Embedded Passives Predictability, As-Received and In-Service

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Abstract

Embedded resistors and capacitors provide high-density high-performance solutions, freeing up the surface for other components and enabling tailored interconnect topology. This technology needs exploration and characterization before it can become a routine resource in high-reliability, harsh-environment and aerospace applications. This paper discusses two critical factors, a) uniformity as-received from the fabricator, and b) long-term stability under extreme environmental conditions. PWB specimens spanned a range of embedded resistors and embedded (distributed and discrete) capacitors, several values of each, from several suppliers, using a variety of materials and processes.

Data on as-received boards and coupons includes: Comparisons between target vs. measured values; comparisons between "expected" vs. measured values; comparison of board–to-board uniformity of equivalent features, uniformity of nominally identical features at various spots on the same PWB; comparison edge-to-edge of the same board; and comparisons between coupon feature vs. equivalent PWB feature, to document how representative the coupon is.
Environmental stability. Performance data includes: resistance and capacitance values as a function of temperature; values measured after long-term storage at elevated humidity and temperature; stability after vibration; stability after long-term thermal-cycling; stability after water immersion, stability after molten-solder-dip thermal-shock; and stability after surface over-heating.

Results are interesting. As-received uniformity data reveals substantial differences (up to 20-40%) between the target value and the actual value, as well as among nominally equivalent features, and between coupon and board. Differences depend on type of element. This is before any of the cherry-picking or screening by the supplier that could happen in typical jobs. Environmental stability is reassuringly robust. Most exposures cause relatively little change. Stability depends on materials, processes and geometries.
This information could help guide procurement documents, to provide realistic expectations regarding tolerances and yield, as well as to develop QC sampling and acceptance protocols. It also should provide guidance to designers and users towards qualification and performance expectations, under nominal and adverse in-service conditions.

Introduction

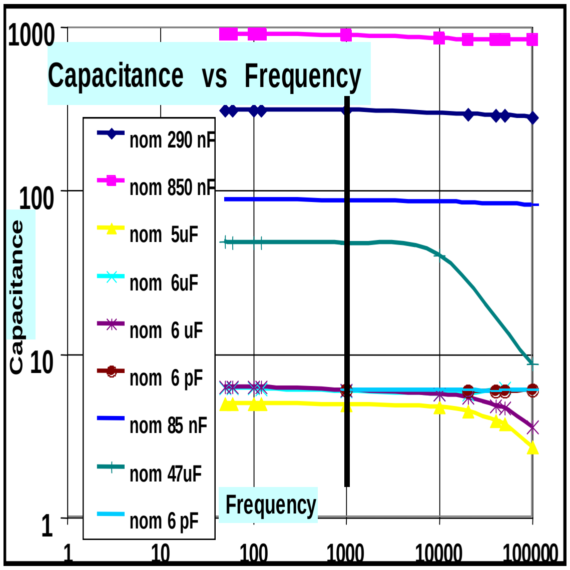
A series of tests were run on several sets of embedded–passives circuit boards. The measurements were simply resistance, for the embedded resistors, and capacitance, for the embedded capacitors, The tests were performed as-received to study uniformity, as well as to study reliability, actually stability during and after environmental conditioning, as described below. Note that the summaries below reflect averages of hundreds of data-points obtained in supporting all the test sequences. For reasons of brevity, these mounds of raw data are not included in this paper. That original raw data is available from the author, on request.

Test Specimens

The major sample set, of ~ 35 boards, was provided by a development partner, Sanmina/SCI in California, These boards are 20-layer, polyimide/glass, densely populated with fine-pitch features both sides, with blind and buried vias, incorporating several values of resistors and capacitors. This test vehicle was a multi-purpose design to evaluate the t-cycle resistance of a range of BGA styles, Because of the design complexity, these were recognized by Sanmina as a processing challenge, going in. In addition, several Crane / Navsea PWB specimens, retains from a separate Crane project, were provided as a courtesy to obtain additional data, taking advantage of the ongoing environmental exposures and testing. Descriptions of the test specimens are also separately available.

Instrumentation

Prior to any experimental work, instrumentation and technique were evaluated. A Qual-Tech Digibridge was chosen, to provide the appropriate measurements. Several characterization studies were run to demonstrate the necessary range and precision and testing protocol. This instrument was used in the bulk of this study. Figure 1 shows one example from a series of tests to arrive at the frequency for the capacitance measurements, for this project. A frequency of 1000 Hz was chosen. Technique centered on probe-positioning finesse. In preliminary measurements, the angle between the probes was seen to introduce significant variability. This had to be controlled. A series of tests were done to arrive at a technique for removing this source of error in future measurements



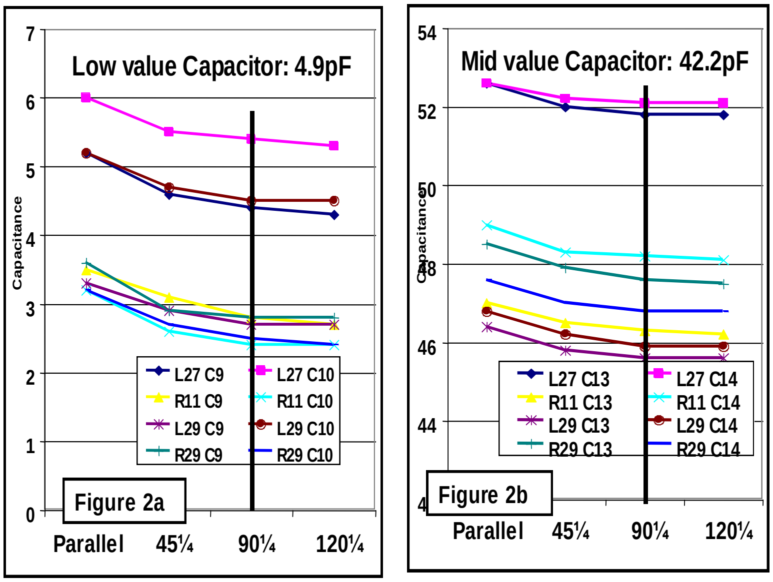


Figure 1 Capacitance vs Frequency **Figure 2 Technique E Probe Positioning**

Figure 2 shows that holding the probes at 90 degrees to each other is feasible and controllable, and would be an effective technique.

Long-term instrumentation drift is always a concern in test spanning many months. To provide a “calibration" standard of sorts, in aging studies and cross-comparisons, a log of calibration values was initiated, using known SMT resistors and capacitors, kept at room temperature, measured periodically.

Results, seen in Figure 3, show the reassuring freedom from instrumentation drift. This helped ensure that measurements taken over many months would accurately reflect the specimens’ changing values, rather than being obscured by instrumental artifacts.

Embedded Passives Study É QuadTech Digibridge, Cal/Repeatability Log

Specimen	1-Nov	2-Nov	7-Nov	9-Nov	15-Nov	28-Nov	22-Dec	3-Jan	11-Jan	12-Jan	17-Jan	2-Feb	3-Feb	6-Feb	7-Feb	8-Feb	16-Feb	24-Feb	6-Mar	9-Mar	16-Mar	ave dev, %
100 nF axial				103.0		102.0	102.0	100.0	102.4	102.3	102.3	100.5	101.7	103.2	102.2	101.0	103.0	100.9	101.0	101.5	101.2	0.7%
axial									52.8	52.7	52.7	52.7	52.8	52.7	52.7	52.7	52.6	52.5	52.7	52.6	52.6	0.1%
axial		99.5	99.5	99.5	99.5	99.5	99.5	99.5	99.5	99.5	99.5	99.5	99.5	99.5	99.5	99.5	99.6	99.5	99.5	99.5	99.5	0.0%
330 pf axial																330.3	330.0	330.9	331.1	330.8	330.7	0.1%
85 nF SMC																86.9	85.3	84.8	84.5	85.1	84.7	0.6%

Figure 3 Repeatability Log

Experimental Details…. Uniformity Studies

It is crucial that the user of embedded passives knows what he is getting. Predictability encompasses several elements: how close the as-received value is to his design expectation, and how uniform those values are across all elements of every board and coupon in the lot. Similarly, the fabricator is obliged to develop and control his process to ensure that he delivers what his customer asks, without excessive yield-loss or escapes. This paper discusses: a) actuals vs. target: b) board–to-board uniformity, c) side to side differences d) equivalent-adjacent points, and e) coupons vs. boards.

Actuals vs. target: How close did the resistance or capacitance value come to the target on the drawing? The most critical metric is that all-important initial T=0 measured result vs. the desired value. Note that in this project the value target was specified, leaving the fab free to select design, material and process. In other jobs around the industry, the detail design and materials and even the nominal process are specified by the customer, leaving the fab with less freedom and responsibility. Either way, this study should be relevant. There are several aspects to this question, which are wrapped up in the fabricators' process. Typically the process includes certain in-process steps wherein preliminary measurements are made, then the process is adjusted slightly, so that the final circuit board is on-target, This iterative process-control technique is needed because of the troublesome nature of embedded-passives fabrication. A successful process is usually considered part that fabricators' intellectual property. Note that for this project, for this beta-site best-effort development, no iteration was attempted. The objective was to run it all the way thru, the fabricator taking whatever in-process measurements felt necessary, but not "tweaking" on the fly. The results in Figure 4 below have two bases. One is a comparison of actuals vs. the customer's original desired target. The other is a comparison of actuals vs. what was expected based on the fab's in-process measurements. Results varied.

Sampling and common-sense prevents making any conclusions except the most general. Resistor actuals came in within +/- 20-50% of design targets. The low-resistance features came out closer to their target, on a proportional percentage basis (~12% low), than did the high-value parts (~ 25% low)... Capacitors showed generally higher values that targeted … some right on, some up to 50% higher.

As mentioned above, most PWB suppliers report that they typically do pilot runs first, before committing to a production run. Their intent is to characterize their particular material/process/geometry situation. Once a response has been determined, and as the fab process proceeds, their internal targets and controls can be corrected and adjusted as appropriate to hit the customers' target. The actual values in this study did, in fact, come out closer to their "expected" values. This suggests that the suppliers will have developed fairly predictable processes and controls, once they nail their internal process shifts. If these had been pilot runs, their later adjusted production runs would have resulted in values much closer to target, probably approaching within +/- 10% for all types and values. It's clear that process experience with a given material set and board construction offers much more target accuracy. Further, it is advisable that the customer should provide costing and scheduling support (for pilot runs and iterations and yield-loss) for these complex new-technology tasks. We are all still learning.

b) board–to-board. The next critical metric is board-to-board variation. How much, on average, do the units vary? Are all the boards the same? Resistance values' average variation from the mean, among board-averages, ranged from 4 to 14%. Capacitance variations were more like ~5%. In general, one could expect one board's passives to average ~5% different from the equivalent passives' average on any other board in the lot. See Figure 5.

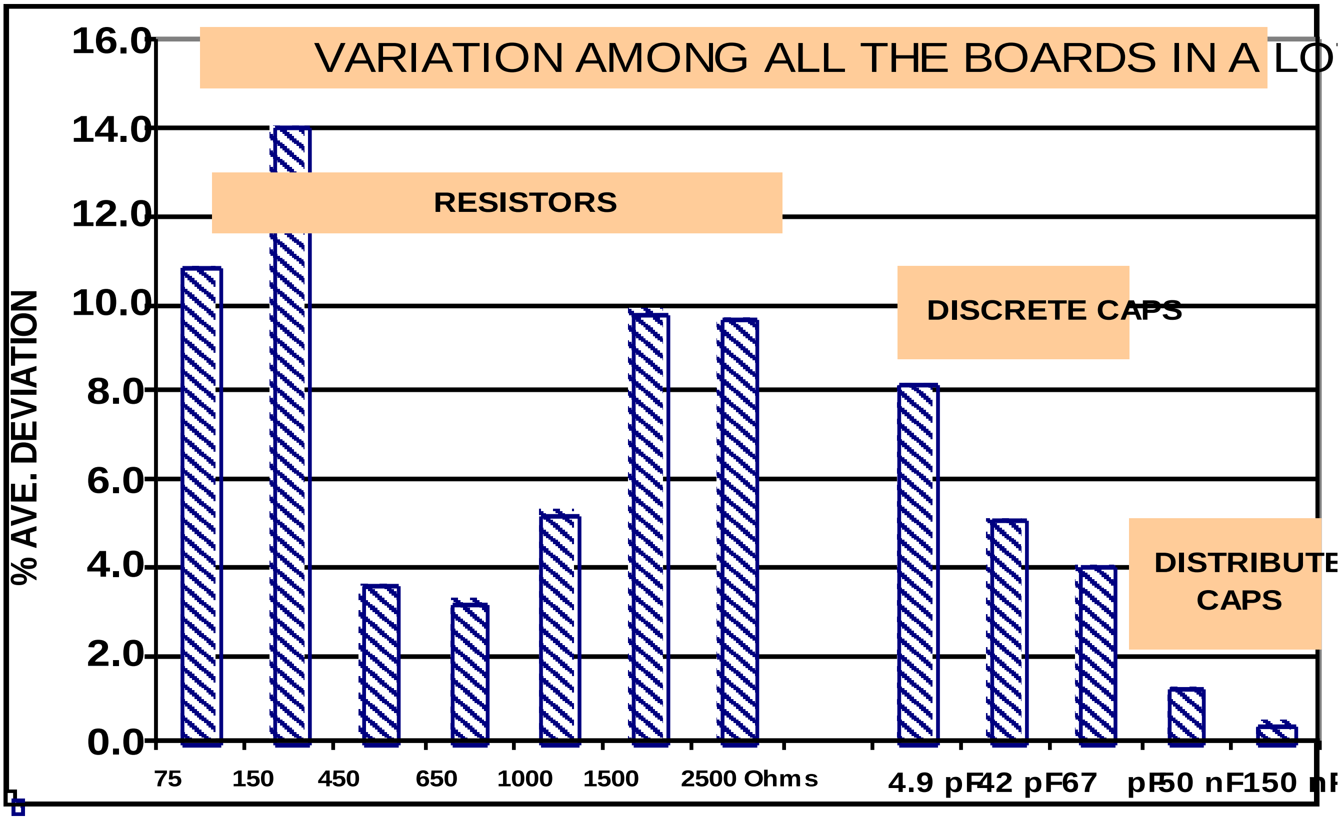


Figure 5 Variations, among all boards in the 35-board lot

For the capacitors the absolute differences were the same for all values, but the percentages were less for the higher-valued elements. Consistent with discussions above, future runs with tighter process control will surely result in tighter board-to-board uniformity.

c) side to side: How systematically symmetrical is the fab's processing? The uncertainty here is the variation across the face of the board: left vs. right, or West vs. East, The test board was designed to include nominally-identical elements spread out in several locations across the board. The as-received data was analyzed to show how the left side differed from the right, on average, for identical elements. Comparative data on capacitors and resistors values, PWBs and coupons, is in Figure 6, below.

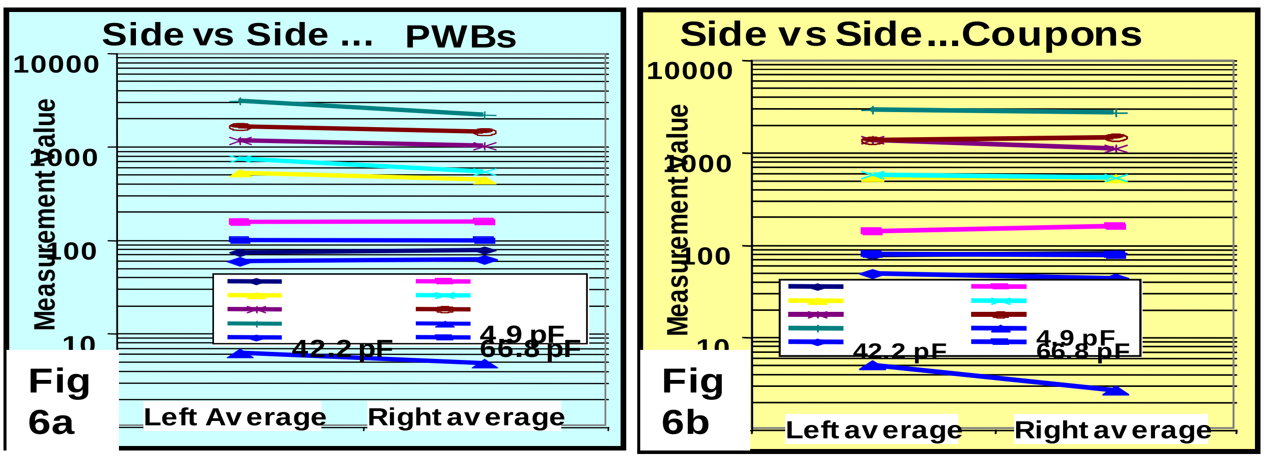


Figure 6 Comparison right side vs left side

These results are more reassuring, but still reveal a possibly systematic difference of a few percent , that should be mitigated by better equipment adjustment and control in future runs.

d) Equivalent points: Specific point-to-point differences are perhaps more important than differences among averages. Differences in nominally-equivalent elements can have profound effects on performance (especially if the magnitude of these lurking differences is not known. As-received data, on every point, on every board, was analyzed to look at the similarity of nominally-equivalent points.
See Figure 7. Resistance values, of equivalent test points on a given board or coupon varied +/- ~7%. Some suppliers' samples varied +/- ~5%. Others' varied +/- ~10%, within the same board. Differences among distant locations on the same board were more pronounced…….variation among close-proximity points was much better. This variation is much greater than mil-space designers have come to expect. Discrete capacitors' values, of equivalent test points on a given board, varied +/- ~ 1% to ~4%, depending on the value. Distributed capacitors' equivalence uniformity is slightly better than that. Also, close-proximity values are even more uniform. Note that coupons' equivalency uniformity is in general better than boards': variation is ~3%.

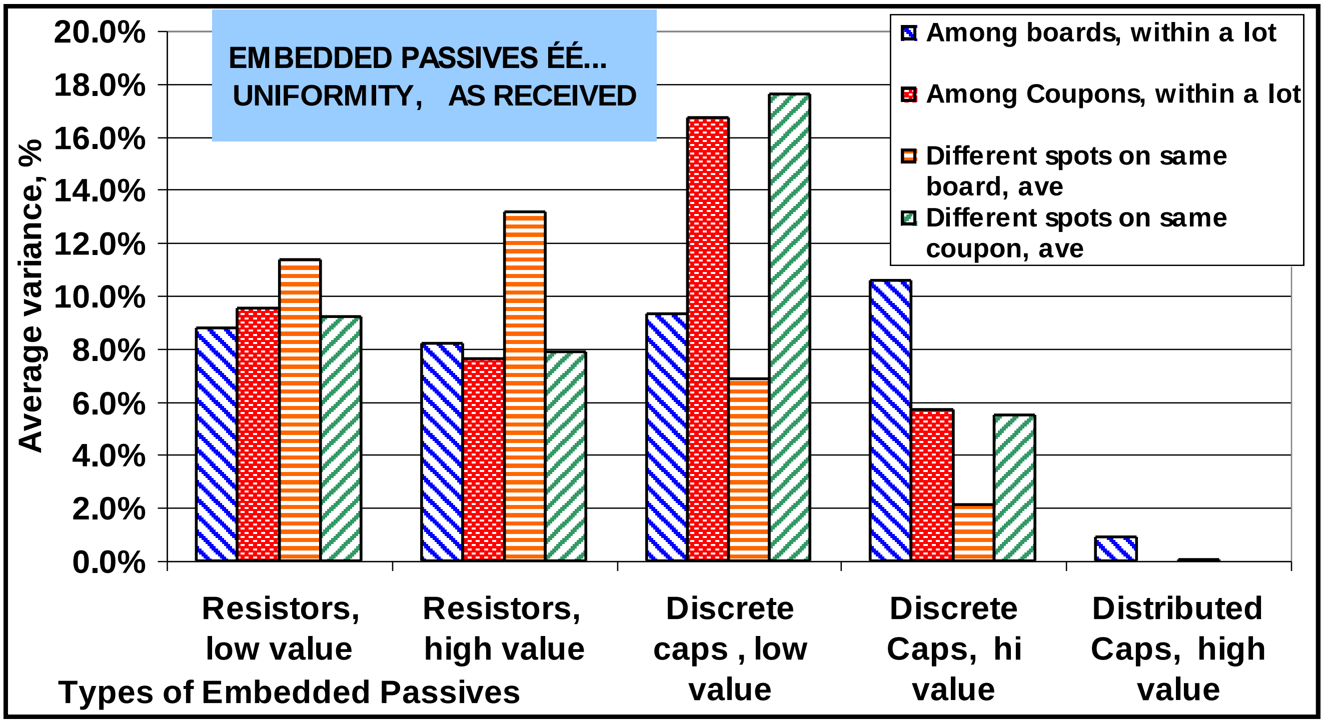


Figure 7 Variations different spots on boards and coupons

e) Coupons vs. boards: The procurement and characterization areas of the PWB industry hinge on the expectation that coupons will represent the equivalent feature on the board. The vendor must control his process and his shipment decisions; and the customer must rely on the coupon to reveal what he is getting: testing the coupon is always desirable, and usually offers the only practical appraisal of the boards' properties. Destroying the board to see what it was is not the best plan. In this study, the as-received data on coupons and boards was analyzed to compare the nominally-identical elements. See Figure 8. How representative were the coupons? Generally the capacitors' coupons values were ~25% lower than the boards values. Resistors coupons' values were from 10% higher to ~30% lower than the boards' values. This was not good news but was somewhat anticipated, based on the variability previously discussed. Clearly, this best-effort beta-site effort appears to be a worst-case, in terms of learning curve with a very complex circuit board.

Compare coupons vs boards: equiv values / points

nominal value	average board value	average coupon value	Coupon, compared to board
100 Ohm	73	81	10.2
150 Ohm	155	154	-1.2
500 Ohm	524	532	1.6
533 Ohm	744	552	-25.7
1000 Ohm	1166	1174	0.7
1500 Ohm	1625	1434	-11.7
2000 Ohm	3074	2109	-31.4
4.9 pF	6.2	3.6	-41.3
42.2 pF	56.6	46.1	-18.6
66.8 pF	95.1	78.2	-17.8

Conclusion: Difference between coupon and board ranged from 0.7% to -41%. Caps' deviation was greater than resistors'.

Fig 8 Comparison coupons vs boards

Wrap-up …. As-received Uniformity

This analysis of a best-effort process-development project offers important insight into process control elements. It confirms expectations, by the fab and the customer, that hitting the target with new materials and processes, in a very complex board design, would be difficult. It shows that variability as-fabricated and received can be a challenge to be minimized by experience.

Certainly this study suggests that mil-aero customers and fabs should not expect the +/- 1-2% on-target accuracy and the element-to-element uniformity that are typical with mil-aero discrete SMT passives. The usual troublesome development efforts (material and process experimentation, DOEs and routine pilot runs, extensive in-process controls, cherry-picking, board-design compromises, test sampling, NRECs. etc. and certainly cost and schedule impacts) must be anticipated by both parties.

Experimental Details…. Environmental studies

After the specimens were characterized for the as-received analysis, they were committed to the environmental-stability series. This included: at-temperature effects, the effect of aging at elevated temperatures, and humidity exposure, the effect of thermal shock, the effect of local overheating ("measling"), the effect of vibration, and the effect of thermal-cycling.

"At-temperature" effect. Several sets of boards and coupons were measured at a series of temperatures. Temperatures were: -77, -20, +32, +75, +175 C, These effects were not intended to reflect "aging" phenomena, but instantaneous at-temperature effects. Therefore the specimens were held at each temperature only long enough to be equilibrated i.e. only minutes, at the specific exposure conditions. Additionally, after each exposure, the specimens were equilibrated for ~5-10 minutes at RT (room temperature), and then measured to check for short-term drift. See figures 9a and 9b.

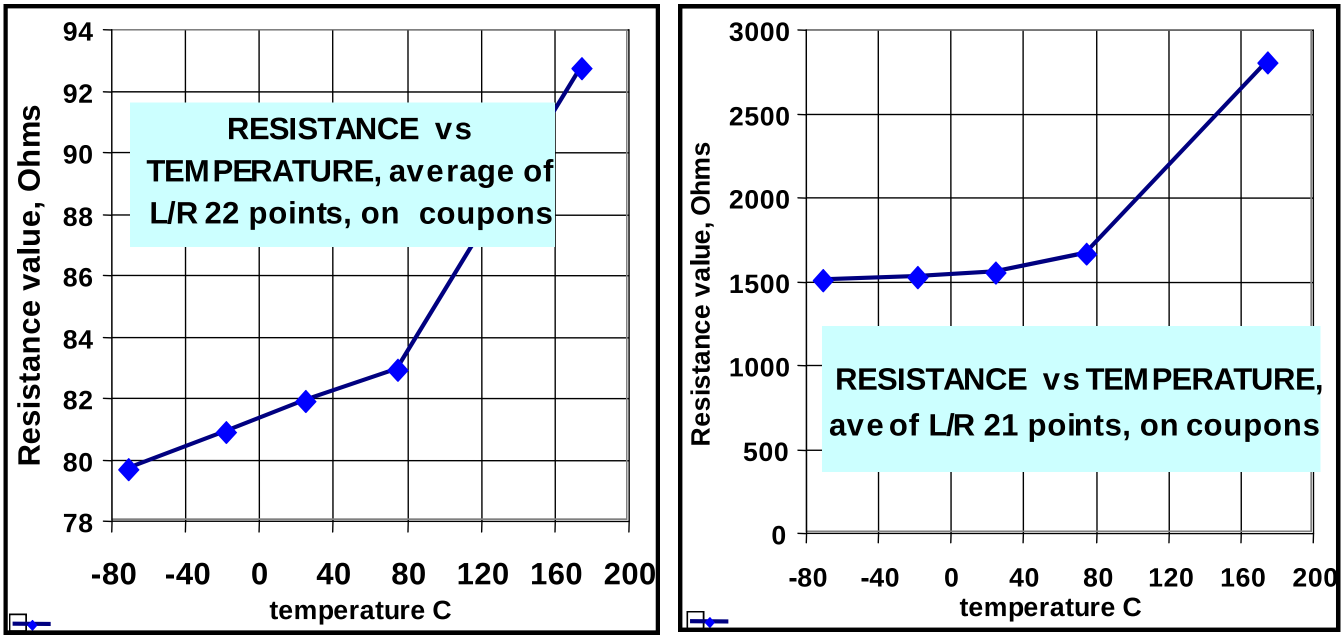


Figure 9a Resistance vs temperature

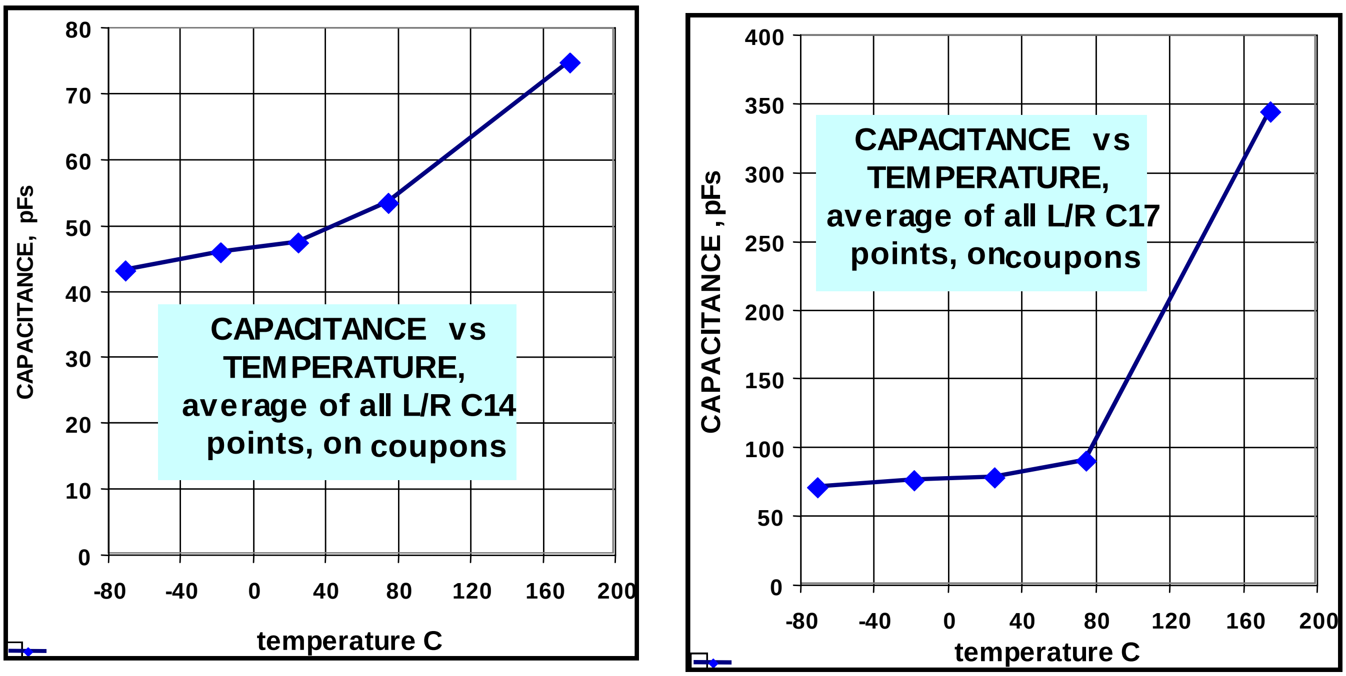


Fig 9b Capacitance vs temperature

Resistance tended to be higher at elevated temperatures: total span -77 to + 175 C, Resistance gained `~25% on average. Some materials gained 10%. Others gained ~ 36%. Between each exposure, values returned to their original near RT values. Therefore the temperature effects is reported as short-term reversible "at-temperature", rather than "aged".

Later discussions will show that this assumption is technically valid. Again, different materials behaved slightly differently. Capacitors behaved similarly, as seen in Figure 9b above. Both types of embedded passives exhibit short-time temperature effects: increasing values with increased temperature. But short-term exposure has no significant lasting effect.

2**) Aging, after humidity conditioning and after thermal exposure.**_ Combinations of humidity and elevated temperature can impact reliability of certain electronics structures. Several sets of specimens were identified and characterized prior to environmental conditioning. These were then conditioned at 85% RH, 85C for one week, then measured at RT; then conditioned at 250F for 1 week, and measured again at RT, then conditioned for another week at 250F , measured, then, and measured at RT. Results on the resistors show a 10% drop, from T=0, due to the 85/85 exposure, then no significant effect due to 3 weeks at 250F. See Figure 10. Capacitance behaved a bit differently, but tended to remain within 10 % of T=0 values: Again different materials behaved slightly differently; depending on the type of material or at least differed among the specimen types. Certain specimens showed a positive temperature effect, others appeared to be temperature insensitive. See Figure 11.

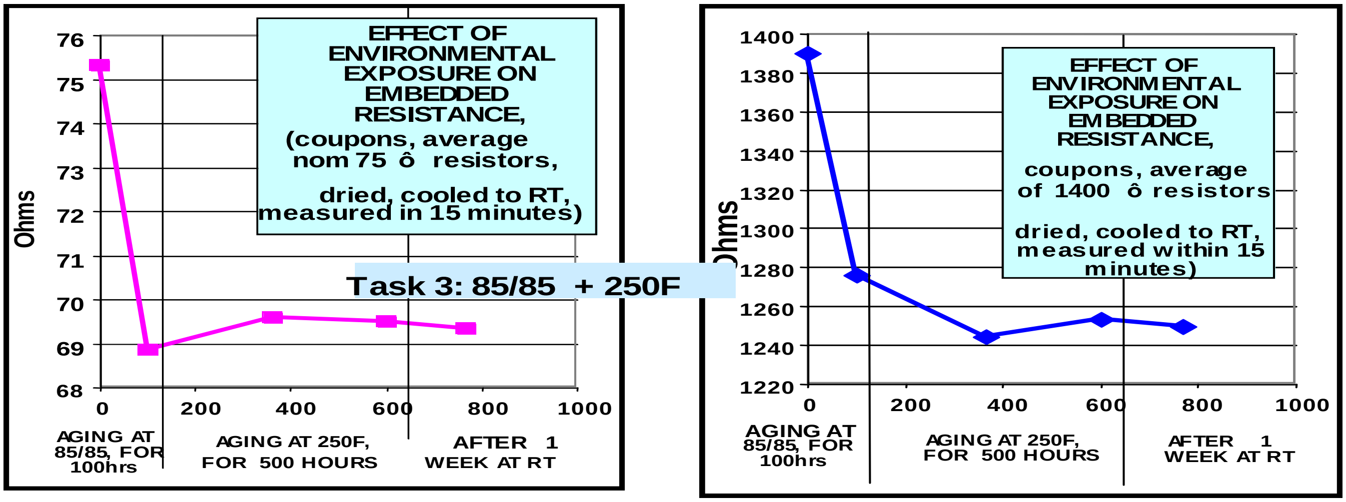


Figure 10 Resistancevs Environmental Exposure

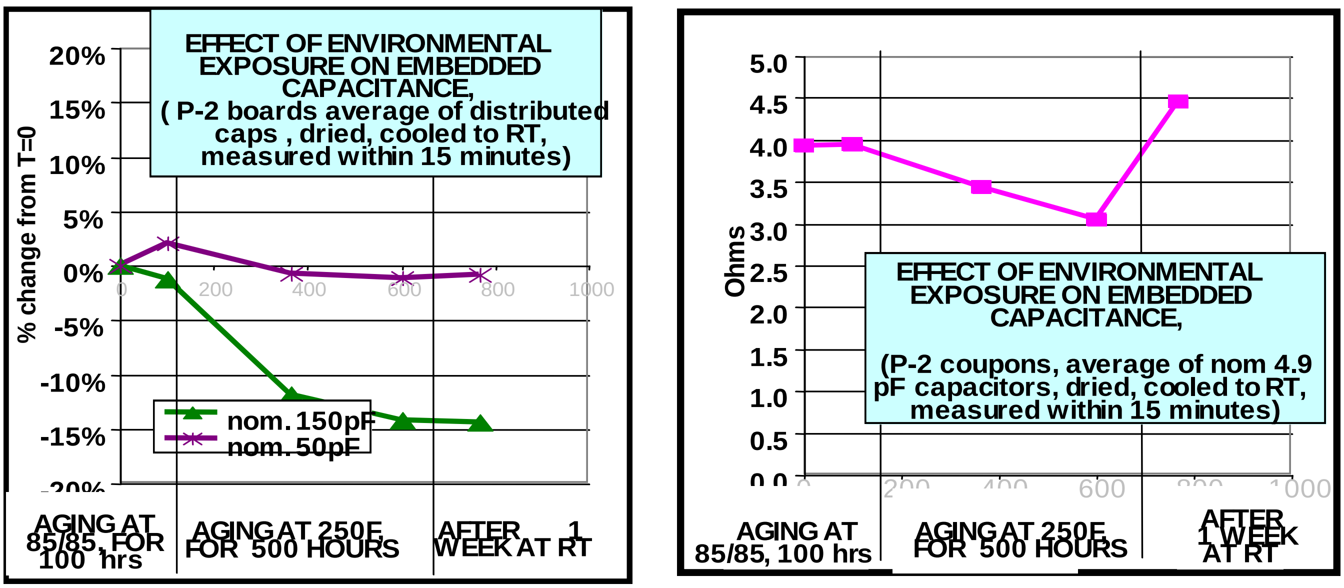
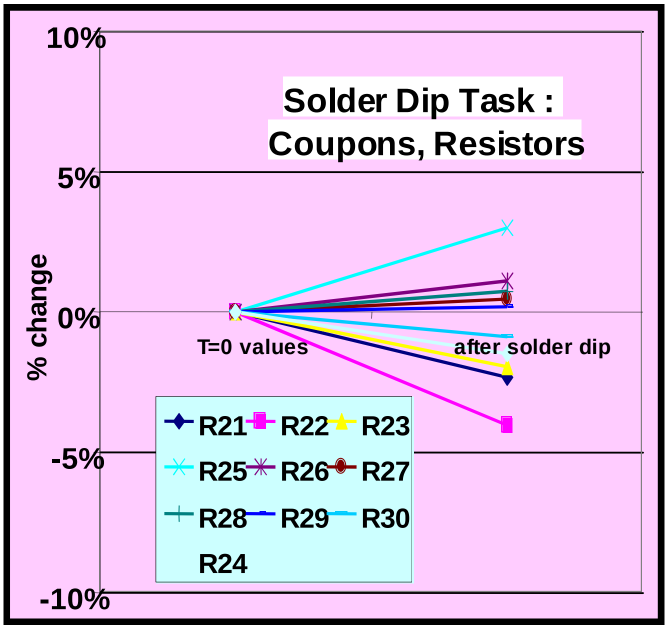


Figure 11 Capacitancevs environmental exposure

3) Thermal shock solder-dip_ Thermal-shock can damage joined materials of different CTEs. This series was intended to simulate assembly conditions, i.e. what is likely to be encountered in reflow conditions, worst-case. Coupons at RT were plunged into molten solder, removed, allowed to cool to RT, and then measured. See Figure 12.



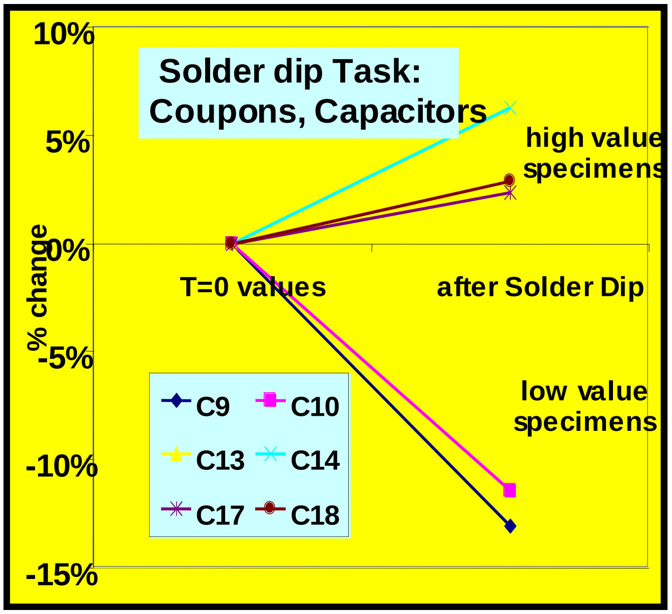


Figure 12 Effect of thermal shock (solder dip) on Capacitance and Resistance

This thermal shock, as administered by solder-pot immersion, has little effect, causing only a small change: up to ~ 10%, varying amongst all types of EPs. This is reassuring: at least the effects encountered in assembly processing are not likely to be catastrophic.

4) Local over-heating "measling"_ This series is even more brutal, simulating extreme surface overheating; the type that will cause point delamination …..“measling”, as seen in Figure 13.

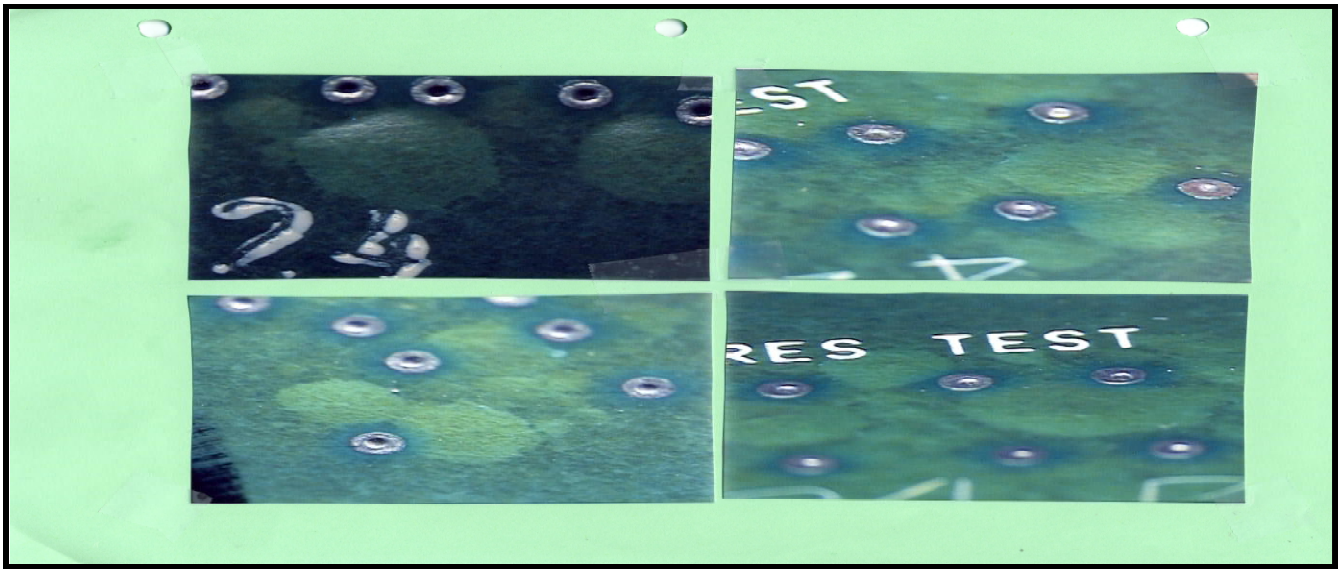


Figure 13 Typical ÒmeaslesÓ localized thermal-damage delamination

The results were very reassuring, as seen in the typical results in figure 14 and 15. The resistors showed changes up to only 3-5%.

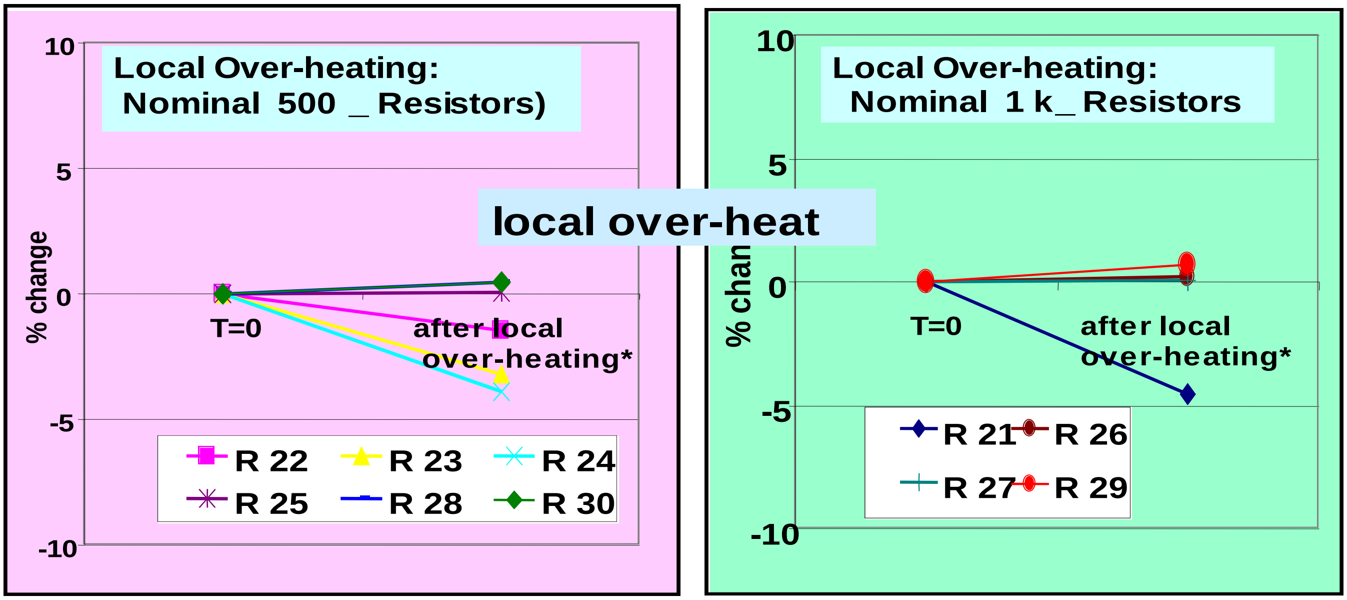


Figure 14 Resistance changes, due to local overheating

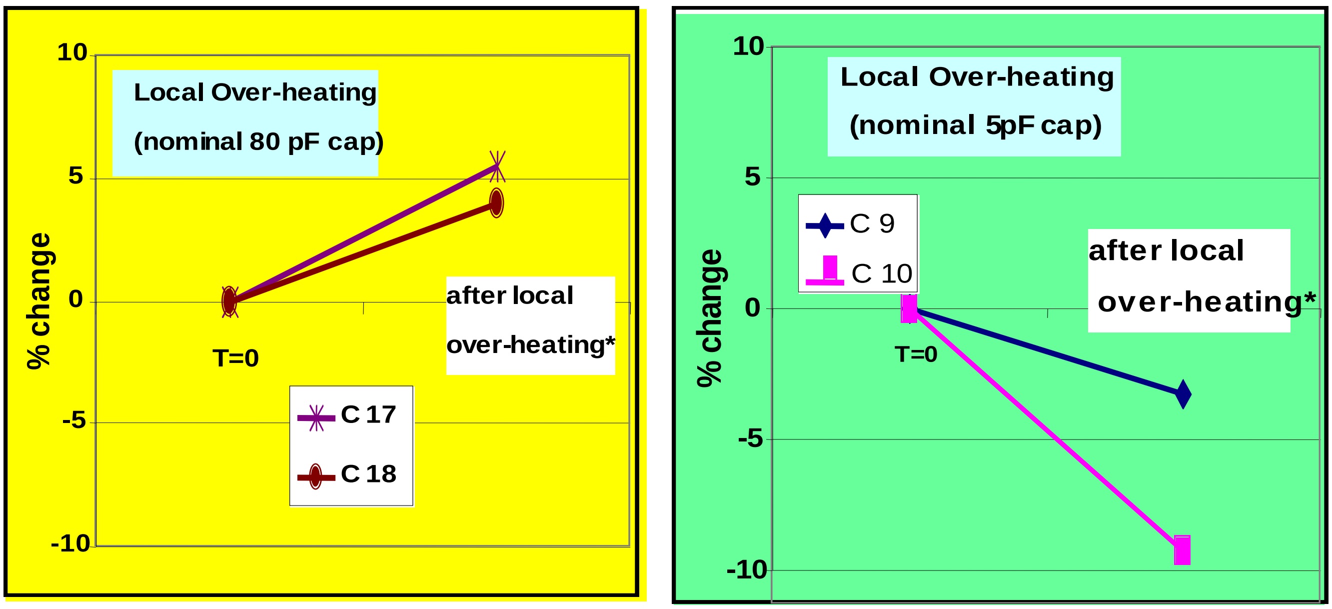


Figure 15 Figure 14 Capacitance changes, due to local overheating

The capacitors changed 5-9%, the magnitude again depending on the materials and value.

5) Extended water immersion_ was intended to simulate in-process washing and/or extreme in-service moisture exposure. Coupons were immersed in room temperature water for several weeks, dried gently, and measured. Again, the stability results were reassuring; only a few % change was observed. See the effects, in Figure 16.

6) Effect of vibration Another environmental exposure encountered in harsh-environment applications is vibration. Several sample sets were selected and sawn into 1' X 3" coupons, and characterized as T=0, preparatory to vibration exposure. The coupon was positioned and clamped at one end with the embedded passive element towards the cantilevered free end, and subjected to a typical qual-level vibration spectrum. Results showed little or no effect.

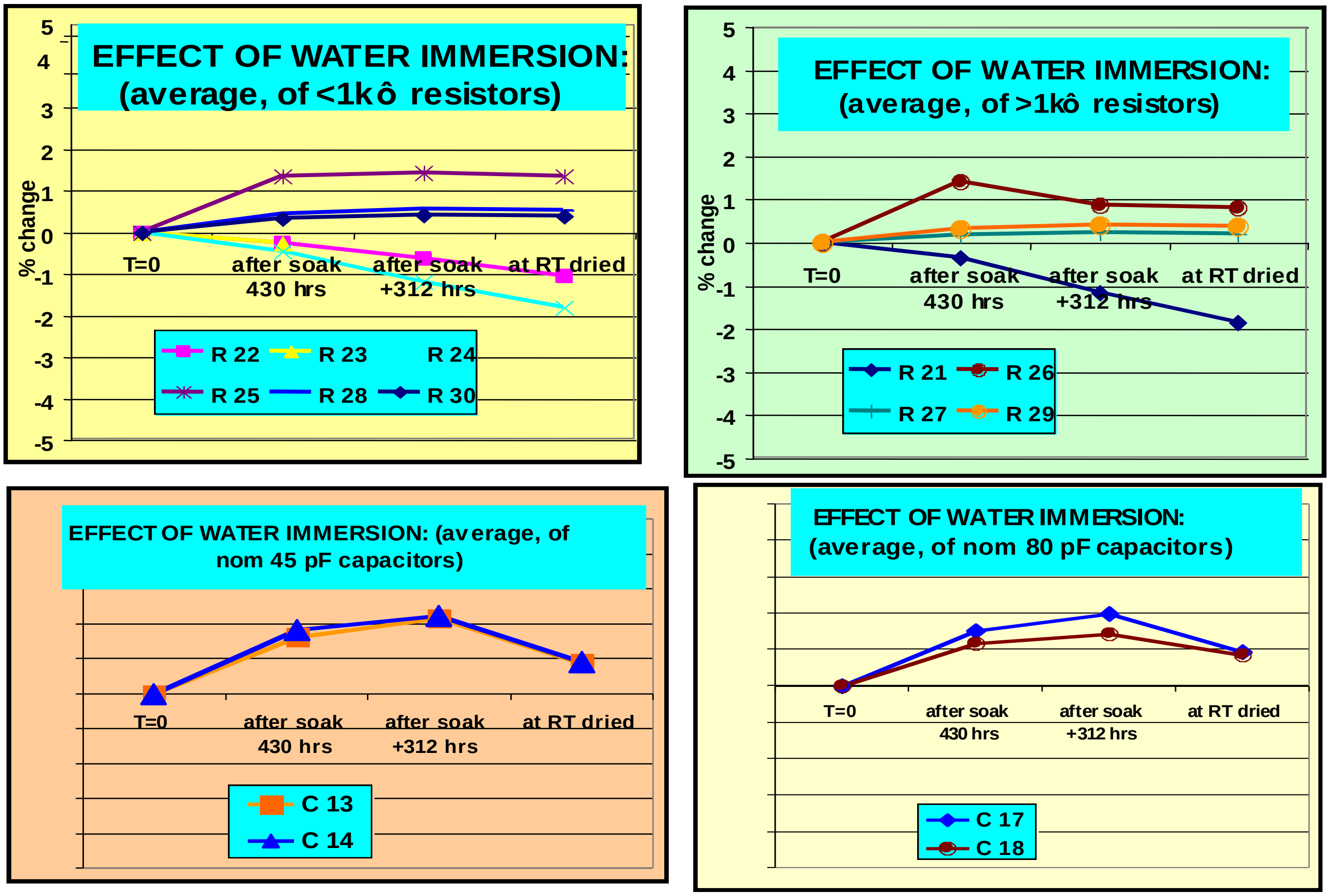


Figure 16 Resistance and Capacitance, after water immersion and drying

See Figures 17. Certainly more extreme vibration, specific designs using different internal construction, and more measurements sensitive to incipient internal delamination or damage, might be appropriate, but at this point a robust situation appears likely.

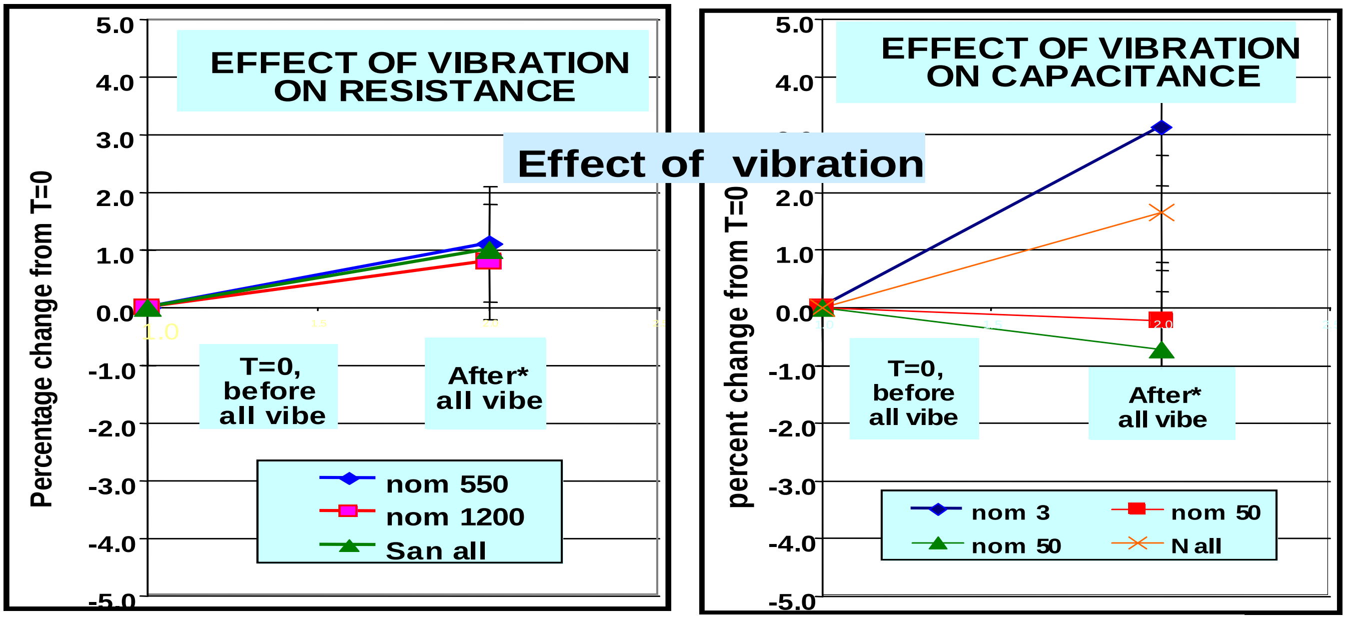


Figure 17 Resistance and Capacitance, effect of vibration

7) T-Cycle Long-term cyclic temperature excursions can initiate and propagate fatigue damage. Several more sets of coupons and boards were selected and characterized prior to t-cycle exposure. Thermal-cycle conditions were -10 C to + 125 C, with 30 minute ramps and dwells. The cycling was interrupted periodically over the 2-month duration, specimens measured at RT, then re-started. See Figure 18. Coupons of the basic Sanmina set showed erratic effects: mostly less than +/- 10%. See Figure 19. Some capacitors were impacted up to ~20%. Retains from the Crane/Navsea series fared a bit better. On average they showed ~5% effects. Based on the results of this series, it appears that extreme deterioration will not be experienced, under these t-cycle conditions. However, compared to conventional SMCs and SMRs, these EPS do exhibit substantial variations that would be of concern and probably unacceptable for designs and applications demanding high precision and stability. More characterization tests, of course, on more mature materials and processes are warranted.

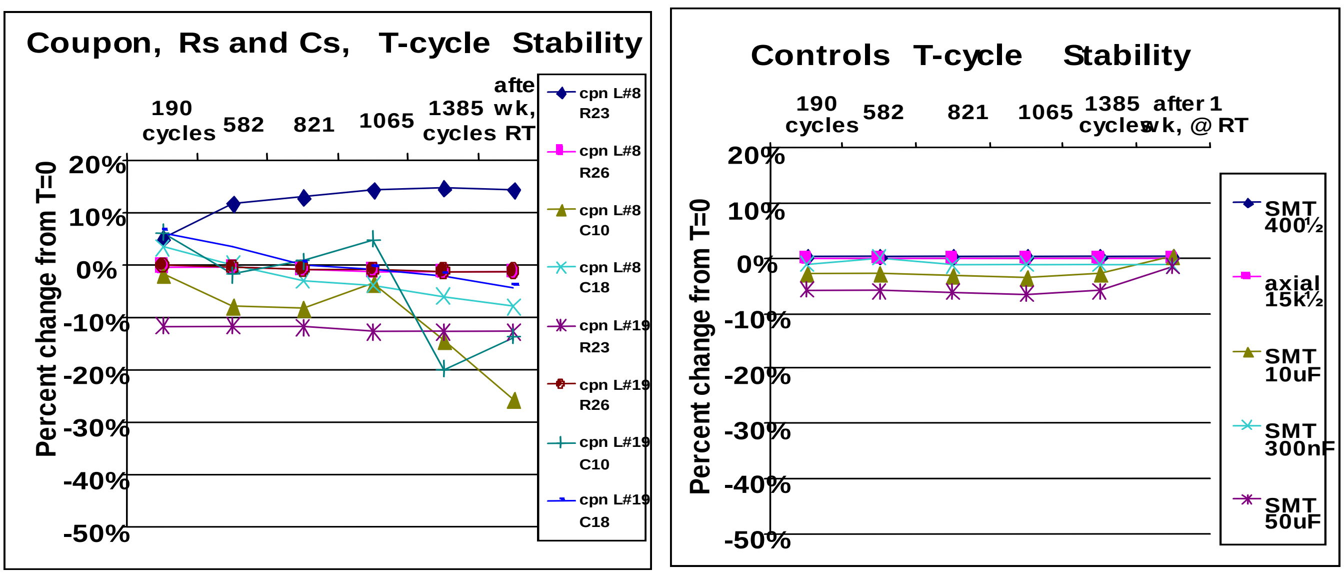


Figure 18 T-cycle stabilityÉ . Basic E-P PWBs, plus SMT controls

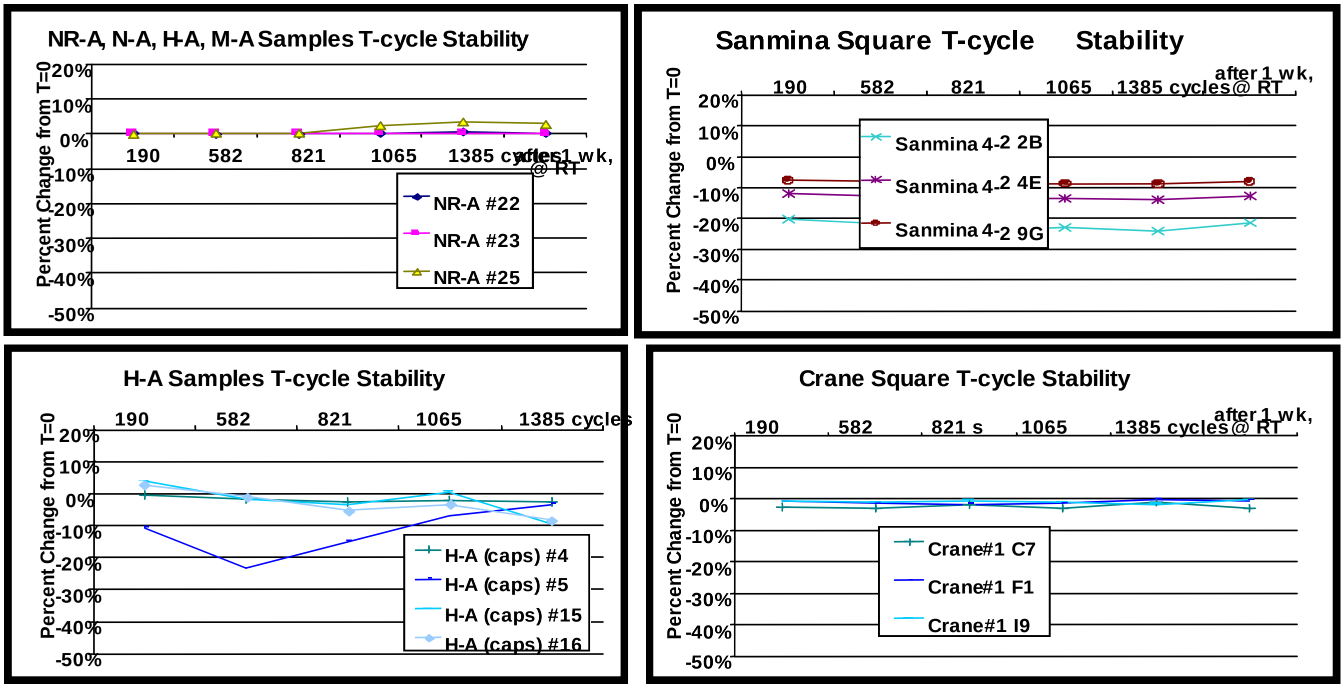


Figure 19 T-Cycle stability É several special sample boards

Wrap-up Environmental stability

1) Exposure to harsh in-service conditions, as exemplified above, can be expected to cause changes of 5-20% in values, the magnitude depending on the nature of materials and conditions.

2) These changes might be acceptable for certain functions in certain applications, but probably not for high-precision, extended-life applications. Long-term aging especially could have larger and possibly lasting effects.

3) Short-term exposures likely to be encountered during processing (thermal, moisture-soak) seem to have relatively minor effects, in general. The resistance and capacitance effects at-temperature seems rational and predictable, and the at-temperature data could be used as design input, and considered an attribute that can be accommodated in product performance considerations.

Overall Summary

1) The use of embedded passives, in complex designs and incorporating several values, will require processing finesse and experience, and doubtless some cherry-picking and yield-loss, by fab and user, in applications that require as-received values whose averages will fall within a few % of target. Processing experience and fabricators' skills and capabilities are maturing. Purchase specifications will need to accommodate the fabricators' capabilities, vs. the products absolute specification needs and acceptable costs. Good business relationships will be important.

2) Uniformity among boards and within the same board, and between board and coupon will remain troublesome, at +/- 10-20 %, until processing conditions become better controlled. Fortunately, characterization is non-destructive, so sampling and tailored allocation might be a useful interim compensatory practice.

3) Short-term processing exposures, nominal or worse, appear to have little lasting effect on EP's values.

4) Long-term in-service conditions will cause embedded passives to be impacted by 5 - 10% or more. Selection and product design must accommodate these changes.

5) Much more work and enlightened fab/user partnership will be necessary, before embedded passives can reach the maturity, and predictable and reliable performance, of conventional SMDs and SMCs.

Acknowledgements

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EMBEDDED PASSIVES …. PREDICTABILITY, AS-RECEIVED AND IN-SERVICE

2008 APEX … LAS VEGAS

TOM CLIFFORD, MELISSA LAU March/April 2008

CONTENT:

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2) UNIFORMITY … AS-RECEIVED

3) STABILITY … IN-SERVICE

4) WRAP-UP ….. Q & A

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Task 1a: actuals vs target
Task 1b: board-to-board
Task 1c: side to side
Task 1d: equiv points
Task 1e: coupons vs PWBs

} uniformity

Task 2: hot and cold
Task 3: after 85/85+250
Task 4: thermal shock
Task 5: local over-heat
Task 6: water immersion
Task 7: vibration
Task 8: t-cycle

} stability

INTRODUCTION

1) OBJECTIVE: EXPLORE PREDICTABILITY OF EMBEDDED PASSIVES, TO GUIDE DESIGN AND PROCUREMENT, FOR MIL-AERO APPLICATIONS.

2) THE PRIMARY TEST VEHICLE WAS A LARGE, COMPLEX, MULTI-LAYER POLYIMIDE/GLASS PWB : MANY VARIETIES OF BGAs, B-B VIAS, HDI GEOMETRY ….

INCLUDING SEVEN LEVELS OF EMBEDDED RESISTORS, AND TWO TYPES AND SEVERAL LEVELS OF EMBEDDED CAPACITORS.

NOTE ON THE TWO SECTIONS:

THE "UNIFORMITY … AS-RECEIVED" SECTION WAS INTENDED TO BE ONE LOOK AT ONE FAB'S EXPERIENCE WITH A VERY COMPLEX TASK.

IT WAS NOT INTENDED TO BE A DEFINITIVE STUDY OF ALL E-P FAB PROCESSING AND QUALITY CONTROL.

THE "STABILITY … IN-SERVICE" SECTION, HOWEVER, WAS INTENDED TO PROVIDE INSIGHT INTO GENERIC AND BROADLY-APPLICABLE BEHAVIOUR.

Instrumentation

Task 1a: actuals vs target
Task 1b: board-to-board
Task 1c: side to side
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Task 1e: coupons vs PWBs

} uniformity

Task 2: hot and cold
Task 3: after 85/85+250
Task 4: thermal shock
Task 5: local over-heat
Task 6: water immersion
Task 7: vibration
Task 8: t-cycle

} stability

INSTRUMENTATION

SELECTION

FREQUENCY

TECHNIQUE

CALIBRATION / DRIFT

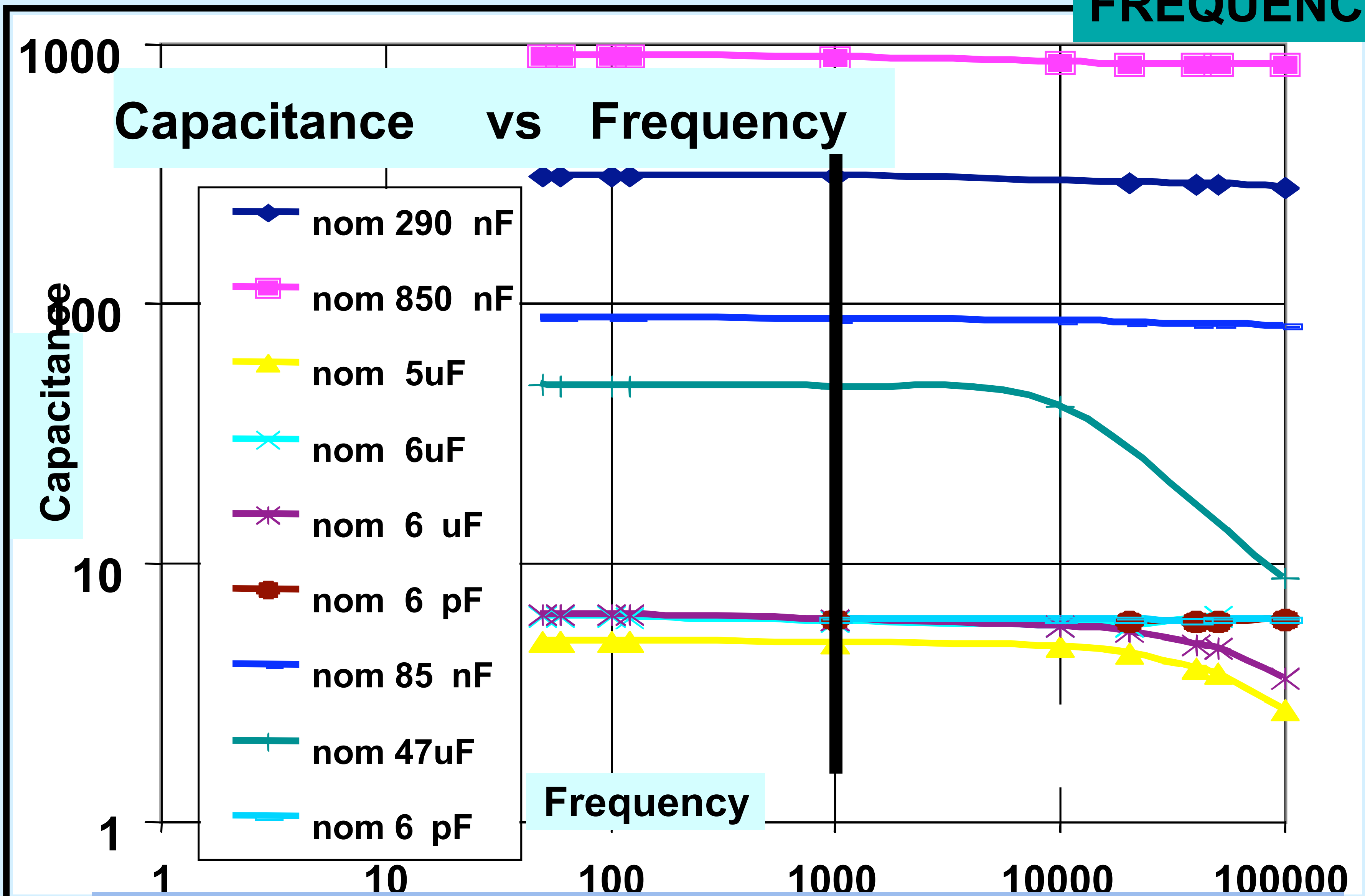
Instrument selection… conclusions

1) The Fluke is convenient, useful for resistance, and possibly for high capacitances; but is noisy and cannot read low cap readings at all.

2) The BK is jittery at low capacitance values.

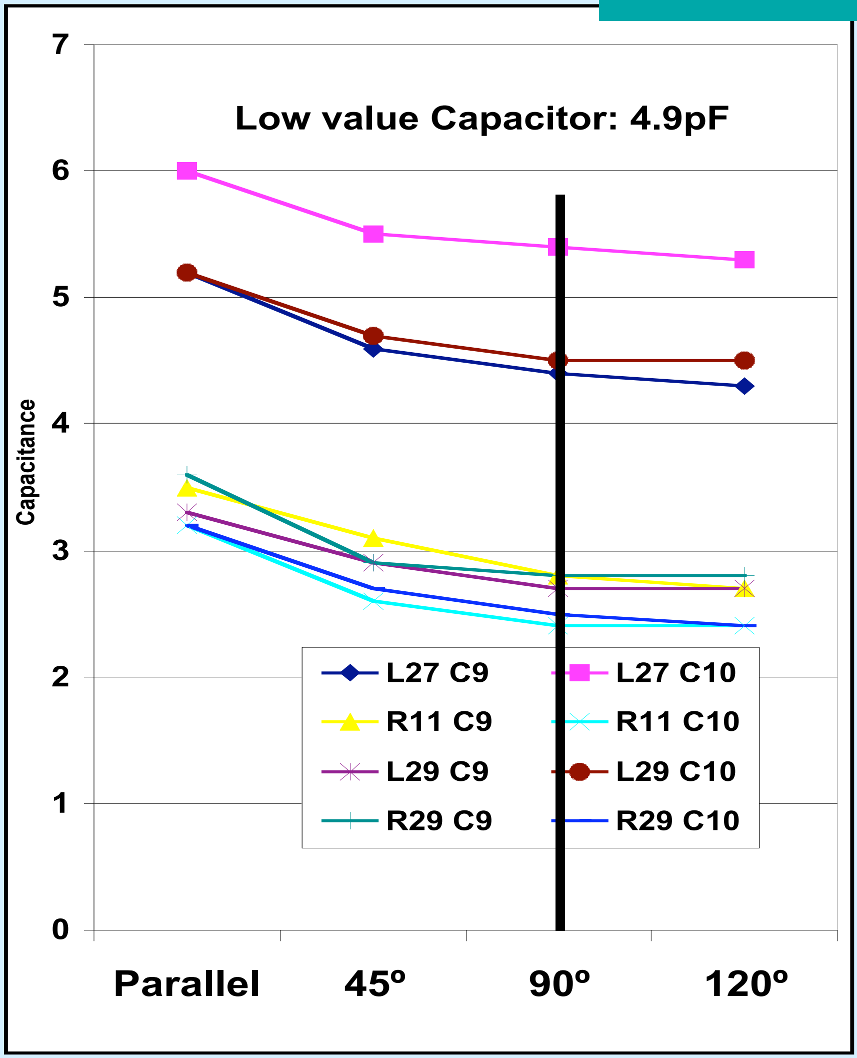
3) The DigiBridge is the proper instrument.

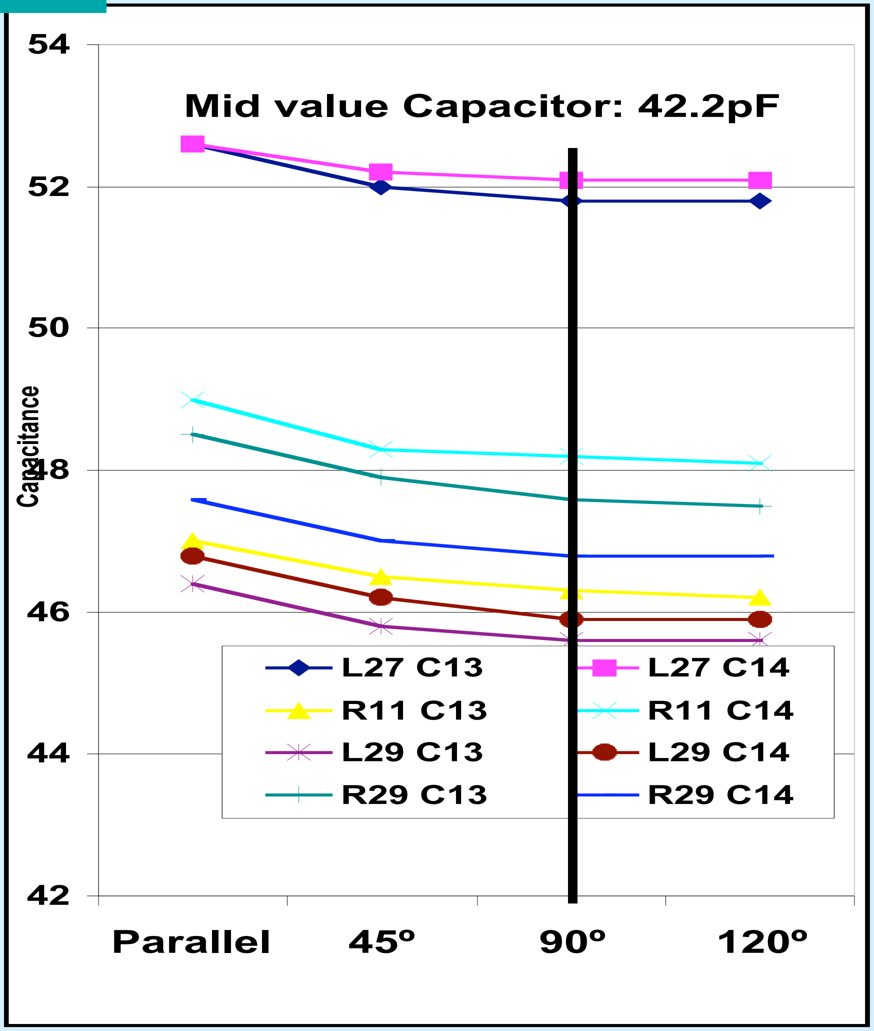
FREQUENCY



Make all the capacitance measurements at 1000hz

TECHNIQUE





Holding probes at 90 degrees looks like good technique

CALIBRATION / DRIFT

Phase 2 Embedded Passives Study ...QuadTech Digibridge, Cal/Repeatability Log																						
Specimen	1-Nov	2-Nov	7-Nov	9-Nov	14-Nov 15-Nov	28-Nov	22-Dec	3-Jan	11-Jan	12-Jan	16-Jan 17-Jan	2-Feb	3-Feb	6-Feb	7-Feb	8-Feb	16-Feb	17-Feb 24-Feb	6-Mar	9-Mar	16-Mar	ave dev, %
100 nF axial				103.0		102.0	102.0	100.0	102.4	102.3	102.3	100.5	101.7	103.2	102.2	101.0	103.0	100.9	101.0	101.5	101.2	0.7%
axial									52.8	52.7	52.7	52.7	52.8	52.7	52.7	52.7	52.6	52.5	52.7	52.6	52.6	0.1%
axial	##	99.5	99.5	99.5	99.5	99.5	99.5	99.5	99.5	99.5	99.5	99.5	99.5	99.5	99.5	99.5	99.6	99.5	99.5	99.5	99.5	0.0%
330 pf axial																330.3	330.0	330.9	331.1	330.8	330.7	0.1%
85 nF SMC																86.9	85.3	84.8	84.5	85.1	84.7	0.6%
50 Ω																						

Re-tests of standard passives: the instrumentation is OK; does not introduce significant bias or variability.

Task 0: Instrumentation

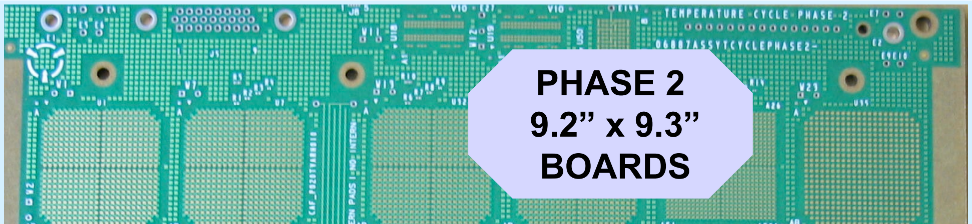
Task 1a: actuals vs target
Task 1b: board-to-board
Task 1c: side-to-side
Task 1d: equiv points
Task 1e: coupons vs PWBs

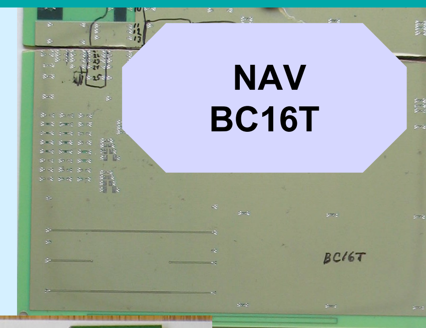
} predictability, uniformity

Task 2: hot and cold
Task 3: after 85/85+250
Task 4: thermal shock
Task 5: local over-heat
Task 6: water immersion
Task 7: vibration
Task 8: t-cycle

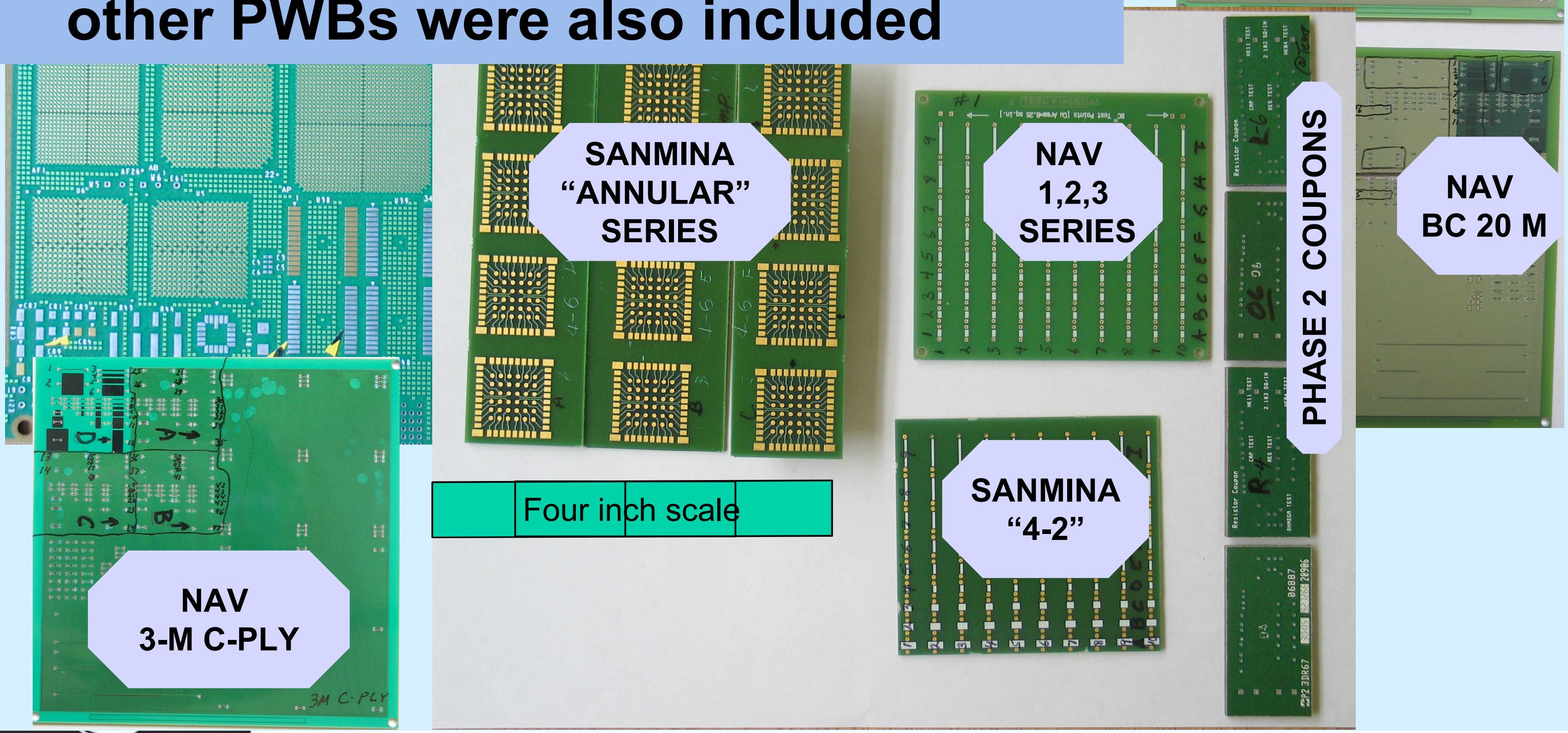
} stability

Test specimens





Basic test specimens: ~ thirty "Phase 2" boards / coupons. A few other PWBs were also included



PHASE 2… EMBEDDED RESISTANCE …. ALL PWBs, ALL VALUES

Board S/N:		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	ave. of ave.
	R 22	70	65	79	82	62	79	81	63	71	110	81	67	62	62	73	121	64	81	59	43	82	52	68	66	86	73
	R 31	85	71	82	81	84	66	84	68	91	86	69	75	81	76	70.3	88	73	82	86	79	73	69	72	50	95	77
average		*78*	*68*	*81*	*82*	*73*	*73*	*83*	*66*	*81*	*98*	*75*	*71*	*72*	*69*	*72*	*105*	*69*	*82*	*73*	*61*	*78*	*61*	[illegible]	*58*	*91*	*75*
ave. Dev. (%)		*9.7*	*4.4*	*1.9*	*0.6*	*15.1*	*9.0*	*1.8*	*3.8*	*12.3*	*12.2*	*8.0*	*5.6*	*13.3*	*10.1*	*1.9*	*15.8*	*6.6*	*0.6*	*18.6*	*29.5*	*5.8*	[illegible]	[illegible]	*13.8*	*5.0*	*9*
	R 23	212	123	209	142	186	199	121	192	167	187	130	148	164	124	167	220	122	185	204	92	[illegible]	[illegible]	[illegible]	[illegible]	131	*155*
	R 32	179	149	170	160	158	141	164	168	178	165	145	158	171	150	138	206	157	184	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	186	*158*
average		*196*	*136*	*190*	*151*	*172*	*170*	*143*	*180*	*173*	*176*	*138*	*153*	*168*	*137*	*153*	*213*	*140*	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	*159*	*157*
ave. Dev.		*8.4*	*9.6*	*10.3*	*6.0*	*8.1*	*17.1*	*15.1*	*6.7*	*3.2*	*6.3*	*5.5*	*3.3*	*2.1*	*9.5*	*9.5*	*3.3*	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	*17.4*	*10*
nominal value: 500	R 25	461	478	498	460	468	430	600	463	471	482	475	445	459	467	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	460	*489*
	R 35	393	392	413	397	381	369	513	374	393	422	403	383	384	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	*410*
	R 28	478	450	436	470	463	435	514	442	473	469	458	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	*469*
	R 38	467	459	476	474	454	444	525	442	484	476	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	*475*
	R 24	601	616	602	582	765	571	508	585	538	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	616	655	*613*
	R 33	452	503	432	404	427	475	351	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	411	479	510	*437*
average		*475*	*483*	*476*	*465*	*493*	*454*	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	*450*	*466*	*489*	*489*	*482*
ave. Dev.		*9.0*	*10.6*	*10.3*	*9.5*	*18.4*	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	*9.5*	*10.6*	*7.7*	*10.1*	*9.0*	*12.8*	*11*
	R 30	776	701	735	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	788	722	736	777	733	714	770	*744*
	R 40	551	506	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	548	542	520	534	569	532	523	555	*539*
average		*664*	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	*675*	*638*	*642*	*665*	*621*	*635*	*673*	*633*	*619*	*663*	*642*
ave. Dev.		[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	*17.1*	*15.8*	*13.9*	*14.6*	*18.5*	*16.3*	*15.9*	*15.5*	*15.9*	*15.4*	*16.2*	*16*
nom: 1000	R 26	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	988	111	985	1271	1186	1000	942	1008	987	952	960	945	*920*
	R 36	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	874	883	935	913	915	1141	1088	868	886	945	938	869	945	906	*927*
	R 29	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	1375	1355	1369	1452	1480	1483	1500	1461	1484	1357	1418	1478	1367	1383	1437	*1378*
	R 39	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	1100	1088	1093	1084	1157	1159	1159	1202	1192	1139	1069	1121	1173	1089	1103	1141	*1123*
average		*1103*	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	*1049*	*911*	*1103*	*1092*	*1059*	*1067*	*1133*	*916*	*1136*	*1279*	*1232*	*1123*	*1064*	*1123*	*1144*	*1069*	*1098*	*1107*	*1087*
ave. Dev.		*16.8*	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	*10.3*	*15.1*	*44.2*	*13.5*	*13.0*	*15.6*	*15.0*	*15.1*	*44.1*	*16.3*	*8.7*	*9.3*	*16.8*	*14.1*	*13.1*	*15.9*	*14.8*	*13.2*	*16.4*	*17*
nom: 1500	R 21	1898	[illegible]	[illegible]	[illegible]	1426	1527	1558	1328	1909	1650	1615	1481	1876	1271	1872	2145	1274	1780	1963	1419	1598	1090	1650	1344	1783	*1625*
	R 34	1289	[illegible]	1459	1467	1291	1402	1148	1274	1377	1510	1611	1510	1318	1325	1460	1832	1436	1742	1399	1054	1493	1266	1352	1506	1770	*1438*
average		*1594*	*1593*	*1680*	*1604*	*1359*	*1465*	*1353*	*1301*	*1643*	*1580*	*1613*	*1496*	*1597*	*1298*	*1666*	*1989*	*1355*	*1761*	*1681*	*1237*	*1546*	*1178*	*1501*	*1425*	*1777*	*1531*
ave. Dev.		*19.1*	*4.8*	*13.1*	*8.5*	*5.0*	*4.3*	*15.2*	*2.1*	*16.2*	*4.4*	*0.1*	*1.0*	*17.5*	*2.1*	*12.4*	*7.9*	*6.0*	*1.1*	*16.8*	*14.8*	*3.4*	*7.5*	*9.9*	*5.7*	*0.4*	*8*
nom: 2000	R 27	2911	2723	7861	2869	2803	2603	3161	2694	2937	2828	2814	2754	2752	2911	2962	2899	3316	3193	2958	2670	2837	2909	2881	2742	2853	*2874*
	R 37	2151	2020	2138	2213	2039	2005	2561	2040	2207	2130	2117	2087	2087	2192	2226	2178	2590	2535	2125	2002	2187	2231	2090	2146	2174	*2179*
average		*2531*	*2372*	*2138*	*2541*	*2421*	*2304*	*2861*	*2367*	*2572*	*2479*	*2466*	*2421*	*2420*	*2552*	*2594*	*2539*	*2953*	*2864*	*2542*	*2336*	*2512*	*2570*	*2486*	*2444*	*2514*	*2512*
ave. Dev.		*15.0*	*14.8*	*0.0*	*12.9*	*15.8*	*13.0*	*10.5*	*13.8*	*14.2*	*14.1*	*14.1*	*13.8*	*13.7*	*14.1*	*14.2*	*14.2*	*12.3*	*11.5*	*16.4*	*14.3*	*12.9*	*13.2*	*15.9*	*12.2*	*13.5*	*13*

(yellow) = omitted. Possible error in measurement.

Sanmina Phase 2 boards: For "identical" values in several locations on a given board, low-value resistors varied ~ 10%; high-value resistors varied ~ 14%

TYPICAL DATA … TERRIBLE EYE CHART

STAY TUNED FOR SUMMARY / CONCLUSION GRAPHICS

TOM CLIFFORD

PHASE 2 … EMBEDDED CAPACITANCE … ALL PWBs, ALL VALUES

		Board S/N:	1	2	3	4	5	6	7	8	9	11	12	14	15	16	17	18	19	20	21	22	23	25	28	ave. of ave. Dev. (%)
EMBEDDED CAPACITORS	nominal value: 4.9 pF	C 9	6.2	5.2	5.4	6.1	5.2	6.3	5.2	5.0	6.2	6.5	5.0	6.1	6.0	4.9	6.2	5.4	6.4	6.3	6.2	4.9	6.6	5.8	6.5	5.8
		C 10	6.9	6.2	6.2	7.2	6.1	6.8	5.9	5.6	6.9	7.8	5.5	6.8	6.2	5.7	6.6	6.0	6.9	6.9	6.8	6.7	7.2	[illegible]	7.0	6.5
		C 11	4.5	3.7	4.5	5.5	2.5	4.5	4.4	3.6	4.9	4.9	5.1	5.3	5.0	3.9	3.9	4.6	5.0	4.9	5.5	[illegible]	[illegible]	[illegible]	4.3	4.5
		C 12	5.3	4.3	5.0	5.6	4.7	5.2	5.0	4.5	5.6	5.5	5.7	5.7	4.9	4.2	4.5	5.2	5.6	5.1	[illegible]	[illegible]	[illegible]	[illegible]	5.0	5.1
	average		4.9	4.0	4.8	5.6	3.6	4.9	4.7	4.1	5.3	5.2	5.4	5.5	5.0	4.1	4.2	4.9	5.3	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	4.7	4.8
	ave. Dev. (%)		8.2	7.5	5.3	0.9	30.6	7.2	6.4	11.1	6.7	5.8	5.6	3.6	1.0	3.7	7.1	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	7.5	6.9
	nominal value: 42.2 pF	C 13	64	60	61	62	60	52	59	58	64	64	58	64	59	59	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	60
		C 14	58	59	59	60	58	51	57	56	61	64	57	62	58	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	58
		C 15	70	62	62	61	60	52	59	59	69	63	65	71	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	62
		C 16	67	65	63	60	58	52	60	59	67	65	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	61
	average		65	61	61	61	59	51	59	58	65	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	60
	ave. Dev. (%)		6.0	3.1	1.9	1.1	1.8	0.7	1.5	1.9	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	2.5
	nominal value: 66.8 pF	C 17	106	100	99	100	100	97	93	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	88	103	99
		C 18	107	105	102	105	100	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	106	90	107	101
		C 19	107	102	101	99	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	99	109	87	98	100
		C 20	104	100	102	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	95	100	96	101	87	98	98
	average		106	102	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	106	97	101	98	105	88	101	99
	ave. Dev. (%)		[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	1.8	2.6	1.7	1.0	1.4	2.3	1.2	3.4	1.8
BURIED CAPACITORS	nominal value: 150 nF	E5 [illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	51.3	51.2	50.9	51.4	51.2	51.1	51.1	48.9	51.2	51.1
		[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	51.1	51.3	51.2	50.8	51.4	51.2	51.1	51.1	48.9	51.2	51.1
		[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	51.2	51.2	51.1	51.3	51.2	50.9	51.4	51.2	51.1	51.1	48.9	51.2	51.1
		[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	51.5	51.2	51.2	51.1	51.3	51.2	50.8	51.4	51.2	51.1	51.1	48.9	51.2	51.1
		[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	51.0	51.5	51.2	51.2	51.1	51.3	51.2	50.9	51.4	51.2	51.1	51.1	48.9	51.2	51.1
		E2[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	51.1	51.0	51.5	51.2	51.2	51.1	51.3	51.4	50.9	51.4	51.2	51.1	51.1	48.9	51.2	51.1
	average		[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	51.1	51.2	51.1	51.0	51.5	51.2	51.2	51.1	51.3	51.2	50.8	51.4	51.2	51.1	51.1	48.9	51.2	51.1
	ave. Dev. (%)		[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	nominal value: 50 nF	E3 E[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	192	188	194	192	197	193	195	195	197	195	193	193	192	194	189	196	195	185	199	193
		E7 E8	[illegible]	[illegible]	196	193	193	188	194	192	197	193	195	196	197	196	193	193	192	194	189	196	195	185	199	193
		E13 E1[illegible]	[illegible]	193	196	193	193	188	194	193	197	193	195	196	197	196	193	194	192	194	189	197	196	186	200	193
		E15 E1[illegible]	186	193	196	193	193	188	194	193	197	193	195	196	197	196	193	194	192	194	189	197	196	186	200	193
		E21 E2[illegible]	187	193	196	193	193	188	194	193	197	193	195	196	197	196	193	194	192	194	189	197	196	186	200	193
		E25 E2[illegible]	187	193	196	193	193	188	194	193	197	193	195	196	197	196	193	192	192	194	189	197	196	185	200	193
	average		186	193	196	193	193	188	194	192	197	193	195	196	197	196	193	193	192	194	189	196	196	185	199	193
	ave. Dev. (%)		0.1	0.1	0.0	0.0	0.1	0.0	0.1	0.1	0.0	0.1	0.1	0.1	0.1	0.1	0.1	0.2	0.1	0.0	0.1	0.1	0.1	0.0	0.1	0.1

Conclusion: Sanmina Phase 2 boards~ for nominally identical values in several locations an a given board, the low value embedded capacitors varied approximately 7% and the high value embedded capacitors varied approximately 2%. Buried capacitors did not

TYPICAL DATA ANOTHER TERRIBLE EYE CHART

STAY TUNED FOR SUMMARY / CONCLUSION GRAPHICS

TYPICAL DATA ANOTHER TERRIBLE EYE CHART

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Resistivity: Embedded Resistance Uniformity within

Board S/N:		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	[illegible]	[illegible]	24	25	ave. of ave. Dev. (%)
nominal value: 100 ohms	R 22	70	65	79	82	62	79	81	63	71	110	81	67	62	62	73	121	64	81	59	43	[illegible]	[illegible]	[illegible]	66	86	
	R 31	85	71	82	81	84	66	84	68	91	86	69	75	81	76	70.3	88	73	82	86	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	95	
average		*77.5*	*68.0*	*80.5*	*81.5*	*73.0*	*72.5*	*82.5*	*65.5*	*81.0*	*98.0*	*75.0*	*71.0*	*71.5*	*69.0*	*71.7*	*104.5*	*68.5*	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	*90.5*	
ave. Dev. (%)		*9.7*	*4.4*	*1.9*	*0.6*	*15.1*	*9.0*	*1.8*	*3.8*	*12.3*	*12.2*	*8.0*	*5.6*	*13.3*	*10.1*	*1.9*	*15.8*	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	*5.0*	*8.9*
nominal value: 150 ohms	R 23	212	123	209	142	186	199	121	192	167	187	130	148	164	124	167	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	131	
	R 32	179	149	170	160	158	141	164	168	178	165	145	158	171	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	186	
average		*196*	*136*	*190*	*151*	*172*	*170*	*143*	*180*	*173*	*176*	*138*	*153*	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	
ave. Dev.		*8.4*	*9.6*	*10.3*	*6.0*	*8.1*	*17.1*	*15.1*	*6.7*	*3.2*	*6.3*	*5.5*	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	*9.6*
nominal value: 500 ohms	R 25	461	478	498	460	468	430	600	463	471	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	
	R 35	393	392	413	397	381	369	513	374	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	409	386	
	R 28	478	450	436	470	463	435	514	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	463	463	461	
	R 38	467	459	476	474	454	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	482	462	471	460	
	R 24	601	616	602	582	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	648	471	607	616	655	
	R 33	452	503	432	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	446	372	445	391	411	479	510	
average		*475*	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	*556*	*476*	*441*	*491*	*450*	*466*	*489*	*489*	
ave. Dev.		[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	*12.7*	*5.6*	*8.3*	*9.5*	*10.6*	*7.7*	*10.1*	*9.0*	*12.8*	*11.1*
nominal value: 533 ohms	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	796	781	727	735	788	722	736	777	733	714	770	
	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	557	564	568	549	548	542	520	534	569	532	523	555	
average		[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	*621*	*664*	*680*	*675*	*638*	*642*	*665*	*621*	*635*	*673*	*633*	*619*	*663*	
ave. Dev.		[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	*16.4*	*16.1*	*15.9*	*16.1*	*17.1*	*15.8*	*13.9*	*14.6*	*18.5*	*16.3*	*15.9*	*15.5*	*15.9*	*15.4*	*16.2*	*15.9*
nominal value: 1000 ohms	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	970	967	914	931	988	988	985	1271	1186	1000	942	1008	987	952	960	945	
	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	915	940	937	874	883	935	913	915	1141	1088	868	886	945	938	869	945	906	
	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	1500	1344	1462	1400	1375	1355	1369	1452	1480	1483	1500	1461	1484	1357	1418	1478	1367	1383	1437	
	R 39	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	1079	1210	1069	1161	1100	1088	1093	1084	1157	1159	1159	1202	1192	1139	1069	1121	1173	1089	1103	1141	
average		[illegible]	[illegible]	[illegible]	[illegible]	*1073*	*1033*	*1244*	*1049*	*911*	*1103*	*1092*	*1059*	*1067*	*1133*	*1135*	*1136*	*1279*	*1232*	*1123*	*1064*	*1123*	*1144*	*1069*	*1098*	*1107*	
ave. Dev.		[illegible]	[illegible]	*13.2*	*24.6*	*14.6*	*16.4*	*10.3*	*15.1*	*44.2*	*13.5*	*13.0*	*15.6*	*15.0*	*15.1*	*16.3*	*16.3*	*8.7*	*9.3*	*16.8*	*14.1*	*13.1*	*15.9*	*14.8*	*13.2*	*16.4*	*15.8*
nominal value: 1500 ohms	R 21	[illegible]	1517	1900	1740	1426	1527	1558	1328	1909	1650	1615	1481	1876	1271	1872	2145	1274	1780	1963	1419	1598	1090	1650	1344	1783	
	R 34	1289	1669	1459	1467	1291	1402	1148	1274	1377	1510	1611	1510	1318	1325	1460	1832	1436	1742	1399	1054	1493	1266	1352	1506	1770	
average		*1594*	*1593*	*1680*	*1604*	*1359*	*1465*	*1353*	*1301*	*1643*	*1580*	*1613*	*1496*	*1597*	*1298*	*1666*	*1989*	*1355*	*1761*	*1681*	*1237*	*1546*	*1178*	*1501*	*1425*	*1777*	
ave. Dev.		*19.1*	*4.8*	*13.1*	*8.5*	*5.0*	*4.3*	*15.2*	*2.1*	*16.2*	*4.4*	*0.1*	*1.0*	*17.5*	*2.1*	*12.4*	*7.9*	*6.0*	*1.1*	*16.8*	*14.8*	*3.4*	*7.5*	*9.9*	*5.7*	*0.4*	*8.0*
nominal value: 2000 ohms	R 27	2911	2723	7861	2869	2803	2603	3161	2694	2937	2828	2814	2754	2752	2911	2962	2899	3316	3193	2958	2670	2837	2909	2881	2742	2853	
	R 37	2151	2020	2138	2213	2039	2005	2561	2040	2207	2130	2117	2087	2087	2192	2226	2178	2590	2535	2125	2002	2187	2231	2090	2146	2174	
average		*2531*	*2372*	*5000*	*2541*	*2421*	*2304*	*2861*	*2367*	*2572*	*2479*	*2466*	*2421*	*2420*	*2552*	*2594*	*2539*	*2953*	*2864*	*2542*	*2336*	*2512*	*2570*	*2486*	*2444*	*2514*	
ave. Dev.		*15.0*	*14.8*	*57.2*	*12.9*	*15.8*	*13.0*	*10.5*	*13.8*	*14.2*	*14.1*	*14.1*	*13.8*	*13.7*	*14.1*	*14.2*	*14.2*	*12.3*	*11.5*	*16.4*	*14.3*	*12.9*	*13.2*	*15.9*	*12.2*	*13.5*	*15.5*

Conclusion: Sanmina Phase 2 boards~ for nominally identical values in several locations an a given board, the low value resistors vaired approximately 10% and the high value resistors varied approximately 14%

Capacitance Uniformity within Board

		Board S/N:	1	2	3	4	5	6	7	8	9	11	12	14	15	16	17	18	19	20	21	22	23	25	28	ave. of ave. Dev.
EMBEDDED CAPACITORS	nominal value: 4.9 pF	C 9	6.2	5.2	5.4	6.1	5.2	6.3	5.2	5.0	6.2	6.5	5.0	6.1	6.0	4.9	6.2	5.4	6.4	6.3	6.2	4.9	[illegible]	[illegible]	6.5	
		C 10	6.9	6.2	6.2	7.2	6.1	6.8	5.9	5.6	6.9	7.8	5.5	6.8	6.2	5.7	6.6	6.0	6.9	6.9	[illegible]	[illegible]	[illegible]	[illegible]	7.0	
		C 11	4.5	3.7	4.5	5.5	2.5	4.5	4.4	3.6	4.9	4.9	5.1	5.3	5.0	3.9	3.9	4.6	5.0	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	4.3	
		C 12	5.3	4.3	5.0	5.6	4.7	5.2	5.0	4.5	5.6	5.5	5.7	5.7	4.9	4.2	4.5	5.2	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	5.0	
	average		*4.9*	*4.0*	*4.8*	*5.6*	*3.6*	*4.9*	*4.7*	*4.1*	*5.3*	*5.2*	*5.4*	*5.5*	*5.0*	*4.1*	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	*4.7*	
	ave. Dev. (%)		*8.2*	*7.5*	*5.3*	*0.9*	*30.6*	*7.2*	*6.4*	*11.1*	*6.7*	*5.8*	*5.6*	*3.6*	*1.0*	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	*6.9*
	nominal value: 42.2 pF	C 13	63.7	60.1	60.6	61.6	59.6	51.8	59.2	57.6	64.2	63.9	57.7	64.0	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	
		C 14	57.8	58.6	59.4	59.9	57.5	50.7	57.0	56.1	61.3	63.8	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	
		C 15	70.1	61.5	62.2	61.3	60.4	51.5	58.8	59.0	68.9	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	
		C 16	66.9	64.9	62.5	60.4	58.2	51.8	60.2	59.2	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	63.7	
	average		*64.6*	*61.3*	*61.2*	*60.8*	*58.9*	*51.5*	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	*51.6*	*63.2*	
	ave. Dev. (%)		*6.0*	*3.1*	*1.9*	*1.1*	*1.8*	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	*3.9*	*1.4*	*1.1*	*2.5*
	nominal value: 66.8 pF	C 17	106	100	99	100	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	100	97	103	88	103	
		C 18	107	105	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	99	103	100	106	90	107	
		C 19	107	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	108	97	99	99	109	87	98	
		C 20	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	92	93	110	95	100	96	101	87	98	
	average		[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	*94*	*95*	*95*	*106*	*97*	*101*	*98*	*105*	*88*	*101*	
	ave. Dev. (%)		[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	*1.3*	*0.8*	*2.4*	*1.8*	*2.6*	*1.7*	*1.0*	*1.4*	*2.3*	*1.2*	*3.4*	*1.8*
BURIED CAPACITORS	nominal value: 50 nF	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	51.5	51.2	51.2	51.1	51.3	51.2	50.9	51.4	51.2	51.1	51.1	48.9	51.2	
		[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	51.0	51.5	51.2	51.2	51.1	51.3	51.2	50.8	51.4	51.2	51.1	51.1	48.9	51.2	
		[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	51.1	51.0	51.5	51.2	51.2	51.1	51.3	51.2	50.9	51.4	51.2	51.1	51.1	48.9	51.2	
		[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	51.1	51.2	51.1	51.0	51.5	51.2	51.2	51.1	51.3	51.2	50.8	51.4	51.2	51.1	51.1	48.9	51.2	
		[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	51.1	51.1	51.2	51.1	51.0	51.5	51.2	51.2	51.1	51.3	51.2	50.9	51.4	51.2	51.1	51.1	48.9	51.2	
		[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	51.2	51.1	51.1	51.2	51.1	51.0	51.5	51.2	51.2	51.1	51.3	51.4	50.9	51.4	51.2	51.1	51.1	48.9	51.2	
	average		[illegible]	[illegible]	*51.1*	*51.3*	*51.2*	*51.1*	*51.1*	*51.2*	*51.1*	*51.0*	*51.5*	*51.2*	*51.2*	*51.1*	*51.3*	*51.2*	*50.8*	*51.4*	*51.2*	*51.1*	*51.1*	*48.9*	*51.2*	
	ave. Dev. (%)		[illegible]	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*0.1*	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*
	nominal value: 150 nF	E3 E4	186	193	196	193	192	188	194	192	197	193	195	195	197	195	193	193	192	194	189	196	195	185	199	
		E7 E8	186	193	196	193	193	188	194	192	197	193	195	196	197	196	193	193	192	194	189	196	195	185	199	
		E13 E14	186	193	196	193	193	188	194	193	197	193	195	196	197	196	193	194	192	194	189	197	196	186	200	
		E15 E16	186	193	196	193	193	188	194	193	197	193	195	196	197	196	193	194	192	194	189	197	196	186	200	
		E21 E22	187	193	196	193	193	188	194	193	197	193	195	196	197	196	193	194	192	194	189	197	196	186	200	
		E25 E26	187	193	196	193	193	188	194	193	197	193	195	196	197	196	193	192	192	194	189	197	196	185	200	
	average		*186*	*193*	*196*	*193*	*193*	*188*	*194*	*192*	*197*	*193*	*195*	*196*	*197*	*196*	*193*	*193*	*192*	*194*	*189*	*196*	*196*	*185*	*199*	
	ave. Dev. (%)		*0.1*	*0.1*	*0.0*	*0.0*	*0.1*	*0.0*	*0.1*	*0.1*	*0.0*	*0.1*	*0.1*	*0.1*	*0.1*	*0.1*	*0.1*	*0.2*	*0.1*	*0.0*	*0.1*	*0.1*	*0.1*	*0.0*	*0.1*	*0.1*

TYPICAL DATA ANOTHER TERRIBLE EYE CHART

STAY TUNED FOR SUMMARY / CONCLUSION GRAPHICS

TOM CLIFFORD

Capacitance Uniformity within Coupon

TYPICAL DATA ANOTHER TERRIBLE EYE CHART

STAY TUNED FOR SUMMARY / CONCLUSION GRAPHICS

Right Side Coupons

Coupon SN:		1	3	4	5	6	7	8	9	11	12	15	16	17	18	20	21	22	[illegible]	25	28	ave. of ave. Dev. (%)
nominal value: 4.9 pF	C 9	2.7	4.9	1.5	1.7	2.2	3.9	3	2.7	2.7	3.7	2.5	2.4	2.7	2.7	3.8	2.4	[illegible]	[illegible]	3	2.4	
	C 10	1.6	1.2	3.1	2.2	1.8	4.5	2.3	2.3	2.3	2.9	2	2	2.4	2.2	2	[illegible]	[illegible]	[illegible]	[illegible]	1.9	
	average	*2.2*	*3.1*	*2.3*	*2.0*	*2.0*	*4.2*	*2.7*	*2.5*	*2.5*	*3.3*	*2.3*	*2.2*	*2.6*	*2.5*	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	*2.2*	
	ave. Dev. (%)	*25.6*	*60.7*	*34.8*	*12.8*	*10.0*	*7.1*	*13.2*	*8.0*	*8.0*	*12.1*	*11.1*	*9.1*	*5.9*	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	*11.6*	*14.6*
nominal value: 42.2 pF	C 13	46.2	47.9	50.5	45.1	39.6	47.1	41.2	45.8	45.5	44.8	42.8	38.2	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	41	
	C 14	46.1	50.4	46.8	48.2	41.3	46.9	43.2	47	47.3	47.5	45	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	42.6	
	average	*46.2*	*49.2*	*48.7*	*46.7*	*40.5*	*47.0*	*42.2*	*46.4*	*46.4*	*46.2*	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	
	ave. Dev. (%)	*0.1*	*2.5*	*3.8*	*3.3*	*2.1*	*0.2*	*2.4*	*1.3*	*1.9*	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	*2.5*
nominal value: 66.8 pF	C17	83.8	86.8	78.6	81.6	75.8	73.9	75.5	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	
	C18	83.5	87.1	79.2	80.4	73	80.7	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	74	
	average	*83.7*	*87.0*	*78.9*	*81.0*	*74.4*	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	*61.8*	*74.7*	
	ave. Dev. (%)	*0.2*	*0.2*	*0.4*	*0.7*	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	*1.6*	*4.5*	*0.9*	*1.2*

Coupon SN:		[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	23	24	25	27	28	29	ave. of ave. Dev. (%)
nominal value: 4.9 pF	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	4.9	4.1	4.5	4.7	4.3	4.4	2.4	
	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	5.5	5.0	4.8	5.4	4.9	5.2	5.5	4.5	
	average	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	*4.9*	*4.9*	*5.0*	*4.5*	*5.0*	*4.8*	*4.8*	*5.0*	*3.5*	
	ave. Dev. (%)	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	*8.1*	*2.0*	*12.2*	*1.0*	*7.9*	*9.1*	*2.1*	*9.5*	*11.1*	*30.4*	*7.6*
nominal value: 42.2 pF	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	47.9	52.7	49.1	51.5	50.0	48.2	49.4	42.2	51.5	53.2	45.4	
	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	48.1	47.5	53.1	48.5	49.1	49.9	47.6	48.4	39.8	51.8	52.6	45.6	
	average	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	*51.0*	*47.8*	*47.7*	*52.9*	*48.8*	*50.3*	*50.0*	*47.9*	*48.9*	*41.0*	*51.7*	*52.9*	*45.5*	
	ave. Dev. (%)	[illegible]	[illegible]	[illegible]	*0.3*	*0.4*	*0.4*	*0.6*	*0.4*	*0.4*	*0.6*	*2.4*	*0.1*	*0.6*	*1.0*	*2.9*	*0.3*	*0.6*	*0.2*	*0.8*
nominal value: 66.8 pF	[illegible]	[illegible]	[illegible]	82.1	74.5	75.4	77.2	78.6	73.8	80.6	72.5	81.1	77.6	76.6	75.7	66.2	78.3	84.7	71.3	
	[illegible]	[illegible]	85.1	85.7	76.2	81.0	83.1	83.7	78.8	80.5	82.6	85.3	84.6	83.2	80.6	66.5	83.1	84.0	76.9	
	average	*85.7*	*76.6*	*83.9*	*75.4*	*78.2*	*80.2*	*81.2*	*76.3*	*80.6*	*77.6*	*83.2*	*81.1*	*79.9*	*78.2*	*66.4*	*80.7*	*84.4*	*74.1*	
	ave. Dev. (%)	*3.3*	*11.2*	*2.1*	*1.1*	*3.6*	*3.7*	*3.1*	*3.3*	*0.1*	*6.5*	*2.5*	*4.3*	*4.1*	*3.1*	*0.2*	*3.0*	*0.4*	*3.8*	*3.3*

Overall average of average deviation			
	nominal value: 4.9 pF	C 9 / C 10	11.1
	nominal value:42.2 pF	C 13 / C 14	1.6
	nominal value:66.8 pF	C17 / C18	2.3

Conclusion: Phase 2 coupons~ for nominally identical values in several locations on a given coupon, the low value embedded capacitors varied approximately 1[illegible] and the high value embedded capacitors varied approximately 2%.

TOM CLIFFORD

Resistance Uniformity within Coupon

Right side Coupons

Coupon SN:		1	3	4	5	6	7	8	9	11	12	15	16	17	18	20	21	22	24	25	28	ave. of ave. Dev.
nominal value: 500 ohms	R 24	580	566	607	408	564	557	583	456	571	432	544	507	586	514	584	486	552	551	[illegible]	577	
	R 25	593	620	572	575	536	766	512	582	622	550	575	591	737	749	549	619	57	[illegible]	[illegible]	563	
	R 28	461	448	450	438	427	583	433	452	454	432	462	454	486	477	441	[illegible]	[illegible]	[illegible]	[illegible]	446	
	average	*545*	*545*	*543*	*474*	*509*	*635*	*509*	*497*	*549*	*471*	*527*	*517*	*603*	*580*	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	*28*	
	ave. Dev. (%)	*10.3*	*11.8*	*11.4*	*14.2*	*10.8*	*13.7*	*10.0*	*11.4*	*11.5*	*11.1*	*8.2*	*9.5*	*14*	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	*4*	*11.3*
nominal value: 1000	R 26	1014	1022	993	956	934	2048	973	1006	1012	945	1008	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	
	R 29	1213	1120	1198	1095	1124	1347	1091	1162	1120	111	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	
	average	*1113*	*1071*	*1095*	*1026*	*1029*	*1697*	*1032*	*1084*	*10*	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	
	ave. Dev. (%)	*8.9*	*4.6*	*9.4*	*6.8*	*9.2*	*20.7*	*5.7*	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	*.2*	*9.2*	*7.2*

Coupon SN:		1	2	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	26	27	28	29	ave. of ave. Dev.
nominal value: 500 ohms	R 24	580	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	494	556	451	457	564	
	R 25	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	581	551	581	639	545	551	569	
	R 28	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	601	527	525	528	545	515	505	513	
	average	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	*646*	*670*	*546*	*524*	*534*	*580*	*504*	*504*	*548*	
	ave. Dev. (%)	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	*4.6*	*3.7*	*22.4*	*18.1*	*4.2*	*3.6*	*5.8*	*6.8*	*7.0*	*6.2*	*4.4*	*6.8*
nominal value: 1000	R 26	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	1464	1471	1417	2530	2344	1416	1389	1546	1234	1377	1331	1408	
	R 29	[illegible]	[illegible]	[illegible]	[illegible]	208	1189	1211	1200	1190	1241	1272	1273	1253	1229	1046	1200	1246	1245	
	average	*13*	[illegible]	[illegible]	*1293*	*1291*	*1236*	*1338*	*1335*	*1304*	*1885*	*1808*	*1344*	*1321*	*1387*	*1140*	*1289*	*1289*	*1326*	
	ave. Dev. (%)	*2.*	[illegible]	*11.0*	*4.2*	*6.4*	*3.8*	*9.5*	*10.1*	*8.7*	*34.2*	*29.6*	*5.3*	*5.1*	*11.4*	*8.3*	*6.9*	*3.3*	*6.1*	*9.8*

Overall average of average deviation			
	nominal value: 500 ohms	R 24, R 25, R 28	9.0
	nominal value: 1000 ohms	R 26, R 29	8.5

Conclusion: Phase 2 coupons~ for nominally identical values in several locations on a given coupon, the low value embedded resistors varied approximately 9% a high value embedded resistors varied approximately 8.5%

TYPICAL DATA ANOTHER TERRIBLE EYE CHART

STAY TUNED FOR SUMMARY / CONCLUSION GRAPHICS

EMBEDDED PASSIVES, DATA SUMMARY . June 2006. "Dupont HK-04 Capacitor" 5"X 5"X.058 " board													
			CRANE'S MEASUREMENTS				L-M MEASUREMENTS						
probe-point #	Location … Layers	Feature Dims (in)	Expected (pF)	Measured (pF)	Delta vs Expected %	size of element L X W	CRANES Measured (Ohms)	Delta vs CRANE, %	Delta v[illegible]				ave dev, sisters, %
1	2 and 3.	.32x.01	2.9	4.9	69.0	32	5.9						11.00
2	2 and 3.	.32x.04	11.7	14.7	25.6	128							21.00
3	2 and 3.	.32x.08	23.4	23.5	0.4								
4	2 and 3.	.32x.16	46.7	44.7									3.00
5	2 and 3.	.16x.02	2.9	4.7								.16x.04	5.90
6	2 and 3.	.16x.04	6.4									.16x.08	11.30
7	2 and 3.	.16x.08									3.70	.16x.16	22.00
8	2 and 3.									*	2.05	.16x.32	42.90
9									-8.1	*	0.85		
10								-6.4	-9.1			average average	19.89
11							21	-11.0	-10.3				
12							3	-33.3	3.4				
13						128	11	-12.0	-6.0				
14					0.2	**512**	42	-10.3	-10.1				
15				7.3	25.9	64	5.3	-27.4	-8.6				
16			11.7	13	11.1	128	10.9	-16.2	-6.8				
17			23.4	23.8	1.7	256	22	-7.6	-6.0				
18		.16x.32	46.7	47.2	1.1	512	43	-8.9	-7.9				
19	6 and 7.	.32x.04	11.7	13.1	12.0	**128**	10	-23.7	-14.5				
20	6 and 7.	.32x.08	23.4	23.3	-0.4	256	21	-9.9	-10.3				
21	6 and 7.	.32x.16	46.7	46.7	0.0	512	42	-10.1	-10.1				
22	6 and 7.	.16x.04	5.8	7.5	29.3	64	6	-20.0	3.4				
23	6 and 7.	.16x.08	11.7	13.3	13.7	128	10	-24.8	-14.5				
24	6 and 7.	.16x.16	23.4	26.3	12.4	256	21	-20.2	-10.3				
25	6 and 7.	.16x.32	46.7	47.5	1.7	512	43	-9.5	-7.9				

TYPICAL DATA ANOTHER TERRIBLE EYE CHART

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Data Summary …. Crane NiCr Embedded Resistor Submittal 8-17-06

probe-point #	Length (inch)	Width (inch)	Expected (Ohms)	size of element, L X W, sq mils	Crane Measured (Ohms)	Crane difference, from expected	LM Measured (Ohms)	LM difference, from expected	LM differen… fro…		ave dev, …isters, %
1	0.32	0.01	1600.0	3200.0	1660.0	4%	1662	[illegible]	[illegible]	[illegible]	[illegible]
2	0.32	0.32	50.0	102400.0	49.6	-1%	48.55	[illegible]	[illegible]	[illegible]	[illegible]
3	0.32	0.02	800.0	6400.0	823.0	3%	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
4	0.32	0.08	200.0	38000.0	194.4	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
5	0.32	0.16	100.0	42000.0	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
6	0.32	0.01	1600.0	3200.0	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
7	0.32	0.32	50.0	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	ave ave	2%
13	0.32	0.01	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]		
14	0.32	0.32	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	-2%		
15	0.32	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	-2%	0%		
16	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	5%	-1%		
17	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	98.7	-1%	-1%		
23	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	-3%	1559.4	-3%	0%		
24	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	-2%	48.1	-4%	-2%		
25	[illegible]	[illegible]	[illegible]	[illegible]	50.3	1%	49.6	-1%	-1%		
26	[illegible]	[illegible]	[illegible]	2500.0	51.8	4%	51	2%	-2%		
27	[illegible]	[illegible]	[illegible]	2500.0	50.3	1%	49.5	-1%	-2%		
28	[illegible]	[illegible]	50.0	2500.0	51.1	2%	50.1	0%	-2%		
29	0.05	0.05	50.0	2500.0	52.1	4%	51	2%	-2%		
30	0.05	0.05	50.0	2500.0	48.6	-3%	47.6	-5%	-2%		
31	0.05	0.05	50.0	2500.0	51.2	2%	50.5	1%	-1%		
32	0.05	0.05	50.0	2500.0	52.7	5%	52	4%	-1%		
33	0.05	0.05	50.0	2500.0	52.1	4%	51.4	3%	-1%		
34	0.05	0.05	50.0	2500.0	51.4	3%	50.5	1%	-2%		

Material details:

TYPICAL DATA ANOTHER TERRIBLE EYE CHART

STAY TUNED FOR SUMMARY / CONCLUSION GRAPHICS

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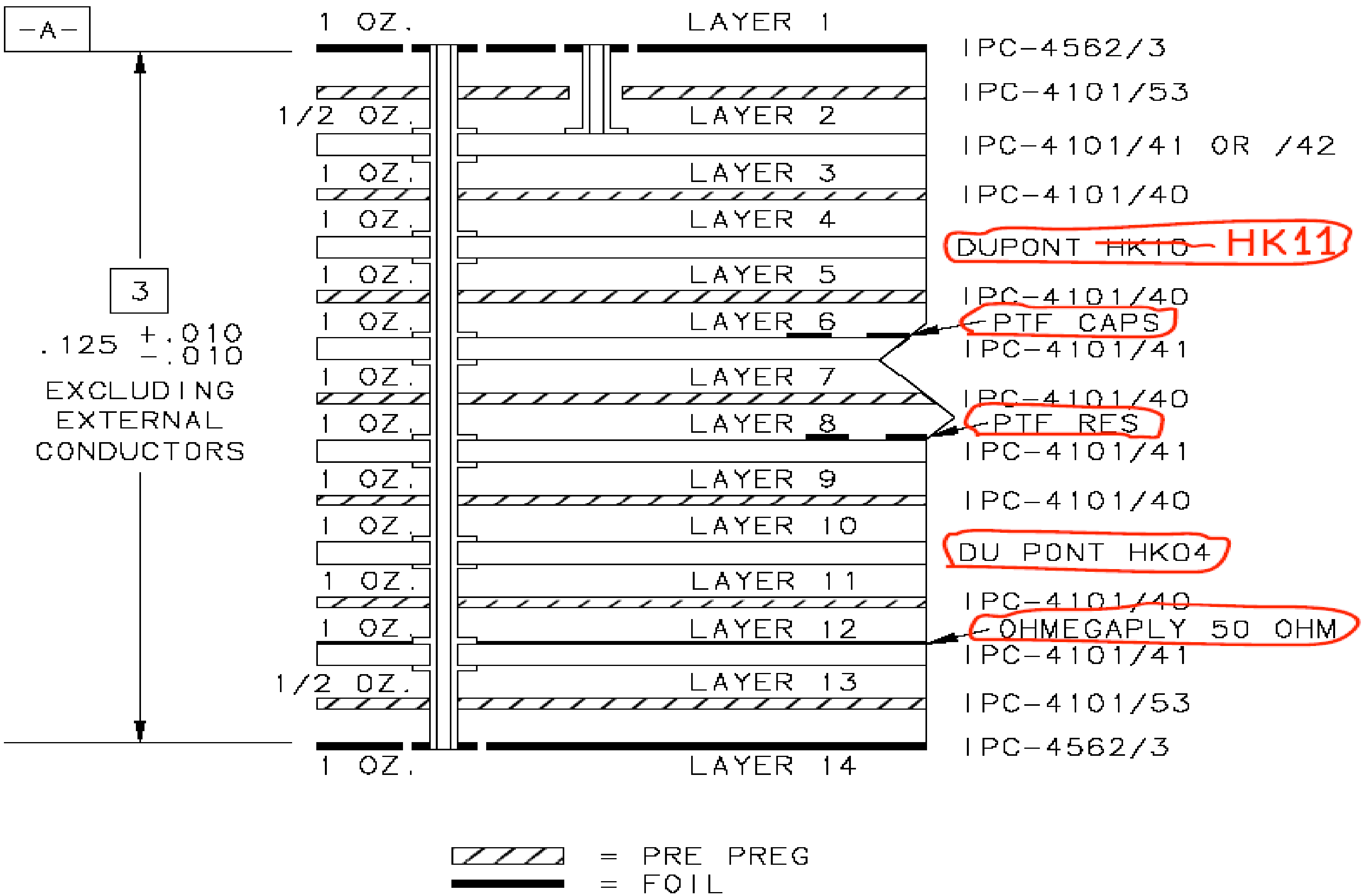
SANMINA's EMBEDDED-PASSIVES TEST VEHICLE CONSTRUCTION



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Two types of planar/distributive capacitor materials:

DuPont HK-04 and HK-11

(http://www2.dupont.com/Interra/en_US/assets/downloads/pdf/Interra_HK04Brochure.pdf)

One kind of discrete capacitor materials:

Asahi CX-16 polymer thick film

(http://www.asahi-kagaku.co.jp/e_polymer.html)

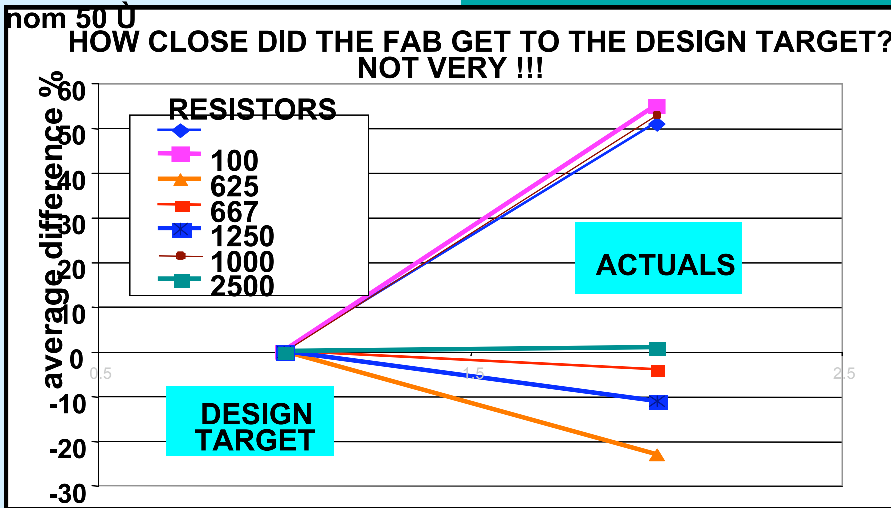
Two kinds of resistor materials:

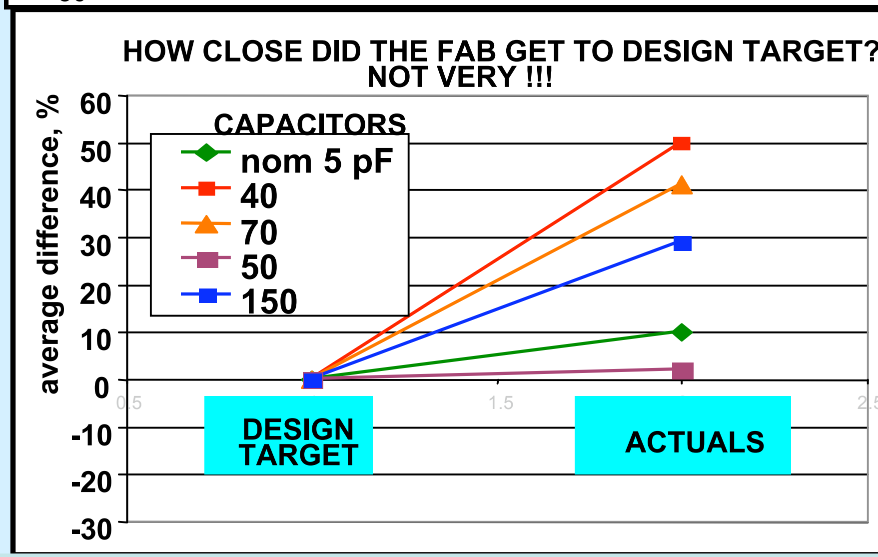
Ohmega-Ply thin film,

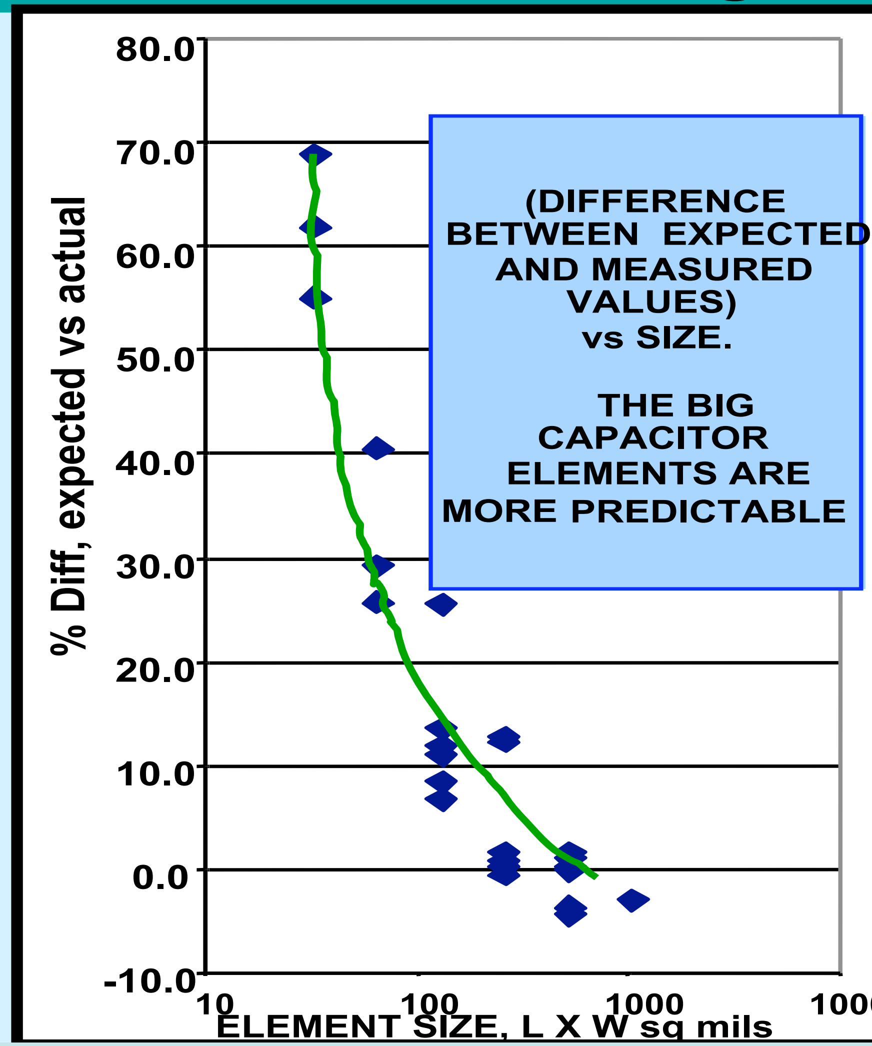
and **Asahi TU-1000-8M polymer thick film**

(http://www.ohmega.com/)

UNIFORMITY actuals vs target

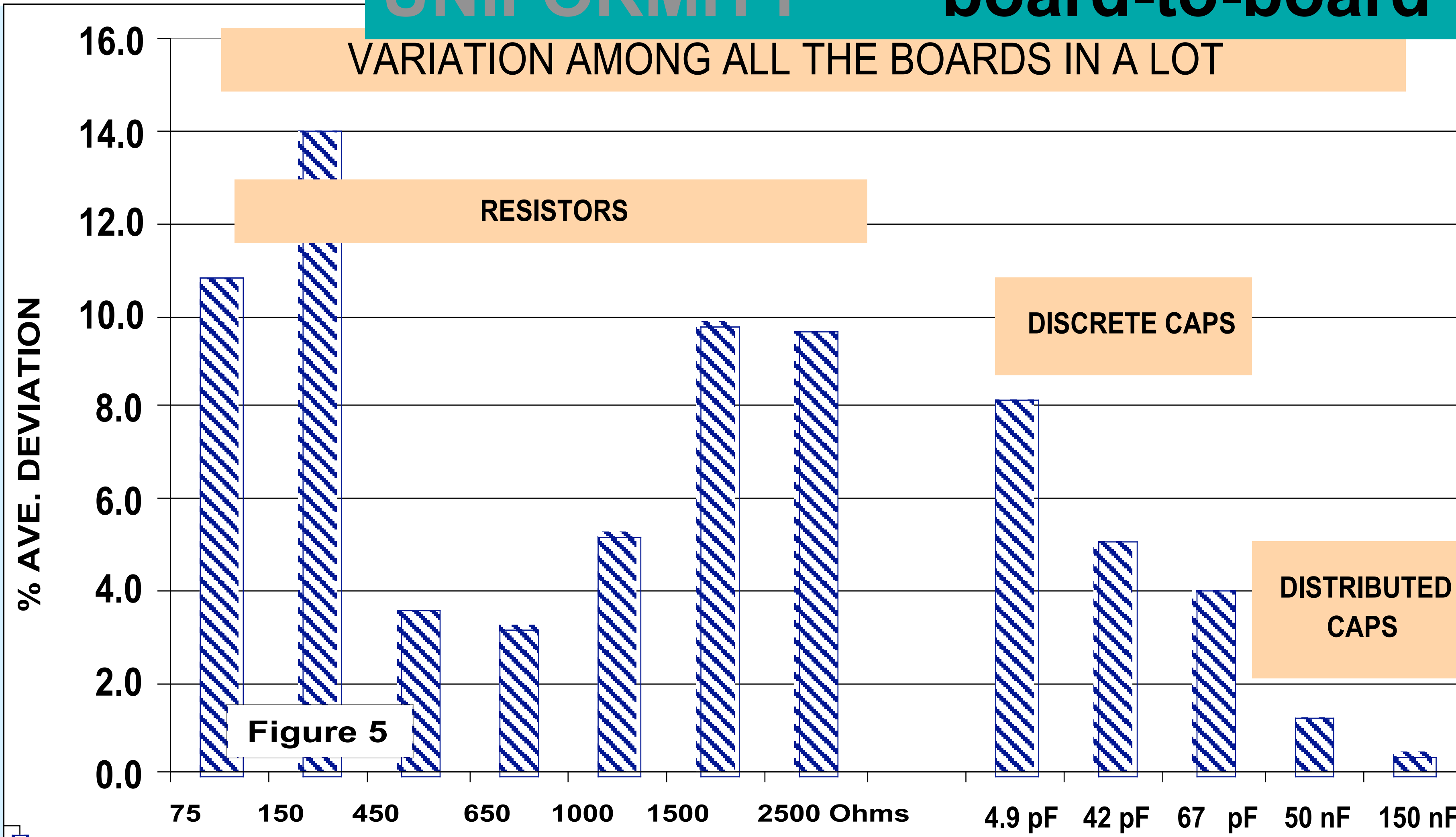






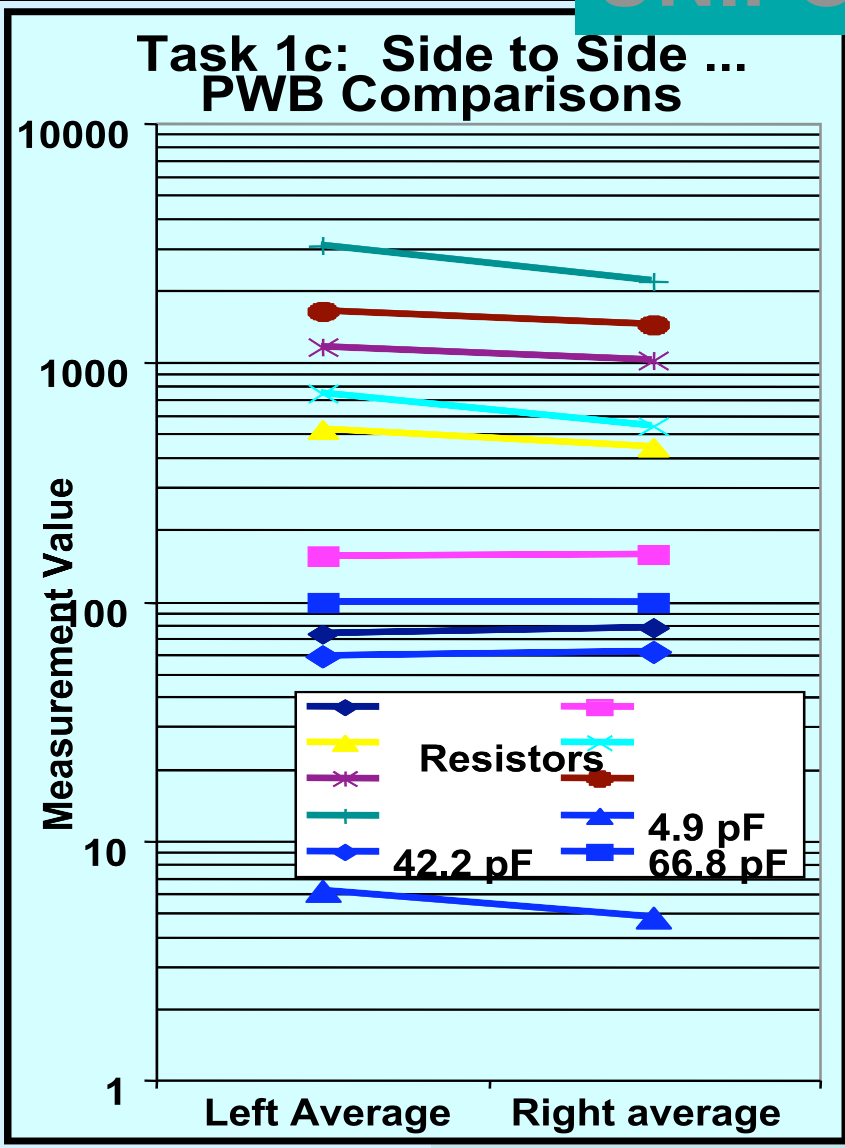
This start-up run was instructive. The supplier missed targets a bit, and their in-process system is still off. Further pilot runs would be necessary, to deliver within 10%. Any EP job must include pilot runs and spec negotiations…

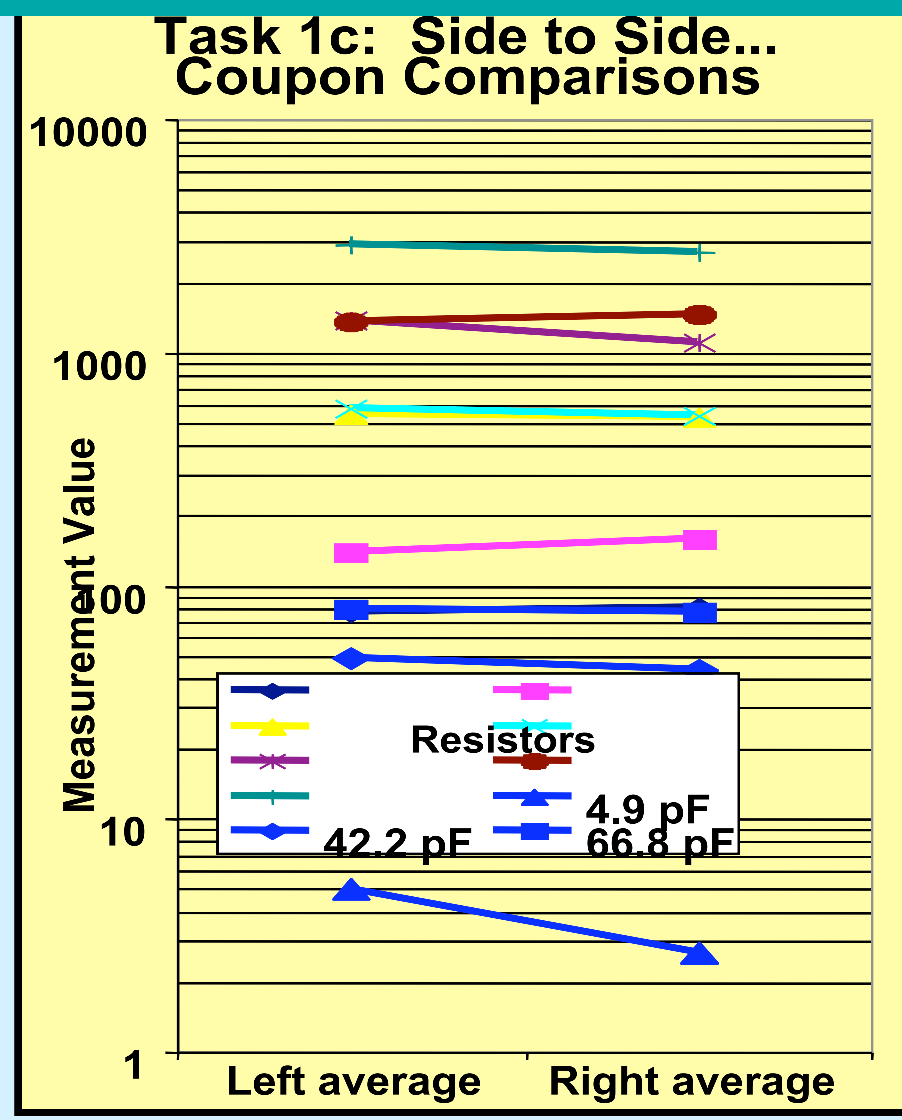
UNIFORMITY board-to-board



In this run, boards varied by up to 10%, comparing averages of all nominal device points. The resistors varied 5-10%, The discrete caps varied ~5% (low values worst). The distributed caps varied ~2%.

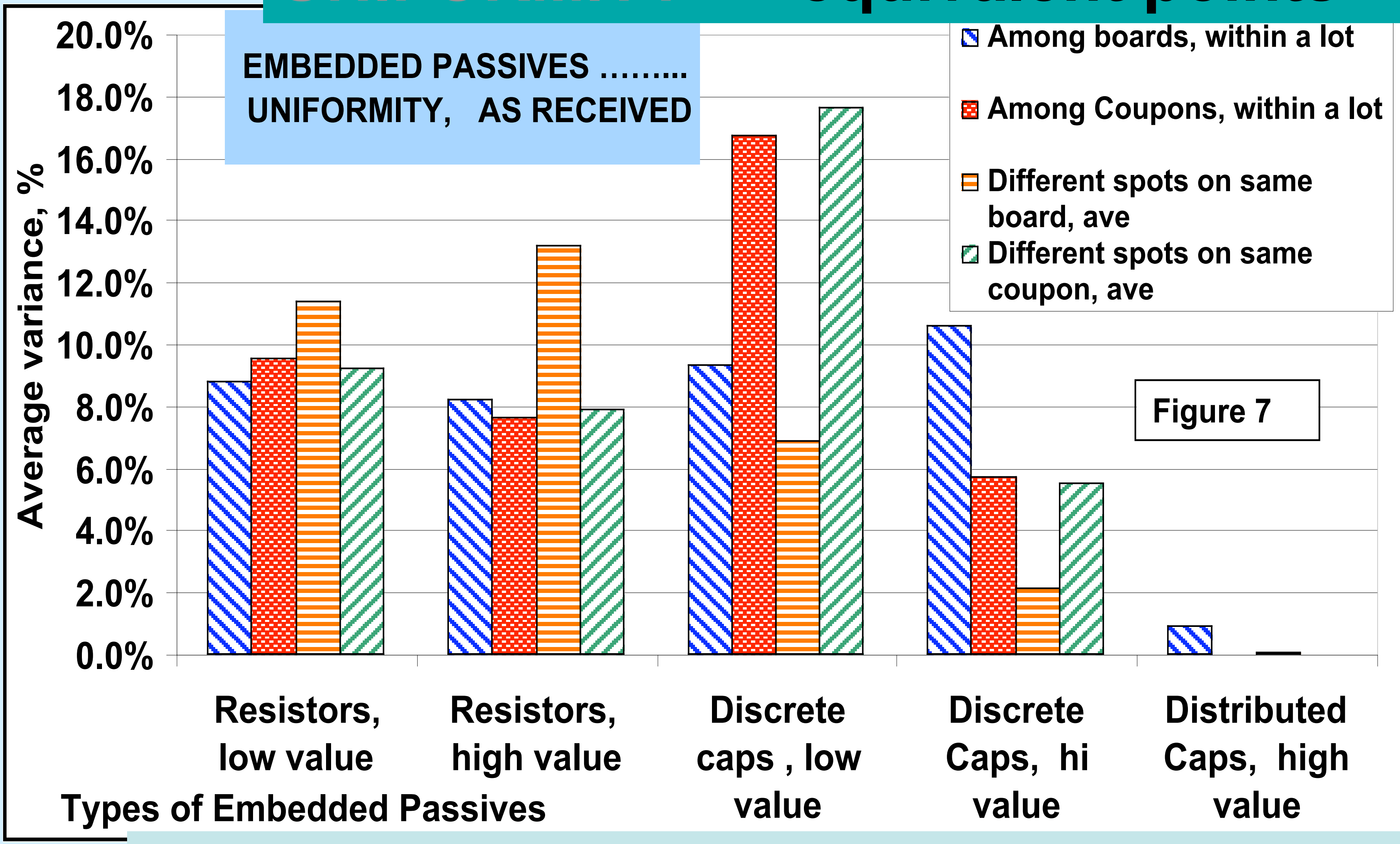
UNIFORMITY side-to-side





In this run, most pairs were within a few percent. In a few, the pairs differed by up to 40%

UNIFORMITY equivalent points



Equivalent resistor and capacitor points on boards and coupons varied by 5% to 10%. The higher value caps varied less.

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UNIFORMITY coupons vs PWBs

Task 1e Compare couponsvs boards: equiv values / points

nominal value	average board value	average coupon value	Coupon, vs board, %
100 Ohm	73	81	10.2
150 Ohm	155	154	-1.2
500 Ohm	524	532	1.6
533 Ohm	744	552	-25.7
1000 Ohm	1166	1174	0.7
1500 Ohm	1625	1434	-11.7
2000 Ohm	3074	2109	-31.4
4.9 pF	6.2	3.6	-41.3
42.2 pF	56.6	46.1	-18.6
66.8 pF	95.1	78.2	-17.8

Conclusion: Difference between coupon and board ranged from 0.7% to -41%. Caps' deviation was greater than resistors'.

CONCLUSIONS: PREDICTABILITY AND UNIFORMITY

1) **Hitting the target will be a challenge, for fab and for the customer, but that should yield to process-control effort.**

2) **Uniformity amongst nominally-identical elements, board-board and within-a-board, will be a concern. Even with experience it will probably not meet all mil-aero specs.**

3) **Elements with larger features and simpler geometries will probably be more predictable and uniform.**

4) **Tolerant designs and enlightened understanding between supplier and customer will be necessary, in addition to dedicated fab process-control work.**

Task 0: Instrumentation

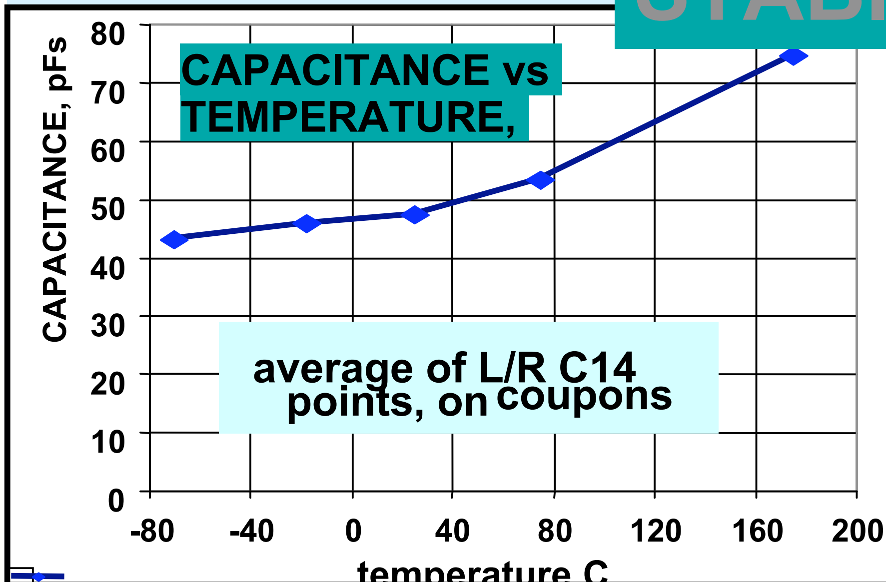
Task 1a: actuals vs target
Task 1b: board-to-board
Task 1c: side to side
Task 1d: equiv points
Task 1e: coupons vs PWBs

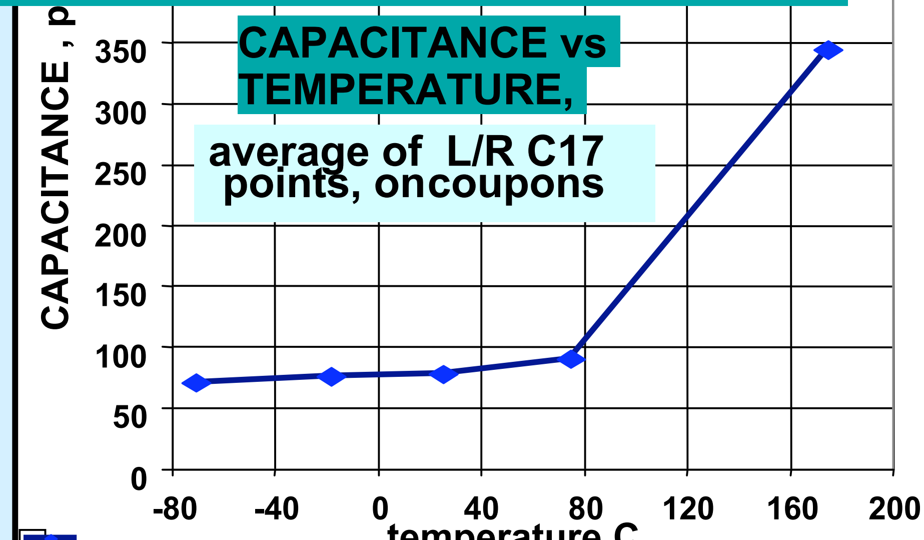
} uniformity

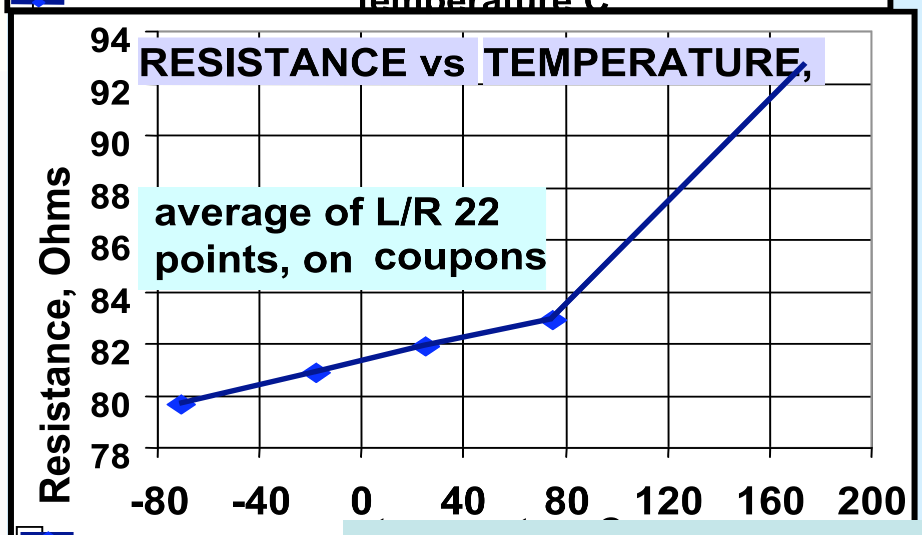
Task 2: hot and cold
Task 3: after 85/85+250
Task 4: thermal shock
Task 5: local over-heat
Task 6: water immersion
Task 7: vibration
Task 8: t-cycle

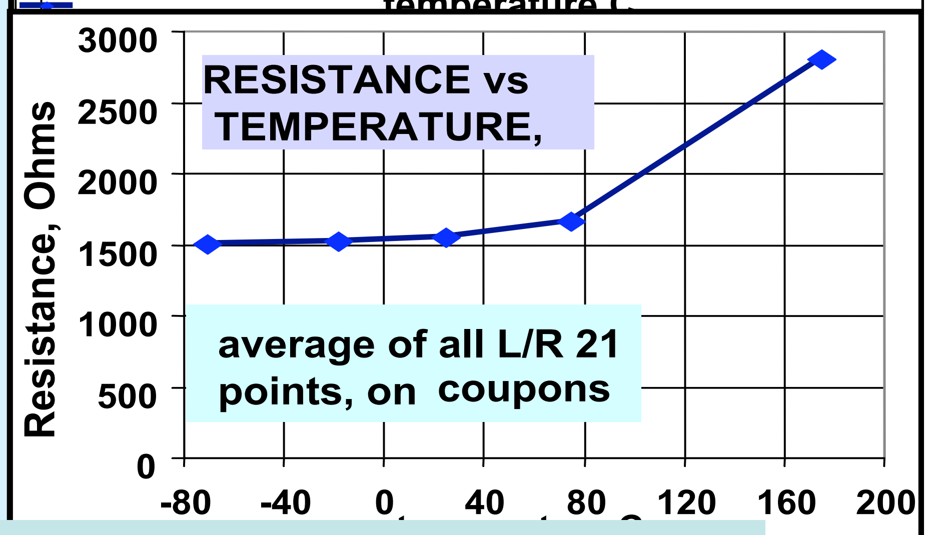
} stability

STABILITY hot and cold



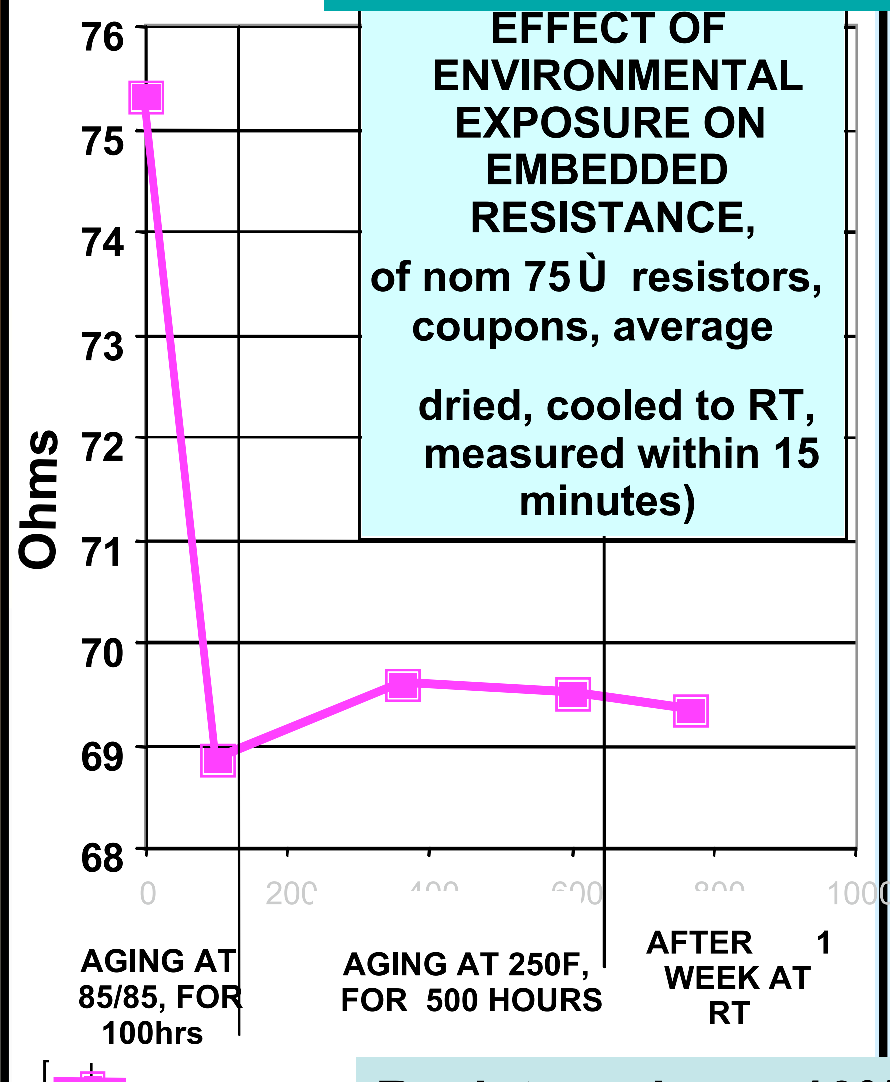


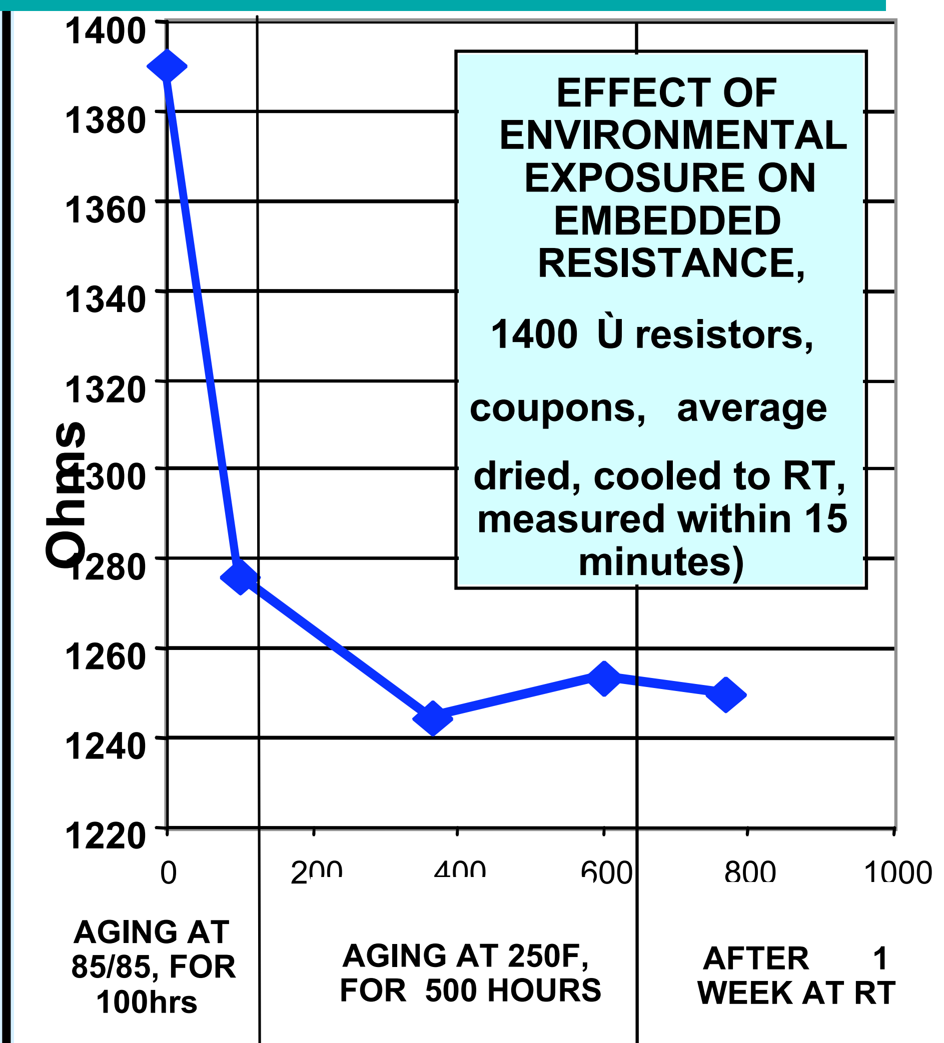




Resistors and capacitors on coupons show increasing values with increases in temperature.

STABILITY after 85/85 + 250





Resistors drop ~10% after 85/85 aging, then are relatively unaffected by extended aging at 250F.

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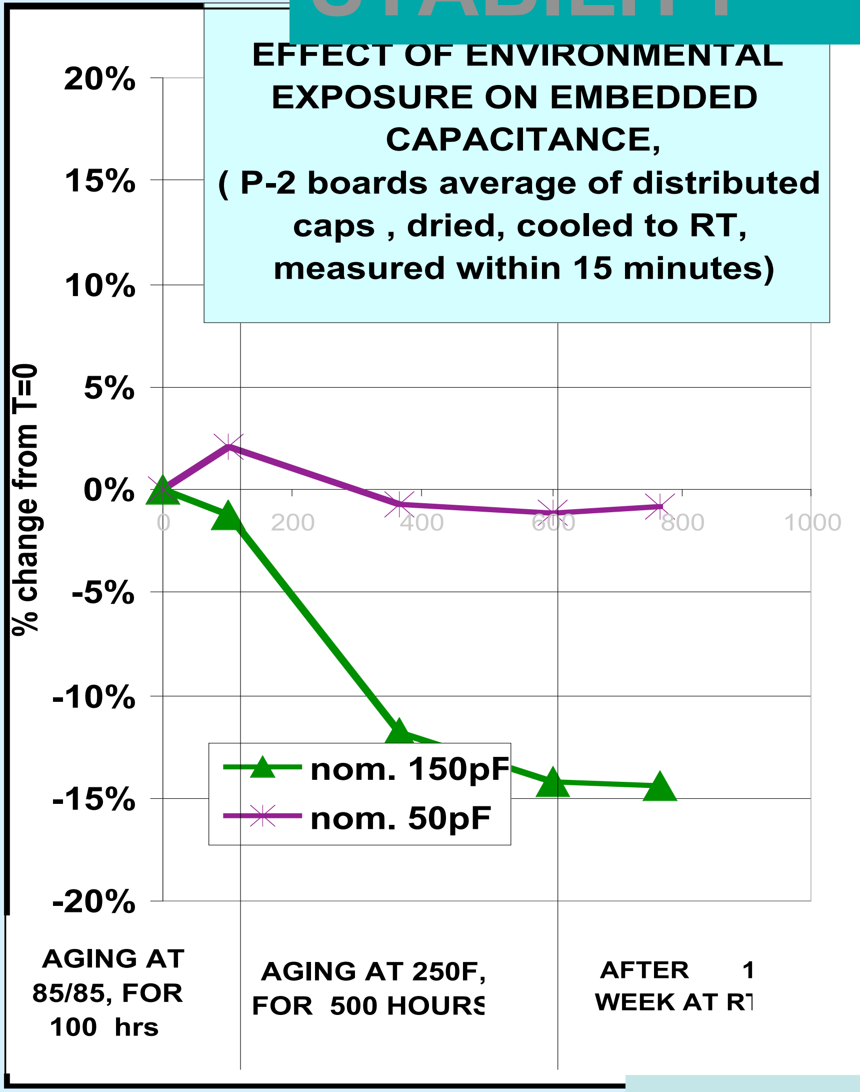
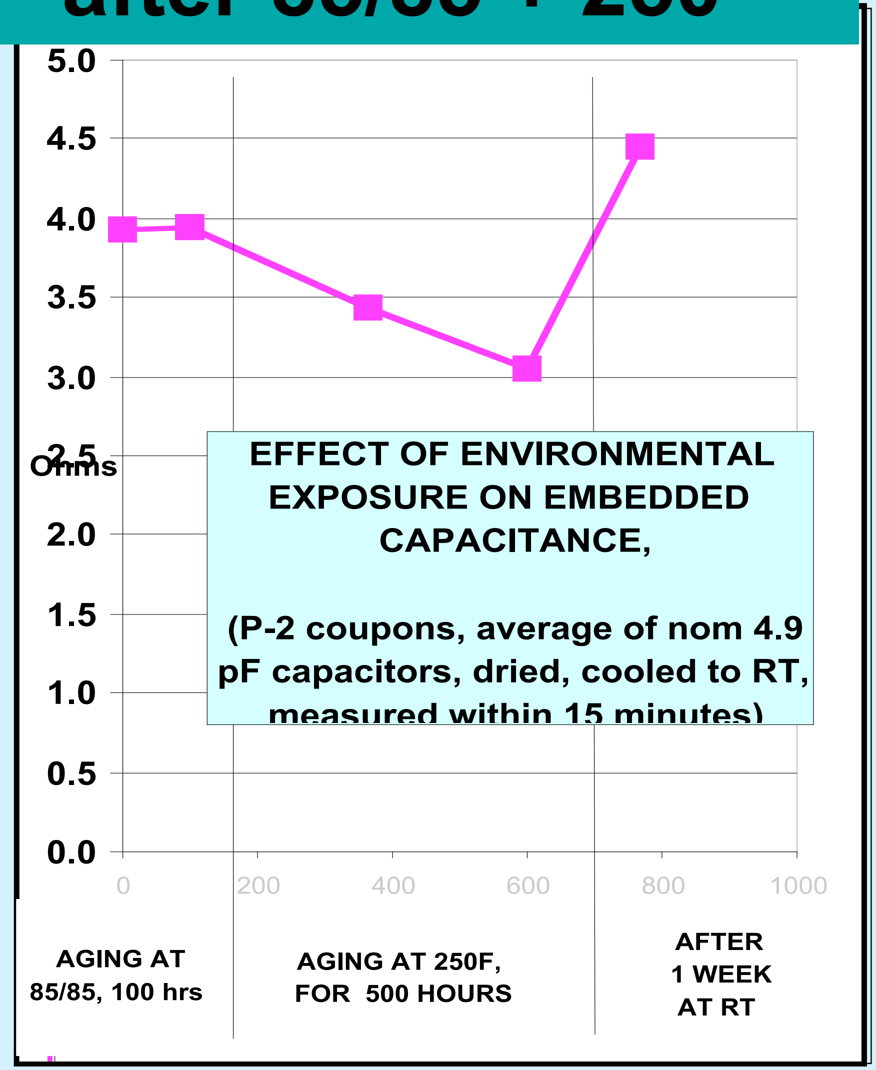
STABILITY after 85/85 + 250





Capacitors appear unaffected by 85/85 aging, then drop ~5% thru extended aging at 250F.

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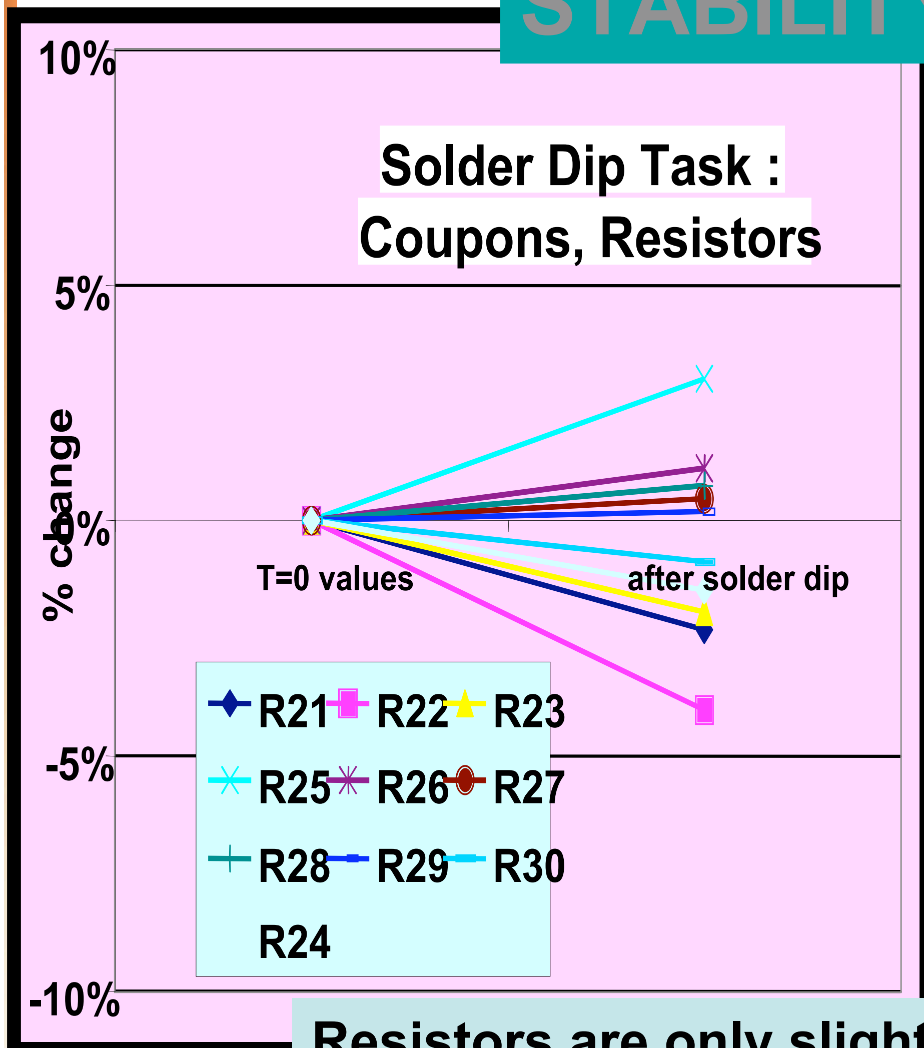
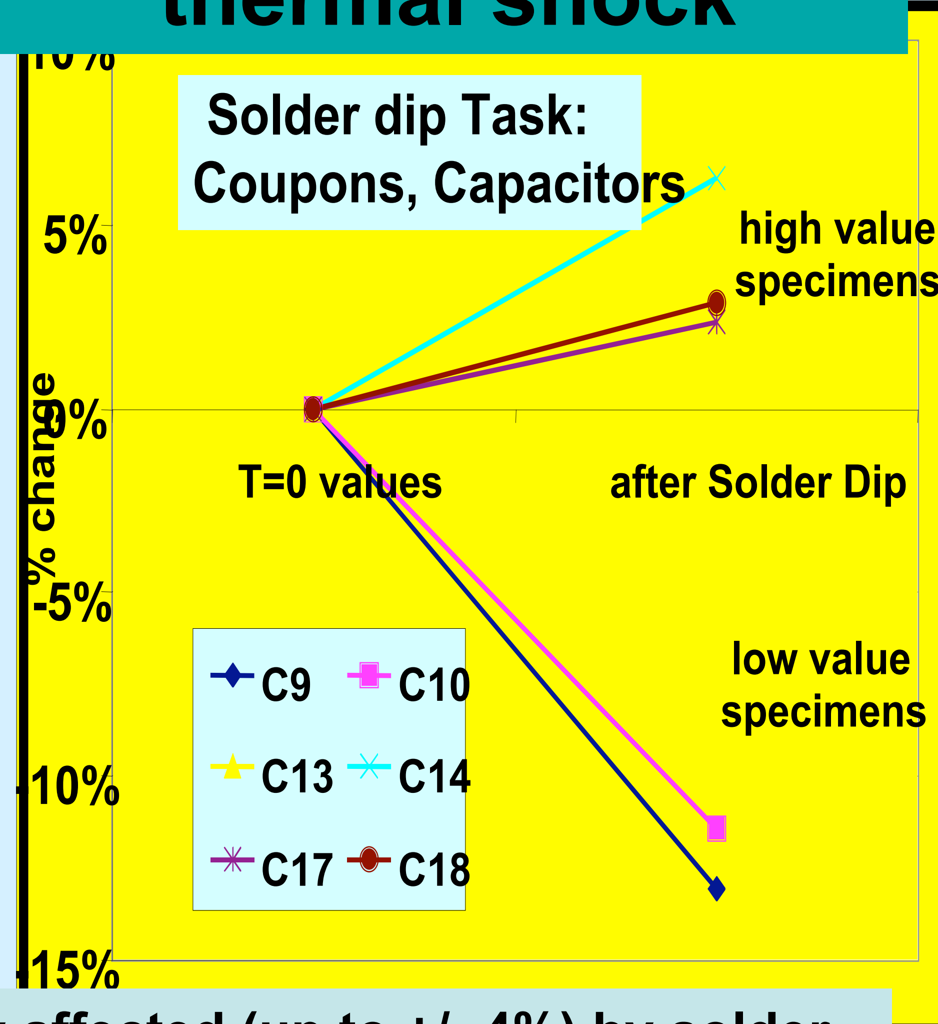
STABILITY thermal shock





Resistors are only slightly affected (up to +/- 4%) by solder-pot dip. Capacitors appear more affected: high value specimens increase ~5%; low value specimens drop ~10%c

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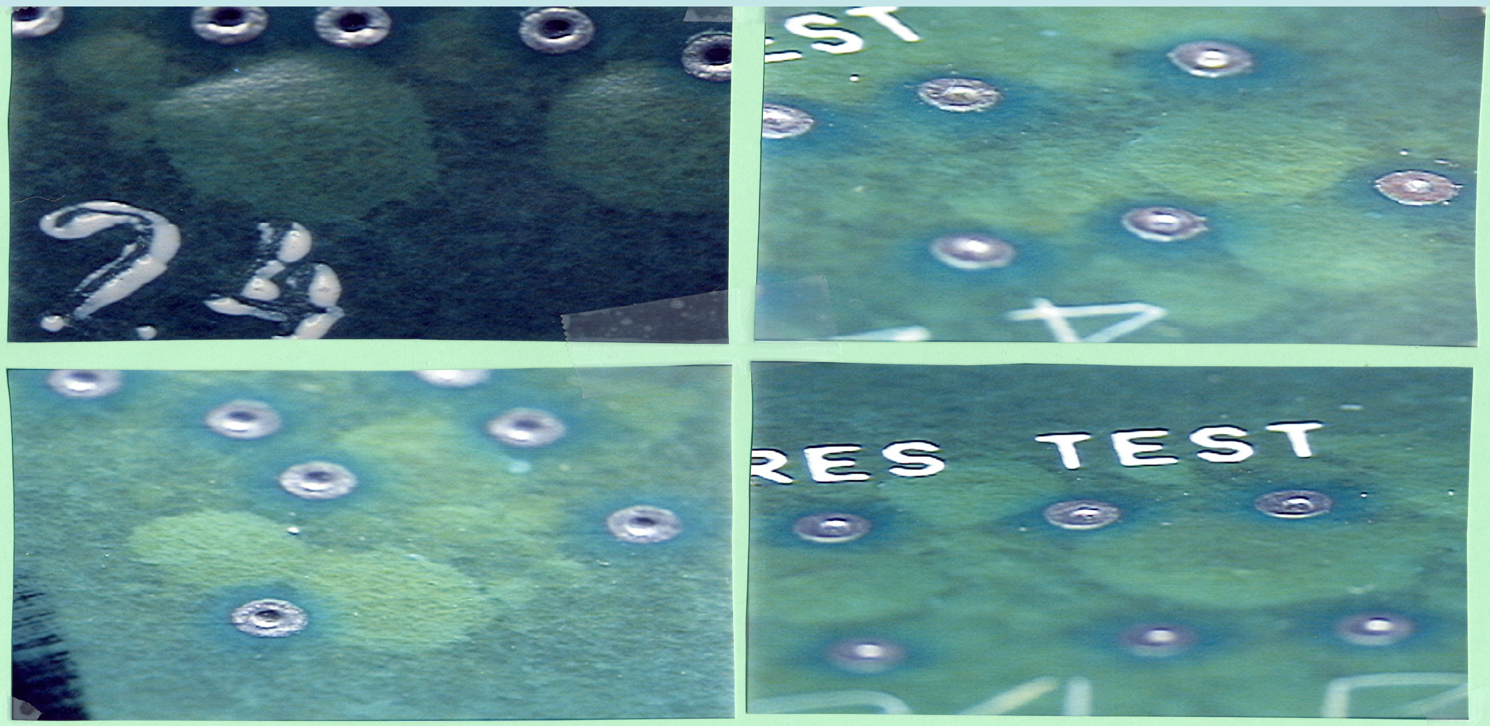
STABILITY local over-heat

The objective was to model thermal extremes during manufacturing, such as might arise from clumsy use of uncontrolled soldering iron or focused point hot-gas soldering process. This overheating causes local delamination (" measling") … applied directly onto the embedded-passives location. Examples are shown below.



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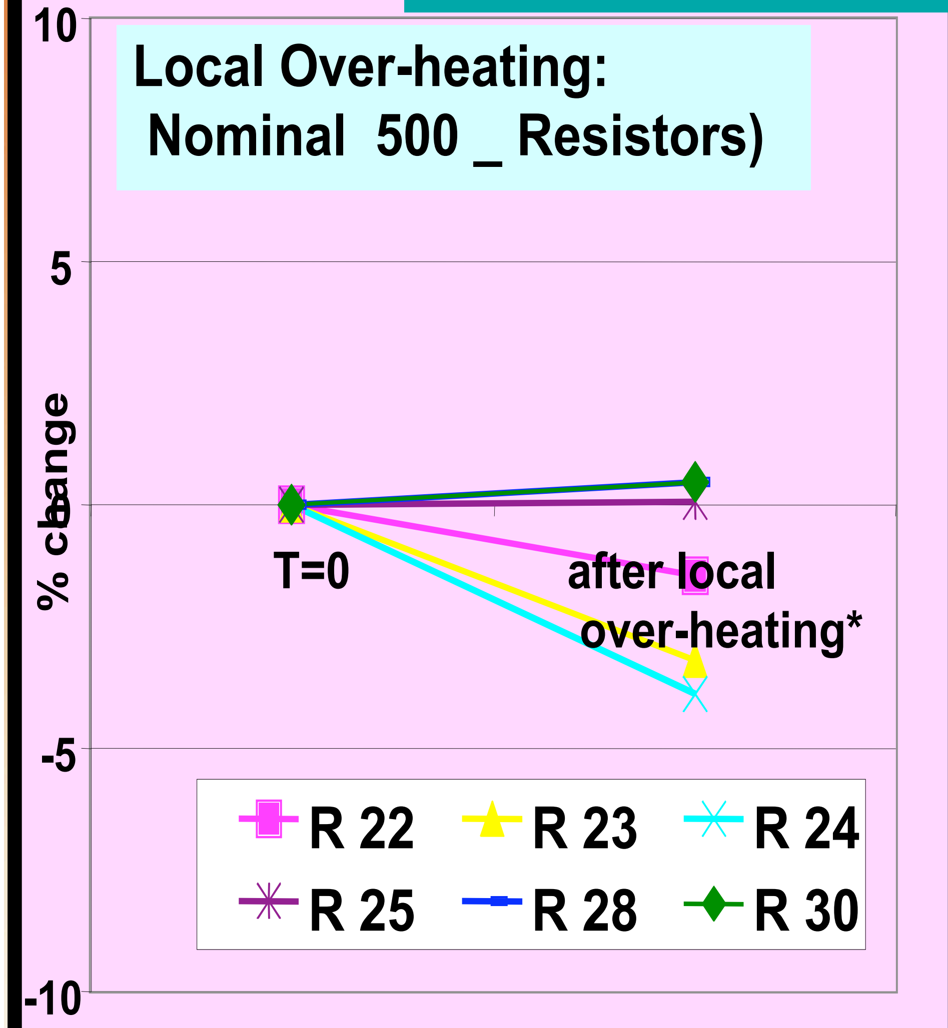
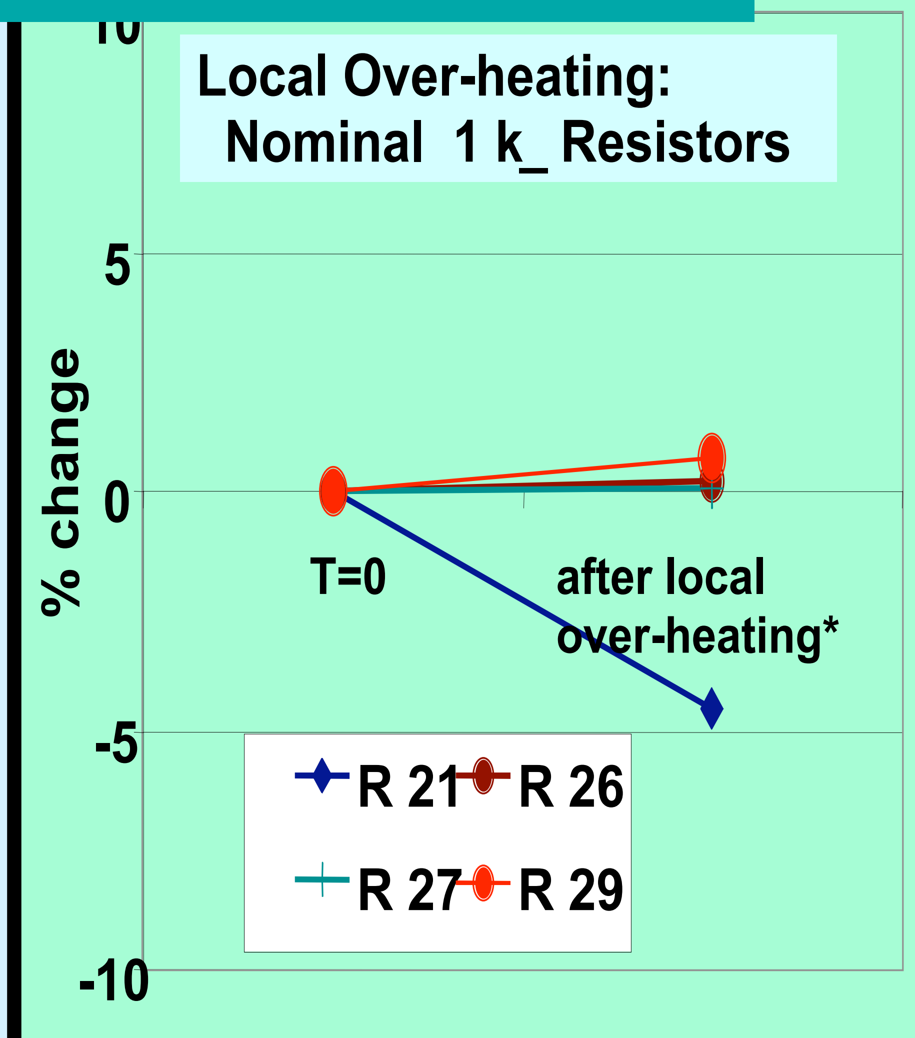
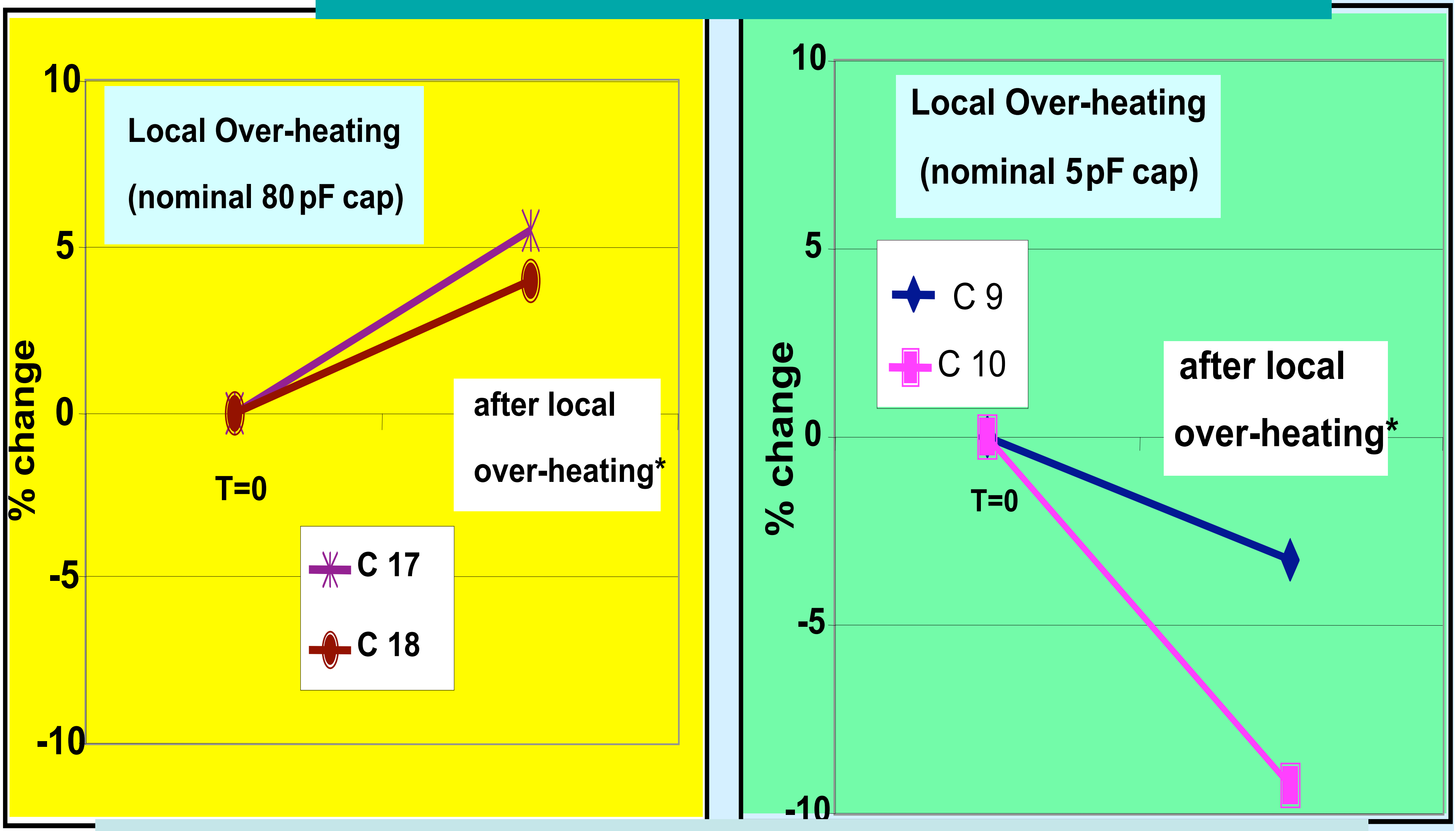
STABILITY local over-heat





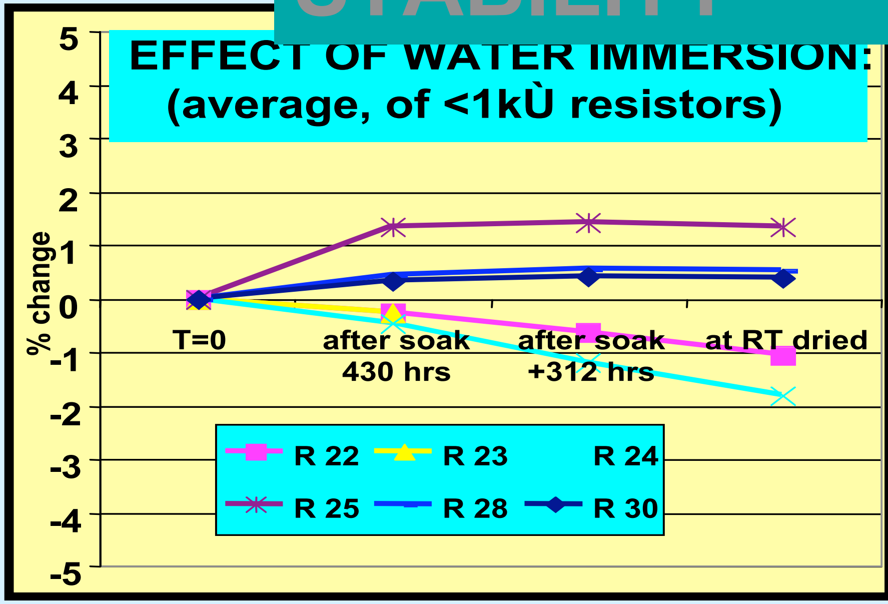
Intentional measling had little or no effect on resistors

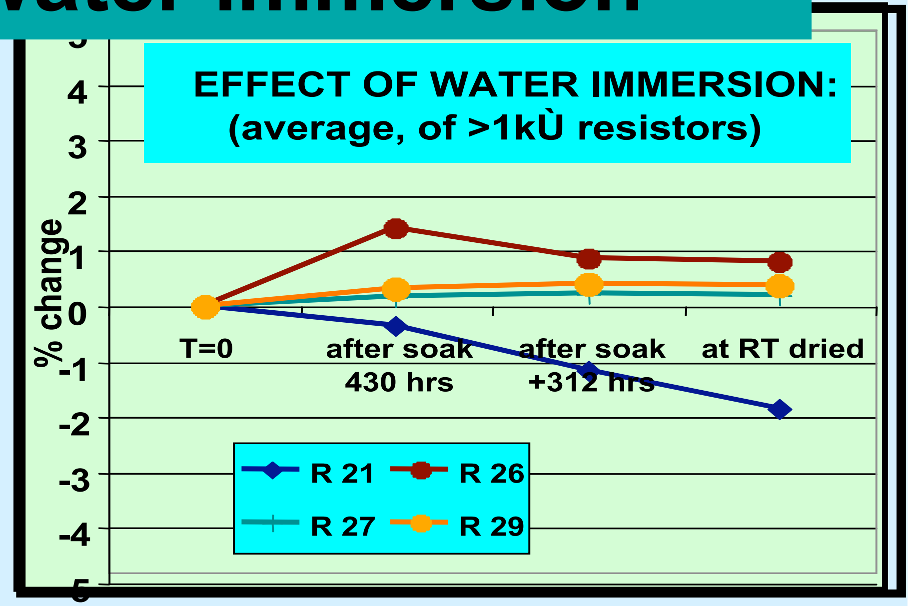
STABILITY local over-heat

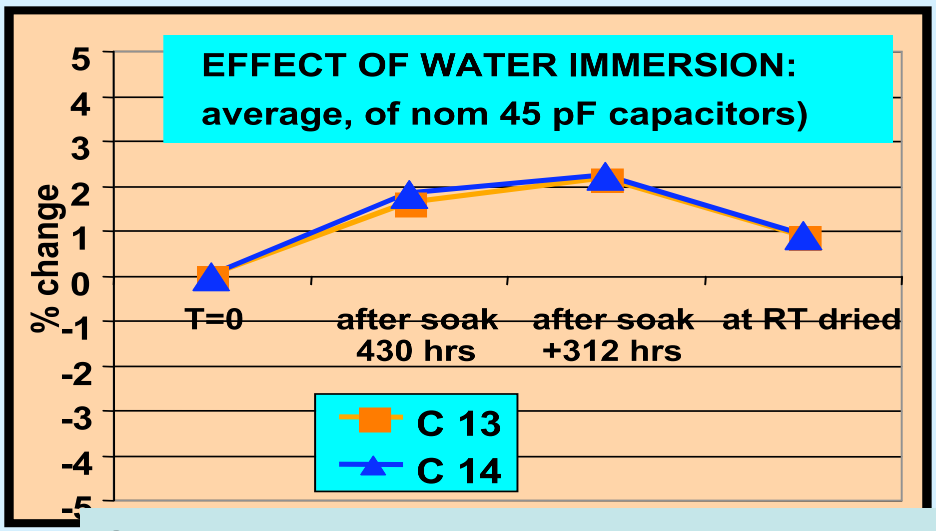


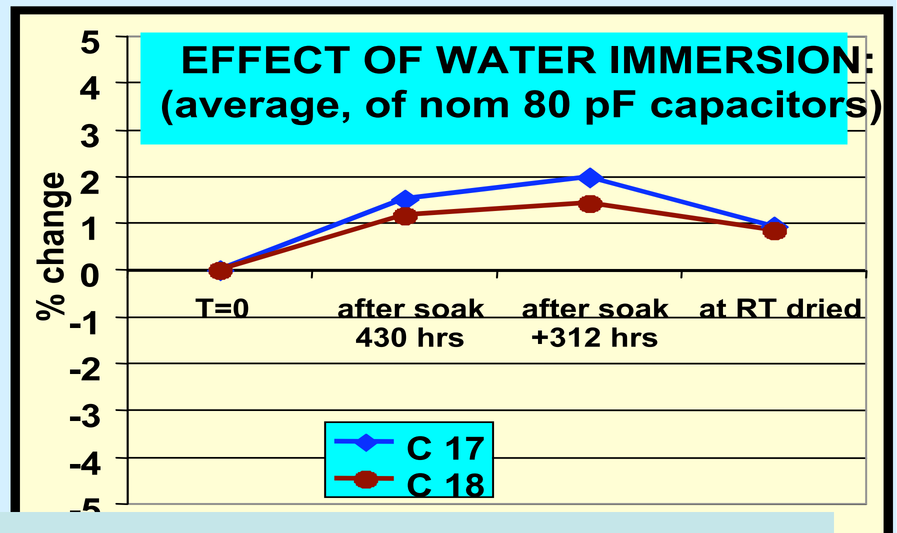
Capacitors showed a bit more effect: plus or minus 5-10%

STABILITY water immersion









Soaking these resistors and capacitors had almost zero effect.

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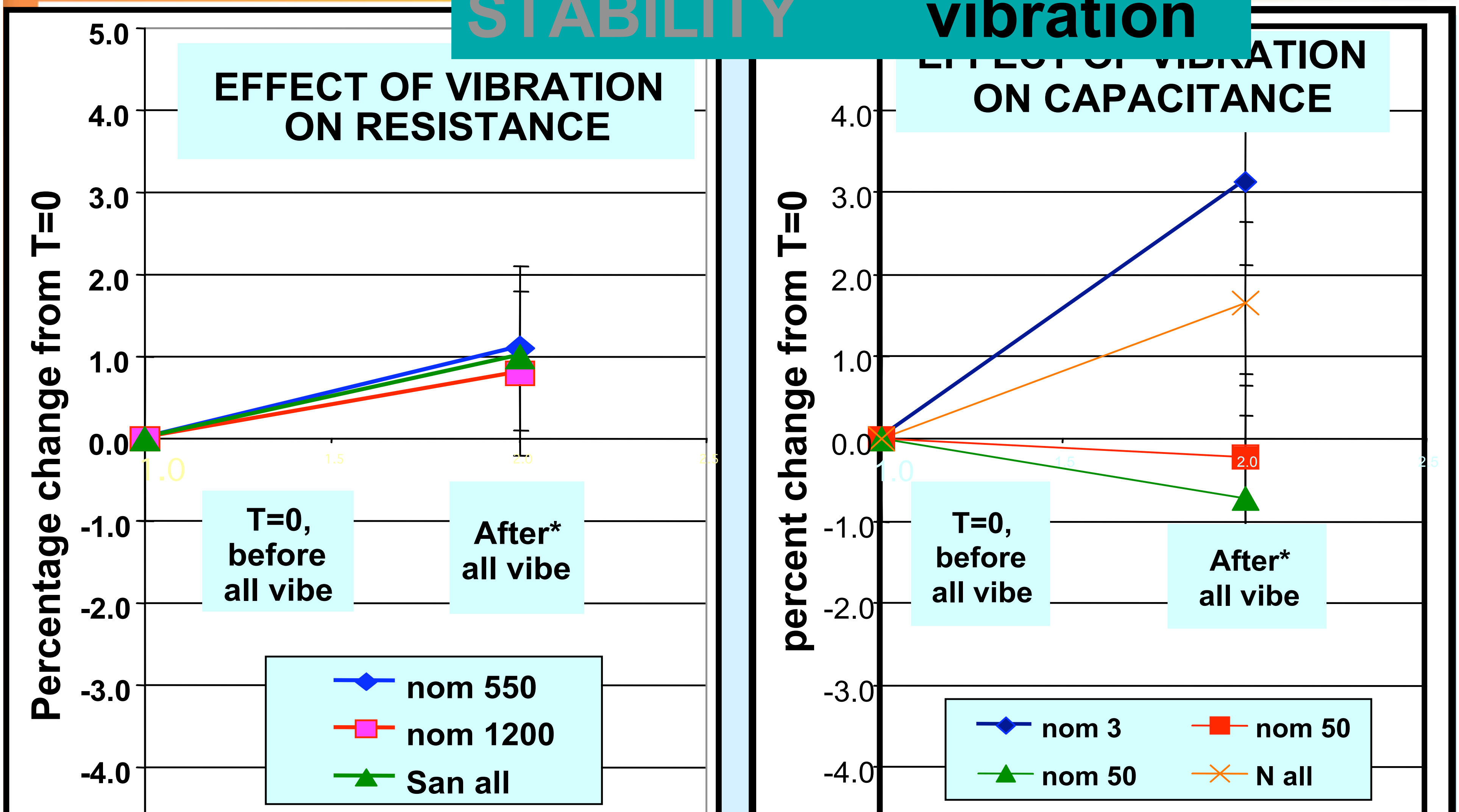
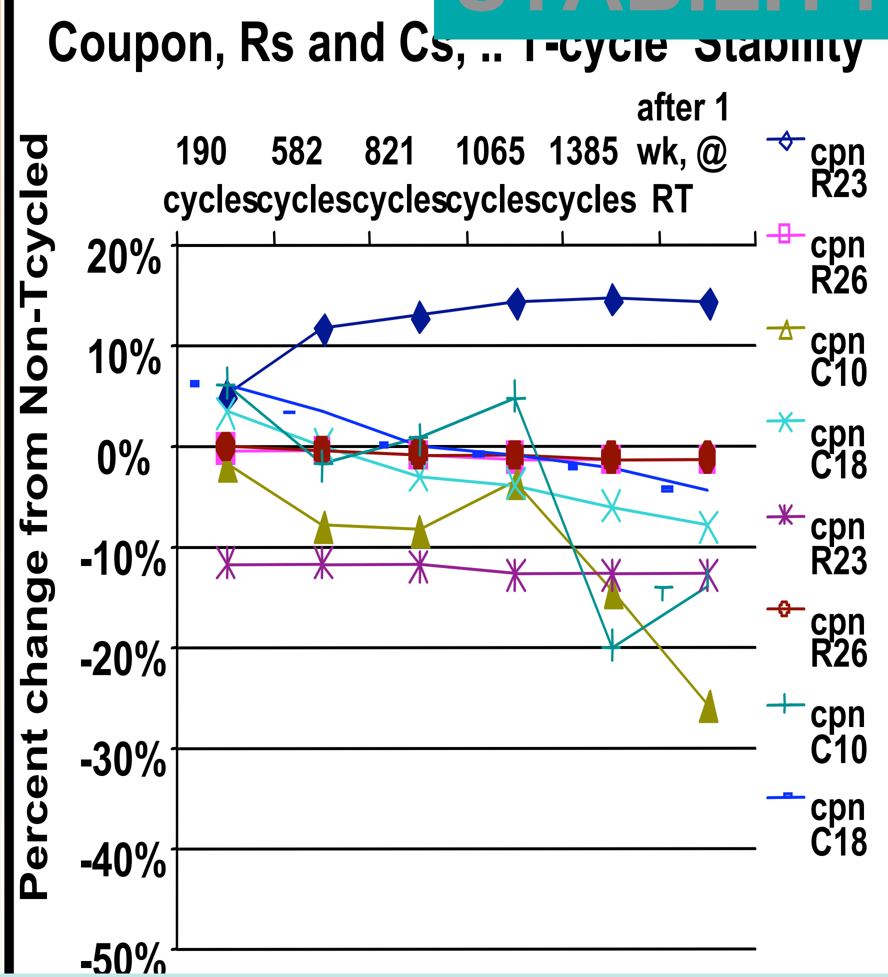
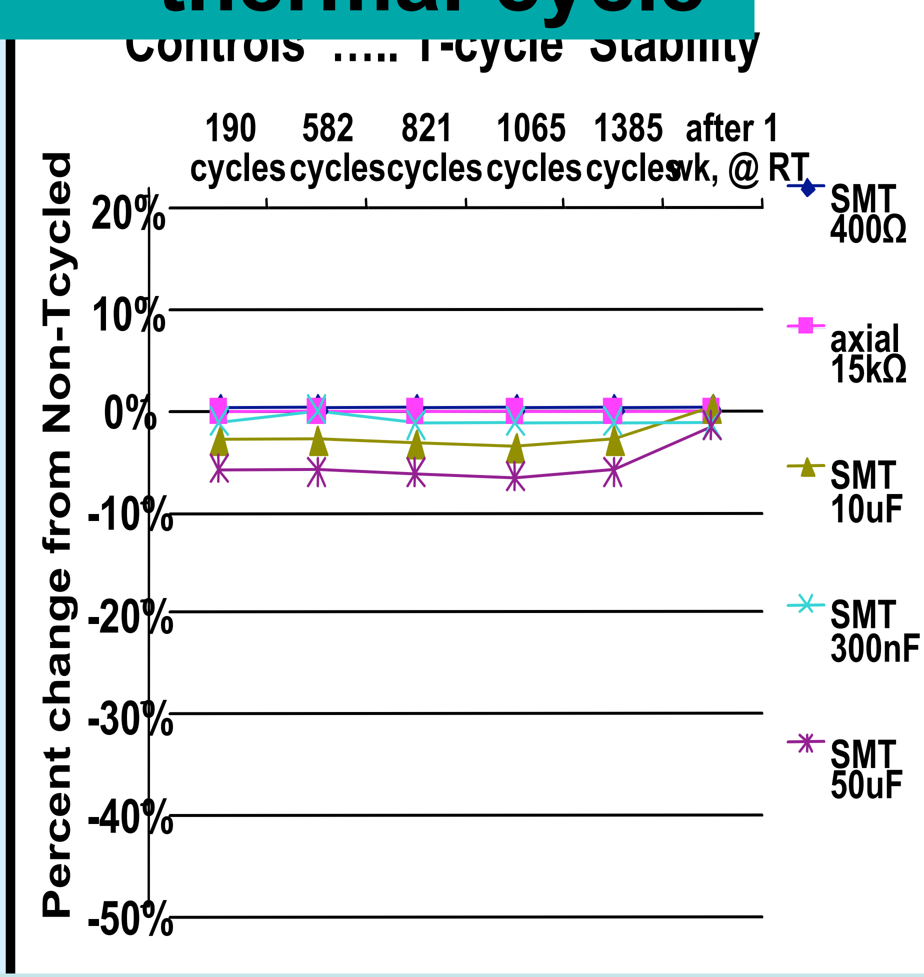
STABILITY vibration



Subjecting coupons (cantilever-clamped) to a qual-level vibration spectrum caused little or no effect on resistor or capacitor values.

STABILITY thermal-cycle





Exposing resistors and capacitors to extended -10C to +125C t-cycling cause erratic changes of up to ~15%. In contrast, conventional SMR and SMC "controls" were more stable; and tended to recover.

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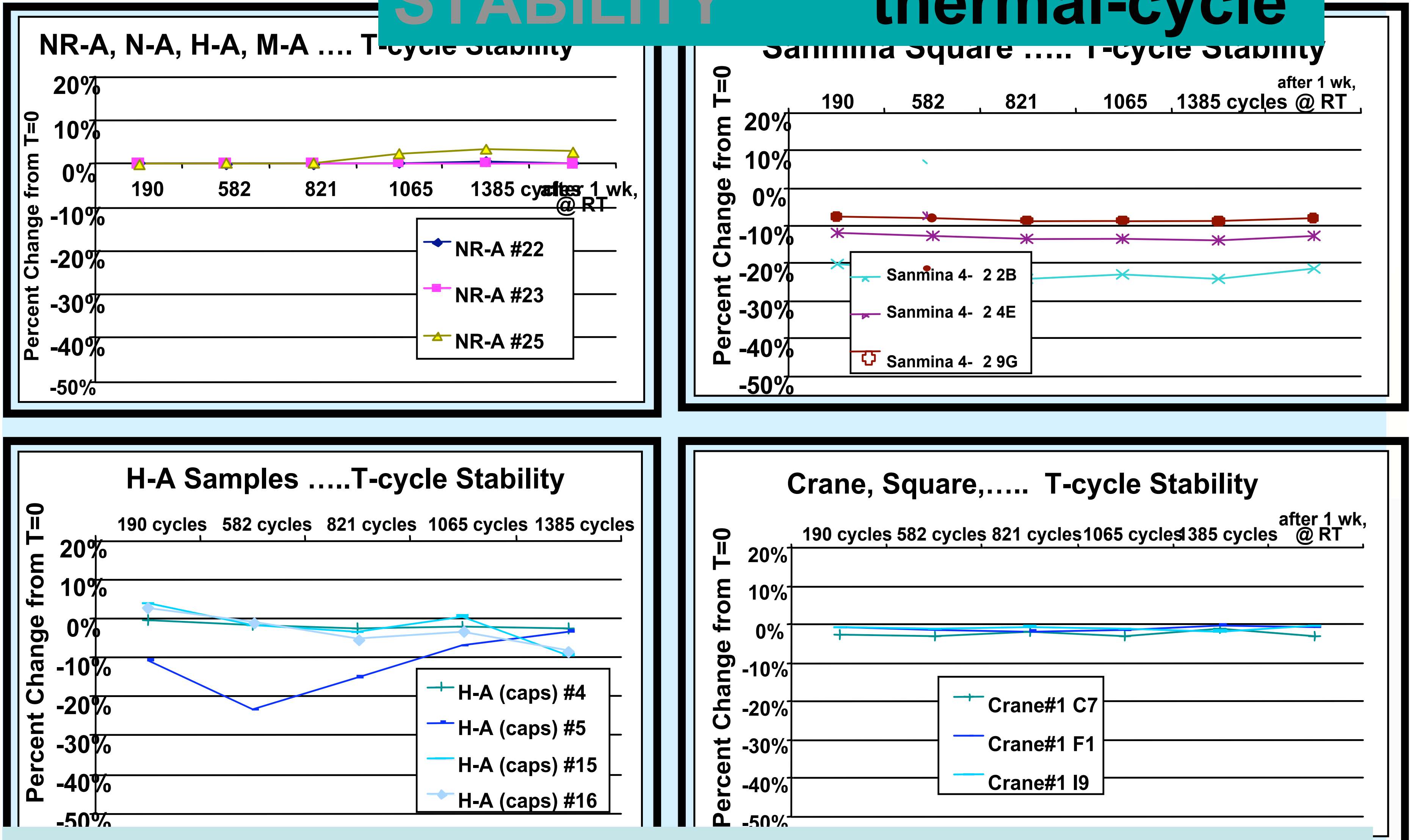
STABILITY thermal-cycle



Other embedded-passives boards were similarly affected : t-cycle exposure caused up to 15% change. The effects are not explained.

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CONCLUSIONS: STABILITY STUDY

1) Embedded passives appear to be relatively robust to short-term common processing extremes.

2) Passives' values during short-term operation at high and low temperatures will be predictable.

3) Long-term exposure to elevated temperature, humidity, t-cycling, and vibration will cause changes, possibly irreversible, of up to 10-25%.

4) Certainly more work (materials, processes, exposures, and metrics) is indicated; especially as critical mil-aero applications are anticipated.

OVERALL SUMMARY AND WRAP-UP

1) Useful exploratory study: good insight into process development with a complex design and new materials, partnering with a good PWB fab.

2) Mil-aero and other critical applications will require tolerant designs, enlightened spec-setting, more materials and process development work; as well as provision for yield and delivery-time impacts. Start-up issues should be anticipated.

3) These actions are underway … embedded passives will become a standard design resource for certain high-density, high-performance applications, but the resultant precision and stability will likely not meet all of the tightest current specifications.

THE AUTHORS GRATEFULLY AKNOWLEDGE THE CONTRIBUTIONS OF THE SANMINA/SCI TEAM, NOTABLY NICK BIUNNO; AS WELL AS THE LOCKHEED-MARTIN DESIGN, MATERIALS-DEVELOPMENT, AND TESTING TEAMS, ESPECIALLY GREGG GADD, DUNG TIET AND RICHARD HARRIS.

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