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Metallization of Ferrite Ceramic Couplings

Jan Burden

KCP-613-4747

Published June 1992

Final Report

Prepared for the United States Department of Energy Under Contract Number DE-ACO4-76-DP00613.

Allied-Signal Aerospace Company
Kansas City Division

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A prime contractor with the United States
Department of Energy under Contract Number
DE-ACO4-76-DP00613.

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METALLIZATION OF FERRITE CERAMIC COUPLINGS

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Final Report
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Abstract

Tests were conducted to determine the optimum sputtering conditions for which the strongest metallization adherence could be achieved for the ferrite safing wheel assemblies. The conditions were varied through four separate test runs with a fifth verification run conducted using parameters selected from the first four runs. The parameters tested were the effects of etching, precleaning, chamber pressures, plating materials, plating thickness, soldering pressures, and cooling rates. The results increased the strength of the metallization to two pounds, well in excess of the required one pound minimum. It was also determined that the gold should be sputtered on and not thermally deposited, which caused cracking in the ferrite material.

Summary

This study is concerned with the different parameters that affect the metallization of ferrite ceramic couplings. Along with the parameters themselves, various levels of these parameters were tried throughout the five tasks that comprise this study. Of the parameters studied, the etching solution, which removes damaged surface material caused by machining, was the most significant. The second important parameter was the nickel overplate. The nickel develops an internal stress depending on the thickness and chamber pressure in which it is applied. Copper was tried as a substitute, but it did not have sufficient internal strength. One important note about the gold layer involves the method by which it is applied. Thermal deposition of the gold (performed by Vendor A) did not yield satisfactory results. Sputtering is the preferred method of applying all three plating layers.

The overall results of Vendor B show an increase from approximately 0.20 pound from the peel test results at the beginning of Task 1 to 1.95 pounds with the final parameters defined in Task 5. The final parameters used were an etch using 30%

HCl at room temperature; vacuum bake for 10-12 hours at 110-120°C at a pressure of less than 150 microns vacuum, pump down pressure of 10^{-4} torr prior to an argon backfill with 0-20 millitorr, the chrome layer of 750-1000 angstroms, followed by 11,000-13,000 angstroms of nickel, and the top gold layer sputtered to a thickness of 6,000 angstroms minimum.

When the metallized parts are soldered, the less heat that can be applied and a slow cooling rate for the solder will increase the overall strength of the soldered ferrite. The ferrite appeared to be sensitive to thermal excursions and ultrasonic cleaning methods.

The experiment was conducted by a primary contractor that coordinated the work through two subcontractors (designated as Vendors A and B) for Allied-Signal Inc., Kansas City Division (KCD). The results of the five tasks had determined a reliable method of producing acceptable metallized ferrite couplings, but due to the time and money constraints should not be considered an all inclusive study of the various parameters and the

relationship they have in one another. Further research would be required to ascertain if all significant conditions were tested, and a higher sampling of those

parameters would be a better statistical base for the parameters chosen.

Discussion

Scope and Purpose

The sputter coating of ferrite ceramic couplings with a Cr/Ni/Au metallization system prior to being soldered into copper-stainless laminated housings has produced high attrition rates and inconsistent quality in safing wheels. The development of controlled sputtering processes is required to meet present and future design requirements for soldered ferrite ceramics.

Solder bonding of ferrite ceramics into metal housings is possible only after the application of a metallized coating to the ceramic surface. Poor adhesion of the metallization to the ceramic will result in the failure of the solder bond, thereby causing product loss and/or inconsistencies. Several variables within the current manufacturing process appear to cause variations in the coating adhesion. These variables include argon pressure, metallization thickness, overplate material, residual gas, pump down pressure, ferrite porosity, and differences in metallization vendors. Development work is required to investigate the effects of each variable and to develop methods to control them. Understanding and control of these variables will benefit the manufacturability of current safing wheels, in addition to future applications for ferrites.

The scope of this project was developed through five different experiments. The technical approach is defined in Tasks 1 through 5.

Task 1

Perform an initial designed experiment to study argon pressure, overplate constituent (Ni versus Cu), metallization thickness, pump down pressure, ferrite porosity, and etching solution variation between two vendors. This

constitutes an L8 orthogonal array comprised of seven tests.

Task 2

Perform a second designed experiment, utilizing data accumulated from the first experiment to study precleaning, argon pressure, etching solutions, surface finish, precleaning, chrome thickness, vendor variation, and interactions between these variables. This is an L8 orthogonal array with seven tests.

Task 3

Perform a designed experiment to study the effects on the etching parameters prior to the sputter coating of ferrite couplings. The parameter of vacuum bake time, chemical etchant, etchant temperature, and dwell time after etch were investigated. Only one vendor was used for this task. This constitutes an L9 orthogonal array comprised of 10 tests.

Task 4

Perform a designed experiment to study the less significant details of processing. The parameters of this experiment include ultrasonic cleaning, vacuum bake temperature, dwell time after etch, nickel thickness, vacuum bake time, and vacuum pressure. Unrelated to the metallizing process, a solder cool rate was also studied. This constitutes an L8 orthogonal array comprised of 10 tests.

Task 5

A fifth experiment was performed as a verification run. It employed all information learned from the designed experiments and included final test results.

Activity

Task 1

The experiment conducted for Task 1 was conducted using two different metallization vendors. Pump down pressure, argon pressure, material over chrome, etching, and ferrite porosity were evaluated.

The pump down pressure is the measure of how much vacuum is produced in the chamber prior to being backfilled with argon. This helps define the quality of the argon gas that will be in the chamber during the sputtering process. The defined pressures to be used were 10 and 20 millitorrs.

The argon gas is used to backfill the chamber prior to sputtering the chrome (nickel or copper) and gold layers onto the ferrite. The pressure held during the sputtering process has been shown to have an effect on the stress of the applied coating. Figure 1 shows that at low atmospheres the plating should be in compression, while at higher atmospheres the plating is in tension. Nickel when applied is a stressful coating and this stress can affect the ferrite stresses; consequently, copper was chosen to replace the nickel. The less stressful coating of copper may induce less stress on the ferrite itself. To study the effect of stress as it relates to the plating over chrome, both nickel and copper were used in a thickness of 4000 angstroms and 13000 angstroms.

During machining of the ferrites, the outer layers of material may become damaged. To remove this layer of material and provide a more solid foundation, the etching of the surface was done using a solution of either 80% phosphoric acid solution at 100°C or a 50% phosphoric acid solution at 100°C, followed by a hot D.I. water rinse, then a 10% hydrochloric acid at 10°C rinse.

Porosity within the ferrite itself will be studied to see if low or high porosity has an effect of the metallization strength. The effect of

porosity may be shown to have some affect on overplate stress.

This experiment was defined using an L8 orthogonal array. The design variables and their corresponding levels are given in Table 1. Table 2 lists the parameters as defined for Task 1.

By defining the parameters of each task, the ferrite test specimens were sent to the suppliers for metallization. After processing at the suppliers, they were returned to the primary contractor where a copper strap was soldered to the metallized ferrite using lead indium solder. Then a peel test was performed with the results charted.

Task 1 Results

Before beginning the results of Task 1 it must be first noted that discrepancies in the metallization process were noted by Vendor A after the product was received back at the primary contractor. Vendor A deviated during the sputtering process by removing the ferrite from the chamber after application of the chrome and nickel (copper) layers and applying the gold layer by thermal resistance. The soldering of both Vendors A and B were the same, so no noticeable difference was ascertained at this time. The second item that deviated was, instead of using 10 and 20 millitorr, Vendor A used 1.5 and 5.0 as low and high argon pressure values. The third deviation from the designed experiment was the application of nickel (copper) in a 250 and 750 angstrom layer instead of the 4000 and 13,000 angstroms specified.

In order to account for these discrepancies, the data were divided into two groups: One group contains the data for Vendor A and its results and the other, Vendor B and its results (Appendix A). Since Vendor A varied from the designed experiment, the comparison of variables is complicated by the various degrees of freedom with two vendors involved. By separating the vendors

Figure 1. Comparison of Plating and Atmospheric Conditions

the degrees of freedom are reduced and a comparison can be made for each vendor.

The data for both vendors were run through a SAS software routine which yields a General Linear Model. These data are shown in Appendix A.

In reviewing the data for Vendor A, the Scheffe's test for variable response indicates that the type of overplate has the most profound effect on strength. The nickel is applied by sputtering, and the thicker the layer the more stress that appears to be induced on the sample. The copper overplate is under less stress; these samples show much lower values in the peel test results.

The second item that has a significant effect on strength is argon pressure. When the

pressure was held at the lower 1.5 millitorr setting, the strength was nearly doubled from 0.65389 to 1.005. The lower pressure leaves the overplate in a compression state and not in tension (Figure 1).

The other contribution to a higher strength was shown by the thickness of the overplate. The thicker 750 angstrom samples showed a slightly higher strength by 0.05737 lb. In a comparison of the etching, the 80% H_3PO_4 solution exhibited higher strengths by nearly a factor of two. This higher concentration cleans the surface more thoroughly and may be providing a more coarse surface for the overplate. This coarse surface relieves the stress in the nickel and therefore provides higher peel test readings.

Table 1. Task 1, Metallization Study Experiment 1

Column	Variable Names	Level 1	Level 2
1	Argon Pressure	10 Torr	20 Torr
2	Over Plate	Ni	Cu
3	Ni Thickness	13 kÅ	4 kÅ
4	Pump Down Pressure	10 ⁻⁵ Torr	10 ⁻⁷ Torr
5	Ferrite Lot	Low Porosity	High Porosity
6	Metallization	Vendor A	Vendor B
7	Etchant	50% H ₃ PO ₄	80% H ₃ PO ₄

Note: Test 1

Objective: Improve System Yields

Characteristic: Ferrite/Metallization System Strength

Experiment Used the Following Orthogonal Array

Trial	1	2	3	4	5	6	7
1	1	1	1	1	1	1	1
2	1	1	1	2	2	2	2
3	1	2	2	1	1	2	2
4	1	2	2	2	2	1	1
5	2	1	2	1	2	1	2
6	2	1	2	2	1	2	1
7	2	2	1	1	2	2	1
8	2	2	1	2	1	1	2

The pump down pressure, which is to be the indication of the environment the argon gas enters, showed that the best setting would be at the 10⁻⁵ torr. Since the lower pressure of argon gas had higher results, the pump down pressure has more importance than first thought. It should be noted that at the 10⁻⁵ torr setting the mean strength was 1.1595 lb compared to 0.5179 lb for the 10⁻⁷ torr setting.

The results from the SEM/EDAX show that for Vendor A the ferrite coupling had a failure

mode generally through the Pb/In solder with only small traces of the ferrite appearing.

The results for Vendor A show that using the 80% H₃PO₄ solution for an etch, a pump down pressure of 10⁻⁵ torr, an argon pressure of 1.5 millitorr, and Ni as the type of overplate, the highest strength results should be achieved.

In reviewing the data for Vendor B (Appendix A), the items showing significant contributions are argon pressure, etching solution, type of overplate, and pump down

Table 2. Task 1, Description of Eight Separate Experimental Conditions

Trial	Condition	Indication	Level
1	Argon Pressure	1.5 torr	1
1	Over Plate	Ni	1
1	Ni Thickness	750 Angstroms	1
1	Pump Down Pressure	10 ⁻⁵ torr	1
1	Ferrite Lot	Low Porosity	1
1	Metallization	Vendor A	1
1	Etching Solution	80% H ₃ PO ₄	2
2	Argon Pressure	10 torr	1
2	Over Plate	Ni	1
2	Ni Thickness	13 kÅ	1
2	Pump Down Pressure	10 ⁻⁷ torr	2
2	Ferrite Lot	High Porosity	2
2	Metallization	Vendor B	2
2	Etching Solution	80% H ₃ PO ₄	2
3	Argon Pressure	10 torr	1
3	Over Plate	Cu	2
3	Ni Thickness	4 kÅ	2
3	Pump Down Pressure	10 ⁻⁵ torr	1
3	Ferrite Lot	Low Porosity	1
3	Metallization	Vendor B	2
3	Etching Solution	80% H ₃ PO ₄	2
4	Argon Pressure	1.5 torr	1
4	Over Plate	Cu	2
4	Ni Thickness	250 Angstroms	2
4	Pump Down Pressure	10 ⁻⁵ torr	2
4	Ferrite Lot	High Porosity	2
4	Metallization	Vendor B	2
4	Etching Solution	80% H ₃ PO ₄	2
5	Argon Pressure	2 torr	1
5	Over Plate	Ni	1
5	Ni Thickness	250 Angstroms	1
5	Pump Down Pressure	10 ⁻⁵ torr	1
5	Ferrite Lot	High Porosity	1
5	Metallization	Vendor A	1
5	Etching Solution	50% H ₃ PO ₄	1
6	Argon Pressure	20 torr	2
6	Over Plate	Ni	1
6	Ni Thickness	4 kÅ	2
6	Pump Down Pressure	10 ⁻⁷ torr	2
6	Ferrite Lot	Low Porosity	1
6	Metallization	Vendor B	2
6	Etching Solution	50% H ₃ PO ₄	1

Table 2 Continued. Task 1, Description of Eight Separate Experimental Conditions

Trial	Condition	Indication	Level
7	Argon Pressure	20 torr	2
7	Over Plate	Cu	2
7	Ni Thickness	13 kÅ	1
7	Pump Down Pressure	10 ⁻⁷ torr	1
7	Ferrite Lot	High Porosity	2
7	Metallization	Vendor B	2
7	Etching Solution	50% H ₃ PO ₄	1
8	Argon Pressure	5 torr	2
8	Over Plate	Cu	2
8	Ni Thickness	750 Angstroms	1
8	Pump Down Pressure	10 ⁻⁷ torr	2
8	Ferrite Lot	Low Porosity	1
8	Metallization	Vendor B	1
8	Etching Solution	50% H ₃ PO ₄	1

pressure. The argon pressure setting of 10 millitorr had a higher strength reading by a factor of two. This setting and that of Vendor A both indicate a lower pressure setting is better. The lower pressure leaves the Ni in compression instead of tension and, therefore, reduces the stress.

In Experiment 1 for Vendor B, the etching solution of 50% H₃PO₄ also shows a significantly higher reading. This is contrary to the results of Vendor A.

The type of overplate for Vendor B shows Ni to be the better choice as Cu does not exhibit sufficient strength.

The pump down pressure setting of 10⁻⁷ torr shows the highest strength results. This is the opposite of the results for Vendor A. The pump down pressure and overplate thickness combination have a significant combined effect. The thicker overplate and higher pressure provided the best results. The effect of the ferrite porosity had little or no effect with Vendors A or B. The results for Vendor B show more inconsistencies than were shown by Vendor A. In Trial 2, the ferrite and strap both exhibit ferrite failure. In Trial 3, the significance was the Cu delaminated from the chrome. A comparison of strap versus ferrite for Trial 6

shows a clean break between the metallization and the ferrite. Trial 7 shows failure was within the Cu metallization. This was the same mode of failure for both the top and side of the ferrite.

Because Vendor A did not follow the defined variables, a comparison of vendors was not possible. Vendor A's failure was normally from the Pb/In solder, and Vendor B had failure caused by the delaminating of the metallization. The SEM/EDAX data showing small ferrite break-up indicates something is degrading the ferrite layer that is being metallized.

Task 2

This experiment was designed to study the effects of precleaning, etching solution, ferrite surface finish, overplate (Ni) thickness, argon pressure, chrome thickness, different vendors, and the effects of precleaning the parts by ultrasonic cleaning in a mild industrial soap at 90-110°C, rinsed in D.I. water, methanol rinse, and dry versus no precleaning. The surface finish of the ferrite was examined. The standard ferrite finish is 16-18 µm, and the "coarse" specimen was produced by sanding with 220 grit paper. This surface finish will produce a different surface to improve adhesion of the

metallization and reduce stress in the nickel. Etching using the "standard" 80% H_3PO_4 solution was compared to ion milling. The effects of Ni thickness, argon pressure, chrome thickness, and vendors are carryover from Task 1 and a description of their purpose remains the same. The experimental conditions are defined in Tables 3 and 4.

Task 2 Results

For Experiment 2, both vendors followed the prescribed variables as they were defined. A comparison between vendors shows that Vendor A has a mean strength of 0.82675 lb compared to 0.42656 lb for Vendor B. The largest disturbance is noted by the surface finish. The "normal" ferrite surface finish yielded 0.93684 lb results compared to the 0.32706 lb for the surface roughed by the 220 grit paper. Roughing the surface does not improve adhesion or the metallization strength and must not relieve the stress of the nickel overplate. The overplate thickness of 22 kiloangstroms yielded a mean reading of 0.96029 compared to the 4500 angstroms mean of 0.37026. This shows that as a mean the thicker plating is better, but two runs of the thinner overplate (Observations 1 and 7) had high strength readings.

The etching of the ferrite using 80% H_3PO_4 was far superior to the ion milling as evidenced by comparison of Observations 1-4 versus Observations 5-8. The precleaning did not significantly help the overall readings and should not be pursued. The ultrasonics may damage the ferrite surface during the cleaning operation. There is not a large difference in readings for the chrome thickness readings of 1500 angstroms or 750 angstroms. If choosing, the 1500 angstroms had slightly higher readings. The higher 20 millitorr setting for argon pressure was better than the lower 1.5 millitorr setting. From this data the optimum settings would be for Vendor A to use an argon pressure of 20 millitorr, an 80% H_3PO_4 etching solution, overplate thickness of 22 kiloangstroms, no precleaning of a

normal ferrite surface, and chrome thickness of 1500 angstroms. These conditions were one of the observations. Observation 1 has these settings and had a mean reading of 1.79 lb. All of the other observations mean readings are below 1.00 lb as shown in the data from Appendix B.

Task 3

From Tasks 1 and 2, the effects of etching had a significant impact on the overall strength of the metallization. This task was designed to explore the etching process itself. The various parameters chosen were vacuum bake time, the type of chemical etch, the etchant temperature, and dwell time after etch. In this experiment, 58% H_3PO_4 (phosphoric acid) will be compared to 30% HCl and 15% HCl (hydrochloric acid) to see if a different strength acid can clean the ferrite surface as well and not change its physical dimensions significantly. The vacuum bake drying is to test the time necessary for thorough drying. The etchant temperature was varied to study its effect on the performance of the chemical etchant at various temperatures. The dwell time after etch was done by allowing the parts to remain at room temperature environment for drying. The experiment was designed using an L9 orthogonol. Reference Tables 5 and 6 for the arrays and parameters used.

Task 3 Results

Review of the data presented in Appendix C indicates the most important variable was the type of etchant used. The 30% HCl had a mean reading of 1.805 lb compared to the 1.1039 lb mean of the 58% H_3PO_4 . Trial 8 was conducted at room temperature using HCl etch and provided the highest strength results. This room temperature is easier to process than holding the other etchants at an elevated temperature during processing. The second major contribution to the etching process was the dwell time after etch. The time of longer than 12 hours worked best. The effects of vacuum bake time and the etchant temperature appear to have little if

Table 3. Task 2, Metallization Study Experiment 2

Column	Variable Names	Level 1	Level 2
1	Etching	80% H ₃ PO ₄	Ion Mill
2	Preclean	No	Yes
3	Finish	Fine	Coarse
4	Ni thick	22 kÅ	4.5 Å
5	Argon Pressure	20 mtorr	1.5 mtorr
6	Chrome Thickness	1.5 kÅ	750 Å
7	Vendor	A	B

Experiment Used the Following Orthogonal Array

Trial	1	2	3	4	5	6	7
1	1	1	1	1	1	1	1
2	1	1	1	2	2	2	2
3	1	2	2	1	1	2	2
4	1	2	2	2	2	1	1
5	2	1	2	1	2	1	2
6	2	1	2	2	1	2	1
7	2	2	1	1	2	2	1
8	2	2	1	2	1	1	2

any effect on the etching process. In comparing results from Appendix C, the optimum choices would be a vacuum bake time of 12-14 hours, 30% HCl etchant at 50°C, and a dwell time of 12-14 hours. Trial 8 most nearly met these conditions with the exception of the etchant being at room temperature instead of 50°C. The average was 2.09 lb for Trial 8. The second highest average was Trial 2 which had the 30% HCl at 50°C with the mean of 1.99 lb. It did have a percent etched of 5.5. The primary contractor chose not to try the 80% H₃PO₄, and only Vendor B performed these experiments. No ultrasonic cleaning was performed on these parts prior to being etched too. The etchant being at room temperature is strongly recommended to

avoid a thermal excursion that could adversely affect the ferrite. The results below show the trial, failure mode, and percent etched and would have to be considered for the dimensional integrity to be held. The results listed earlier for Trial 8 are within the acceptable dimensional limits.

Task 4

This experiment was designed to further study the effects of vacuum bake time, dwell time after etch, and overplate thickness previously studied in Tasks 1-3. The effects of ultrasonic cleaning on the ferrite and strength were studied. The ultrasonic cleaning was done at the primary contractor

Table 4. Task 2, Description of Eight Separate Experimental Conditions

Trial	Condition	Indication	Level
1	Etching	80% H ₃ PO ₄	1
1	Preclean	No	1
1	Finish	Fine	1
1	Ni Thick	22 kÅ	1
1	Argon Pressure	20 mtorr	1
1	Chrome Thickness	1.5 Angstroms	1
1	Vendor	A	1
2	Etching	80% H ₃ PO ₄	1
2	Preclean	No	1
2	Finish	Fine	1
2	Ni Thick	4.5 kÅ	2
2	Argon Pressure	1.5 mtorr	2
2	Chrome Thickness	750 Angstroms	2
2	Vendor	B	2
3	Etching	80% H ₃ PO ₄	1
3	Preclean	Yes	2
3	Finish	Coarse	2
3	Ni Thick	22 kÅ	1
3	Argon Pressure	20 mtorr	1
3	Chrome Thickness	750 Angstroms	2
3	Vendor	B	2
4	Etching	80% H ₃ PO ₄	1
4	Preclean	Yes	2
4	Finish	Coarse	2
4	Ni Thick	4.5 kÅ	2
4	Argon Pressure	1.5 mTorr	2
4	Chrome Thickness	1.5 kÅ	1
4	Vendor	A	1
5	Etching	Ion Mill	2
5	Preclean	No	1
5	Finish	Coarse	2
5	Ni Thickness	22 kÅ	2
5	Argon Pressure	1.5 mtorr	1
5	Chrome Thickness	1500 Angstroms	2
5	Vendor	Ion Mill	1
6	Etching	Ion Mill	2
6	Preclean	No	2
6	Finish	Coarse	1
6	Ni Thickness	4500 Angstroms	1
6	Argon Pressure	20 mtorr	2
6	Chrome Thickness	750 Angstroms	2
6	Vendor	A	1

Table 4. Continued. Task 2, Description of Eight Separate Experimental Conditions

Trial	Condition	Indication	Level
7	Etching	Ion Mill	2
7	Preclean	Yes	2
7	Finish	Fine	1
7	Ni Thickness	22 kÅ	2
7	Argon Pressure	1.5 mtorr	1
7	Chrome Thickness	750 Angstroms	1
7	Vendor	Ion Mill	2
8	Etching	Ion Mill	2
8	Preclean	Yes	2
8	Finish	Fine	1
8	Ni Thickness	4500 Angstroms	2
8	Argon Pressure	20 mtorr	1
8	Chrome Thickness	1500 Angstroms	1
8	Vendor	B	2

Table 5. Task 3, Ferrite Metallization Study

Column	Variable	Level 1	Level 2	Level 3
1	Vacuum Bake	None	4-6 Hours	12-14 Hours
2	Chemical Etch	58% H ₃ PO ₄	30% HCl	15% HCl
3	Etchant Temperature	Room	50°C	100°C
4	Dwell Time After Etch	0-2 Hours	12-14 Hours	24-36 Hours

using a mild industrial soap at a frequency of 40 kHz for 30 minutes. The vacuum bake temperature was added to study the effect of various temperatures. The vacuum bake was deemed important to processing by the contractor.

One other item that was studied during this experiment was soldering, which is not concerned with the metallization of the ferrite coupling. However, the ferrite soldering is considered important to the overall strength of the assembly. To study the solder process, the solder cool down rate and vacuum pressure used for cooling down the solder were tested. In testing prior to this experiment the lead indium solder showed a higher tensile strength (5100 psi versus

4000 psi) given a faster cooling rate. The higher cooling rate, however, has been shown to be detrimental to the ferrite coupling. This experiment is defined in Table 8 using an L8 orthogonal array.

Task 4 Results

The results of Task 4 are shown in Table 8 (Appendix D). The largest contribution to greater strength is the solder cool rate. The solder cool rate of <2°C provided greater than 0.33 lb improvement over the >6°C cooling rate. This slower cooling rate is better for the ferrite but may not provide as high a tensile strength for the solder. The dwell time after etch remained as important in this task as it was in Task 3. In Task 3,

Experiment Used the Following Orthogonal Array

Trial	Columns	1	2	3	4
Trial	1	1	1	1	1
Trial	2	1	2	2	2
Trial	3	1	3	3	3
Trial	4	2	1	2	3
Trial	5	2	2	3	1
Trial	6	2	3	1	2
Trial	7	3	2	3	2
Trial	8	3	2	1	3
Trial	9	3	3	2	1

greater than 12 hours was determined to be best. In Task 4, the greater than 20 hours minimum was found to be important for processing. The third most significant parameter was the vacuum bake time. In Task 3, the optimum vacuum bake time was 12-14 hours but in Task 4, the period of 4-6 hours provided the best results. The effects of ultrasonic cleaning are detrimental to the ferrite structure itself.

The results of this experiment prove that no ultrasonic cleaning should be performed. The Scheffe groupings of overplate thickness, vacuum bake temperature, and the vacuum pressure for cooling solder had little effect on the strength based on either of the defined settings. With these parameters now further defined, the final task can be defined and executed.

Task 5

This task was the culmination of Tasks 1-4. The primary contractor used the optimum conditions determined from the Tasks 1-4 and sent parts to both Vendors A and B. The results of the two vendors will be maintained separately due to both vendors doing the same processing per the same parameters.

The settings from Task 2 for overplate thickness indicated 22,000 angstroms would be optimum; however, 11,000-13,000 were chosen. From Task 3 the vacuum bake time optimum was 12-14 hours, and the 4-6 hour range was optimum for Task 4. The primary contractor chose a range of 10-12 hours.

Table 9 lists the parameters used for Task 5, and with the exceptions noted in the preceding paragraph, the parameters chosen by the primary contractor are those proven by the SAS program to be the optimum choices.

Task 5 Results

The results for Vendor A show the response mean to be 0.789625 lb (Appendix E). This is below the 1.00 lb minimum required. From the results the units were determined to have surface damage to the ferrite caused by the thermal deposition of the gold layer. The heat must affect the ferrite causing it to fail during the peel tests. The results of the tests for Vendor A cannot be considered representative of the results that should be expected based on the parameter settings.

Vendor B results are what was anticipated based on the parameter settings from the previous tasks. For Vendor B, the response

Table 6. Task 3, Description of Nine Separate Experimental Conditions

Trial	Condition	Indication	Level
1	Vacuum Bake	None	1
1	Chemical Etch	58% H ₃ PO ₄	1
1	Etchant Temperature	Room	1
1	Dwell Time After Etch	0-2 Hours	1
2	Vacuum Bake	None	1
2	Chemical Etch	30% HCl	2
2	Etchant Temperature	50°C	2
2	Dwell Time After Etch	12-14 Hours	2
3	Vacuum Bake	None	1
3	Chemical Etch	15% HCl	3
3	Etchant Temperature	50°C	3
3	Dwell Time After Etch	24-36 Hours	3
4	Vacuum Bake	4-6 Hours	2
4	Chemical Etch	58% H ₃ PO ₄	1
4	Etchant Temperature	50°C	2
4	Dwell Time After Etch	0-2 Hours	3
5	Vacuum Bake	None	2
5	Chemical Etch	58% H ₃ PO ₄	2
5	Etchant Temperature	Room	3
5	Dwell Time After Etch	24-36 Hours	1
6	Vacuum Bake	4-6 Hours	2
6	Chemical Etch	15% HCl	3
6	Etchant Temperature	Room	1
6	Dwell Time After Etch	12-14 Hours	2
7	Vacuum Bake	12-14 Hours	3
7	Chemical Etch	58% H ₃ PO ₄	1
7	Etchant Temperature	100°C	3
7	Dwell Time After Etch	12-14 Hours	2
8	Vacuum Bake	12-14 Hours	3
8	Chemical Etch	30% HCl	2
8	Etchant Temperature	Room	1
8	Dwell Time After Etch	24-36 Hours	3
9	Vacuum Bake	12-14 Hours	3
9	Chemical Etch	15% HCl	3
9	Etchant Temperature	50°C	2
9	Etchant Temperature	0-2 Hours	1

mean was 1.9406 lb with a standard deviation of only 0.33 lb. Given the parameters used, the lowest reading found was 1.26 lb, which is still above the 1.00 lb minimum requirement. The recommendation

made from this study would be to use the parameters defined for Task 5 at Vendor B.

Table 7. Task 4, Ferrite Metallization Study

Column	Variable Names	Level 1	Level 2
1	Ultrasonic Cleaning	No	Yes
2	Vacuum Bake Temperature	Room	110°C
3	Dwell Time After Etch	0-2 Hours	20 Hours Minimum
4	Nickel Thickness	12 kÅ	5 kÅ
5	Vacuum Bake Time	10-12 Hours	4-6 Hours
6	Solder Cool Rate	< 2°C	> 6°C
7	Vacuum Pressure	< 150	20-30 PSI

Accomplishments

This study is concerned with the different parameters that affect the metallization of ferrite ceramic couplings. Along with the parameters themselves, various levels of these parameters were tried throughout the five tasks that comprise this study. Of the parameters studied, the etching solution (which removes damaged surface material caused by machining) was the most significant. The second important parameter was the nickel overplate. The nickel develops an internal stress, depending on the thickness and chamber pressure in which it is applied. Copper was tried as a substitute but did not have sufficient internal strength.

One important note about the gold layer involves the method in which it is applied. Thermal deposition of the gold (performed by Vendor A) did not yield satisfactory results. Sputtering is the preferred method of applying all three plating layers.

The results of the five tasks had determined a reliable method of producing acceptable metallized ferrite couplings, but due to the time and money constraints, this should not be considered an all-inclusive study of the various parameters and the relationship they have to one another. Further research would be required to ascertain if all significant

conditions were tested and a higher sampling of those parameters would be a better statistical base for the parameters chosen applying all three plating layers.

Table 8. Task 4, Description of Eight Separate Experimental Conditions

Trial	Condition	Indication	Level
1	Ultrasonic Cleaning	No	1
1	Vacuum Bake Temp.	Room	1
1	Dwell Time After Etch	0-2 Hours	1
1	Nickel Thickness	12 kÅ	1
1	Vacuum Bake Time	10-12 Hours	1
1	Solder Cool Rate	<2°C	1
1	Vacuum Pressure	<150	1
2	Ultrasonic Cleaning	No	1
2	Vacuum Bake Temp.	Room	1
2	Dwell Time After Etch	0-2 Hours	1
2	Nickel Thickness	5 kÅ	2
2	Vacuum Bake Time	4-6 Hours	2
2	Solder Cool Rate	>6°C	2
2	Vacuum Pressure	20-30 PS	2
3	Ultrasonic Cleaning	No	1
3	Vacuum Bake Temp.	110°C	2
3	Dwell Time After Etch	20 Hours Minimum	2
3	Nickel Thickness	12 kÅ	1
3	Vacuum Bake Time	10-12 Hours	1
3	Solder Cool Rate	>6°C	2
3	Vacuum Pressure	25-30 PSI	2
4	Ultrasonic Cleaning	No	1
4	Vacuum Bake Temp.	110°C	2
4	Dwell Time After Etch	20 Hours Minimum	2
4	Nickel Thickness	5 kÅ	2
4	Vacuum Bake Time	4-6 Hours	2
4	Solder Cool Rate	No <2°C	1
4	Vacuum Pressure	<150	1
5	Ultrasonic Cleaning	Yes	2
5	Vacuum Bake Temp.	Room	1
5	Dwell Time After Etch	20 Hours Minimum	2
5	Nickel Thickness	4-6 Hours	1
5	Vacuum Bake Time	12 kÅ	2
5	Solder Cool Rate	<2°C	1
5	Vacuum Pressure	<150	2
6	Ultrasonic Cleaning	Yes	2
6	Vacuum Bake Temp.	Room	1
6	Dwell Time After Etch	20 Hours Minimum	2
6	Nickel Thickness	5 kÅ	2
6	Vacuum Bake Time	10-12 Hours	1
6	Solder Cool Rate	>6°C	2
6	Vacuum Pressure	<150	4

Table 8 Continued. Task 4, Description of 8 Separate Conditions

Trial	Condition	Indication	Level
7	Ultrasonic Cleaning	Yes	2
7	Vacuum Bake Temp.	110°C	1
7	Dwell Time After Etch	0-2 Hours	1
7	Nickel Thickness	12 kÅ	2
7	Vacuum Bake Time	4-6 Hours	2
7	Solder Cool Rate	>6°C	1
7	Vacuum Pressure	150	
8	Ultrasonic Cleaning	Yes	2
8	Vacuum Bake Temp.	110°C	2
8	Dwell Time After Etch	0-2 Hours	1
8	Nickel Thickness	5 kÅ	2
8	Vacuum Bake Time	10-12 Hours	1
8	Solder Cool Rate	<2°C	1
8	Vacuum Pressure	25-30 PSI	2

Table 9. Ferrite Metallization Study: Task 5 Parameters for Metallizing Ferrite Couplings

Etching	Procedure
Solution	30% HCl (muriatic acid and DI water if necessary) Solutions to be at room temperature (20-27°C). Parts are not to be processed using ultrasonic actions.
Procedure	Immerse couplings in HCl solution for 2 minutes using slight agitation to ensure even exposure to solution. Double rinse parts in DI water, 1 minute each. Rinse in alcohol and dry.
Vacuum Baking	Within 2 hours after etching, parts are to be baked for 10-12 hours at 110-120°C at a pressure of less than 150 µm vacuum pressure.
Sputter Coating	Within 1 hour after vacuum baking, parts are to be sputter coated. Pump down pressure prior to backfilling with argon to be less than 1 x 10 ⁻⁴ torr, and argon pressure to be 10-20 millitorr.
Metallization Scheme	First layer: chrome at 670-1000 Angstroms Second Layer*: Nickel at 11,000-13,000 angstroms Top Layer: Gold at 6000 angstroms minimum (may be applied by thermal deposition).

*Nickel layer is 8000-10,500 angstroms thick; 10 parts selected at random from 250 couplings for soldering.

Appendix A

Definitions of Variables and Levels, Experiment 1, Vendors A and B

1

14:42 TUESDAY, NOVEMBER 27, 1990

STD
DEV

2

14:42 TUESDAY, NOVEMBER 27, 1990

2

2

2

EXPERIMENT 1 VENDOR A

14:42 TUESDAY, NOVEMBER 27, 1990 3

GENERAL LINEAR MODELS PROCEDURE

DEPENDENT VARIABLE: RESPONSE

SOURCE	DF	SUM OF SQUARES	MEAN SQUARE	F VALUE	PR > F	R-SQUARE	C.V.
MODEL	3	5.08363643	1.69454548	20.56	0.0001	0.644622	34.2328
ERROR	34	2.80259778	0.08242935		ROOT MSE		RESPONSE MEAN
CORRECTED TOTAL	37	7.88623421			0.28710511		0.83868421

SOURCE	DF	TYPE I SS	F VALUE	PR > F	DF	TYPE III SS	F VALUE	PR > F
V2	1	1.16790643	14.17	0.0006	0	0.00000000	.	.
V3	0	0.00000000	.	.	0	0.00000000	.	.
V4	1	0.03126579	0.38	0.5421	0	0.00000000	.	.
V5	1	3.88446421	47.12	0.0001	0	0.00000000	.	.
V6	0	0.00000000	.	.	0	0.00000000	.	.
V7	0	0.00000000	.	.	0	0.00000000	.	.

EXPERIMENT 1 VENDOR A

14:42 TUESDAY, NOVEMBER 27, 1990 4

GENERAL LINEAR MODELS PROCEDURE

SCHEFFE'S TEST FOR VARIABLE: RESPONSE

NOTE: THIS TEST CONTROLS THE TYPE I EXPERIMENTWISE ERROR RATE
BUT GENERALLY HAS A HIGHER TYPE II ERROR RATE THAN REGWF
FOR ALL PAIRWISE COMPARISONS

ALPHA=0.05 DF=34 MSE=.0824293
CRITICAL VALUE OF F=4.13002
MINIMUM SIGNIFICANT DIFFERENCE=.18956

WARNING: CELL SIZES ARE NOT EQUAL.
HARMONIC MEAN OF CELL SIZES=18.9474

MEANS WITH THE SAME LETTER ARE NOT SIGNIFICANTLY DIFFERENT.

SCHEFFE GROUPING	MEAN	N	V2
A	1.00500	20	1.5
B	0.65389	18	5

EXPERIMENT 1 VENDOR A

14:42 TUESDAY, NOVEMBER 27, 1990 5

GENERAL LINEAR MODELS PROCEDURE

SCHEFFE'S TEST FOR VARIABLE: RESPONSE

NOTE: THIS TEST CONTROLS THE TYPE I EXPERIMENTWISE ERROR RATE
BUT GENERALLY HAS A HIGHER TYPE II ERROR RATE THAN REGWF
FOR ALL PAIRWISE COMPARISONS

ALPHA=0.05 DF=34 MSE=.0824293
CRITICAL VALUE OF F=4.13002
MINIMUM SIGNIFICANT DIFFERENCE=.18956

WARNING: CELL SIZES ARE NOT EQUAL.
HARMONIC MEAN OF CELL SIZES=18.9474

MEANS WITH THE SAME LETTER ARE NOT SIGNIFICANTLY DIFFERENT.

SCHEFFE GROUPING	MEAN	N	V3
A	1.00500	20	80
B	0.65389	18	50

GENERAL LINEAR MODELS PROCEDURE

SCHEFFE'S TEST FOR VARIABLE: RESPONSE

NOTE: THIS TEST CONTROLS THE TYPE I EXPERIMENTWISE ERROR RATE
BUT GENERALLY HAS A HIGHER TYPE II ERROR RATE THAN REGWF
FOR ALL PAIRWISE COMPARISONS

ALPHA=0.05 DF=34 MSE=.0824293
CRITICAL VALUE OF F=4.13002
MINIMUM SIGNIFICANT DIFFERENCE=0.1893

MEANS WITH THE SAME LETTER ARE NOT SIGNIFICANTLY DIFFERENT.

SCHEFFE	GROUPING	MEAN	N	V4
	A	0.86737	19	750
	A			
	A	0.81000	19	250

EXPERIMENT 1 VENDOR A

14:42 TUESDAY, NOVEMBER 27, 1990

7

GENERAL LINEAR MODELS PROCEDURE

SCHEFFE'S TEST FOR VARIABLE: RESPONSE

NOTE: THIS TEST CONTROLS THE TYPE I EXPERIMENTWISE ERROR RATE
BUT GENERALLY HAS A HIGHER TYPE II ERROR RATE THAN REGWF
FOR ALL PAIRWISE COMPARISONS

ALPHA=0.05 DF=34 MSE=.0824293
CRITICAL VALUE OF F=4.13002
MINIMUM SIGNIFICANT DIFFERENCE=0.1893

MEANS WITH THE SAME LETTER ARE NOT SIGNIFICANTLY DIFFERENT.

SCHEFFE	GROUPING	MEAN	N	V5
	A	1.15947	19	NI
	B	0.51789	19	CU

EXPERIMENT 1 VENDOR A

14:42 TUESDAY, NOVEMBER 27, 1990

8

GENERAL LINEAR MODELS PROCEDURE

SCHEFFE'S TEST FOR VARIABLE: RESPONSE

NOTE: THIS TEST CONTROLS THE TYPE I EXPERIMENTWISE ERROR RATE
BUT GENERALLY HAS A HIGHER TYPE II ERROR RATE THAN REGWF
FOR ALL PAIRWISE COMPARISONS

ALPHA=0.05 DF=34 MSE=.0824293
CRITICAL VALUE OF F=4.13002
MINIMUM SIGNIFICANT DIFFERENCE=0.1893

MEANS WITH THE SAME LETTER ARE NOT SIGNIFICANTLY DIFFERENT.

SCHEFFE	GROUPING	MEAN	N	V6
	A	0.86737	19	LO
	A			
	A	0.81000	19	HI

EXPERIMENT 1 VENDOR A

14:42 TUESDAY, NOVEMBER 27, 1990

9

GENERAL LINEAR MODELS PROCEDURE

SCHEFFE'S TEST FOR VARIABLE: RESPONSE

NOTE: THIS TEST CONTROLS THE TYPE I EXPERIMENTWISE ERROR RATE
BUT GENERALLY HAS A HIGHER TYPE II ERROR RATE THAN REGWF
FOR ALL PAIRWISE COMPARISONS

ALPHA=0.05 DF=34 MSE=.0824293
CRITICAL VALUE OF F=4.13002
MINIMUM SIGNIFICANT DIFFERENCE=0.1893

MEANS WITH THE SAME LETTER ARE NOT SIGNIFICANTLY DIFFERENT.

SCHEFFE	GROUPING	MEAN	N	V7
	A	1.15947	19	-5
	B	0.51789	19	-7

19-M -1990 16:17:58

TRIAL 1, STRAP, BETWEEN FERRITE GRAINS
Vert= 524 counts Disp= 1

Preset=
Elapsed=

100 secs
71 secs

TABLE 3.A.3

TABLE 3.A.4

19-M --1990 16:02:56

TRIAL 1, FERRITE

Vert= 2421 counts

Disp= 1

Preset=

100 secs

Elapsed=

100 secs

TABLE 3.A.5

19-Mar-1990 16:41:11

TRIAL 4, STRAP

Vert= 1467 counts Disp= 1

Preset= 100 secs

Elapsed= 100 secs

TABLE 3.A.11

TABLE 3.A.12

TABLE 3.A.14

12 Jul 1998 11:01:00
TRIAL 8, FERRITE

Vert= 3110 counts Disp= 1

Preset= 100 secs
Elapsed= 100 secs

20 KV

TABLE 3.A.15

GENERAL LINEAR MODELS PROCEDURE

DEPENDENT VARIABLE: RESPONSE

SOURCE	DF	SUM OF SQUARES	MEAN SQUARE	F VALUE	PR > F	R-SQUARE	C.V.
MODEL	3	0.32393697	0.10797899	6.87	0.0012	0.415465	57.7790
ERROR	29	0.45576000	0.01571586			ROOT MSE	RESPONSE MEAN
CORRECTED TOTAL	32	0.77969697				0.12536292	0.21696970

SOURCE	DF	TYPE I SS	F VALUE	PR > F	DF	TYPE III SS	F VALUE	PR > F
V2	1	0.18400285	11.71	0.0019	0	0.00000000	.	.
V3	0	0.00000000	.	.	0	0.00000000	.	.
V4	1	0.00526217	0.33	0.5673	0	0.00000000	.	.
V5	1	0.13467195	8.57	0.0066	0	0.00000000	.	.
V6	0	0.00000000	.	.	0	0.00000000	.	.
V7	0	0.00000000	.	.	0	0.00000000	.	.

EXPERIMENT 1 VENDOR B

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GENERAL LINEAR MODELS PROCEDURE

SCHEFFE'S TEST FOR VARIABLE: RESPONSE

NOTE: THIS TEST CONTROLS THE TYPE I EXPERIMENTWISE ERROR RATE
BUT GENERALLY HAS A HIGHER TYPE II ERROR RATE THAN REGWF
FOR ALL PAIRWISE COMPARISONS

ALPHA=0.05 DF=29 MSE=.0157159
CRITICAL VALUE OF F=4.18296
MINIMUM SIGNIFICANT DIFFERENCE=.08931

WARNING: CELL SIZES ARE NOT EQUAL.
HARMONIC MEAN OF CELL SIZES=16.4848

MEANS WITH THE SAME LETTER ARE NOT SIGNIFICANTLY DIFFERENT.

SCHEFFE	GROUPING	MEAN	N	V2
	A	0.28941	17	10
	B	0.14000	16	20

EXPERIMENT 1 VENDOR B

14:42 TUESDAY, NOVEMBER 27, 1990 14

GENERAL LINEAR MODELS PROCEDURE

SCHEFFE'S TEST FOR VARIABLE: RESPONSE

NOTE: THIS TEST CONTROLS THE TYPE I EXPERIMENTWISE ERROR RATE
BUT GENERALLY HAS A HIGHER TYPE II ERROR RATE THAN REGWF
FOR ALL PAIRWISE COMPARISONS

ALPHA=0.05 DF=29 MSE=.0157159
CRITICAL VALUE OF F=4.18296
MINIMUM SIGNIFICANT DIFFERENCE=.08931

WARNING: CELL SIZES ARE NOT EQUAL.
HARMONIC MEAN OF CELL SIZES=16.4848

MEANS WITH THE SAME LETTER ARE NOT SIGNIFICANTLY DIFFERENT.

SCHEFFE	GROUPING	MEAN	N	V3
	A	0.28941	17	50
	B	0.14000	16	80

GENERAL LINEAR MODELS PROCEDURE

SCHEFFE'S TEST FOR VARIABLE: RESPONSE

NOTE: THIS TEST CONTROLS THE TYPE I EXPERIMENTWISE ERROR RATE
BUT GENERALLY HAS A HIGHER TYPE II ERROR RATE THAN REGWF
FOR ALL PAIRWISE COMPARISONS

ALPHA=0.05 DF=29 MSE=.0157159
CRITICAL VALUE OF F=4.18296
MINIMUM SIGNIFICANT DIFFERENCE=.08931

WARNING: CELL SIZES ARE NOT EQUAL.
HARMONIC MEAN OF CELL SIZES=16.4848

MEANS WITH THE SAME LETTER ARE NOT SIGNIFICANTLY DIFFERENT.

SCHEFFE	GROUPING	MEAN	N	V4
	A	0.24000	17	13K
	A			
	A	0.19250	16	4K

EXPERIMENT 1 VENDOR B

14:42 TUESDAY, NOVEMBER 27, 1990 16

GENERAL LINEAR MODELS PROCEDURE

SCHEFFE'S TEST FOR VARIABLE: RESPONSE

NOTE: THIS TEST CONTROLS THE TYPE I EXPERIMENTWISE ERROR RATE
BUT GENERALLY HAS A HIGHER TYPE II ERROR RATE THAN REGWF
FOR ALL PAIRWISE COMPARISONS

ALPHA=0.05 DF=29 MSE=.0157159
CRITICAL VALUE OF F=4.18296
MINIMUM SIGNIFICANT DIFFERENCE=.09031

WARNING: CELL SIZES ARE NOT EQUAL.
HARMONIC MEAN OF CELL SIZES=16.1212

MEANS WITH THE SAME LETTER ARE NOT SIGNIFICANTLY DIFFERENT.

SCHEFFE	GROUPING	MEAN	N	V5
	A	0.27368	19	NI
	B	0.14000	14	CU

EXPERIMENT 1 VENDOR B

14:42 TUESDAY, NOVEMBER 27, 1990 17

GENERAL LINEAR MODELS PROCEDURE

SCHEFFE'S TEST FOR VARIABLE: RESPONSE

NOTE: THIS TEST CONTROLS THE TYPE I EXPERIMENTWISE ERROR RATE
BUT GENERALLY HAS A HIGHER TYPE II ERROR RATE THAN REGWF
FOR ALL PAIRWISE COMPARISONS

ALPHA=0.05 DF=29 MSE=.0157159
CRITICAL VALUE OF F=4.18296
MINIMUM SIGNIFICANT DIFFERENCE=.08931

WARNING: CELL SIZES ARE NOT EQUAL.
HARMONIC MEAN OF CELL SIZES=16.4848

MEANS WITH THE SAME LETTER ARE NOT SIGNIFICANTLY DIFFERENT.

SCHEFFE	GROUPING	MEAN	N	V6
	A	0.24000	17	HI
	A			
	A	0.19250	16	LO

EXPERIMENT 1 VENDOR B

14:42 TUESDAY, NOVEMBER 27, 1990 18

GENERAL LINEAR MODELS PROCEDURE

SCHEFFE'S TEST FOR VARIABLE: RESPONSE

NOTE: THIS TEST CONTROLS THE TYPE I EXPERIMENTWISE ERROR RATE
BUT GENERALLY HAS A HIGHER TYPE II ERROR RATE THAN REGWF
FOR ALL PAIRWISE COMPARISONS

ALPHA=0.05 DF=29 MSE=.0157159

CRITICAL VALUE OF F=4.18296

MINIMUM SIGNIFICANT DIFFERENCE=.09031

WARNING: CELL SIZES ARE NOT EQUAL.

HARMONIC MEAN OF CELL SIZES=16.1212

MEANS WITH THE SAME LETTER ARE NOT SIGNIFICANTLY DIFFERENT.

SCHEFFE	GROUPING	MEAN	N	V7
	A	0.27368	19	-7
	B	0.14000	14	-5

9-Mar-1990 09:39:19

TRIAL 2, FERRITE

Vert= 1782 counts Disp= 1

Preset= 100 secs

Elapsed= 100 secs

20 KV

9-Mar-1990 09:55:38

TRIAL 3, STRAP

Vert= 1590 counts Disp= 1

Preset= 100 secs

Elapsed= 100 secs

9-Mar-1990 10:17:26

TRIAL 6, STRAP

Vert= 2031 counts Disp= 1

Preset=

100 secs

Elapsed=

100 secs

20 KV

9-Mar-1990 10:19:55

TRIAL 6, FERRITE

Vert= 1852 counts Disp= 1

Preset=

100 secs

Elapsed=

100 secs

20 KV

3-Mar-1990 10:11:44

TRIAL 7, STRAP, TOP

Vert= 1650 counts Disp= 1

Preset= 100 secs

Elapsed= 100 secs

9-Mar-1990 10:06:21

TRIAL 7, FERRITE, SIDE

Vert= 2351 counts Disp= 1

Preset= 100 secs

Elapsed= 100 secs

20 KV

Appendix B

Definitions of Variables and Levels, Experiment 2

V1 = VENDOR	V2 = ARGON PRESSURE
V3 = ETCHING SOLUTION	V4 = OVERPLATE THICKNESS
V5 = TYPE OF OVERPLATE	V6 = FERRITE POROSITY
V7 = PUMP DOWN PRESSURE	V8 = PRECLEAN
V9 = TYPE OF FINISH	V10 = CHROME THICKNESS
V11 = VACUUM BAKE TIME	V12 = ETCHANT TEMPERATURE
V13 = DWELL TIME AFTER ETCH	V14 = ULTRASONIC CLEANING
V15 = VACUUM BAKE TEMPERATURE	V16 = SOLDER COOL RATE
V17 = VACUUM PRESSURE FOR COOLING SOLDER	R = RESPONSE, STRENGTH

GENERAL LINEAR MODELS PROCEDURE

CLASS	LEVELS	VALUES
V1	2	A B
V2	2	1.5 20
V3	2	10 80
V4	2	22 45
V8	2	NO YE
V9	2	CO FI
V10	2	15 7.5

NOTE: ALL DEPENDENT VARIABLES ARE CONSISTENT WITH RESPECT TO THE PRESENCE OR ABSENCE OF MISSING VALUES. HOWEVER, ONLY 72 OBSERVATIONS CAN BE USED IN THIS ANALYSIS.

EXPERIMENT 2

14:42 TUESDAY, NOVEMBER 27, 1990 21

GENERAL LINEAR MODELS PROCEDURE

DEPENDENT VARIABLE: RESPONSE

SOURCE	DF	SUM OF SQUARES	MEAN SQUARE	F VALUE	PR > F	R-SQUARE	C.V.
MODEL	7	19.22624861	2.74660694	32.87	0.0001	0.782378	44.5482
ERROR	64	5.34786250	0.08356035				
CORRECTED TOTAL	71	24.57411111					

ROOT MSE 0.28906807 RESPONSE MEAN 0.64888889

SOURCE	DF	TYPE I SS	F VALUE	PR > F	DF	TYPE III SS	F VALUE	PR > F
V1	1	2.84711174	34.07	0.0001	1	3.33878776	39.96	0.0001
V2	1	0.50917677	6.09	0.0162	1	0.53576160	6.41	0.0138
V3	1	2.98106152	35.68	0.0001	1	2.63303083	31.51	0.0001
V4	1	4.83987714	57.92	0.0001	1	3.73870314	44.74	0.0001
V8	1	1.99128523	23.83	0.0001	1	0.97550006	11.67	0.0011
V9	1	6.04910231	72.39	0.0001	1	5.89170314	70.51	0.0001
V10	1	0.00863391	0.10	0.7489	1	0.00863391	0.10	0.7489

EXPERIMENT 2

14:42 TUESDAY, NOVEMBER 27, 1990 22

GENERAL LINEAR MODELS PROCEDURE

SCHEFFE'S TEST FOR VARIABLE: RESPONSE

NOTE: THIS TEST CONTROLS THE TYPE I EXPERIMENTWISE ERROR RATE
BUT GENERALLY HAS A HIGHER TYPE II ERROR RATE THAN REGWF
FOR ALL PAIRWISE COMPARISONS

ALPHA=0.05 DF=64 MSE=.0835604
CRITICAL VALUE OF F=3.99092
MINIMUM SIGNIFICANT DIFFERENCE=.13696

WARNING: CELL SIZES ARE NOT EQUAL.
HARMONIC MEAN OF CELL SIZES=35.5556

MEANS WITH THE SAME LETTER ARE NOT SIGNIFICANTLY DIFFERENT.

SCHEFFE GROUPING	MEAN	N	V1
A	0.82675	40	A
B	0.42656	32	B

EXPERIMENT 2

14:42 TUESDAY, NOVEMBER 27, 1990 23

GENERAL LINEAR MODELS PROCEDURE

SCHEFFE'S TEST FOR VARIABLE: RESPONSE

NOTE: THIS TEST CONTROLS THE TYPE I EXPERIMENTWISE ERROR RATE
BUT GENERALLY HAS A HIGHER TYPE II ERROR RATE THAN REGWF
FOR ALL PAIRWISE COMPARISONS

ALPHA=0.05 DF=64 MSE=.0835604
CRITICAL VALUE OF F=3.99092
MINIMUM SIGNIFICANT DIFFERENCE=.13632

WARNING: CELL SIZES ARE NOT EQUAL.
HARMONIC MEAN OF CELL SIZES=35.8889

MEANS WITH THE SAME LETTER ARE NOT SIGNIFICANTLY DIFFERENT.

SCHEFFE GROUPING	MEAN	N	V2
A	0.71658	38	20

B 0.57324 34 1.5
EXPERIMENT 2

14:42 TUESDAY, NOVEMBER 27, 1990 24

GENERAL LINEAR MODELS PROCEDURE

SCHEFFE'S TEST FOR VARIABLE: RESPONSE

NOTE: THIS TEST CONTROLS THE TYPE I EXPERIMENTWISE ERROR RATE
BUT GENERALLY HAS A HIGHER TYPE II ERROR RATE THAN REGWF
FOR ALL PAIRWISE COMPARISONS

ALPHA=0.05 DF=64 MSE=.0835604
CRITICAL VALUE OF F=3.99092
MINIMUM SIGNIFICANT DIFFERENCE=.13696

WARNING: CELL SIZES ARE NOT EQUAL.
HARMONIC MEAN OF CELL SIZES=35.5556

MEANS WITH THE SAME LETTER ARE NOT SIGNIFICANTLY DIFFERENT.

SCHEFFE	GROUPING	MEAN	N	V3
	A	0.80150	40	80
	B	0.45812	32	10

EXPERIMENT 2

14:42 TUESDAY, NOVEMBER 27, 1990 25

GENERAL LINEAR MODELS PROCEDURE

SCHEFFE'S TEST FOR VARIABLE: RESPONSE

NOTE: THIS TEST CONTROLS THE TYPE I EXPERIMENTWISE ERROR RATE
BUT GENERALLY HAS A HIGHER TYPE II ERROR RATE THAN REGWF
FOR ALL PAIRWISE COMPARISONS

ALPHA=0.05 DF=64 MSE=.0835604
CRITICAL VALUE OF F=3.99092
MINIMUM SIGNIFICANT DIFFERENCE=.13632

WARNING: CELL SIZES ARE NOT EQUAL.
HARMONIC MEAN OF CELL SIZES=35.8889

MEANS WITH THE SAME LETTER ARE NOT SIGNIFICANTLY DIFFERENT.

SCHEFFE	GROUPING	MEAN	N	V4
	A	0.96029	34	22
	B	0.37026	38	45

EXPERIMENT 2

14:42 TUESDAY, NOVEMBER 27, 1990 26

GENERAL LINEAR MODELS PROCEDURE

SCHEFFE'S TEST FOR VARIABLE: RESPONSE

NOTE: THIS TEST CONTROLS THE TYPE I EXPERIMENTWISE ERROR RATE
BUT GENERALLY HAS A HIGHER TYPE II ERROR RATE THAN REGWF
FOR ALL PAIRWISE COMPARISONS

ALPHA=0.05 DF=64 MSE=.0835604
CRITICAL VALUE OF F=3.99092
MINIMUM SIGNIFICANT DIFFERENCE=.13632

WARNING: CELL SIZES ARE NOT EQUAL.
HARMONIC MEAN OF CELL SIZES=35.8889

MEANS WITH THE SAME LETTER ARE NOT SIGNIFICANTLY DIFFERENT.

SCHEFFE	GROUPING	MEAN	N	VB
	A	0.82294	34	NO

B 0.49316 38 VE
EXPERIMENT 2

14:42 TUESDAY, NOVEMBER 27, 1990 27

GENERAL LINEAR MODELS PROCEDURE

SCHEFFE'S TEST FOR VARIABLE: RESPONSE

NOTE: THIS TEST CONTROLS THE TYPE I EXPERIMENTWISE ERROR RATE
BUT GENERALLY HAS A HIGHER TYPE II ERROR RATE THAN REGWF
FOR ALL PAIRWISE COMPARISONS

ALPHA=0.05 DF=64 MSE=.0835604
CRITICAL VALUE OF F=3.99092
MINIMUM SIGNIFICANT DIFFERENCE=.13632

WARNING: CELL SIZES ARE NOT EQUAL.
HARMONIC MEAN OF CELL SIZES=35.8889

MEANS WITH THE SAME LETTER ARE NOT SIGNIFICANTLY DIFFERENT.

SCHEFFE	GROUPING	MEAN	N	V9
	A	0.93684	38	FI
B		0.32706	34	CO
EXPERIMENT 2				

14:42 TUESDAY, NOVEMBER 27, 1990 28

GENERAL LINEAR MODELS PROCEDURE

SCHEFFE'S TEST FOR VARIABLE: RESPONSE

NOTE: THIS TEST CONTROLS THE TYPE I EXPERIMENTWISE ERROR RATE
BUT GENERALLY HAS A HIGHER TYPE II ERROR RATE THAN REGWF
FOR ALL PAIRWISE COMPARISONS

ALPHA=0.05 DF=64 MSE=.0835604
CRITICAL VALUE OF F=3.99092
MINIMUM SIGNIFICANT DIFFERENCE=.13696

WARNING: CELL SIZES ARE NOT EQUAL.
HARMONIC MEAN OF CELL SIZES=35.5556

MEANS WITH THE SAME LETTER ARE NOT SIGNIFICANTLY DIFFERENT.

SCHEFFE	GROUPING	MEAN	N	V10
	A	0.72281	32	15
	A			
	A	0.58975	40	7.5

Appendix C

Definitions of Variables and Levels, Experiment 3

14:42 TUESDAY, NOVEMBER 27, 1990 29

V1 = VENDOR	V2 = ARGON PRESSURE
V3 = ETCHING SOLUTION	V4 = OVERPLATE THICKNESS
V5 = TYPE OF OVERPLATE	V6 = FERRITE POROSITY
V7 = PUMP DOWN PRESSURE	V8 = PRECLEAN
V9 = TYPE OF FINISH	V10 = CHROME THICKNESS
V11 = VACUUM BAKE TIME	V12 = ETCHANT TEMPERATURE
V13 = DWELL TIME AFTER ETCH	V14 = ULTRASONIC CLEANING
V15 = VACUUM BAKE TEMPERATURE	V16 = SOLDER COOL RATE
V17 = VACUUM PRESSURE FOR COOLING SOLDER	R = RESPONSE, STRENGTH

																													M E A N		R A N G E		S T D D E V
O B S	V 1	V 2	V 3	V 4	V 5	V 6	V 7	V 8	V 9	V 10	V 11	V 12	V 13	V 14	V 15	V 16	R 1	R 2	R 3	R 4	R 5	R 6	R 7	R 8	R 9	R 10	N						
1	—	—	58%	—	—	—	—	—	—	—	NO	ROOM 0-2	—	—	—	—	0.68	0.50	0.09	0.15	0.51	0.04	—	0.33	—	0.20	8	0.31	0.64	0.23			
2	—	—	30%	—	—	—	—	—	—	—	NO	50C 12-1	—	—	—	—	2.07	1.59	1.83	1.84	1.37	1.83	2.73	2.73	1.88	2.07	10	1.99	1.36	0.44			
3	—	—	15%	—	—	—	—	—	—	—	NO	100C 24-3	—	—	—	—	1.67	0.33	0.57	1.47	0.72	0.79	0.97	0.92	0.84	0.92	10	0.92	1.34	0.39			
4	—	—	58%	—	—	—	—	—	—	—	4-6	50C 24-3	—	—	—	—	1.52	2.55	1.01	1.21	1.19	1.63	1.20	1.28	1.16	1.42	10	1.42	1.54	0.44			
5	—	—	30%	—	—	—	—	—	—	—	4-6	100C 0-2	—	—	—	—	1.68	1.32	0.56	1.76	1.95	0.88	1.53	0.96	1.37	1.33	10	1.33	1.39	0.43			
6	—	—	15%	—	—	—	—	—	—	—	4-6	ROOM 12-1	—	—	—	—	0.82	—	0.24	0.93	0.68	2.93	1.54	0.44	1.21	0.35	9	1.02	2.69	0.83			
7	—	—	58%	—	—	—	—	—	—	—	12-1	100C 12-1	—	—	—	—	1.16	1.76	1.58	1.26	1.66	1.26	1.40	1.01	1.28	1.87	10	1.42	0.86	0.28			
8	—	—	30%	—	—	—	—	—	—	—	12-1	ROOM 24-3	—	—	—	—	2.10	2.47	1.93	2.58	1.36	2.36	2.27	1.36	1.87	2.57	10	2.09	1.22	0.45			
9	—	—	15%	—	—	—	—	—	—	—	12-1	50C 0-2	—	—	—	—	1.53	—	0.53	1.34	0.94	1.58	0.99	1.58	0.40	0.99	9	1.10	1.18	0.44			

GENERAL LINEAR MODELS PROCEDURE

CLASS LEVEL INFORMATION

CLASS	LEVELS	VALUES
V11	3	NO 12-1 4-6
V3	3	15% 30% 58%
V12	3	ROOM 100C 50C
V13	3	0-2 12-1 24-3

NUMBER OF OBSERVATIONS IN DATA SET = 90

NOTE: ALL DEPENDENT VARIABLES ARE CONSISTENT WITH RESPECT TO THE PRESENCE OR ABSENCE OF MISSING VALUES. HOWEVER, ONLY 86 OBSERVATIONS CAN BE USED IN THIS ANALYSIS.

EXPERIMENT 3

14:42 TUESDAY, NOVEMBER 27, 1990 31

GENERAL LINEAR MODELS PROCEDURE

DEPENDENT VARIABLE: RESPONSE

SOURCE	DF	SUM OF SQUARES	MEAN SQUARE	F VALUE	PR > F	R-SQUARE	C.V.
MODEL	8	21.62826245	2.70353281	12.57	0.0001	0.566405	35.2038
ERROR	77	16.55686778	0.21502426			ROOT MSE	RESPONSE MEAN
CORRECTED TOTAL	85	38.18513023			0.46370708		1.31720930

SOURCE	DF	TYPE I SS	F VALUE	PR > F	DF	TYPE III SS	F VALUE	PR > F
V11	2	2.65430265	6.17	0.0033	2	3.06245239	7.12	0.0015
V3	2	11.14105734	25.91	0.0001	2	11.69601477	27.20	0.0001
V12	2	2.02869247	4.72	0.0117	2	2.04984563	4.77	0.0112
V13	2	5.80421000	13.50	0.0001	2	5.80421000	13.50	0.0001

EXPERIMENT 3

14:42 TUESDAY, NOVEMBER 27, 1990 32

GENERAL LINEAR MODELS PROCEDURE

SCHEFFE'S TEST FOR VARIABLE: RESPONSE

NOTE: THIS TEST CONTROLS THE TYPE I EXPERIMENTWISE ERROR RATE
BUT GENERALLY HAS A HIGHER TYPE II ERROR RATE THAN REGWF
FOR ALL PAIRWISE COMPARISONS

ALPHA=0.05 DF=77 MSE=0.215024
CRITICAL VALUE OF F=3.11537
MINIMUM SIGNIFICANT DIFFERENCE=.30577

WARNING: CELL SIZES ARE NOT EQUAL.
HARMONIC MEAN OF CELL SIZES=28.6588

MEANS WITH THE SAME LETTER ARE NOT SIGNIFICANTLY DIFFERENT.

SCHEFFE	GROUPING	MEAN	N	V11
	A	1.5514	29	12-1
	A			
B	A	1.2638	29	4-6
B				
B		1.1300	28	NO

EXPERIMENT 3

14:42 TUESDAY, NOVEMBER 27, 1990 33

GENERAL LINEAR MODELS PROCEDURE

SCHEFFE'S TEST FOR VARIABLE: RESPONSE

NOTE: THIS TEST CONTROLS THE TYPE I EXPERIMENTWISE ERROR RATE
BUT GENERALLY HAS A HIGHER TYPE II ERROR RATE THAN REGWF
FOR ALL PAIRWISE COMPARISONS

ALPHA=0.05 DF=77 MSE=0.215024
CRITICAL VALUE OF F=3.11537
MINIMUM SIGNIFICANT DIFFERENCE=.30589

WARNING: CELL SIZES ARE NOT EQUAL.
HARMONIC MEAN OF CELL SIZES=28.6364

MEANS WITH THE SAME LETTER ARE NOT SIGNIFICANTLY DIFFERENT.

SCHEFFE	GROUPING	MEAN	N	V3
	A	1.8050	30	30%
	B	1.1039	28	58%

B
B 1.0079 28 15%
EXPERIMENT 3

14:42 TUESDAY, NOVEMBER 27, 1990 34

GENERAL LINEAR MODELS PROCEDURE

SCHEFFE'S TEST FOR VARIABLE: RESPONSE
NOTE: THIS TEST CONTROLS THE TYPE I EXPERIMENTWISE ERROR RATE
BUT GENERALLY HAS A HIGHER TYPE II ERROR RATE THAN REGWF
FOR ALL PAIRWISE COMPARISONS

ALPHA=0.05 DF=77 MSE=0.215024
CRITICAL VALUE OF F=3.11537
MINIMUM SIGNIFICANT DIFFERENCE=.30603

WARNING: CELL SIZES ARE NOT EQUAL.
HARMONIC MEAN OF CELL SIZES=28.6114

MEANS WITH THE SAME LETTER ARE NOT SIGNIFICANTLY DIFFERENT.

SCHEFFE	GROUPING	MEAN	N	V12
	A	1.5169	29	50C
	A			
B	A	1.2260	30	100C
B				
B		1.2041	27	ROOM

EXPERIMENT 3

14:42 TUESDAY, NOVEMBER 27, 1990 35

GENERAL LINEAR MODELS PROCEDURE

SCHEFFE'S TEST FOR VARIABLE: RESPONSE
NOTE: THIS TEST CONTROLS THE TYPE I EXPERIMENTWISE ERROR RATE
BUT GENERALLY HAS A HIGHER TYPE II ERROR RATE THAN REGWF
FOR ALL PAIRWISE COMPARISONS

ALPHA=0.05 DF=77 MSE=0.215024
CRITICAL VALUE OF F=3.11537
MINIMUM SIGNIFICANT DIFFERENCE=.30603

WARNING: CELL SIZES ARE NOT EQUAL.
HARMONIC MEAN OF CELL SIZES=28.6114

MEANS WITH THE SAME LETTER ARE NOT SIGNIFICANTLY DIFFERENT.

SCHEFFE	GROUPING	MEAN	N	V13
	A	1.4938	29	12-1
	A			
	A	1.4747	30	24-3
B		0.9526	27	0-2

Appendix D

Definitions of Variables and Levels, Experiment 4

EXPERIMENT 4

14:42 TUESDAY, NOVEMBER 27, 1990 38

GENERAL LINEAR MODELS PROCEDURE

DEPENDENT VARIABLE: RESPONSE

SOURCE	DF	SUM OF SQUARES	MEAN SQUARE	F VALUE	PR > F	R-SQUARE	C.V.
MODEL	7	3.44882688	0.49268955	5.58	0.0001	0.361296	18.6405
ERROR	69	6.09689000	0.08836072		ROOT MSE		RESPONSE MEAN
CORRECTED TOTAL	76	9.54571688			0.29725532		1.59467532

SOURCE	DF	TYPE I SS	F VALUE	PR > F	DF	TYPE III SS	F VALUE	PR > F
V11	1	0.55054607	6.23	0.0149	1	0.56650288	6.41	0.0136
V15	1	0.10580123	1.20	0.2777	1	0.10606898	1.20	0.2770
V13	1	0.58067009	6.57	0.0125	1	0.53100458	6.01	0.0168
V4	1	0.04842856	0.55	0.4616	1	0.03230085	0.37	0.5474
V14	1	0.33995262	3.85	0.0539	1	0.26544119	3.00	0.0875
V16	1	1.82290509	20.63	0.0001	1	1.82133000	20.61	0.0001
V17	1	0.00052322	0.01	0.9389	1	0.00052322	0.01	0.9389

EXPERIMENT 4

14:42 TUESDAY, NOVEMBER 27, 1990 39

GENERAL LINEAR MODELS PROCEDURE

SCHEFFE'S TEST FOR VARIABLE: RESPONSE

NOTE: THIS TEST CONTROLS THE TYPE I EXPERIMENTWISE ERROR RATE
BUT GENERALLY HAS A HIGHER TYPE II ERROR RATE THAN REGWF
FOR ALL PAIRWISE COMPARISONS

ALPHA=0.05 DF=69 MSE=.0883607
CRITICAL VALUE OF F=3.97981
MINIMUM SIGNIFICANT DIFFERENCE=.13526

WARNING: CELL SIZES ARE NOT EQUAL.
HARMONIC MEAN OF CELL SIZES=38.4416

MEANS WITH THE SAME LETTER ARE NOT SIGNIFICANTLY DIFFERENT.

SCHEFFE	GROUPING	MEAN	N	V11
	A	1.67600	40	4
	B	1.50676	37	10

EXPERIMENT 4

14:42 TUESDAY, NOVEMBER 27, 1990 40

GENERAL LINEAR MODELS PROCEDURE

SCHEFFE'S TEST FOR VARIABLE: RESPONSE

NOTE: THIS TEST CONTROLS THE TYPE I EXPERIMENTWISE ERROR RATE
BUT GENERALLY HAS A HIGHER TYPE II ERROR RATE THAN REGWF
FOR ALL PAIRWISE COMPARISONS

ALPHA=0.05 DF=69 MSE=.0883607
CRITICAL VALUE OF F=3.97981
MINIMUM SIGNIFICANT DIFFERENCE=.13526

WARNING: CELL SIZES ARE NOT EQUAL.
HARMONIC MEAN OF CELL SIZES=38.4416

MEANS WITH THE SAME LETTER ARE NOT SIGNIFICANTLY DIFFERENT.

SCHEFFE	GROUPING	MEAN	N	V15
	A	1.62700	40	RO
	A			

A 1.55973 37 110
EXPERIMENT 4

14:42 TUESDAY, NOVEMBER 27, 1990 41

GENERAL LINEAR MODELS PROCEDURE

SCHEFFE'S TEST FOR VARIABLE: RESPONSE

NOTE: THIS TEST CONTROLS THE TYPE I EXPERIMENTWISE ERROR RATE
BUT GENERALLY HAS A HIGHER TYPE II ERROR RATE THAN REGWF
FOR ALL PAIRWISE COMPARISONS

ALPHA=0.05 DF=69 MSE=.0883607
CRITICAL VALUE OF F=3.97981
MINIMUM SIGNIFICANT DIFFERENCE=.13526

WARNING: CELL SIZES ARE NOT EQUAL.
HARMONIC MEAN OF CELL SIZES=38.4416

MEANS WITH THE SAME LETTER ARE NOT SIGNIFICANTLY DIFFERENT.

SCHEFFE	GROUPING	MEAN	N	V13
	A	1.67325	40	20
	B	1.50973	37	02

EXPERIMENT 4

14:42 TUESDAY, NOVEMBER 27, 1990 42

GENERAL LINEAR MODELS PROCEDURE

SCHEFFE'S TEST FOR VARIABLE: RESPONSE

NOTE: THIS TEST CONTROLS THE TYPE I EXPERIMENTWISE ERROR RATE
BUT GENERALLY HAS A HIGHER TYPE II ERROR RATE THAN REGWF
FOR ALL PAIRWISE COMPARISONS

ALPHA=0.05 DF=69 MSE=.0883607
CRITICAL VALUE OF F=3.97981
MINIMUM SIGNIFICANT DIFFERENCE=.13526

WARNING: CELL SIZES ARE NOT EQUAL.
HARMONIC MEAN OF CELL SIZES=38.4416

MEANS WITH THE SAME LETTER ARE NOT SIGNIFICANTLY DIFFERENT.

SCHEFFE	GROUPING	MEAN	N	V4
	A	1.61025	40	12
	A			
	A	1.57784	37	5

EXPERIMENT 4

14:42 TUESDAY, NOVEMBER 27, 1990 43

GENERAL LINEAR MODELS PROCEDURE

SCHEFFE'S TEST FOR VARIABLE: RESPONSE

NOTE: THIS TEST CONTROLS THE TYPE I EXPERIMENTWISE ERROR RATE
BUT GENERALLY HAS A HIGHER TYPE II ERROR RATE THAN REGWF
FOR ALL PAIRWISE COMPARISONS

ALPHA=0.05 DF=69 MSE=.0883607
CRITICAL VALUE OF F=3.97981
MINIMUM SIGNIFICANT DIFFERENCE=.13526

WARNING: CELL SIZES ARE NOT EQUAL.
HARMONIC MEAN OF CELL SIZES=38.4416

MEANS WITH THE SAME LETTER ARE NOT SIGNIFICANTLY DIFFERENT.

SCHEFFE	GROUPING	MEAN	N	V14
	A	1.64875	40	NO
	A			

A 1.53622 37 VE
EXPERIMENT 4

14:42 TUESDAY, NOVEMBER 27, 1990 44

GENERAL LINEAR MODELS PROCEDURE

SCHEFFE'S TEST FOR VARIABLE: RESPONSE

NOTE: THIS TEST CONTROLS THE TYPE I EXPERIMENTWISE ERROR RATE
BUT GENERALLY HAS A HIGHER TYPE II ERROR RATE THAN REGWF
FOR ALL PAIRWISE COMPARISONS

ALPHA=0.05 DF=69 MSE=.0883607
CRITICAL VALUE OF F=3.97981
MINIMUM SIGNIFICANT DIFFERENCE=.13526

WARNING: CELL SIZES ARE NOT EQUAL.
HARMONIC MEAN OF CELL SIZES=38.4416

MEANS WITH THE SAME LETTER ARE NOT SIGNIFICANTLY DIFFERENT.

SCHEFFE	GROUPING	MEAN	N	V16
A		1.76757	37	<2
B		1.43475	40	>6

EXPERIMENT 4

14:42 TUESDAY, NOVEMBER 27, 1990 45

GENERAL LINEAR MODELS PROCEDURE

SCHEFFE'S TEST FOR VARIABLE: RESPONSE

NOTE: THIS TEST CONTROLS THE TYPE I EXPERIMENTWISE ERROR RATE
BUT GENERALLY HAS A HIGHER TYPE II ERROR RATE THAN REGWF
FOR ALL PAIRWISE COMPARISONS

ALPHA=0.05 DF=69 MSE=.0883607
CRITICAL VALUE OF F=3.97981
MINIMUM SIGNIFICANT DIFFERENCE=.13526

WARNING: CELL SIZES ARE NOT EQUAL.
HARMONIC MEAN OF CELL SIZES=38.4416

MEANS WITH THE SAME LETTER ARE NOT SIGNIFICANTLY DIFFERENT.

SCHEFFE	GROUPING	MEAN	N	V17
A		1.60297	37	25
A		1.58700	40	150

Appendix E

Definitions of Variables and Levels, Experiment 5

My dear friend,
I have just received your letter of the 10th inst. and am
glad to hear from you. I am well and hope these few
lines will find you the same. I have been thinking
much of late about the future of our country and
the state of our Union. It seems to me that we are
passing through a great crisis, and that the result
will determine whether we are to remain a united
people or become a collection of warring states.
I believe that the only way to preserve our Union
is by a firm adherence to the principles of liberty
and justice for all. We must not allow ourselves
to be divided by sectional interests or by the passions
of the moment. We must stand together, and we must
stand for the right. I am sure that if we do this,
our Union will be preserved, and our country will
remain a free and happy land. I am, my friend,
your sincere friend,
Wm. Lloyd Garrison

DEFINITIONS OF VARIABLES AND LEVELS, EXPERIMENT 5 14:42 TUESDAY, NOVEMBER 27, 1990 50

V1 = VENDOR	V2 = ARGON PRESSURE
V3 = ETCHING SOLUTION	V4 = OVERPLATE THICKNESS
V5 = TYPE OF OVERPLATE	V6 = FERRITE POROSITY
V7 = PUMP DOWN PRESSURE	V8 = PRECLEAN
V9 = TYPE OF FINISH	V10 = CHROME THICKNESS
V11 = VACUUM BAKE TIME	V12 = ETCHANT TEMPERATURE
V13 = DWELL TIME AFTER ETCH	V14 = ULTRASONIC CLEANING
V15 = VACUUM BAKE TEMPERATURE	V16 = SOLDER COOL RATE
V17 = VACUUM PRESSURE FOR COOLING SOLDER	R = RESPONSE, STRENGTH

OBS	TRIAL	V1	V2	V3	V4	V5	V6	V7	V8	V9	V10	V11	V12	V13	V14	V15	V16	V17	R1	R2	R3	R4	R5	R6	R7	N	MEAN	RANGE	STD_DEV
1	1	A	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	0.08	0.32	1.08	1.00	0.82	0.99	0.72	10	0.64	1.00	0.35
2	2	A	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	0.06	0.88	0.26	0.28	0.32	0.40	0.24	7	0.35	0.82	0.26
3	3	A	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	0.36	0.86	1.06	0.76	0.60	0.42	0.36	9	0.66	0.70	0.27
4	4	A	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	2.34	1.62	0.76	1.62	0.36	0.46	0.90	8	1.23	1.98	0.71
5	5	A	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	1.62	0.54	0.18	0.00	0.18	0.12	.	6	0.44	1.62	0.61
6	6	A	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	1.80	1.48	0.90	0.38	0.36	0.22	0.56	8	0.89	1.58	0.61
7	7	A	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	1.26	2.84	1.14	0.90	0.84	0.68	0.54	7	1.17	2.30	0.78
8	8	A	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	1.80	1.90	1.44	0.54	0.40	0.54	0.40	8	0.95	1.50	0.65
9	9	A	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	0.30	0.90	0.54	0.38	0.26	0.18	0.28	9	0.44	0.72	0.24
10	10	A	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	1.08	0.90	1.50	1.08	1.00	1.44	0.90	8	1.11	0.60	0.23

EXPERIMENT 5, VENDOR A

14:42 TUESDAY, NOVEMBER 27, 1990 51

GENERAL LINEAR MODELS PROCEDURE

CLASS LEVEL INFORMATION

CLASS	LEVELS	VALUES
TRIAL	10	1 10 2 3 4 5 6 7 8 9

NUMBER OF OBSERVATIONS IN DATA SET = 100

NOTE: ALL DEPENDENT VARIABLES ARE CONSISTENT WITH RESPECT TO THE PRESENCE OR ABSENCE OF MISSING VALUES. HOWEVER, ONLY 80 OBSERVATIONS CAN BE USED IN THIS ANALYSIS.

EXPERIMENT 5, VENDOR A

14:42 TUESDAY, NOVEMBER 27, 1990 52

GENERAL LINEAR MODELS PROCEDURE

DEPENDENT VARIABLE: RESPONSE

SOURCE	DF	SUM OF SQUARES	MEAN SQUARE	F VALUE	PR > F	R-SQUARE	C.V.
MODEL	9	7.25408510	0.80600946	3.25	0.0024	0.294519	63.0968
ERROR	70	17.37620365	0.24823148		ROOT MSE		RESPONSE MEAN
CORRECTED TOTAL	79	24.63028875			0.49822834		0.78962500

SOURCE	DF	TYPE I SS	F VALUE	PR > F	DF	TYPE III SS	F VALUE	PR > F
TRIAL	9	7.25408510	3.25	0.0024	9	7.25408510	3.25	0.0024
			EXPERIMENT 5, VENDOR A			14:42 TUESDAY, NOVEMBER 27, 1990		53

GENERAL LINEAR MODELS PROCEDURE

SCHEFFE'S TEST FOR VARIABLE: RESPONSE

NOTE: THIS TEST CONTROLS THE TYPE I EXPERIMENTWISE ERROR RATE
BUT GENERALLY HAS A HIGHER TYPE II ERROR RATE THAN REGWF
FOR ALL PAIRWISE COMPARISONS

ALPHA=0.05 DF=70 MSE=0.248231
CRITICAL VALUE OF F=2.01660
MINIMUM SIGNIFICANT DIFFERENCE=1.0717

WARNING: CELL SIZES ARE NOT EQUAL.
HARMONIC MEAN OF CELL SIZES=7.84558

MEANS WITH THE SAME LETTER ARE NOT SIGNIFICANTLY DIFFERENT.

SCHEFFE	GROUPING	MEAN	N	TRIAL
	A	1.2325	8	4
	A	1.1714	7	7
	A	1.1125	8	10
	A	0.9525	8	8
	A	0.8925	8	6
	A	0.6600	9	3
	A	0.6430	10	1
	A	0.4444	9	9
	A	0.4400	6	5
	A	0.3486	7	2

DEFINITIONS OF VARIABLES AND LEVELS, EXPERIMENT 5 14:42 TUESDAY, NOVEMBER 27, 1990 46

V1 = VENDOR	V2 = ARGON PRESSURE
V3 = ETCHING SOLUTION	V4 = OVERPLATE THICKNESS
V5 = TYPE OF OVERPLATE	V6 = FERRITE POROSITY
V7 = PUMP DOWN PRESSURE	V8 = PRECLEAN
V9 = TYPE OF FINISH	V10 = CHROME THICKNESS
V11 = VACUUM BAKE TIME	V12 = ETCHANT TEMPERATURE
V13 = DWELL TIME AFTER ETCH	V14 = ULTRASONIC CLEANING
V15 = VACUUM BAKE TEMPERATURE	V16 = SOLDER COOL RATE
V17 = VACUUM PRESSURE FOR COOLING SOLDER	R = RESPONSE, STRENGTH

OBS	TRIAL	V1	V2	V3	V4	V5	V6	V7	V8	V9	V10	V11	V12	V13	V14	V15	V16	V17	R1	R2	R3	R4	R5	R6	R7	N	MEAN	RANGE	STD_DEV
1	1	B	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	2.50	2.25	1.98	1.94	1.88	1.92	1.54	7	2.01	1.02	0.32
2	2	B	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	1.50	1.98	1.92	1.26	1.62	1.80	1.98	7	1.72	0.72	0.27
3	3	B	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	1.62	1.80	2.60	2.84	2.34	2.25	1.98	7	2.20	1.22	0.44
4	4	B	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	2.08	1.80	1.80	1.44	1.70	1.44	1.62	7	1.70	0.64	0.23
5	5	B	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	1.56	1.50	1.44	1.68	1.88	2.16	2.88	7	1.87	1.44	0.51
6	6	B	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	2.25	2.48	1.74	2.25	2.06	1.62	1.50	7	1.99	0.98	0.37
7	7	B	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	1.80	1.84	2.25	1.80	1.70	1.44	2.04	7	1.84	0.81	0.26
8	8	B	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	1.86	2.16	2.16	2.12	1.92	1.92	2.04	7	2.03	0.30	0.13
9	9	B	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	2.10	2.40	2.52	2.25	1.98	1.92	1.44	7	2.09	1.08	0.36
10	10	B	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	1.50	1.80	1.98	1.86	1.86	2.34	2.40	7	1.96	0.90	0.32

EXPERIMENT 5, VENDOR B

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GENERAL LINEAR MODELS PROCEDURE

CLASS LEVEL INFORMATION

CLASS	LEVELS	VALUES
TRIAL	10	1 10 2 3 4 5 6 7 8 9

NUMBER OF OBSERVATIONS IN DATA SET = 70

TABLE 16

EXPERIMENT 5, VENDOR B

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GENERAL LINEAR MODELS PROCEDURE

DEPENDENT VARIABLE: RESPONSE

SOURCE	DF	SUM OF SQUARES	MEAN SQUARE	F VALUE	PR > F	R-SQUARE	C.V.
MODEL	9	1.59232000	0.17692444	1.58	0.1432	0.191215	17.2650
ERROR	60	6.73505714	0.11225095		ROOT MSE		RESPONSE MEAN
CORRECTED TOTAL	69	8.32737714			0.33503873		1.94057143

SOURCE	DF	TYPE I SS	F VALUE	PR > F	DF	TYPE III SS	F VALUE	PR > F
TRIAL	9	1.59232000	1.58	0.1432	9	1.59232000	1.58	0.1432

EXPERIMENT 5, VENDOR B

14:42 TUESDAY, NOVEMBER 27, 1990 49

GENERAL LINEAR MODELS PROCEDURE

SCHEFFE'S TEST FOR VARIABLE: RESPONSE

NOTE: THIS TEST CONTROLS THE TYPE I EXPERIMENTWISE ERROR RATE
BUT GENERALLY HAS A HIGHER TYPE II ERROR RATE THAN REGWF
FOR ALL PAIRWISE COMPARISONS

ALPHA=0.05 DF=60 MSE=0.112251
CRITICAL VALUE OF F=2.04010
MINIMUM SIGNIFICANT DIFFERENCE=.76738

MEANS WITH THE SAME LETTER ARE NOT SIGNIFICANTLY DIFFERENT.

SCHEFFE	GROUPING	MEAN	N	TRIAL
A		2.2043	7	3
A				
A		2.0871	7	9
A				
A		2.0257	7	8
A				
A		2.0100	7	1
A				
A		1.9857	7	6
A				
A		1.9629	7	10
A				
A		1.8714	7	5
A				
A		1.8386	7	7
A				
A		1.7229	7	2
A				
A		1.6971	7	4