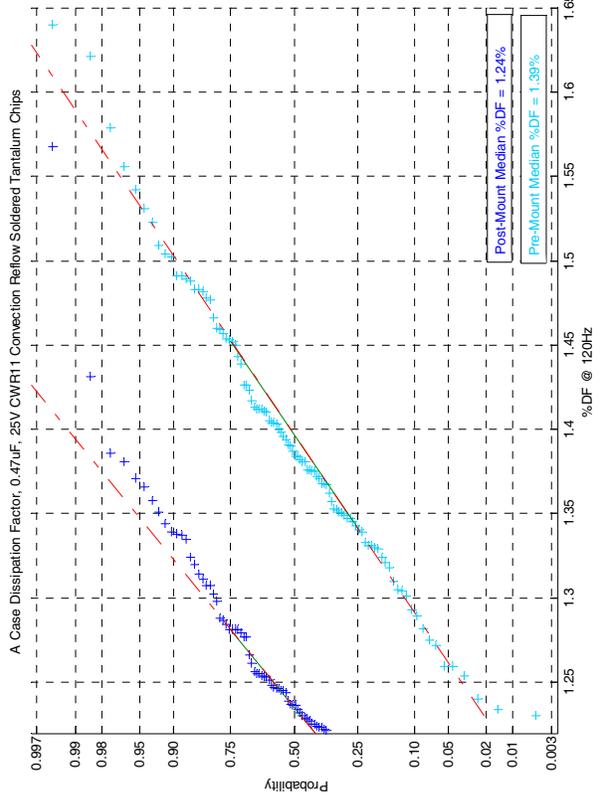
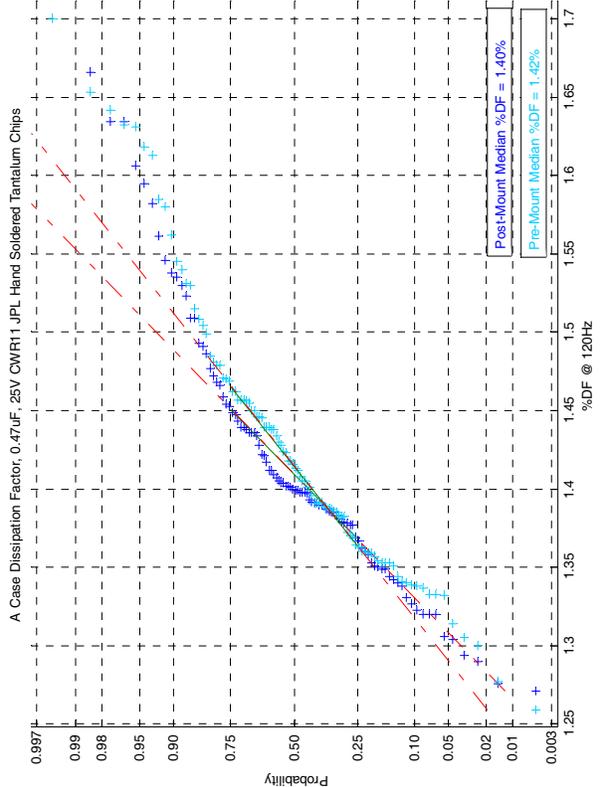




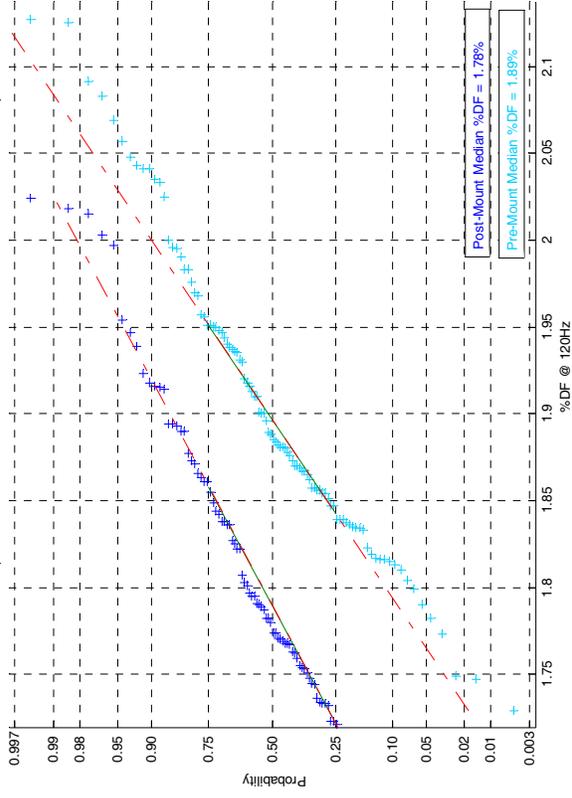




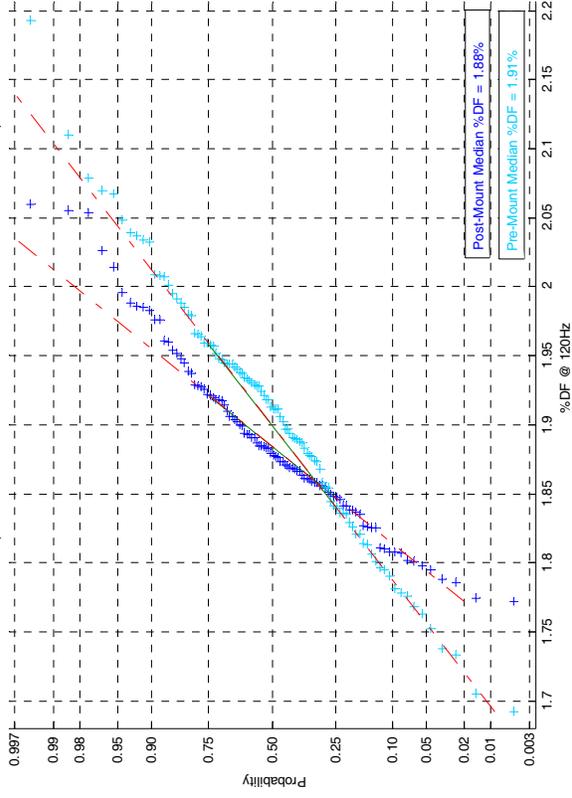
Appendix D



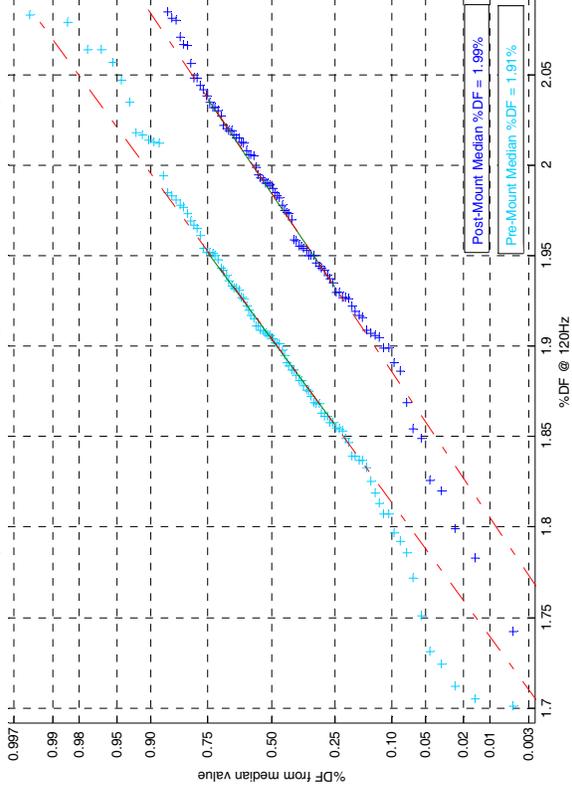
B Case Dissipation Factor, 2.2uF, 20V CWR11 Convection Reflow Soldered Tantalum Chips

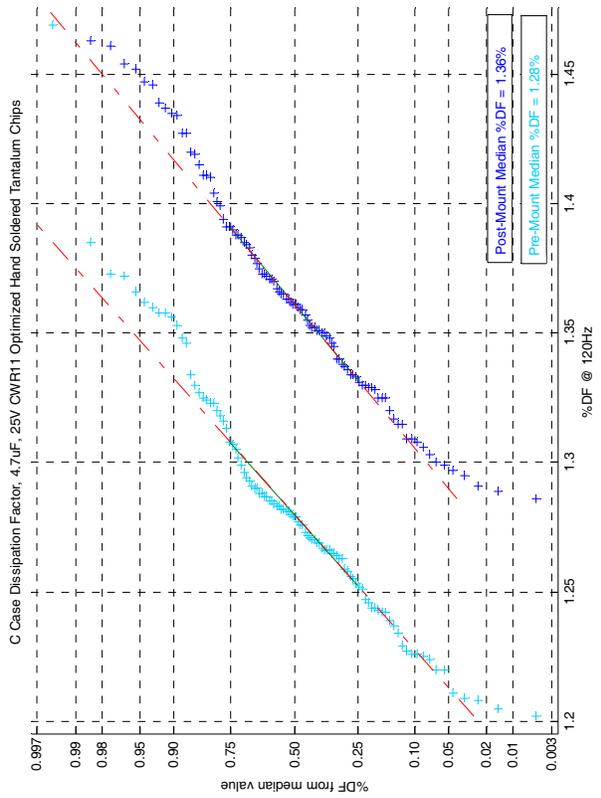
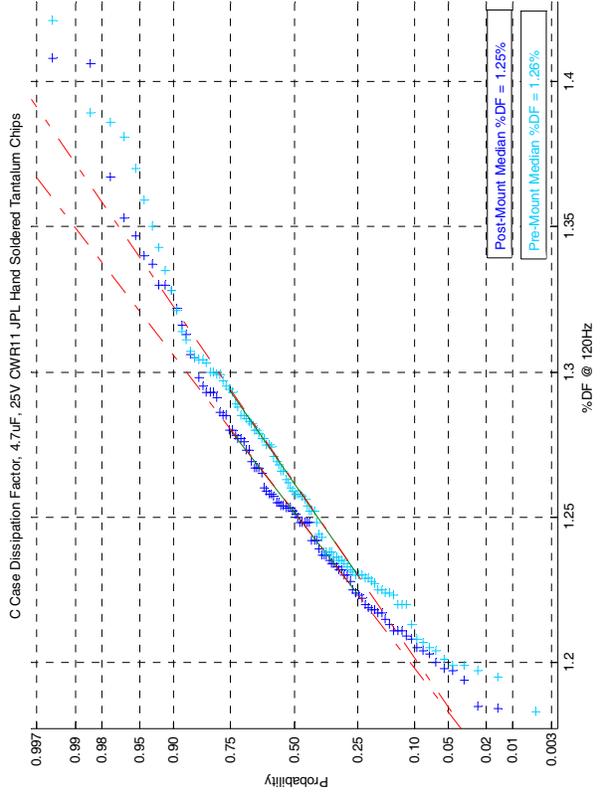
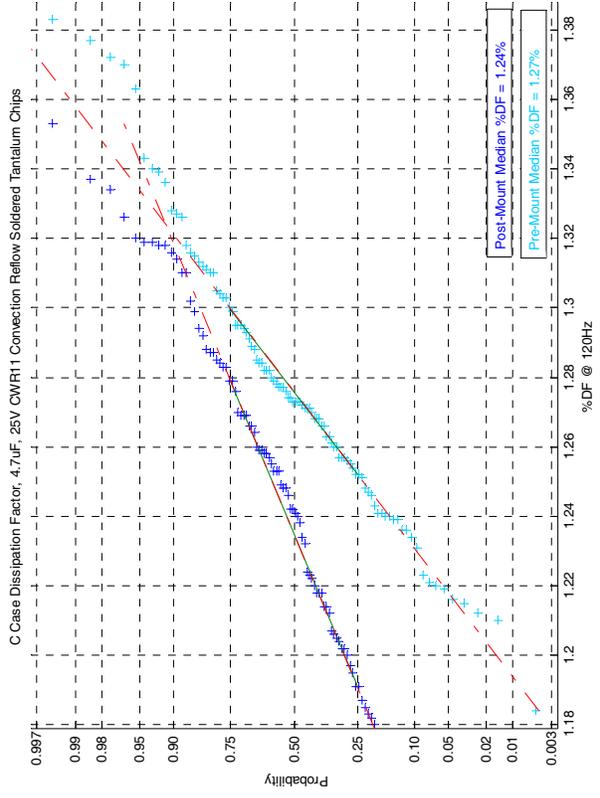


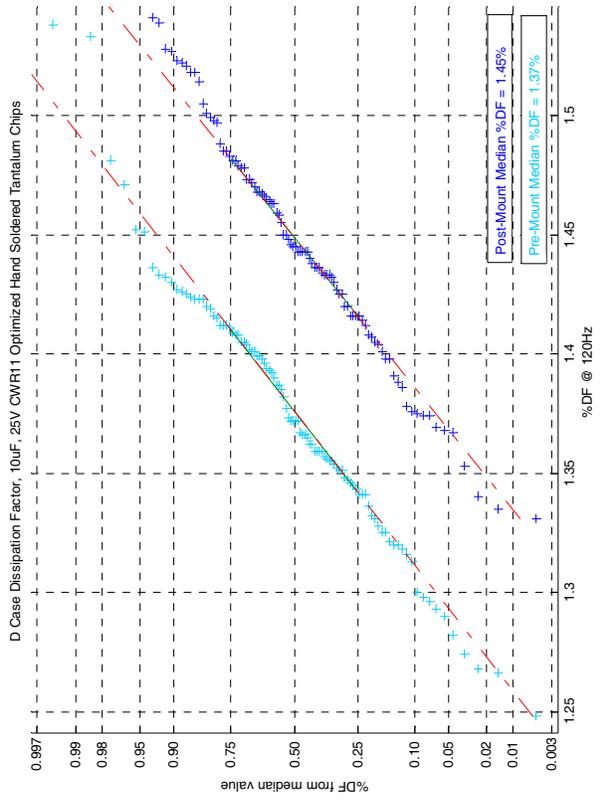
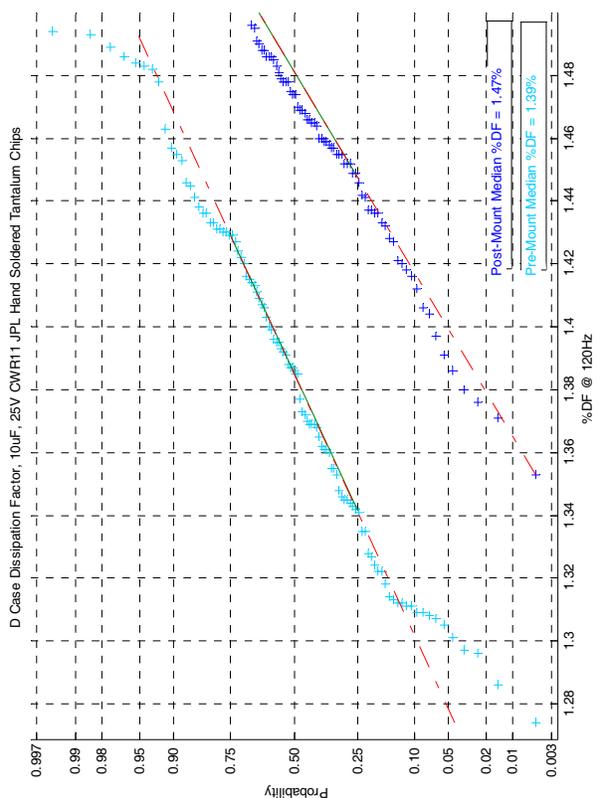
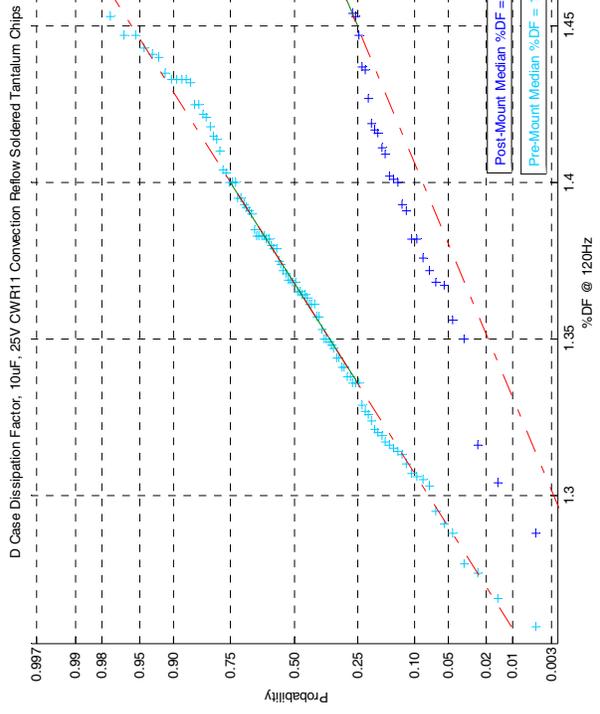
B Case Dissipation Factor, 2.2uF, 20V CWR11 JPL Hand Soldered Tantalum Chips



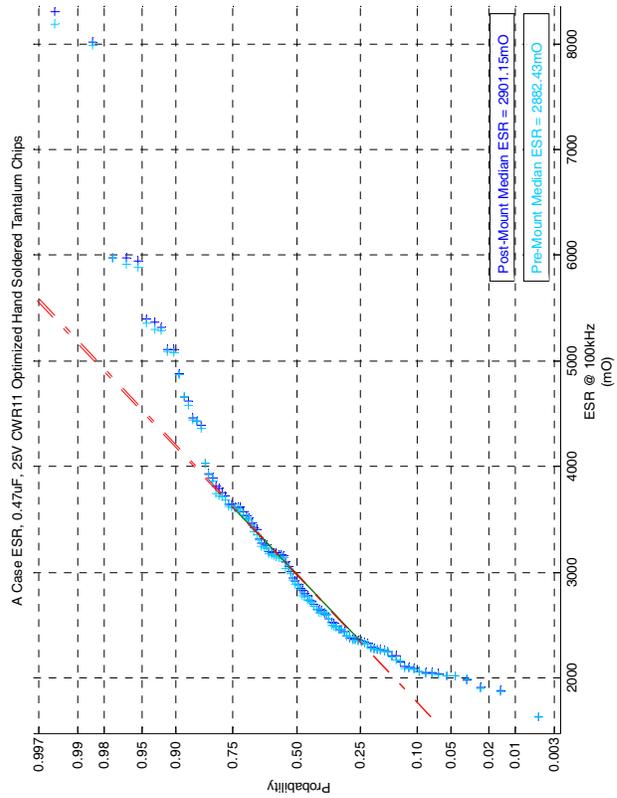
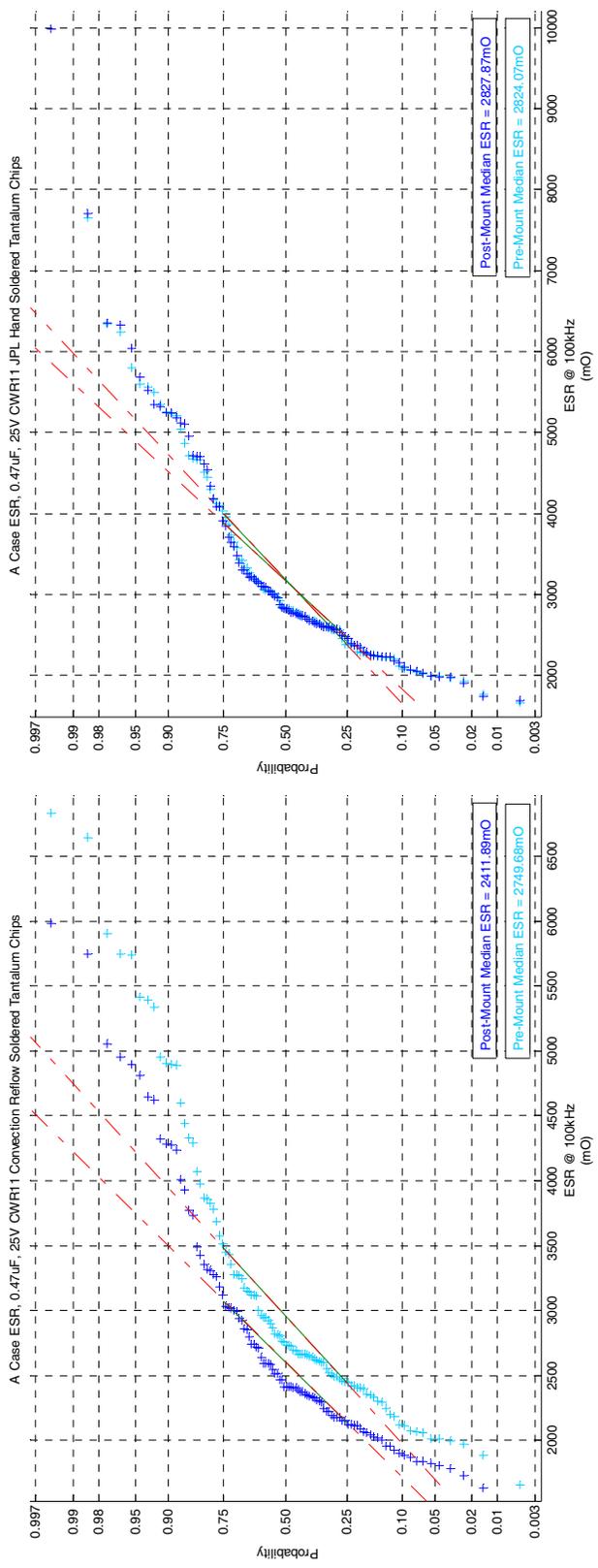
B Case CWR11 Optimized Hand Soldered Tantalum Chips



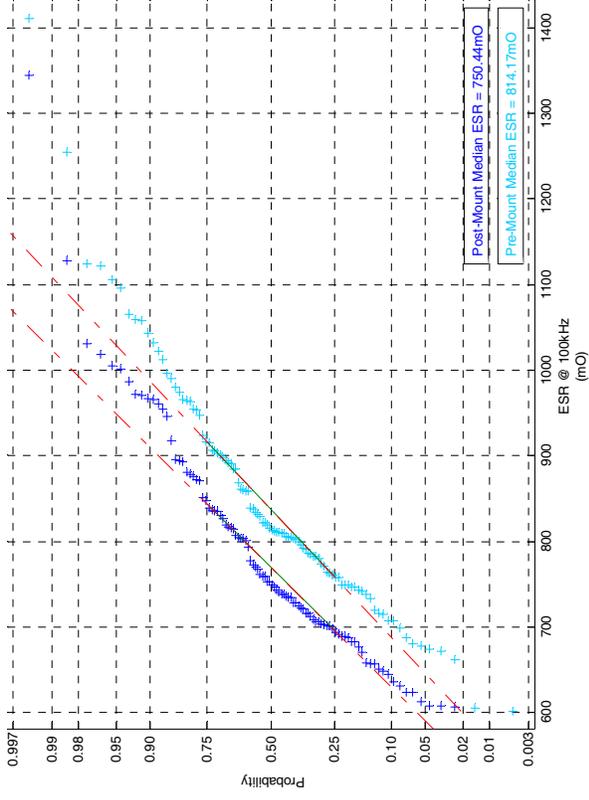




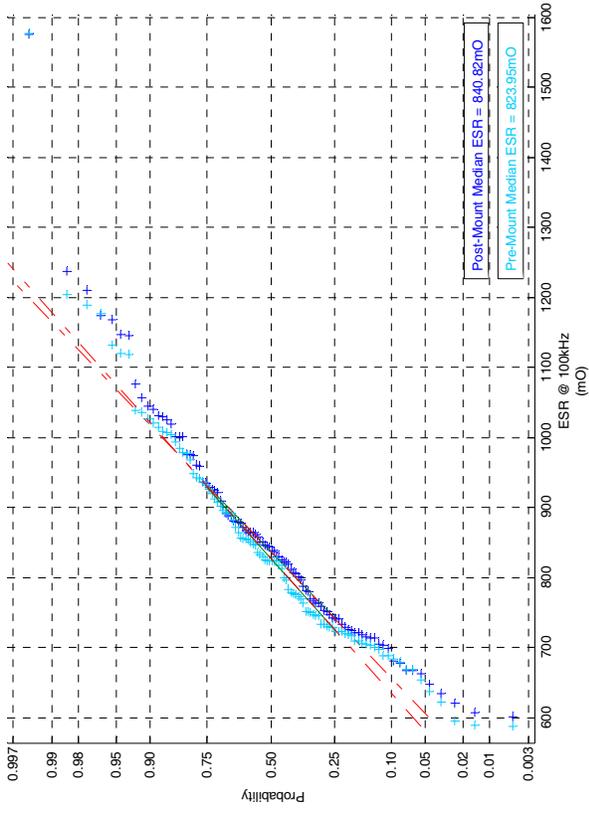
Appendix E



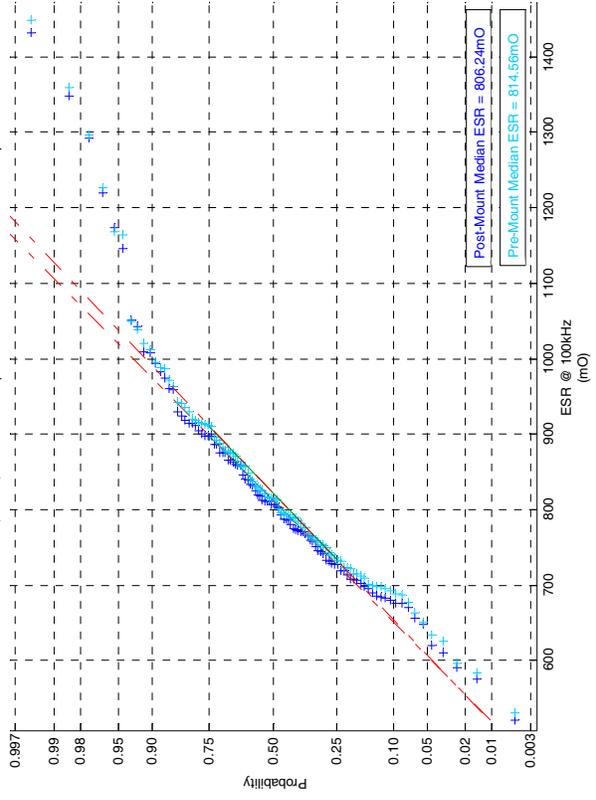
B Case ESR, 2.2uF, 20V CWR11 Convection Reflow Soldered Tantalum Chips

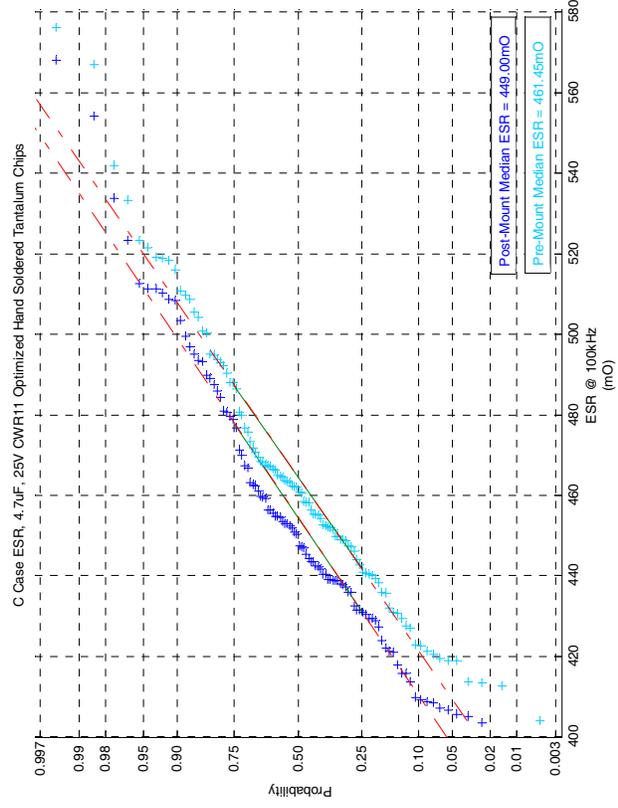
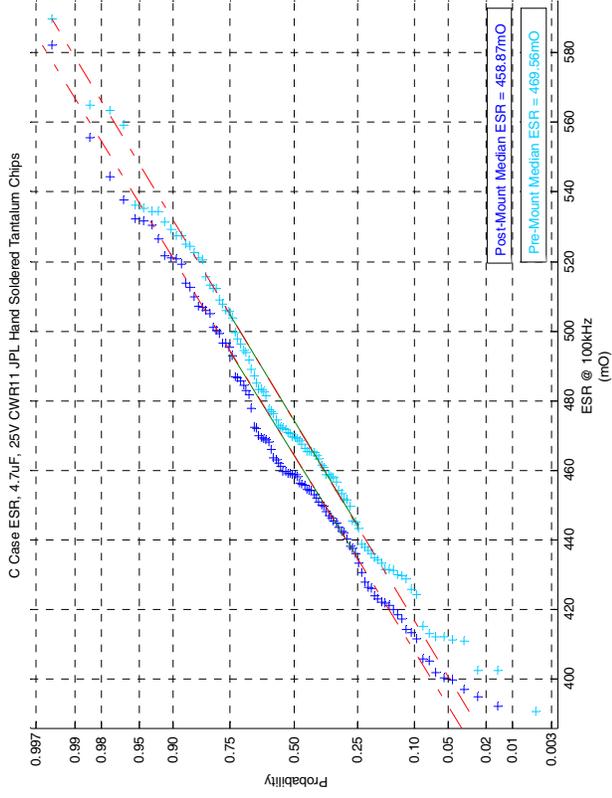
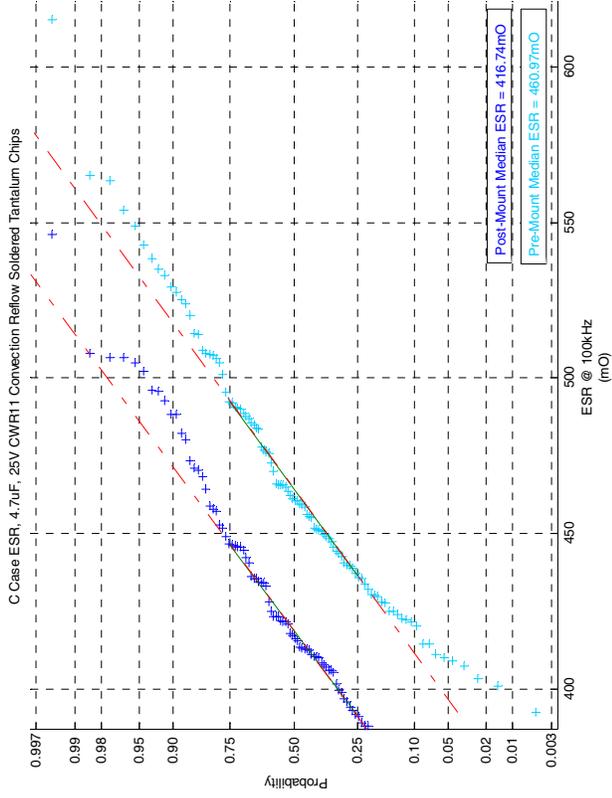


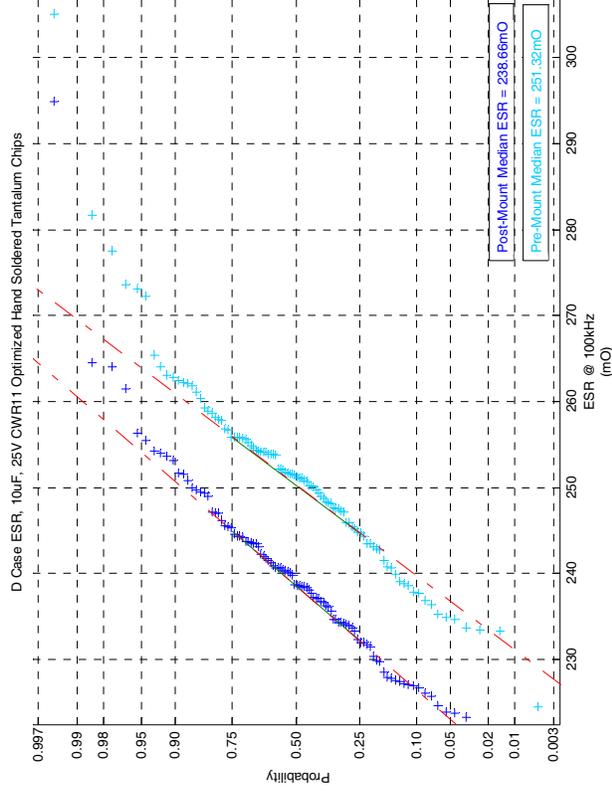
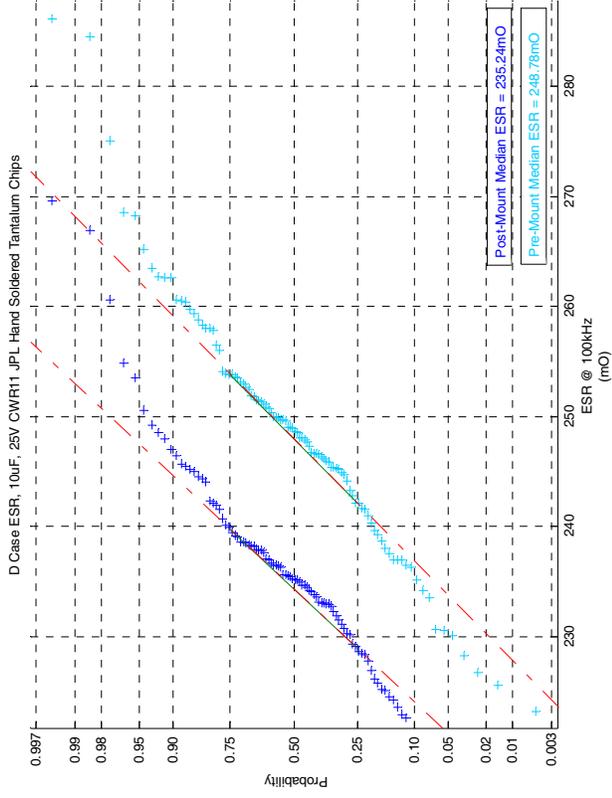
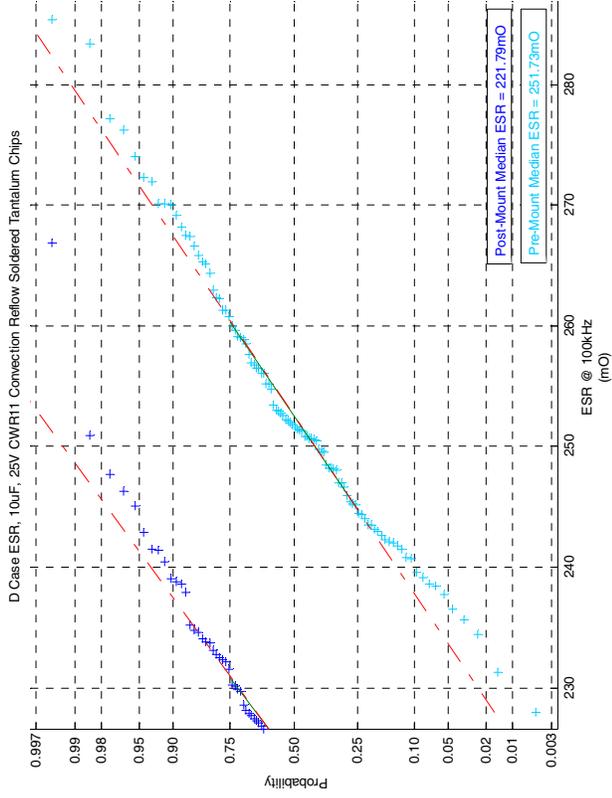
B Case ESR, 2.2uF, 20V CWR11 JPL Hand Soldered Tantalum Chips



B Case ESR, 2.2uF, 20V CWR11 Optimized Hand Soldered Tantalum Chips







Appendix F

