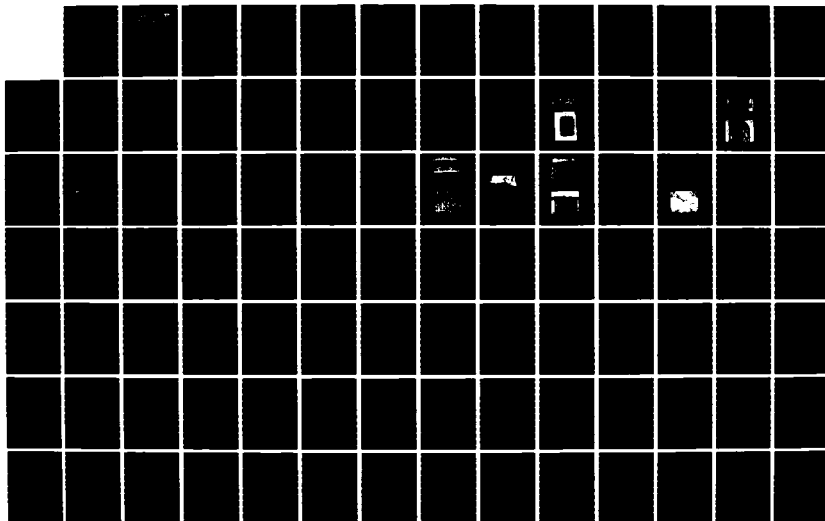SOLDERING TECHNOLOGY (4TH) PROCEEDINGS OF ANNUAL
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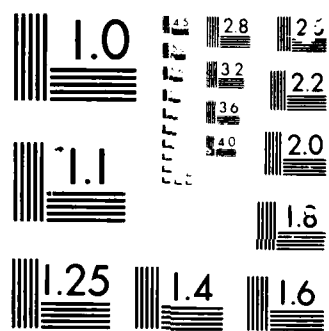UNCLASSIFIED   F/G 13/8   NL

Soldering Technology

PROCEEDINGS

OF
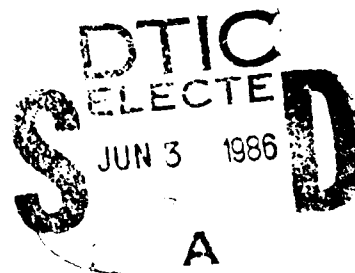
4TH ANNUAL SEMINAR

20 - 21 February 1980

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CODE 3681

NAVAL WEAPONS CENTER

CHINA LAKE, CALIFORNIA

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Thank you for your interest in soldering technology, and your attendance at this seminar.
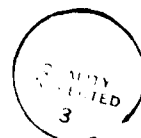
It is vital that we maintain a continued interest and attempt to resolve our many production problems prior to adverse effects on fleet hardware. It is necessary that we design for ease of manufacturing and it is necessary that we eliminate the unjustified amounts of touch-up that is going on throughout industry today. The only way that this can be done is to understand our many problems and admit that they are there, then do something to eliminate them – corrective measures.

These proceedings are published for your information and do not necessarily reflect the views of the Naval Weapons Center or the Government.

Thank you for your attendance.

JIM D. RABY
Head, Soldering Technology Branch
Code 3681

Sn

TIN RESEARCH INSTITUTE, INC.

2600 EL CAMINO REAL-SUITE 224

PALO ALTO, CALIFORNIA 94306

(415) 327-6650

January 16, 1980
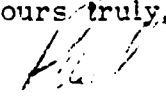
Mr. James D. Raby
Naval Weapons Center
China Lake, CA 93555

Dear Jim:

A copy of my paper "A Comparison of Solderability Values as
Measured by Different Solderability Test Methods", for the Fourth
Annual N.W.C. Soldering Technology Seminar is enclosed. I regret
this being late but I spent all last week at home entertaining a virus
and am just now beginning to catch up. I trust this will arrive in
sufficient time for you to prepare all the material for the Seminar.

With kind regards.

Yours truly,

Paul E. Davis

PED/ch

Encl: paper copy

A comparison of solderability values as measured by different solderability test methods.

by Paul E. Davis
Tin Research Institute, Inc.
Palo Alto, CA

An awareness of the significance of solderability as an influence on production and quality assurance, particularly in the fields of electronic and electromechanical engineering, is becoming increasingly appreciated due to the work of Thwaites and others. Its importance owes much to the fact that certain specific tests allow numerical assignment of degrees of solderability so that by discussion acceptable levels can be established. Many tests have been reported in the literature, most of them based on some aspect of the soldering process although attempts have been made to use basic physical properties of solders and substrate systems as a measure of solderability.

These can be divided into the broad headings.

(a) Visual assessment including Soldering Iron tests

(b) Area of Spread tests

(c) Edge Dip tests

(d) Capillary tests

(e) Globule tests

(f) Rotary Dip test

(g) Surface Tension Balance test

Of these probably the most widely used is the first, most production is given some scrutiny for quality maintenance reasons, although since this method specifically excludes any quantifiable parameters acceptance levels and criteria are necessarily widely different and menaingful comparisons are difficult. Procedural Specifications such as WS 6536B: 1971, MIL-STD.440 (Ships) U.K. and Post Office QS 0001 have been published whilst many others specify the appearance of acceptably soldered surfaces. Of the remainder probably the most widely specified are the dip test (IEC 68-2-20 Test T BS 1872: 1964 and BS 2011:1966 Pt.2T: MIL-STD - 202E: Method 208: 1973), the Globule test (IEC 68-2-20) Test T, BS.2011: 1966,pt. 2T and DIN 40046: 1968) and the Rotary Dip test (IEC

68-2-20 Test T, BS. 4025: 1966 App.J.) More recently a surface tension balance test has been incorporated in to a U.S. Standard MIL-STD-883B: 1977. Area of spread based tests have occasionally been specified but such specifications are now rare.

Quantitative solderability tests usually measure the area over which a standard tablet of a specified solder will spread or the height it will rise vertically when wetting a test sample or the time taken to wet a sample. All obvious parameters of such tests are carefully standardised so that results may be as reproducible as possible. The most widely used tests are more fully described below.

Globule Test.

This test which is widely used throughout Europe developed out of the work of Ten Duis and measures the time taken for a molten solder globule bisected by a round wire to climb around, wet and remake itself about the fluxed wire lead or termination. The size and material of the heated anvil on which the solder globule rests are usually specified as is the composition of the flux and the test temperature. The size of the solder globule to be used is related to wire diameter under test. Time may be measured automatically via electrical contacts or by manually stopping a timer when the edges of the divided globule are observed to have coalesced. Results are usually expressed in seconds or occasionally as reference numbers (i.e. ball solderability numbers).

Vertical Dip Tests.

These are more widely used in the U.S.A. and call for the edgewise immersion of fluxed test pieces into a bath of 60% tin - 40% lead solder at a specified temperature. The rate of immersion and the dwell times are also specified. Evaluation of results is visual and often calls for estimation of the percentage of non-wetting or dewetting, but this can be very subjective unless an extremely well trained and experienced operative is used.

Rotary Dip Test

This test is designed to measure the wetting time of flat sheet material, especially printed circuit board laminate by copying the relative motion between the board and the solder bath of a wave soldering or dip soldering process. The

-2-

4

test is specified in both BS. 4025 App: J: 1966 and IEC 68-2-20C, Test T. Prefluxed flat test pieces are mounted on a rotating arm which carried them into tangential contact with a dross free solder surface. An electrical contact probe allows measurement of the median contact time which is varied by altering the rotation speed. The minimum wetting time is given by the shortest contact time which produces a fully wetted and covered test coupon.

Surface Tension Balance.

This test measures the changes in the vertical force acting on a test sample from the time wetting is initiated until after it is completed or up until the experiment has exceeded a fixed duration. A common solderability parameter derived from the data is the time to reach a certain predefined stage in the wetting process. The test is more general than many in that it allows testing of both sheet or wire specimens but not printed circuit boards. Being the most recently inovated test it has not yet been fully integrated into specifications and is as yet only incorporated into the United States Specification MIL-STD-883B: 1977.

Having included a particular test in a specification, a specifying body then proceeds to define what is an acceptable result from that test so that statements about the maximum acceptable wetting times for example become incorporated and these in turn then become acceptability levels for the materials themselves. Once having specified a limit for acceptable solderability it seems that this limit has then been used as a guide in setting acceptability limits for other tests. This naturally ignores the subtle differences in both specimen geometries and orientations in the individual tests and also differences in their mechanics. Thus, whilst in the Rotary Dip test we are often forcing solder into contact with the sample surface by squeegee action at a rate which often exceeds the natural equilibrium spreading rate of the system, results from this test are often compared with Surface Tension Balance tests in which care is taken to ensure that the wetting rate is neither hindered nor enhanced.

It is the object of this paper to compare results obtained from many different solderability tests on material which has different but controlled levels of solderability as commonly indicated by wetting time. In this way it is hoped that a correlation can be obtained between solderability values obtained in one test with the value obtained on as nearly identical material as possible from another test.

-3-

Production of Test Material.

Preliminary experiments on copper wire indicated that a simple chemical treatment in an 0.25% aqueous benztriazole solution (BTA) would provide the required levels of solderability simply by varying immersion times. Subsequent experimentation uncovered a tendency towards poor repeatability which was associated with the initial etching and rinsing treatment prior to chemical treatment. Figure 1 shows the effect of increasing rinsing time at room temperature and the results of using water from different sources and of different qualities. Any appreciable variation in rinsing treatment was producing a surface cleaned to a different degree with a slightly different response to the chemical treatment hence producing surfaces of different levels of solderability from identical chemical immersion times. Dissolved salts in tapwater play a large part in contaminating the surface but even when these are removed as for demineralised water there is still an effect on surface cleanliness of prolonged rinsing. When the pH of the water was reduced to 1.0, very short wetting times, with a narrow range, could be achieved which were unaffected by rinsing time variations. This was because at this pH copper oxide dissociates as rapidly as it forms so that oxidation of the highly reactive copper surface by oxygen dissolved in the rinse water or by complexation of copper by hydroxyl groups in the water was counteracted.

In this way a cleaning cycle as follows was developed for bare copper wires and foils.

1. Degrease in trichlorethylene for 10 seconds.

2. 2 1/2 mins etch in 25 wt % aqueous ammonium persulphate solution.

3. 2-3 seconds rinse in 0.2 vol % solution of sulphuric acid with agitation.

4. 5 seconds dip in acetone with agitation.

5. Warm air dry.

Repeating the simple chemical treatment in benztriazole with material cleaned in this way showed that the simple linear relationship between immersion time and solderability was not reproduced demonstrating that very clean copper did not respond to this chemical treatment in the same way as did copper carrying a light oxide film.

-4-

6

Solderability Test Results.

When wire samples subjected to the original cleaning treatment involving a brief but unspecified rinse in running tapwater, were immersed in the BTA solution for periods up to 20 mins. they gave wetting times in the Globule test which were a good fit on a straight line plot. Extension of the immersion time to 40 minutes (2400 s) gave samples with wetting times indicating that a parabolic or exponential form was probably a better fit (Fig. 2) to the data.

When this experiment was repeated using the revised cleaning procedure, the results illustrated in Fig. 3 were obtained. This showed the short wetting time resulting from the new cleaning treatment. The shortest immersion time (10 seconds) produced a sudden sharp increase in wetting time followed by a linear increase in wetting time as the chemical treatment period is increased.

The effect of BTA treatment on solderability of wires as tested on the Meniscograph is shown in Fig. 4 and this again shows a similar pattern. As the traces obtained from all samples tested in this programme were of the "normal" type the endpoint used to determine wetting times in this test was the time for the trace to cross the zero force axis and this was the endpoint used for all Meniscograph wetting time results reported in this paper.

For copper foil samples, the Meniscograph wetting time was plotted as a function of increasing contamination film thickness and is shown in Fig. 5. In this instance the function appears to be more parabolic with no well defined linear region of the curve. However, Rotary Dip test wetting times for different chemical immersion times shown in Fig. 6 parallel the results on copper wires, exhibiting an essentially linear relationship after the first initial sharp increase in wetting time. The linearity in this Figure is most obvious even in the absence of error bands which are not determined in this test. The wetting rate , measured on the Surface Tension Balance as the slope of the trace at the zero force axis, shows a fairly large range for each value but still indicates as an exponential, the effect of increasing surface contamination, Fig. 7, whilst Fig. 3 shows that the maximum wetting force in these tests, also demonstrating a large spread of results, but apparently unaffected by the presence of different contaminant film thicknesses.

Comparison of Results from different Tests.

By taking an envelope of curves that covered the best fit through both the σ and $-\sigma$ levels on the above curves for wetting times, estimates of the range of wetting times measured by each solderability test for a particular BTA

-5-

treatment time can be obtained. When the results from two different tests for the same immersion time are plotted together correlation curves can be constructed.

Figure 9 shows such a curve for wires comparing wetting times obtained by the Meniscograph with those from the Globule test. The points show the ranges of values along both axes and the linear correlation between the results of both tests is also clearly seen. When the wetting time results on foils from the Meniscograph and the Rotary Dip test are treated in the same way, Fig.10 is obtained. Again the linearity of the correlation is fairly clear although there is a greater scatter of results about the line than was the case for wires; the points could however accommodate a more complex curve. Correlation curves, between wetting rate with wetting times measured by either test are exponential as seen in Fig.11 which relates the two parameters measured on the Meniscograph. Since wetting time measured by the Surface Tension Balance is linearly related to the same parameter as measured by the Rotary Dip test, a similar curve to Fig.11 would be obtained if this latter parameter were correlated with wetting rate.

Discussion.

The essential difference between results reported previously for solderability testing of copper, artificially contaminated by immersion in aqueous BTA, and those reported here is that following the development of an improved cleaning cycle the introduction of even a mild contamination treatment produces a readily detectable effect on solderability parameters. After the shortest immersion time successive increases in immersion time produce essentially linear increases in the wetting times in almost all cases. In the cases of the parameters wetting force and wetting rate, this is not so, the first parameter being essentially independant of contamination level whilst the latter obeys and exponential law.

For wires, the rates of increase of wetting times in the linear region of the curves for both tests were very similar for samples prepared according to the improved cleaning schedules, whereas the curves obtained from samples prepared in the original schedule were both more widely different from one another and greater than the results reported here. This is in keeping with the findings of the investigation to determine the best cleaning treatment, that

-6-

dissolved oxygen in the rinsing water or reaction of freshly prepared copper with hydroxyl groups of the water resulted in the production of a less than perfectly clean copper surface. Consequently, identical immersion treatments in BTA resulted in different contamination films and, if the chemical contamination treatment is additive with natural oxidation/contamination, an overall more heavily contaminated surface would be obtained from perfectly clean copper starting material. The test most sensitive to these slight differences is the surface tension balance test where metal to metal contact is not under applied force and the technique records reactions proceeding under more nearly equilibrium conditions.

In the case of copper foils, comparison of Figs. 5 and 6 shows that changes in wetting time with increase in the contamination level are more variable than with wires and the form of the curve drawn from the Meniscograph results is slightly different from those obtained for other tests. It appears therefore that the Surface Tension Balance test on samples of appreciable circumferential length is the more sensitive method for indication of the presence and effect of even very low levels of contamination: it is detecting the effect of a film which probably consists of a chemical compound attached by ligand formation to a clean copper surface, whereas in the previous work on investigating the effect of rinsing, the method detected the formation of oxide or hydroxide films. The fact that the method is sensitive in both cases, tends to indicate the validity of this approach to comparison of solderability.

If one examines the wetting times of the clean copper in each test it is possible to infer some effect resulting from the method of performing the test. For example, when a wire is pressed into the surface of a molten globule of solder the change in shape away from that of the steady state sphere, is being counteracted by the surface tension across the interface of the deformed drop resulting in an internal hydrostatic pressure. As wetting proceeds therefore the molten solder is being squeezed onto the sample resulting in quicker wetting than would be observed in the absence of such a perturbation. Similarly in the case of the Rotary Dip test, especially when the wetting time is short, the rapid washing of the solder over the sample surface, together with the associated pressure developed, effectively produces a squeegee action between the two components of the test. Despite the fact that the flux is simultaneously being washed away, very short wetting times are observed.

-7-

In this case, the wetting time for clean copper, i.e. about 0.15 seconds, is so short that it is probably at the limit of detection of the equipment. Such comments are probably only of esoteric interest however since it is at the boundary between acceptable and non-acceptable that practical interest lies.

From Fig.7 the extreme sensitivity of the rate of wetting to different levels of surface contamination can be readily seen. Such large variations in a solderability parameter must limit the usefulness of such a parameter as a routine indicator of surface quality. Its application would mean that the small sample to sample variations in surface condition within a batch would result in unnacceptably large variations in test parameter in some regions whilst being effectively insensitive to surface changes in others. The large range of values observed from samples subjected to an identical surface treatment also mitigates against its use. Wetting force, as should be expected, was insensitive to the presence of a surface contamination film. Once the surface has been wetted and any surface film disrupted or decomposed it would be expected that the surface tension value observed would be the equilibrium value for the system basis metal/solder. Variations in this should only reflect variations in composition of the two materials.

Fig.9 shows the relationship of specific values obtained by one test for wires compared to the value obtained for an essentially identical sample by a second test. Thus we can see that a 2 second wetting time measured in the Globule test corresponds to about 2.6 ± 0.2 seconds measured on the Meniscograph taking into account the errors of our technique and experiments. A 2 second wetting time measured on the Meniscograph in turn represents a 1.5 ± 0.5 second value from the Globule test reflecting the wider scatter of results obtained with this latter test as contamination levels build up. For foils the correlation curve is not so well established but the best fit line indicates essentially 1:1 equivelance with near identical wetting times being indicated by both the Meniscograph and Rotary Dip tests.

The practical significance of a correlation curve such as Fig.10, between a useful, linearly dependent parameter and such an apparently surface sensitive parameter as wetting rate is at present difficult to imagine. It is precisely in the region of specific interest to quality control engineers that wetting rate appears to lose its sensitivity.

Extension of this work to include Rotary Dip tests on wires (which we have found to be possible, but difficult to perform) would allow correlation of the same tests for both forms of sample which would be used as an indication of the effect of sample geometry on test results. Such indications would be most useful when considering ways of testing say, leads and terminations of different cross-sectional shape. Comparisons with other less widely used tests would be interesting but of less wide practical significance. Extension of the programme to include investigations of the effects of alternative surface contamination techniques such as the sulphide contamination method of Barranger and the oxygen injected humidity test would help to indicate the validity of this approach to comparing solderability results.

Conclusions.

The wetting time solderability parameters for both wire and flat foil samples measured where appropriate with the Globule test, the Meniscograph and the Rotary Dip test bear a linear relationship one to the other. For wires, Meniscograph measurements of wetting time are consistently shorter than those from the Globule test. For foils measured values by Meniscograph are the same as those from the Rotary Dip test.
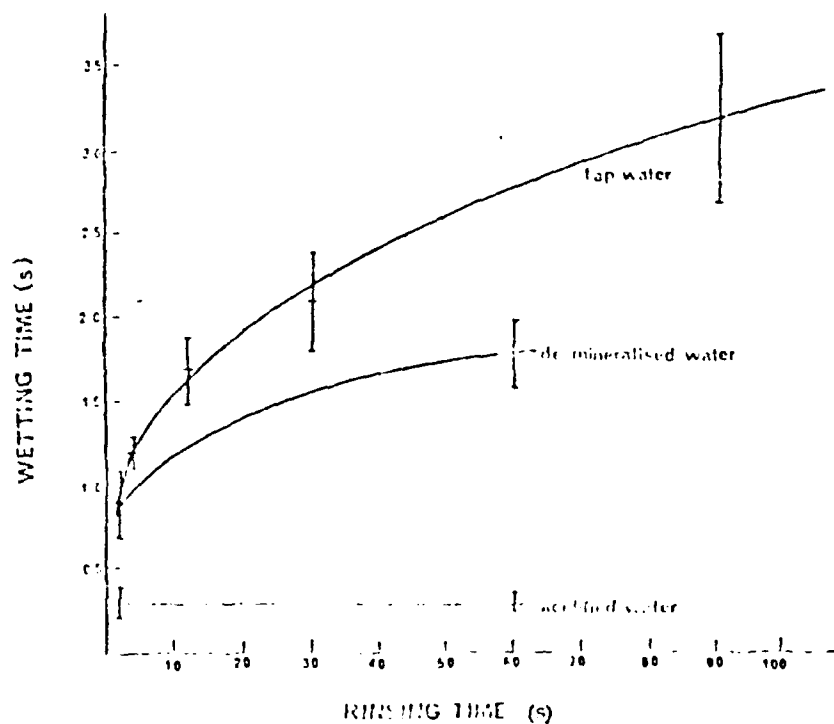
Figure 1   Effect on wetting time of increasing rinsing times in water from different sources and of different qualities.
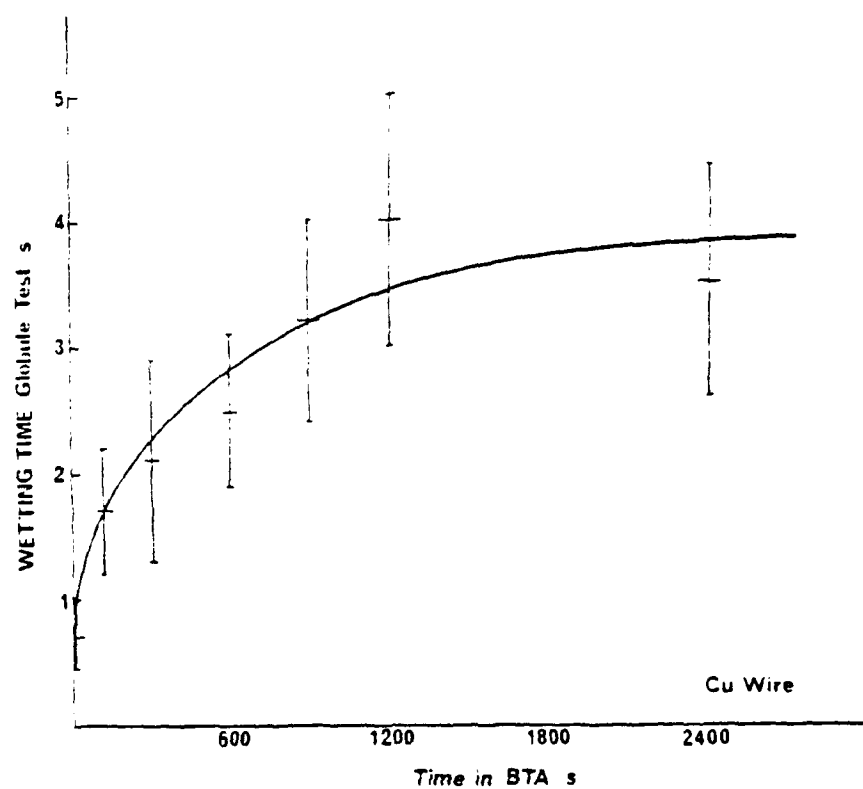
Figure 2   Wetting time measured by Globule Test for different contamination levels in Benztriazole at 60° C for copper wire rinsed without control.
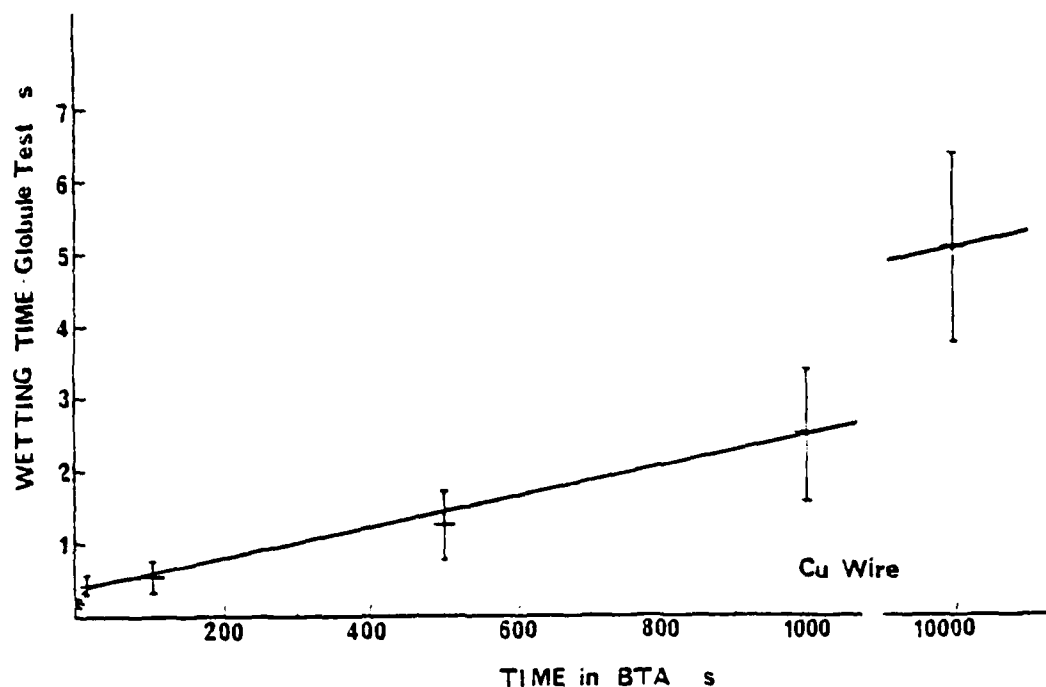
Figure 3   Wetting time measured by Globule Test for different
contamination levels in Benztriazole at 60° C for
copper wire rinsed with control of both rinse pH.
and rinse time.
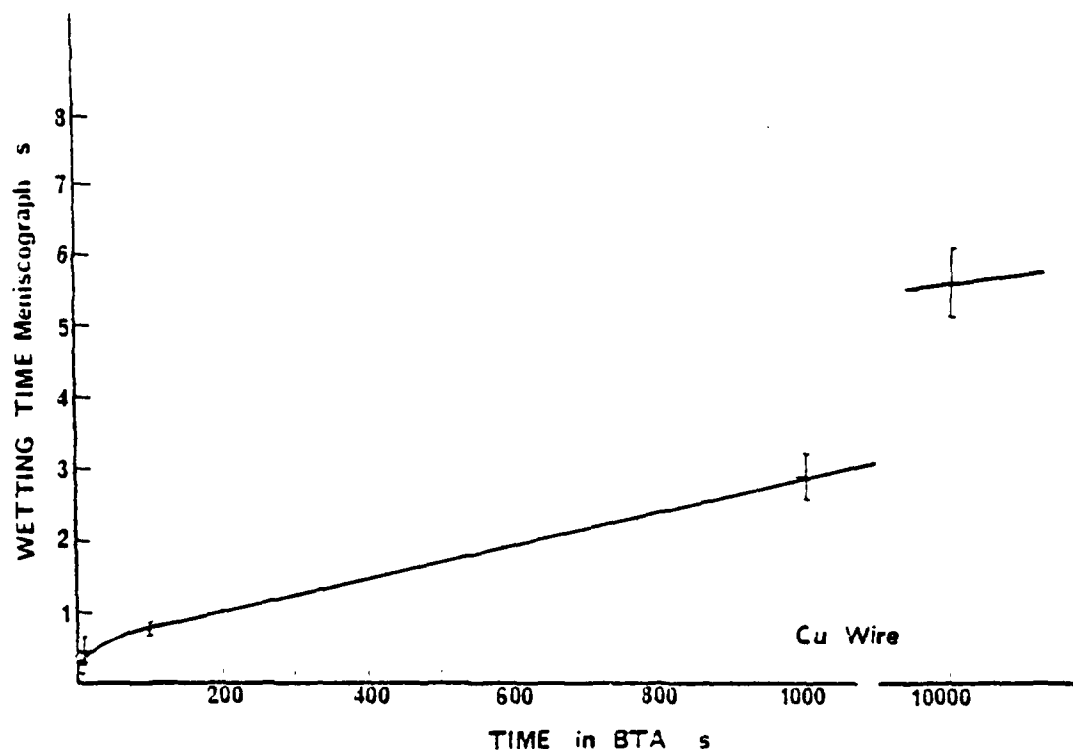
Figure 4   Wetting time measured by Memiscograph for different
contamination levels in Benztriazole at 60° C for
copper wire rinsed with control of pH and time.
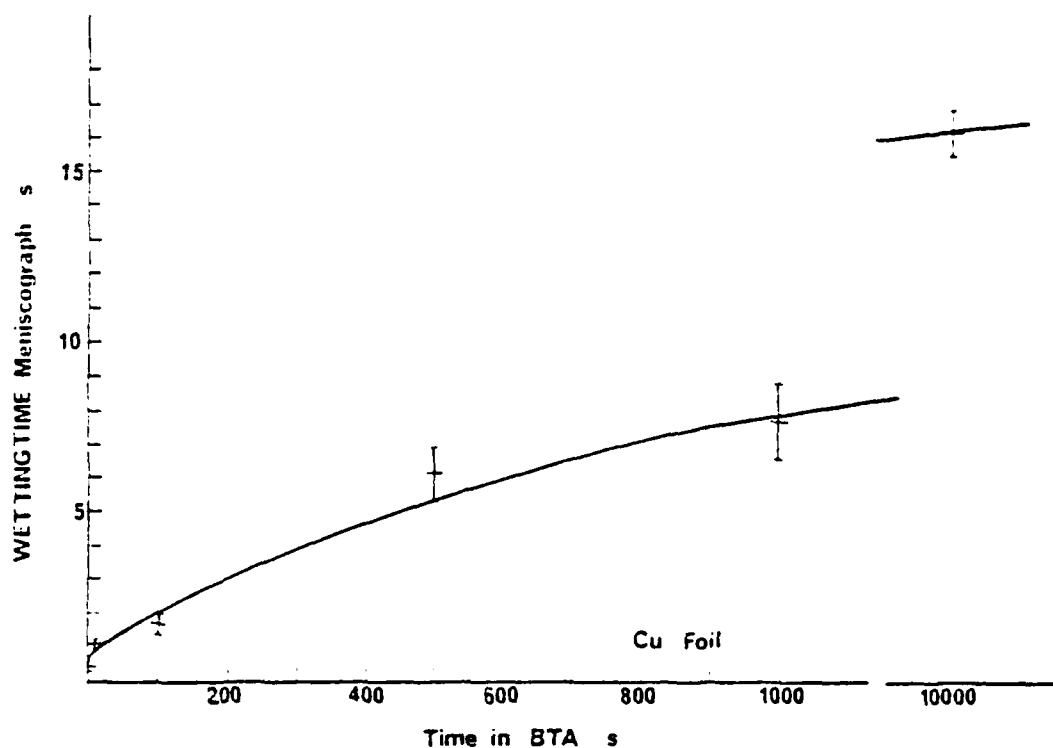
Figure 5   Wetting time measured by Memiscograph for different
            contamination levels in Benztriazole at 60° C for
            copper foil rinsed with control of pH and time.
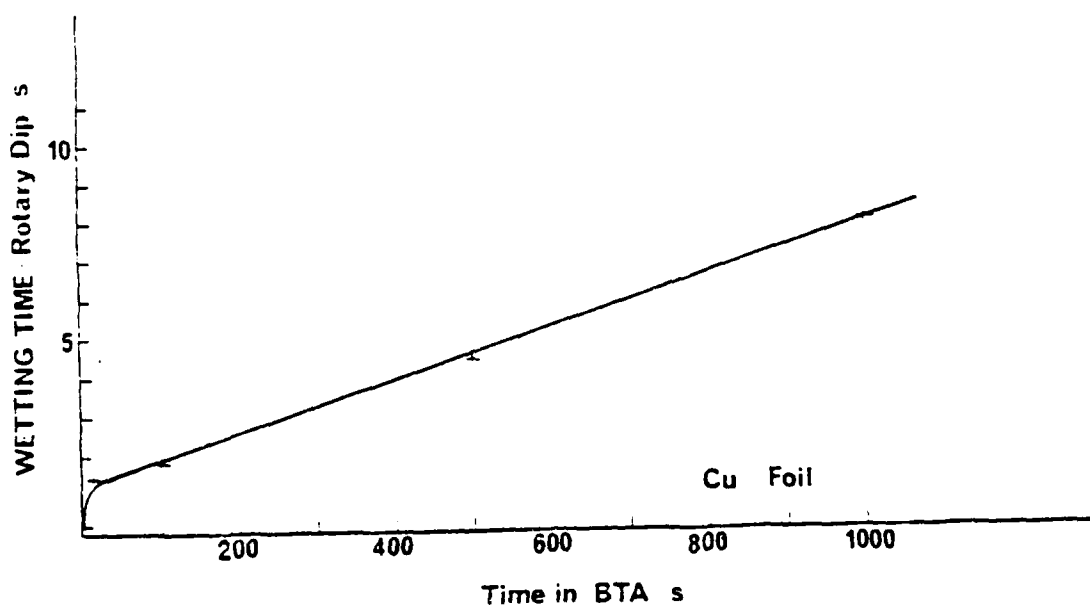
Figure 6   Wetting time measured by Rotary Dip for different
            contamination levels in Benztriazole at 60° C for
            copper foil rinsed with control of pH and time.
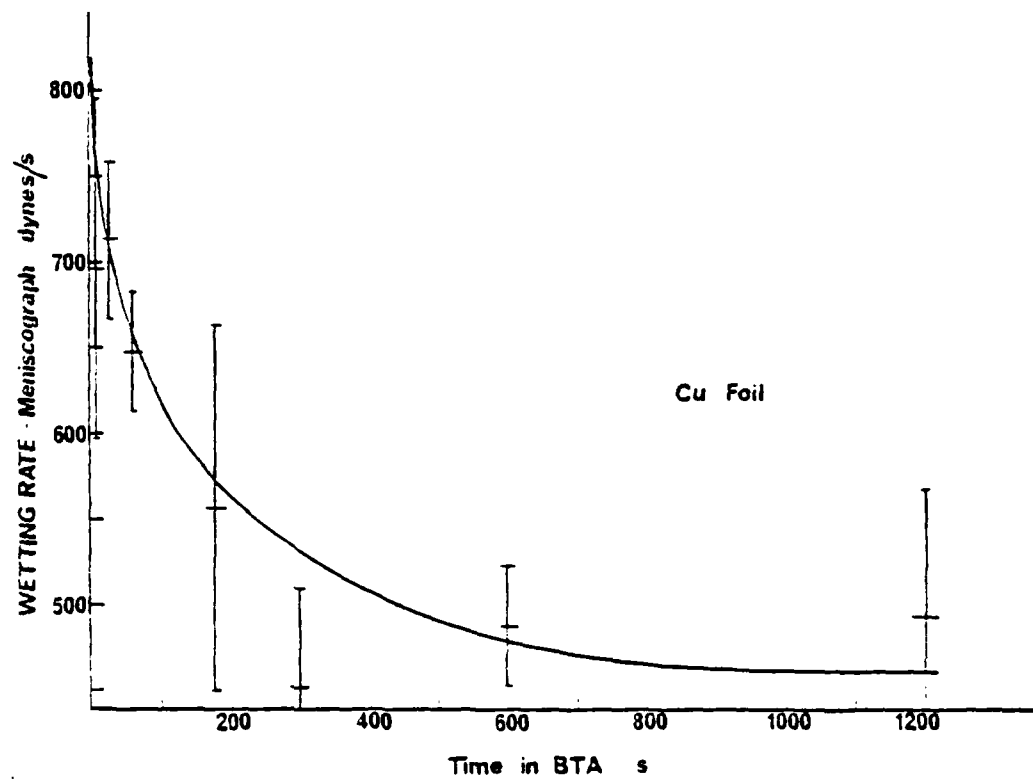
Figure 7   Wetting rate measured by Memiscograph, measured
as the slope of the trace at the zero force axis for
copper foil.
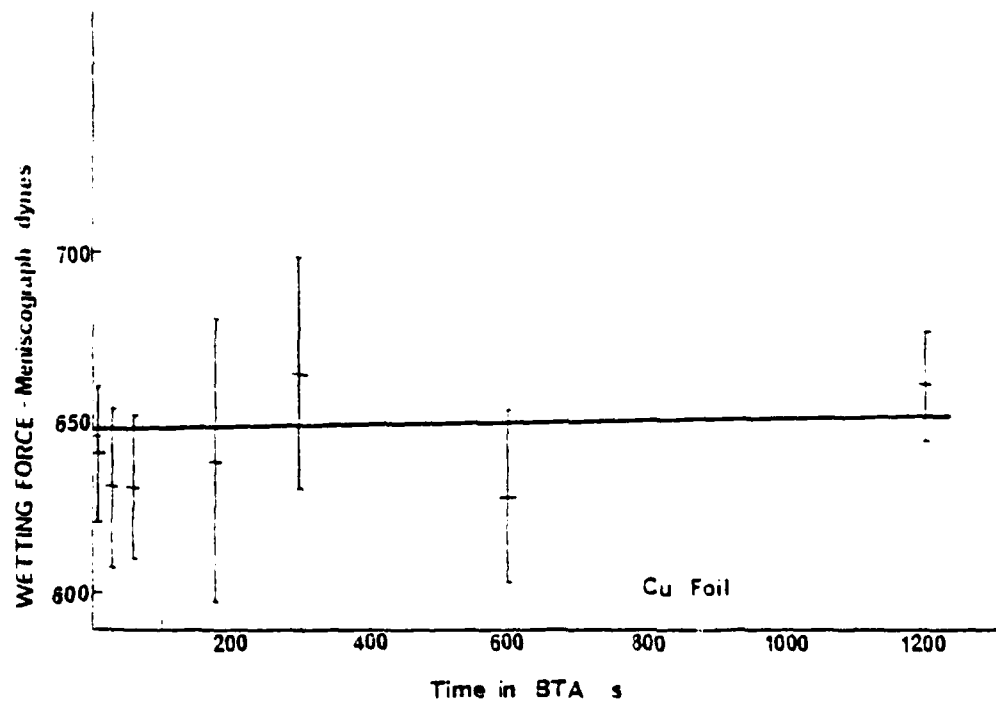
Figure 8   Maximum wetting force measured by Memiscograph
for different contamination levels in Benztiazole at
60° C for copper foil.
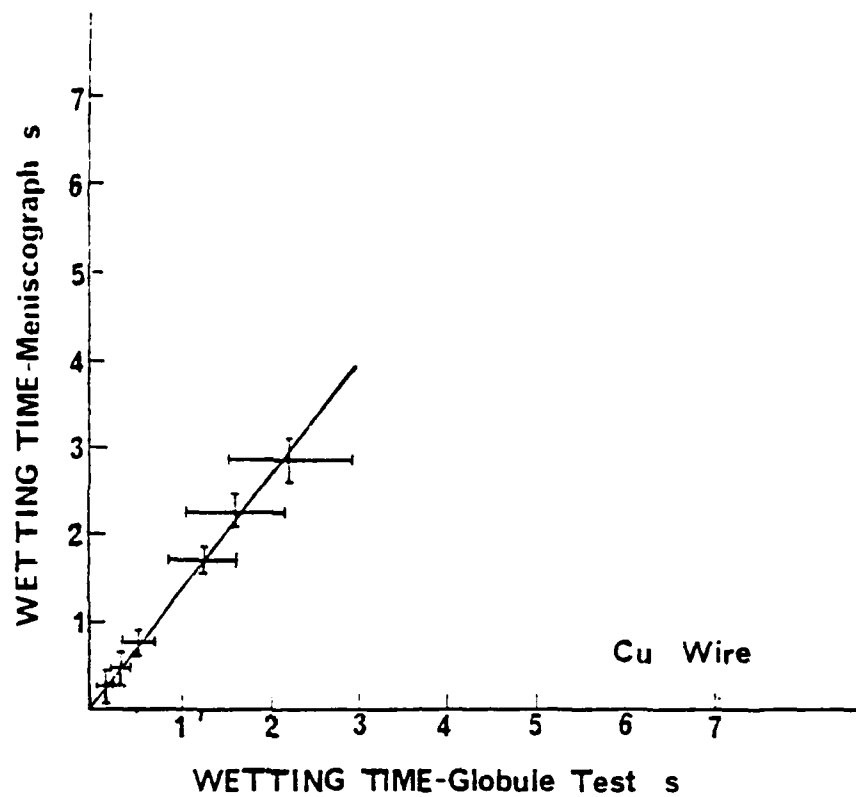
Figure 9   Comparison of wetting times obtained by Globule Test
and Memiscograph on copper wire.
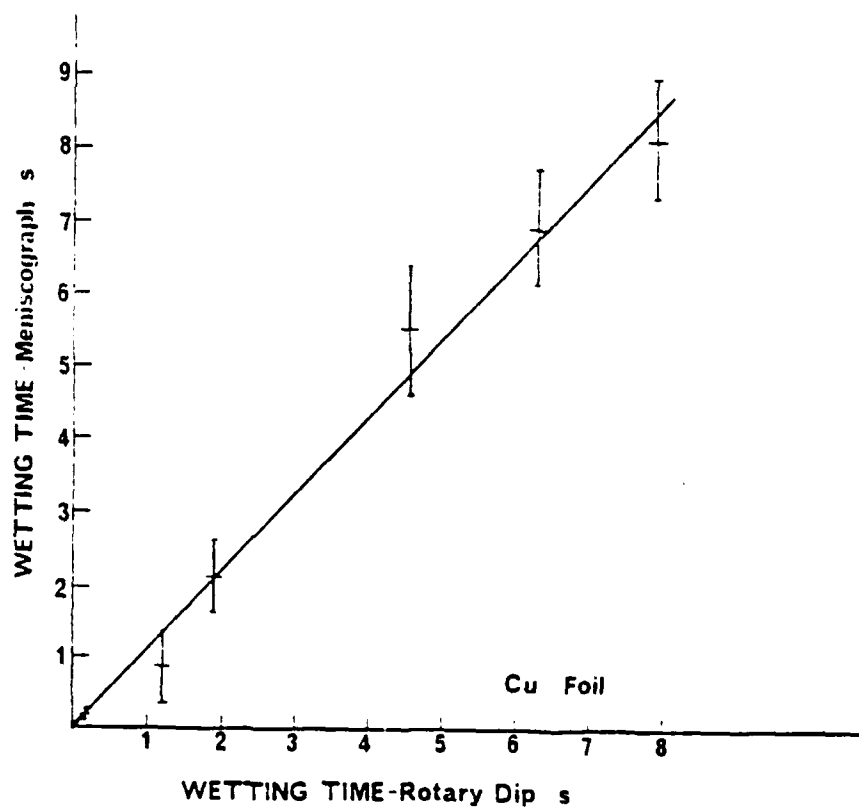
Figure 10   Comparison of wetting times obtained by Globule Test
and Memiscograph on copper foil.
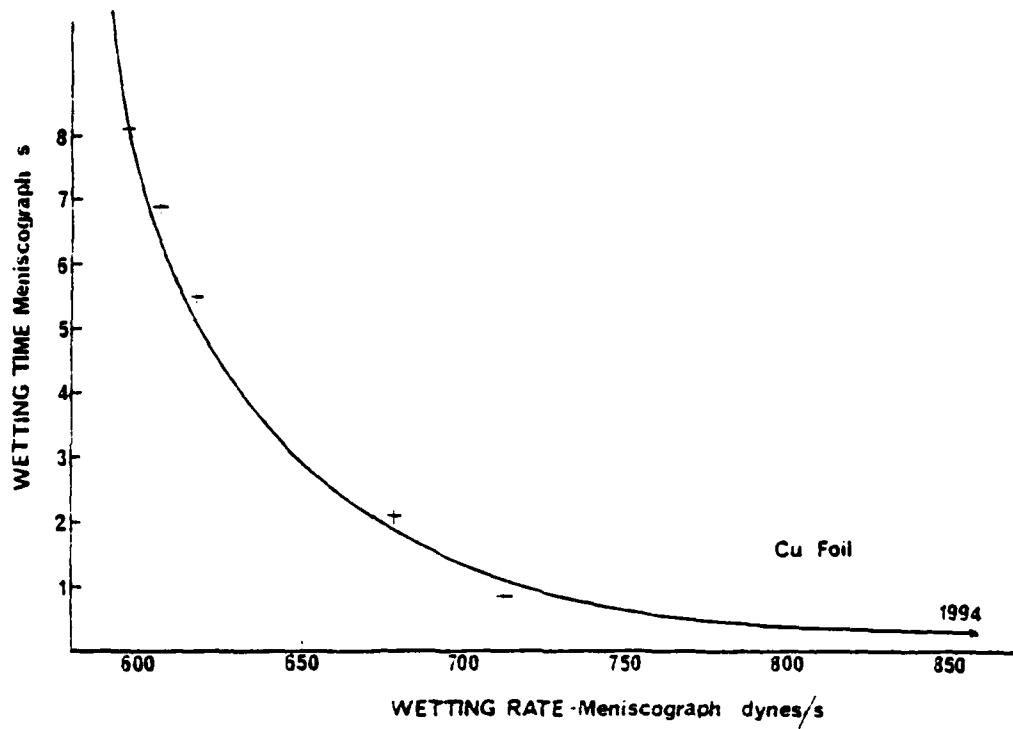
Figure 11   Correllation of wetting time vs. wetting rate meas-
              ured by Memiscograph for copper foil.

"The Evasive Contamination - Our Problem"

Dr. Michael Luciano, Litton Systems

INTRODUCTION

Printed circuit boards as received from our vendors have been solder plated and reflowed. The quality of a solder plate is determined by the cleanliness of the copper surface, the purity of the plating bath and the current density during electrolysis.[1] Each of these areas if they are uncontrolled can have a marked effect on both the solder plate and subsequent soldering operations. A contaminated copper surface will result in poor adhesion of the solder plate and dewetting either during fusing or soldering. Impurities in the plating bath will affect alloy composition and solderability.[1] The most common impurity in plating baths which codeposits with tin and lead and greatly influences solderability is copper[2]. Variations in current densities will normally affect alloy composition and also cause co-deposition of impurities, especially copper.

A common method of soldering printed circuit boards is wave soldering. This process requires as much control as the plating process. The factors involved in the wave soldering process that will affect the quality of the final solder joint are the temp and quality of the solder, the fluxing of the board, the preheat temperature, the rate of travel over the wave and the angle and depth of the board entering the wave.

1. C. J. Tautscher, "The Contamination of Printed Wiring Boards and Assemblies", Omega Scientific Services, 1976

2. G. Cavanaugh and J. Langan, Effects of Solution Impurities on Tin Lead Electrodeposits, Second Plating to the Electronics Industry Symposium, 1969

INTRODUCTION (CONT.)

The specific problem discussed in this paper is shown in the photos, Figure 1A and 1B, taken by optical and scanning electron photography. The photos show that the problem is exhibited as a roughness of the surface of the solder and has been termed "lumpy" solder. Although the condition was first observed and was more prevalent after wave soldering, it has also been observed before wave soldering.

A series of investigations were undertaken to determine the cause and/or origin of the condition and its effects on the reliability of the solder joint. A number of techniques were employed in these investigations which included optical and scanning electron microscopy, energy dispersive x-ray microprobe analysis, Auger spectroscopy and arc emission spectroscopy. Various processing tests were also performed during these investigations.

EXPERIMENTAL

1. Sample Preparation

Metallurgical specimens were prepared by the following procedure. Sections of circuit boards which contained lumpy solder were mounted in epoxy, ground and polished. In certain instances a 2% alcoholic nitric acid solution was used for etching specimens. Samples used for SEM and microprobe analyses were either metallurgical specimens or sections of circuit boards containing lumpy solder. Due to the high vacuum ($< 10^{-8}$ torr) of the Auger spectrometer sample preparation was much more tedious. For circuit pads the sample was lifted off the board to isolate it from board material. For solder specimens

Figure 1A   Optical photo of the "lumpy" solder condition.

Figure 1B   SEM photo of the "lumpy" solder condition.

1. Sample Preparation (cont.)

in plated thru holes the solder was cut from the top of the hole.

Samples for emission spectroscopy to determine impurity levels were

scraped off the tops of lumpy solder. Miscellaneous processing

tests were conducted on scrap sample boards which had a history of

exhibiting lumpy solder.

2. Instrumentation

The technique of energy dispersion x-ray analysis (EDX) measures the

energy of x-rays emitted from a sample upon excitation by a high

energy source of electrons. Each element of the sample will emit

characteristic x-rays. Measurements of the energy of these x-rays

allow identification of elements present in the sample. The technique

can detect all elements above fluorine with a detection limit of 1

atomic %. The average depth of analysis is 1 micron (.04 mil).

Auger spectroscopy measures the energy of Auger electrons emitted

from a sample upon excitation by an electron beam. Each element

emits characteristic Auger electrons whereby the measurement of their

energies can identify the elements present. The Auger technique has

a distinct advantage over EDX in that it can detect all element whose

atomic number is greater than lithium. The bulk sensitivity is

approximately 0.1 atomic % and the depth of analysis is approximately

10-40Å ($4 \times 10^{-5} - 16 \times 10^{-5}$ mils).

Emission spectroscopy measures the wavelength of light emitted from

a sample upon excitation by an external source. The source may be a flame,

a.c. arc, d.c. arc or a.c. spark. The wavelength of the light emitted

is characteristic of the elements present and the intensity of the light

2. Instrumentation (cont.)

is proportional to its concentration.

RESULTS AND DISCUSSION

Two pads removed from a printed circuit board, one exhibiting lumpy
solder and the other one not exhibiting the condition, were examined
by scanning electron microscopy. The surface condition is shown in
Figure 2. EDX analysis of the lumps did not identify any elements
other than tin and lead, and the composition was similar to that ob-
tained from analysis of the smooth solder pad. This data indicated
the cause of the condition was not related to surface contamination.

To probe the material below the surface of a lump Auger analysis in
conjunction with ion etching was selected. Auger analysis is capable
of identifying the presence of organic as well as inorganic impurities
and although it is a surface technique when it is used with ion
etching elemental depth profiles can be obtained. This approach
was selected since it provides information without altering the
condition of the sample.

Four samples were selected for analysis. Two samples (1 and 2)
were removed from the top side of a wave soldered board, one sample
(3) was removed from the bottom or back side of a wave soldered board
and the fourth (4) sample was removed from the top side of a fused
board. The surface of each sample was analyzed and the elemental
composition is given in Table I. The presence of carbon and oxygen
on the surface is most probably due to atmospheric contamination.
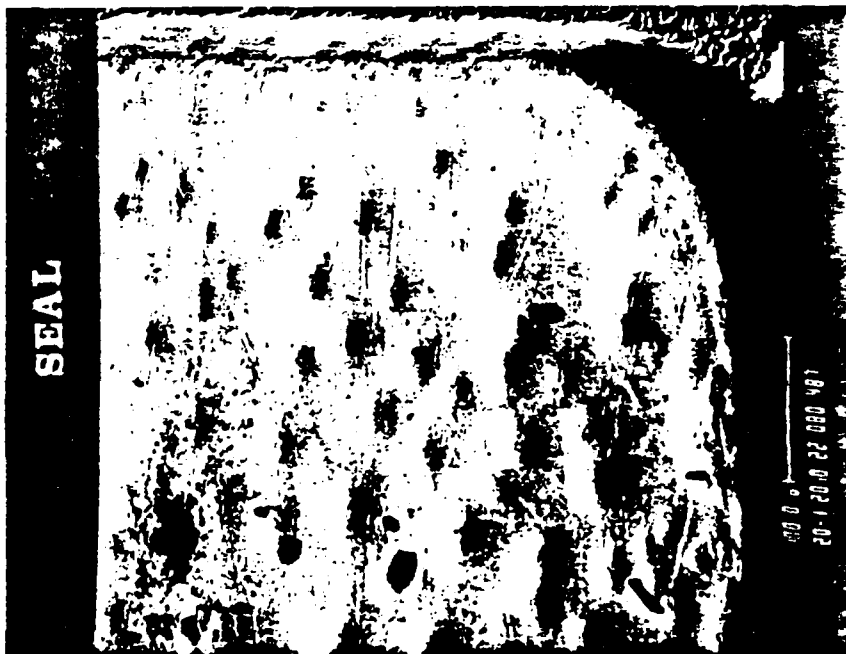
Figure 2   SEM photos comparing the topographies of a "lumpy" solder pad and a smooth solder pad.

TABLE I

The table lists the elemental composition of the surface for 4 samples
investigated by Auger spectroscopy.

Sample	Composition
1	C, O, S, Cl, Pb, Sn
2	C, O, S, Cl, Pb, Sn
3	C, O
4	C, O, S, Cl, Pb, Sn, F, Cu

RESULTS AND DISCUSSION (CONT.)

For samples one and two measurements were made at a lump and a clear
area of the surface. For samples three and four measurements were
made only at the lumps.

Figure 3 shows the areas that were analyzed for sample #1. Point 1
is a lump and point 2 is a clear area. The depth profile data indicated
the presence of copper under the surface of the lump but not in the
clear area. Figure 4 shows the Auger spectrum obtained after etching
to a depth of approximately 2.5 microns (.1 mils) under a lump. This
spectrum can be compared to the spectrum obtained from a clear area
shown in Figure 5. A depth profile of sample #2 and #3 gave the same
results except the copper concentration was less. These spectra are
shown in Figures 6 and 7. Auger analysis of sample 4 indicated the
presence of copper near the surface but it was not detected below .25
microns. The results of these analyses indicated that the only impurity
that is present in the solder samples is copper. Since the technique
is semiquantitative only approximate concentration levels are attain-
able and in this case copper levels of 1 to 5 atomic % were calculated.
It should also be noted that the area of analysis is on the order of
0.5 microns.

The amount of copper present in the solder was determined by emission
spectroscopy. The samples analyzed were obtained by scrapping 15-20
solder joints that exhibited the lumpy condition from boards that were

Figure 3   Photo indicating the areas of sample one that were analyzed by
            Auger spectroscopy.
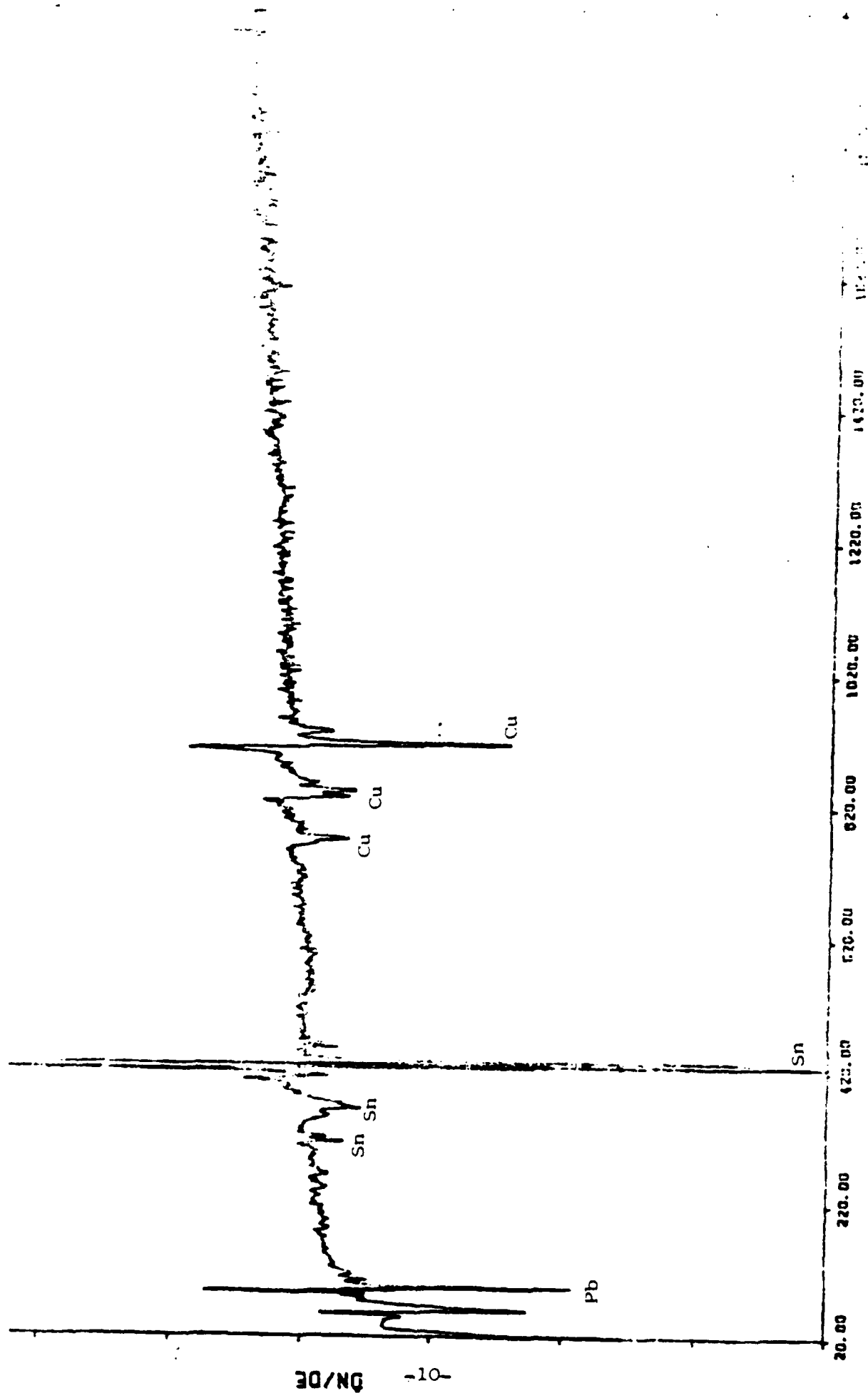
ELECTRON ENERGY, EV

Figure 4. Auger spectrum of sample one after removing 2.5 microns of material from the surface of a lump. The spectrum shows the presence of copper.
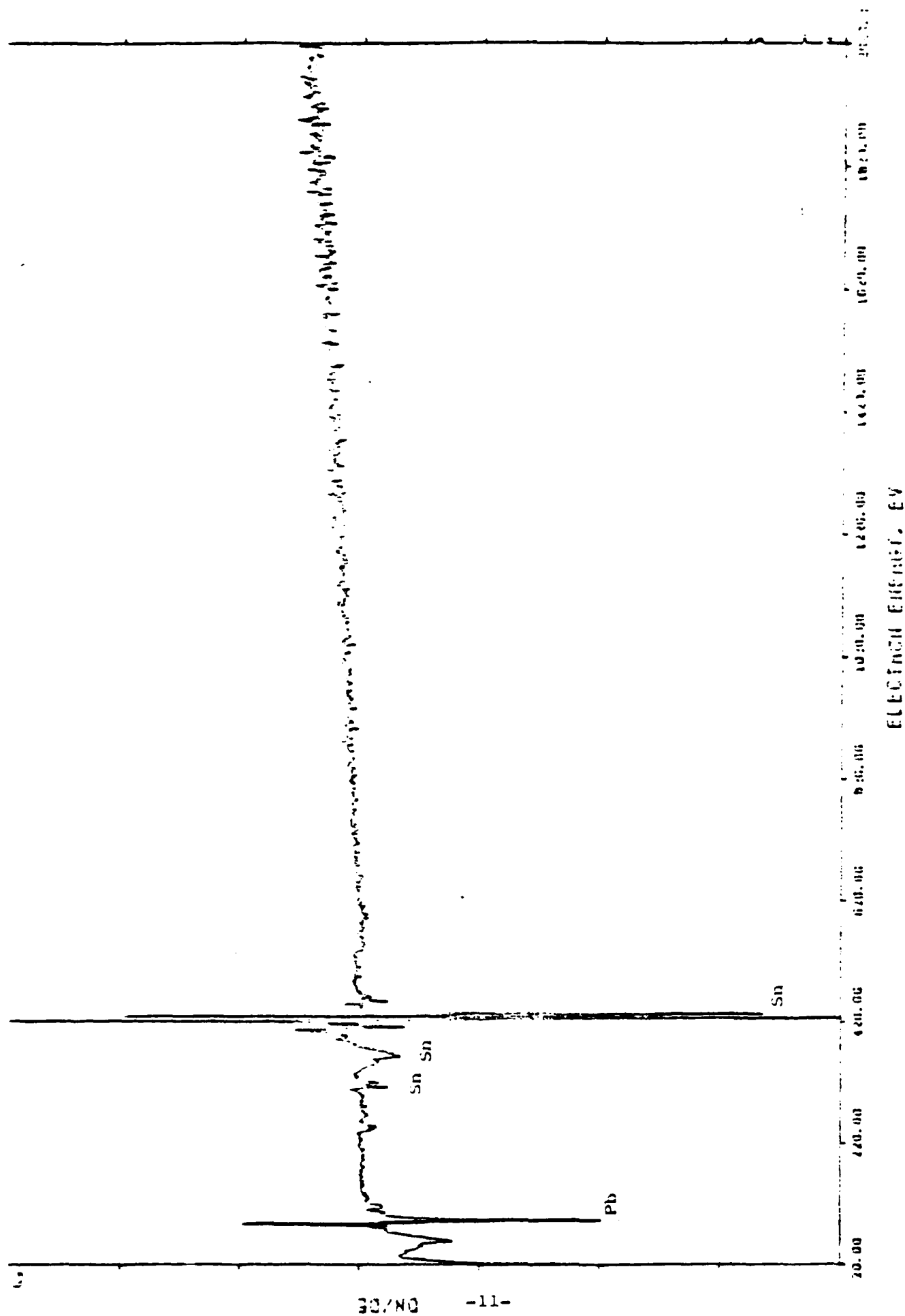
Figure 5. Auger spectrum obtained from sample one after removing 2.5 microns of material from the surface void of lumps. No copper was detected.
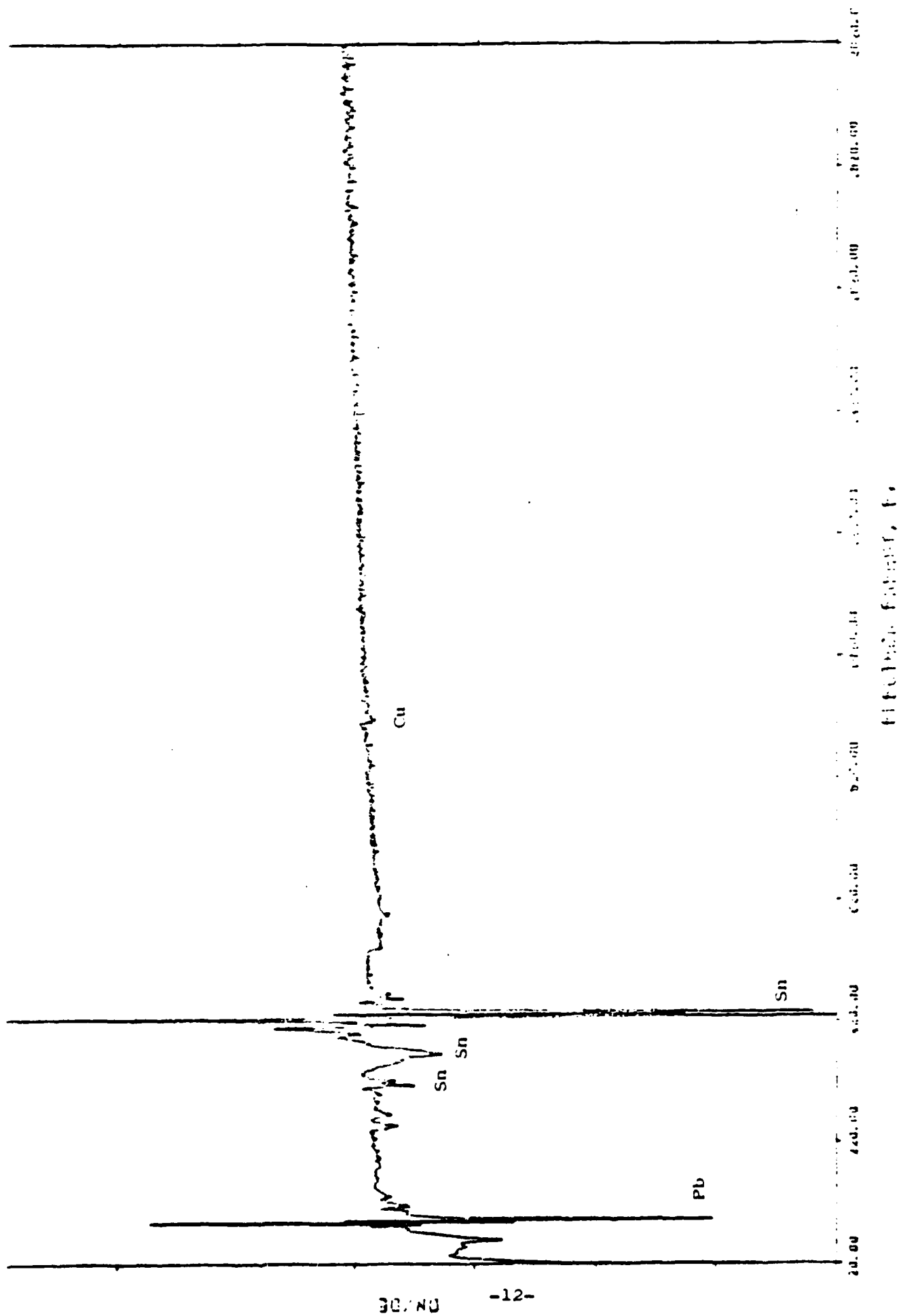
Figure 6.   Auger spectrum of sample two after sputtering 2.5 microns of material.
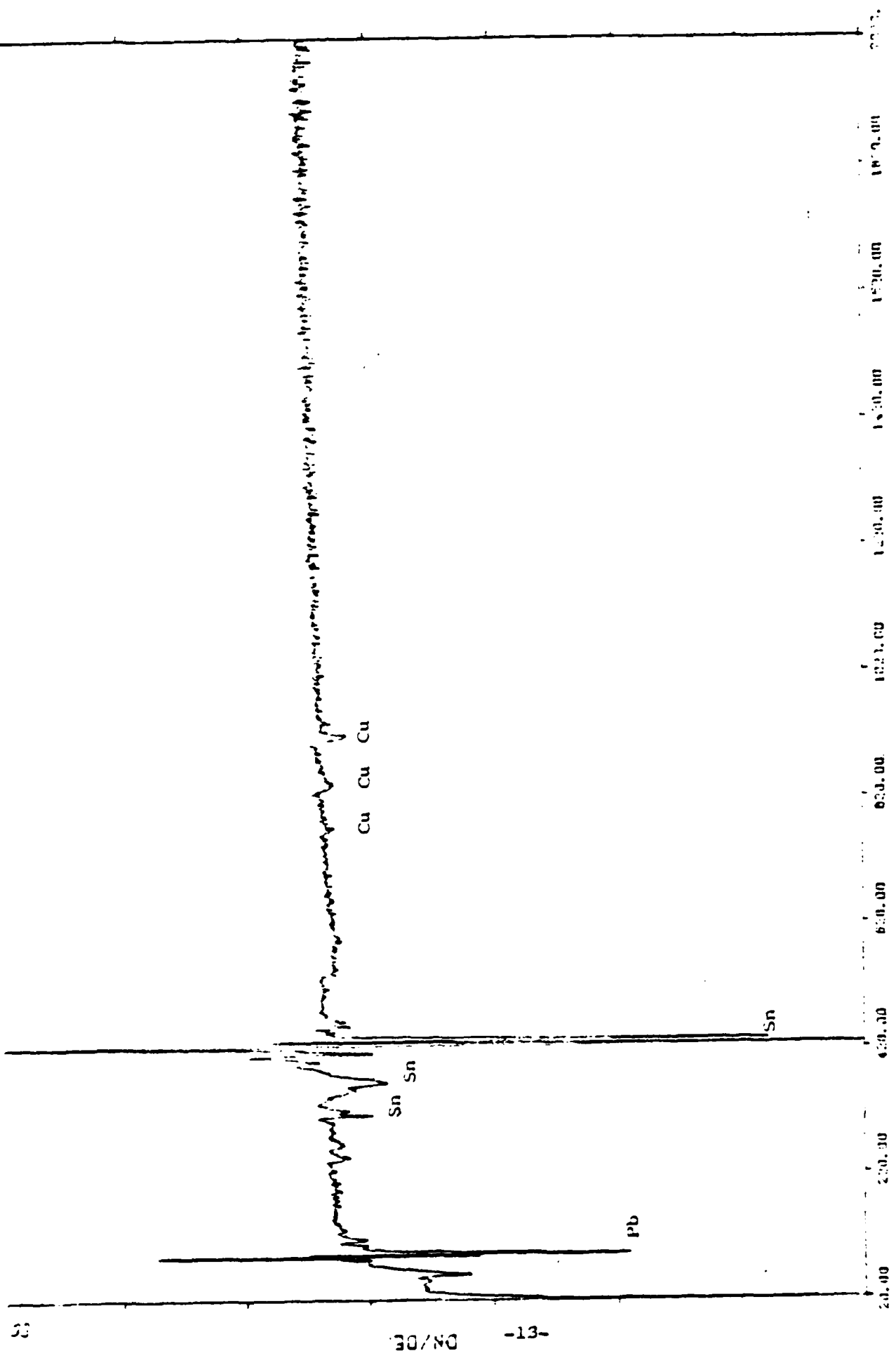
Figure 7. Auger spectrum of sample three after sputtering 2.5 microns of material.

-13-

previously wave soldered. The copper concentrations for two samples were 0.28% and 0.45%. These results do not indicate an excessive amount of copper in the solder and should not affect the reliability of the solder joint. It is unlikely that the copper, in the form of copper-tin intermetallic, is a major factor contributing to the lumpy solder condition.

An optical photo of a cross-sectioned soldered pad is shown in Figure 8. It can be seen from the photo that large alpha particles are present in the solder, and in this case are near the solder copper interface. An SEM photo of a solder cross section is shown in Figure 9. Using the one micron marker in the photo, the lead particles measures 10.0 u in length. The effect of these particles on the solder topography is shown in Figure 10. Here the size of the particle is larger than the average height of the solder thereby causing a lump at the surface of the solder. This is probably the worst case when the average solder thickness measures approximately 6 micron. The next series of figures show various types of photographs of the same cross section which exhibited lumpy solder. The first, Figure 11, is an optical photo of the solder in a plated through hole. The photo shows the presence of large α particles near the surface of the solder. This condition should not exist if the solder is a pure eutectic. As the solder becomes more lead rich these particles will increase in size
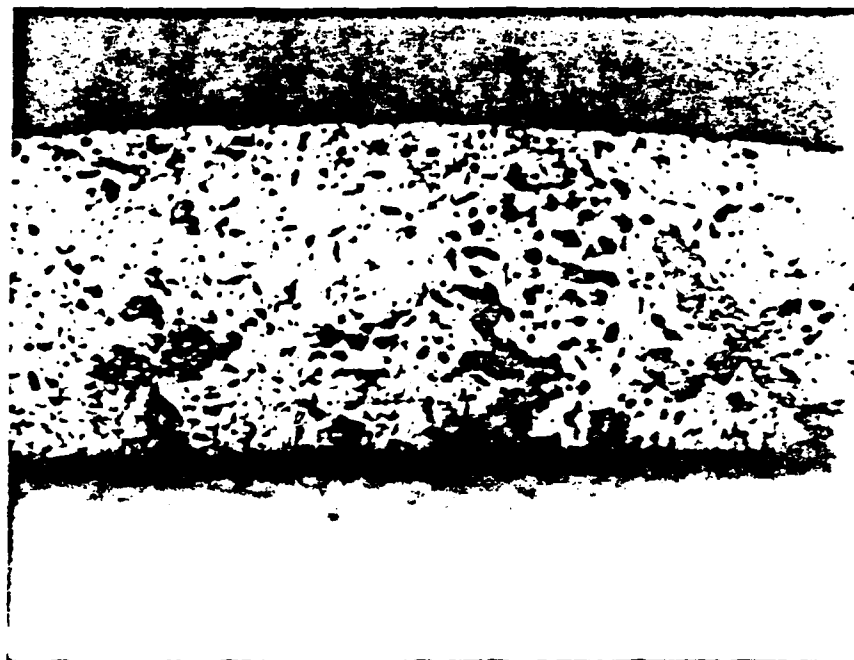
Figure 8   Optical photo of a cross-sectioned solder sample showing the large
            lead particle formation near the solder-copper interface.

Figure 9   SEM photo of a large α particle measuring 10 microns in length.

Figure 10   SEM photo of a cross section showing the effect of a large α particle
on the surface topography when the average solder thickness is less
than the particle height.
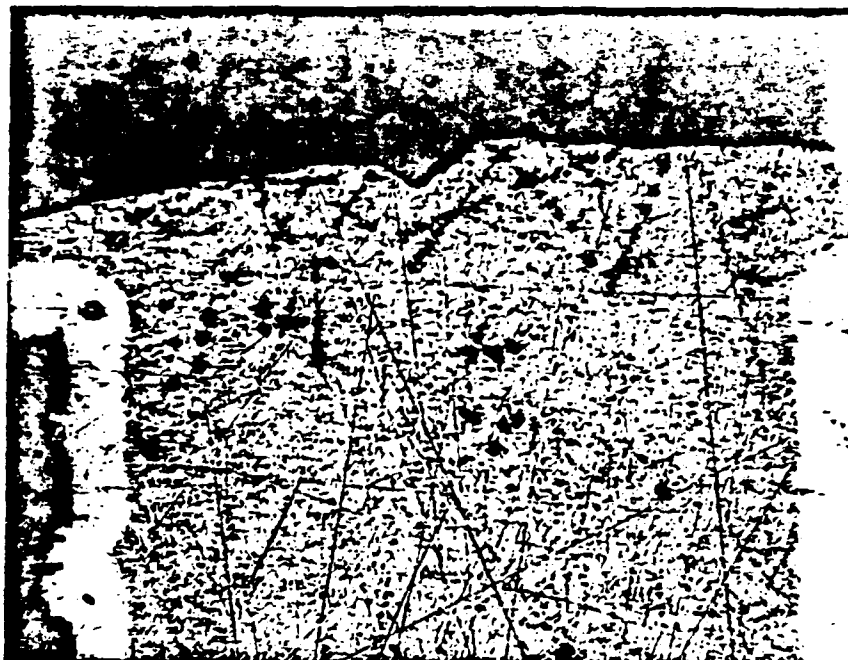
Figure 11   Optical photo showing large lead particles segreated near the surface
              of the solder in a plated thru hole of a printed circuit board.
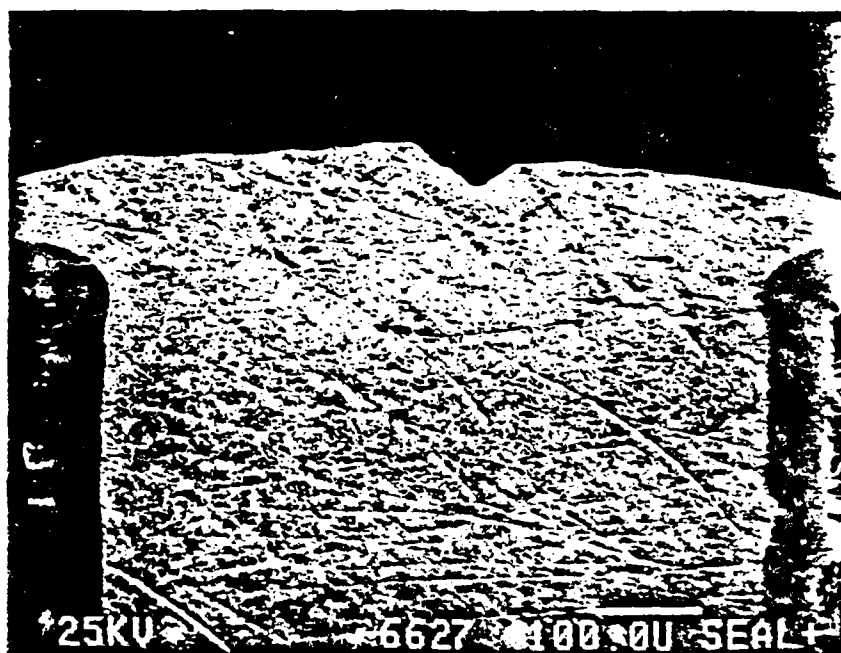
Figure 12   SEM photo of the same mount shown in Figure 11.   The large α particles
              appear as indentations in the solder.   Note that the lumps on the
              surface corresponds to the area of a segregation near the surface.

and number. Figure 12 is an SEM photo of the same sample mount.
In this photo the lead rich particles appear as identations in the
solder. It is more apparent in this photo that the lumps on the
surface correspond to the large alpha growth under the surface. The
orientation of the α particle is more evident at higher magnification
as shown in Figure 13. A lead mapping (Figure 14) of the area in
Figure 13 confirms these particles as lead rich α particles. The
spot analysis of this particle is shown in Figure 15. This spectra
shows the large concentration of lead when compared to Figure 16
which is the spectrum obtained from an analysis of a large area of
solder not containing large particles.

It is apparent that the lumpy solder condition is a direct result of
the presence of large α particles near the surface of the solder. As
was mentioned above the growth of α particles will result when the
solder composition differs from the eutectic composition and as the
solder becomes more lead rich the size and number of these particles
will increase. There are a number of factors that can cause the
formation of a non-eutectic solder, for example:

1) Solder plate composition may vary from 30 to 50% in lead.

2) Wave solder may vary in composition.

3) Copper impurities may deplete eutectic solder of tin by forming
    intermetallics.

4) Copper tin intermetallic layer, as it increases in thickness,
    will deplete solder of tin.
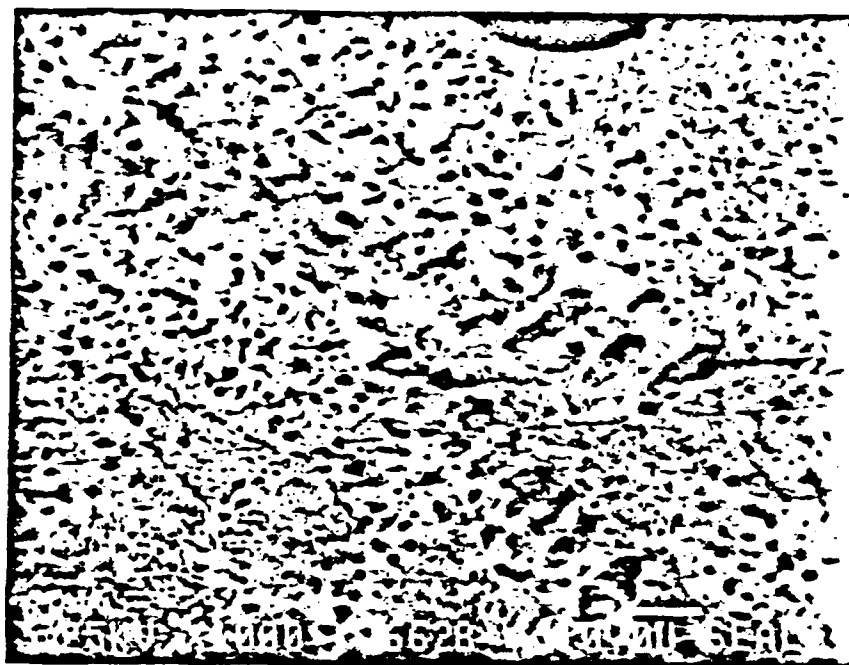
Figure 13   A 1000X magnification of a larger particle taken by SEM of the mount shown in Figure 11.
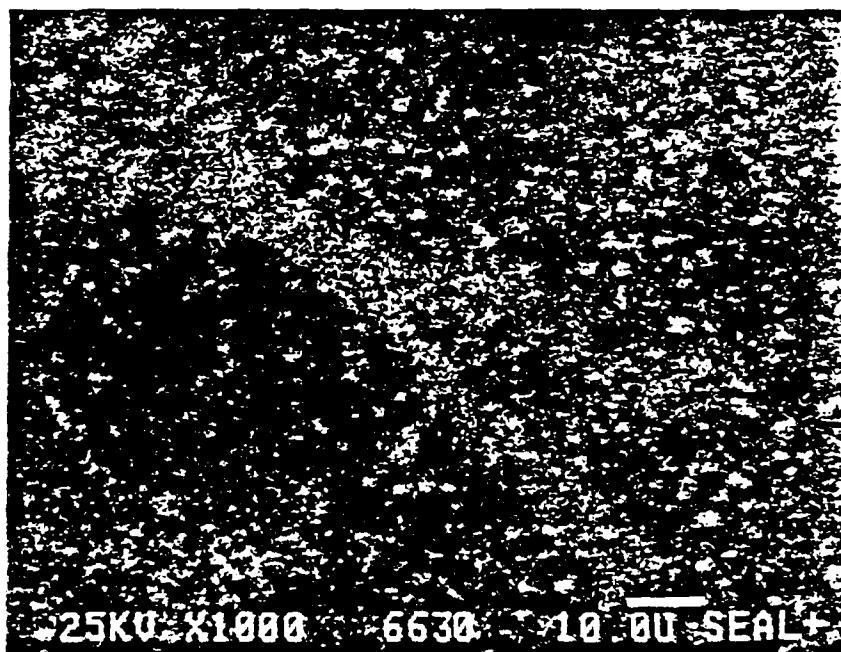
Figure 14   A lead x-ray map of the same area shown in Figure 13.
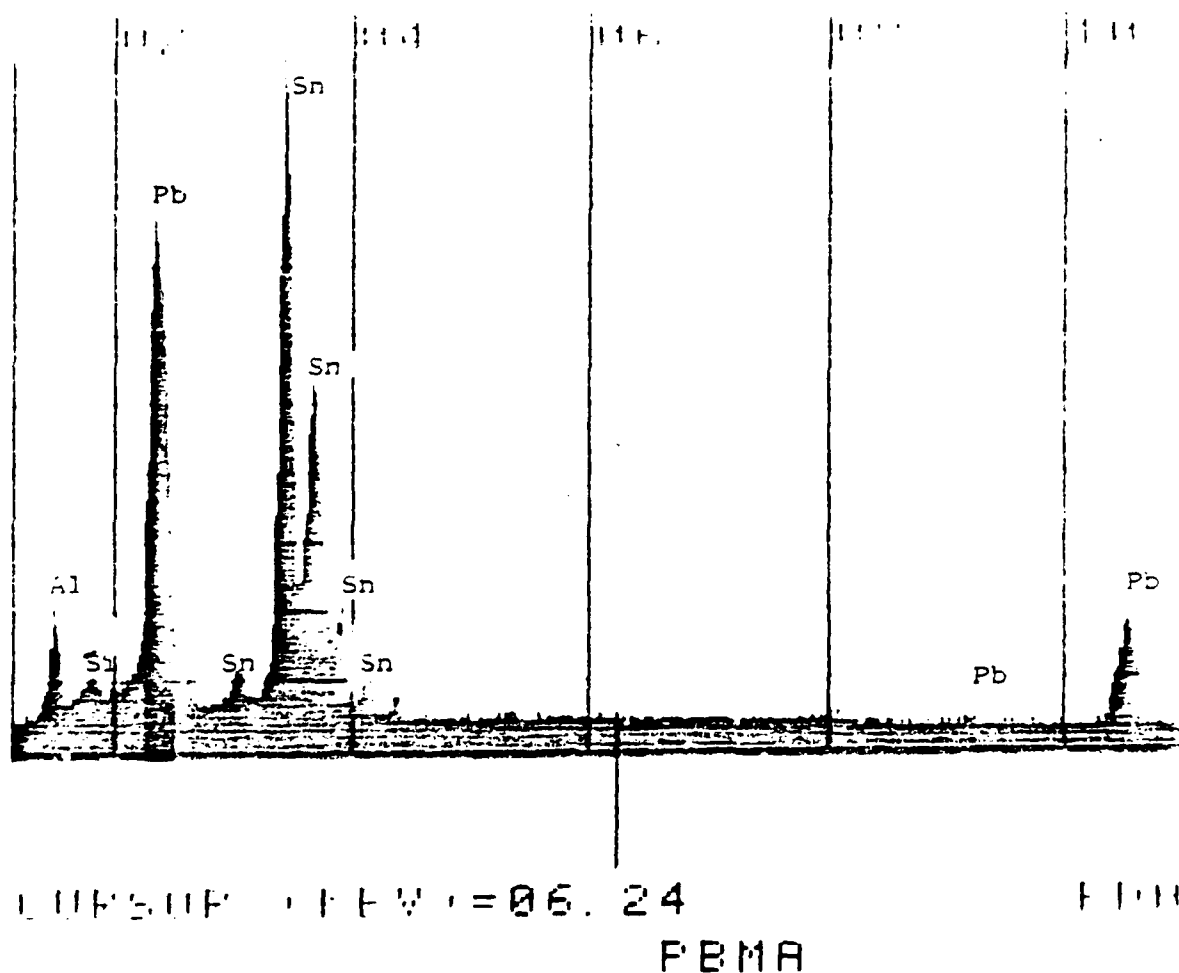
Figure 15.   EDX spectrum of α particle shown in Figure 13.
              Spectrum indicates a large concentration of lead
              in the area analyzed.
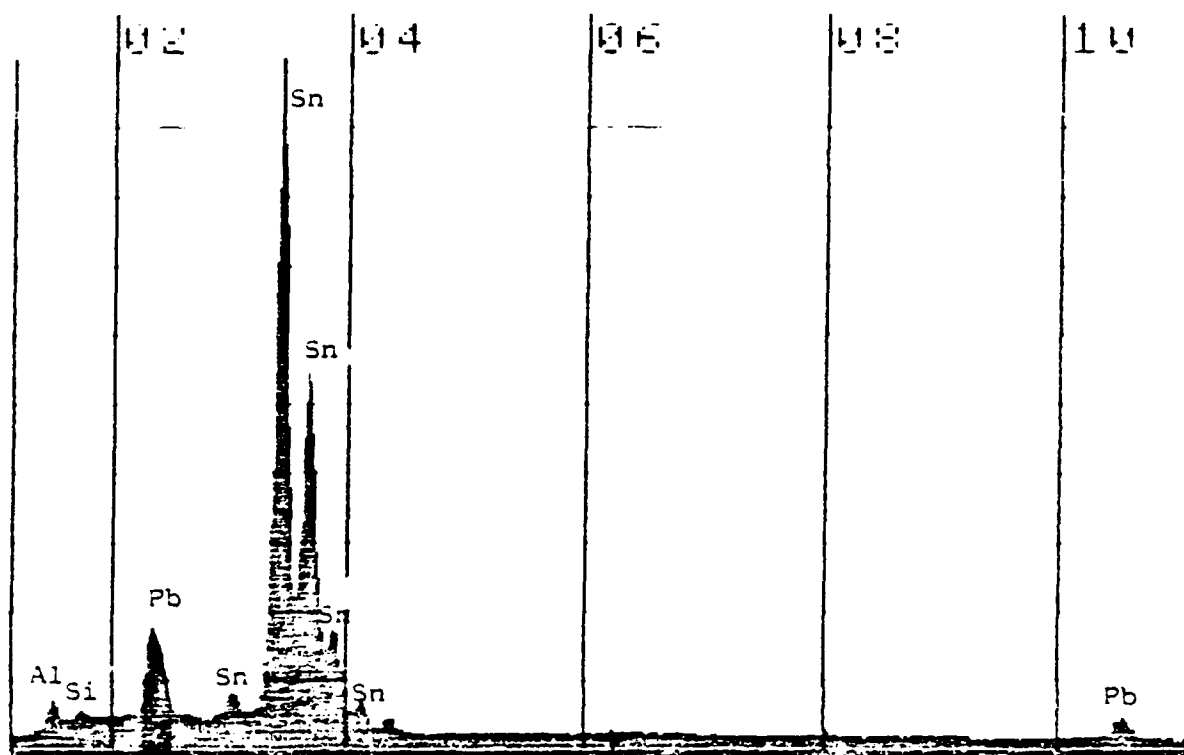
Figure 16.   EDX spectrum of solder area whose metallurgy is more representative of eutectic solder.

The solder plate composition is not tested in-house and since analysis of the solder plate was not possible after wave soldering this factor cannot be discussed. Analysis of the solder in the wave soldering apparatus is conducted regularly and no anomolies were observed for the solder used on the affected boards. Auger analysis and emission spectroscopy detected the presence of copper in the solder. The amount detected does not appear to be directly responsible for the lumps but this amount will deplete some of the tin and will help enhance the formation of particles. The fourth factor only appears to be important when the solder thickness is small.

A number of processing tests were conducted to determine if the lumpy solder condition could be eliminated by varying certain parameters during wave soldering.

1) Elimination of vibrations by realignment of pullies and replacement of belts did not reduce the appearance of lumps.

2) Testing various combinations of fluxes and oils resulted in no lumpiness only when an organic flux was used.

3) Increasing the normal cooling rate by doubling the air flow or turning off the air flow after the wave had no effect.

4) Increasing the speed of the board to 10 ft per minute through the solder was found to reduce the condition.

RESULTS AND DISCUSSION (CONT.)

5) Pre-cleaning of boards had no effect.

6) Wave soldering the boards at 475, 500 and 545°F did not eliminate
the condition.

Miscellaneous tests were also performed in an attempt to find the cause
of the problem. Hand soldering of solder plate produced lumpy solder.
A re-fusing of an as received board from a vendor resulted in some
lumpy solder. Stripping off the solder plate, re-cleaning the copper
and hot air-leveling followed by wave-soldering produce virtually no
lumps. Touching up solder joints with a soldering iron caused the
lumps to disappear by reflowing the solder.

CONCLUSIONS

Based on analytical and process testing our condition termed "lumpy"
solder is directly caused by the presence of large lead particles near
the surface of the solder. The solder plate appears to be the source
of the excess lead and the main factor contributing to this condition.
This conclusion is based on the facts that the hot air levelling
produces virtually no lumps, that the use of an organic flux results
in no lumps, that tests of the solder purity of the wave eliminates
it as a probable cause and that lumps have been observed on as-received
or plated only boards. The large lead particle formation is also
enhanced by the presence of copper in the solder and in certain cases
by the formation of the copper-tin intermetallic layer at the copper-
lead interface.

The formation and presence of large particles in the solder will not impair the solder joint nor will it affect the reliability of the product.

SOLDERABILITY ASSURANCE IS QUALITY INSURANCE

by

Dennis F. Bernier

Vice President, Research & Development

Kester Solder Company

Chicago,Illinois, U.S.A.

Abstract

The soldering process is a total system of interrelated factors
beginning at the time materials are selected and fabricated.
This paper discusses production soldering problems and
excessive touchup costs resulting from an inadequate under-
standing of the requirements for reliable soldering. The
ability to easily solder a printed circuit assembly to produce
a reliable, quality product is directly related to assuring
solderability of the circuit board and components during
fabrication and assembly.

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Naval Weapons Center

China Lake, California

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This paper is directed to those people who solder printed
circuit board assemblies and the goal is to try to interest
them in solderability testing. Only by testing can we
determine if solder will properly bond to metal surfaces and
that these surfaces are assembled in a solderable configuration.
There are many ways to discuss solderability. Rather than look
at the methods for testing solderability, one way to present
the subject is to look at problems, those expensive, trouble-
some defects that are the result of not being concerned
enough about solderability. We can look at these problems not
just from the printed circuit board or component manufacturer's
viewpoint, not from the assembler's viewpoint, not from the
touchup operator's viewpoint, but from the solder's viewpoint.
Molten solder must come into intimate contact with clean
metal to make a bond. It doesn't matter whether the metal is
copper, brass, nickel-iron, or steel, the metal has to be
clean, non-contaminated and active enough for the solder to
bond.

Everybody has some type of soldering problem requiring some
amount of rework or touchup. In surveys that have been run,

we find that the cost to touchup each bad solder connection is about 4-5 times the cost to make the solder joint the first time, not including the decrease in productivity. To circumvent the solderability problem we seem to require more active fluxes to obtain reliable soldering. It is true that the more active fluxes permit higher speed soldering but the choice is still made most often only because of inadequate solderability of boards and component leads. It is not unusual to attend soldering seminars and hear a production engineer say, "If your circuit boards do not solder properly, use a stronger flux". Trying to solder parts that are not solderable will only reduce reliability and increase expensive touchup. This situation can be compared to your automobile running out of gasoline and, because gasoline is too expensive to buy, hiring several people to push your car around at a slower, less efficient pace. Buying the gasoline, like building solderability into your electronic assemblies, can save cost and increase your speed of operation.

There are many soldering defects that are not just related to the solderability of metal surfaces. For instance, production requirements may specify that in single-sided boards all the holes must be drilled the same size to cut down on the cost. Unfortunately, component leads are not all the same size and bridging across a large hole to a small lead becomes difficult. Drilling procedures should not leave a raised edge or burr around a hole. Solder, like any liquid, does not flow easily

over a sharp edge and, again, touchup is the result. Also, the nonmetallic surfaces may contribute to soldering defects. Solder might stick to uncured solder mask or glass epoxy. Looking from the solder's viewpoint, if the proper flux and correct amount of heat have not been used, the high surface tension of the solder can result in bridges where you don't want them (shorts) and no bridges where you do want them (voids). Nobody wants the excessive cost of touchup operators, but the electronics industry is becoming dependent on this part of the soldering process. It is not unusual to see twelve touchup people positioned at the end of a wave soldering machine. Some companies may have twenty or twenty-five people touching up solder joints, trying to cover over defects that may not have occurred if some attention was given to solderability considerations before and during assembly. We have to put the qualified people where they will do the most good, namely in preproduction testing and operating the wave soldering machine. The machine operators who are trained can spot the solderability defects and action can be taken to correct the problem rather than have touchup people attack the symptoms.

Wave soldering is a rapid process capable of soldering 200 or more connections per second. Anything in the process that causes the solder to take a longer time to wet metal surfaces properly will result in soldering defects. Loss of control of the flux, solder purity and heating are important, but

solderability, the selection of solderable metals and putting
the metals together so they solder quickly are the main
considerations for reliable soldering. Soldering is a total
system of interrelated factors. Figure 1 shows all of the
parameters involved in controlling any process of soldering
and particularly the high speed wave soldering process.
Before the solder contacts the printed circuit assembly a
considerable amount of prelimina _ work has to be done to
help minimize the amount of rework or touchup. Many people
look at the flux as the most important factor to preparation
for the solder. Most ignore proper heating considerations.
Everyone should be looking at the top of the chart. The degree
of reliability, the productivity, the amount of touchup are all
directly related to the selection of materials, fabrication and
the effort made to obtain and maintain solderability.

The development of the electronics industry is closely related
to the ease of joining copper surfaces with solder. There is
no more economical way than soldering to make these connections.
The amount of solder on an entire circuit board assembly
usually costs less than the cheapest component part. Electronics
has changed, however, and the biggest change affecting the speed
of soldering has been the increased use of nickel-iron component
leads. Unless these leads are properly tinned, soldering with
mild fluxes is nearly impossible. To make these leads solder,
component manufacturers plate on copper, silver, gold, tin and
solder coatings because these are more solderable metals.

FIGURE 1   SOLDERING SYSTEM

```
        ┌─────────────────────┐
        │  Material Selection │
        │     and Design      │
        └─────────────────────┘
                  │
                  ▼
        ┌─────────────────────┐
        │     Fabrication     │
        └─────────────────────┘
                  │
                  ▼
        ┌─────────────────────┐
        │  Surface Cleaning   │
        │  for Solderability  │
        └─────────────────────┘
                                    ┌──────────────────┐
                                    │ Extra Precleaning │
                                    └──────────────────┘
                                              │
                                              ▼
┌──────────────┐   ┌──────────────┐   ┌──────────────────┐
│ Organic Flux │   │ RA Rosin Flux│   │ RMA Rosin Flux   │
└──────────────┘   └──────────────┘   └──────────────────┘
                          │
                          ▼
                   ┌──────────────┐
                   │     Heat     │
                   └──────────────┘
                          │
                          ▼
                   ┌──────────────┐
                   │    Solder    │
                   └──────────────┘
                          │
                          ▼
                   ┌──────────────┐
                   │    Rework    │
                   └──────────────┘
                          │
                          ▼
                   ┌──────────────┐
                   │ Post Cleaning│
                   └──────────────┘
```

FIGURE 1   SOLDERING SYSTEM
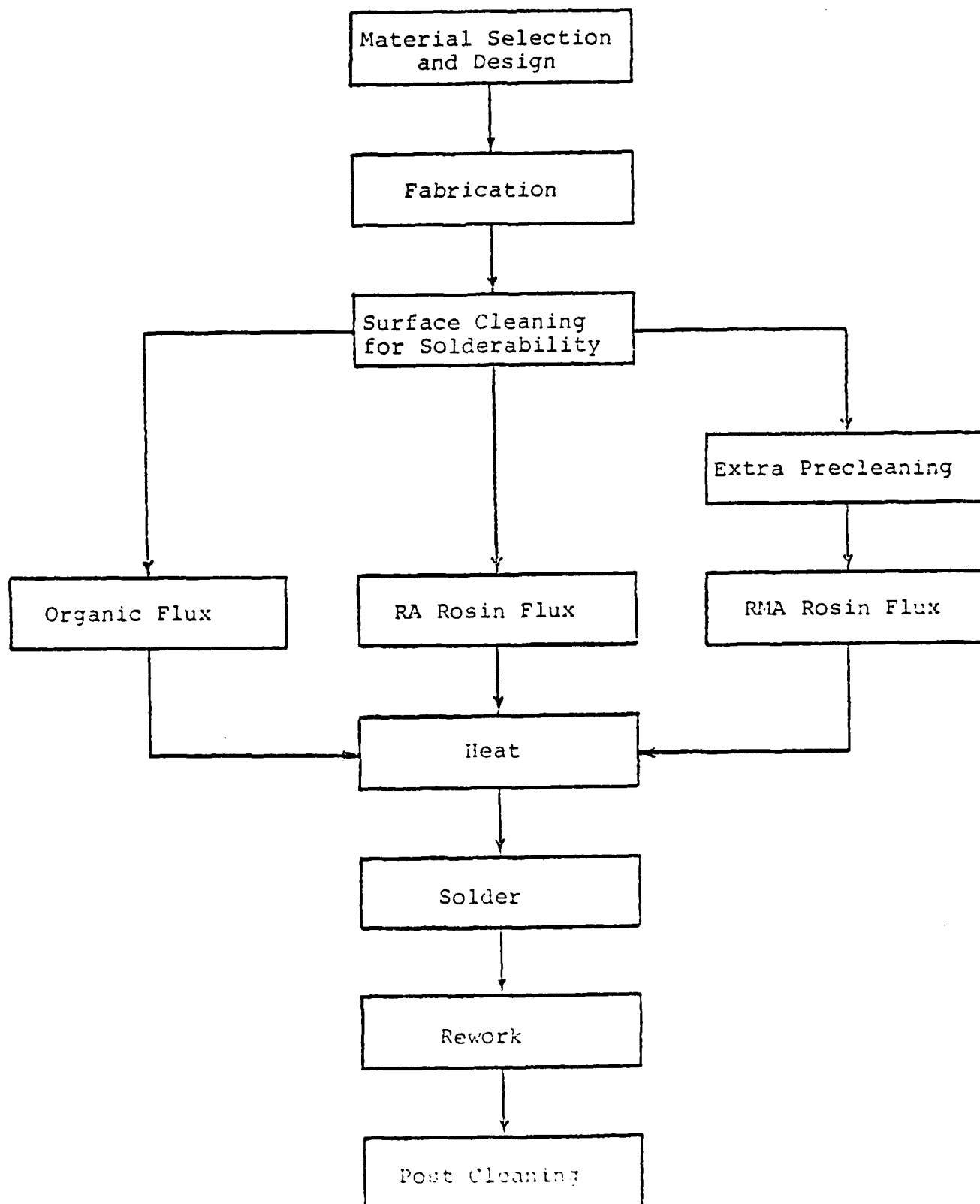
These metal coatings all dissolve away in molten solder and if dirty, unsolderable base metal had been plated, the leads do not solder. The result is excessive touchup. The only way to know that a surface is not solderable is to test for solderability. A simple test will tell if these parts are ready to put together and solder will bond properly. Without this control over the solderability the rest of the process is really out of control. The selection of flux type is dependent on the solderability level, the amount of heat depends on the flux being used and post cleaning is related to the amount and type of flux residue.

Solderability - Copper is selected as the base metal not only because of its good electric conductivity but also because of the ease of soldering. Copper is very solderable. Even without flux a fairly clean copper surface will wet with solder when dipped into a solder bath. Figure 2 is an illustration of a copper surface which has been soldered.

FIGURE 2   TINNED COPPER SURFACE CROSS SECTION
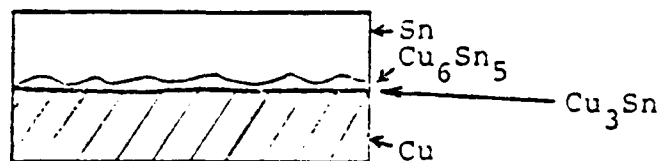
The tin in the solder actually does the bonding as the solder penetrates the grain boundaries of the clean copper surface. At the solder-copper interface two copper-tin intermetallics form rapidly during the heat of soldering. Typically, the

thickness of the intermetallics is about 10 micro-inches. The formation of the intermetallic compounds, $Cu_6 Sn_5$ and $Cu_3 Sn$, is indeed an indication that the molten solder came in contact with clean copper metal; but the quality of the joint would be better if the solder could wet the copper without the formation of the thick intermetallic. If the copper-tin intermetallic gets too thick, exceeding about 20 micro-inches, the solder no longer bonds and we have dewetting. So, the amount of time that solder is melted on copper becomes important. When people specify thick-fused solder coating on copper, they assume that the shiny solder surface exhibits the good solderability of the circuit board. We cannot make such an assumption since the solder may have been melted too long at too high a temperature. Quite often an infrared reflowed board will exhibit a shiny solder surface which actually conceals an already too thick intermetallic layer. On subsequent melting of the solder coating during wave soldering, the surface may dewet when the intermetallic layer thickens. Running a solderability test across the wave soldering machine after components are put into the board is the wrong time. Never conclude that any surface is solderable until after a solderability test is run.

Gold also forms intermetallics with solder. Unlike copper which does not form intermetallic compounds with lead, gold dissolves rapidly in solder forming lead-gold and tin-gold intermetallics which flake off the base metal and float to the

solder surface. Gold plating less than 80 micro-inches thick dissolves instantly in hot solder. A common soldering defect is associated with gold-plated component leads soldered into plated through holes in printed circuit boards. The gold is washed off the component lead as the solder fills the hole. The solder at the top of the hole may contain as much as 20% gold, is very brittle and can be the source of cracked joints. If we are striving for soldering reliability, gold should be removed from all surfaces by hot solder dipping before assembling these parts into a circuit board.

From the solder's viewpoint the best surface to solder is bare copper. Any coating applied to the copper surface should not inhibit solderability. Like the nickel-iron component leads, the copper under the coatings -- such as tin, solder, silver, gold or rosin -- should be solderable since dirty copper can be plated over but not soldered.If a metal surface is fluxed and then dipped into molten solder, the metal surface will exhibit some degree of solderability. A surface is solderable when molten solder will completely flow out on the surface, forming a uniform, tight molecular bond between the solder and the metal surface. Only a clean surface is a solderable surface.

> Wetting - A surface is wetted when the solder flows
> well, forming a continuous, unbroken film, free of
> pinholes and depressions.

Nonwetting - Areas of the base metal are visible through the solder coating. The contact angle between the solder and the base metal is very large and there are distinct boundary ridges.

Dewetting - The solder appears to have wetted the surface but then immediately pulled back from areas leaving an irregular, lumpy coating.

FIGURE 3   VARIOUS DEGREES OF SOLDERABILITY

Solder surface is smooth, bright and completely covered.	Solder does not flow and leaves exposed base metal.	Solder withdraws from areas leaving a thin film without exposing the copper.
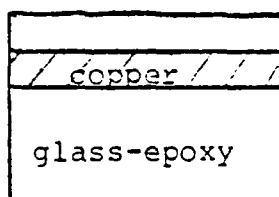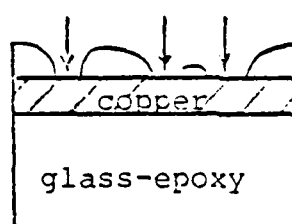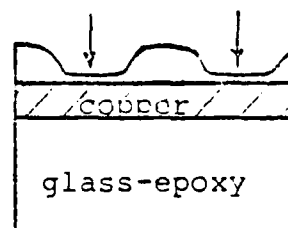
WETTED	NONWETTED	DEWETTED

Nonwetting is most common on circuit boards with overcured rosin protective coating that acts like an epoxy barrier since it does not dissolve in the flux. Thin tin coatings or flashes, 10-20 micro-inches, are rapidly migrated through by copper, resulting in a nonwettable tin-copper intermetallic surface. Brass quite often is coated with an immersion or

electroless thin tin, and after migration occurs the tin-copper intermetallic coating is covered with zinc oxide. Certainly this cannot be soldered with a rosin flux. Nickel-iron component leads are often nonwetted but the situation is difficult to see because the nickel-iron is the same color as solder.

Dewetting is more common than nonwetting but not a much different situation. The intermetallic formation just described as nonwetting can also be the cause of dewetting. If a copper surface is exposed to molten solder for too long a time, either continuously -- during infrared reflow-- or repeatedly -- during unnecessary touchup -- the tin-copper intermetallic thickens and the solder pulls back leaving a dewetted surface. Dewetting can also be caused by contamination in the metal surface. Copper is a soft metal and hard particles like pumice or aluminum oxide grit can be ground into the surface during improper cleaning procedures. These trapped particles do not wet with solder and the inclusions inhibit proper wetting of the copper. Additives such as brighteners and leveling agents in the copper plating bath cause dewetting when an excessive amount is codeposited with the plating. Solder generally wants nothing to do with a "bright" plated surface because of the nonmetallic inclusions in the plating. If plated through holes are being used in a printed circuit board, the plating baths -- copper, tin, solder -- should contain minimum organic or metallic impurities since these unsolderable materials deposit in the area of

lowest current density -- in the plated through holes. Then
the soldering problems are built into the board.

Preserving Solderability - The best surface for soldering is
bare copper. There is no reason to plate or otherwise coat a
single-sided circuit board with anything other than possibly
a rosin protective coating to preserve solderability. Extensive
testing several years ago revealed some interesting facts
concerning various "protective" coatings on copper.

Bare Copper - the easiest surface to clean and
activate for soldering by a simple chemical
immersion. No other metal can be cleaned with
so little effort and expense.

Modified Rosin Coating - Provides very good protection
during storage of the circuit boards. Solderability
is good for six months to one year depending on the
environment and handling. Even if a problem develops,
the rosin coating can be easily removed with solvent,
the copper recleaned and coated again. The coating
prevents contamination during handling and assembly
and is compatible with rosin flux.

Solder Coating - Provides good solderability protection
but is subject to control problems. Contamination in
the plating bath or dip solder pot creates soldering
problems. The degree of protection is directly
dependent on the solder thickness and,if the solder
was fused or reflowed, how thick is the intermetallic.
Assuming the impurity level is low, a solder thickness
less than 20-30 micro-inches actually degrades

solderability of the copper surface. A thin plated porous solder coating is rapidly migrated through by the copper and converted to lead covered tin-copper intermetallic. A roll-solder coating or liquid squeegeed board falls into this category. Thicker solder plating in the 100-300 micro-inch range provides good protection especially if the solder plating has been fused or reflowed or if the solder was applied by hot air leveling. Still, the question remains, "Was the solder melted on the copper for a minimum time and was the solder purity level high enough for a quality coating?"

Tin Coating - Tin provides the same protection as solder and the problems are the same. Electroless and immersion tin coatings are very thin (10-20 micro-inches) and degrade solderability. Thicker tin coatings (100-200 micro-inches) provide good protection.

Gold Coating - Not worth bothering with unless at least 50 micro-inches are used. Even then, migration of the copper is a problem and the gold dissolution in the solder causes serious soldering problems. If gold is plated over nickel, the thin (10-20 micro-inches) gold coating can help preserve the solder-ability of an active nickel or tin-nickel surface.

After considering all of the problems introduced by plating over the copper, if single-sided boards are being used, quality and productivity can be better assured by using bare

copper boards, coated if necessary with the modified rosin.

Double-sided boards with bare copper plated through holes and circuit traces are becoming more popular for the same reasons. All of the impurities in a solder plating bath deposit in the holes and the solder serves no function other than protecting the copper for subsequent soldering. Solder resist or mask can be screened directly on bare copper, eliminating the solder mask crinkling problem experienced when solder plating melts under the mask during the soldering operation. Solder mask is often applied to cover the outer edge of pads to reduce solder pull-back on large pads which tends to result in solder joints with too little solder. Pads on the top of the board are being covered as near as possible to the hole since joint reliability does not require solder flow on the top of the board. Bare copper holes are easier to inspect visually for plating defects like rifling, nodules or cracks and for etch residue impurities. The only metal coating for copper that appears reliable is hot air leveled solder since immersion time of the copper in molten solder is minimal and the coating thickness is controllable in the 100-300 micro-inches range.

Solderability Does Not Just Happen - The supplier or manufacturer of the printed circuit board or components should be building these parts to the specifications of his customer. If a company has no specification describing exactly what is desired in dimensions, coatings, thicknesses and solderability, that company is taking a chance that the boards will not solder

and probably the money they saved by buying from that supplier
will be lost in expensive touchup of defective soldered
connections.

Other Solderability Problems - Solderability involves more
than just the metal surfaces. The glass-epoxy laminate G-10
has been replaced by FR-4 for the purpose of providing a flame
resistant circuit board. The fire retardant chemistry contains
bromine which causes several soldering problems. The resin
system quite often does not completely cure. This is more
evident with multilayer boards which always seem to require
baking to minimize blowholes in the solder joints. Volatile
chemicals in the resin system or moisture trapped under the
plating in through holes blows out when the hot solder enters
the hole and creates a blowhole. Most of the time a blowhole
is only cosmetic. But the presence of a blowhole indicates
there is a problem with the board. Touching up blowholes serves
no functional purpose if quality control personnel are not aware
that the problem exists. Strong solvents such as methylene
chloride or methyl chloroform can also attack this soft resin
on the board surface, resulting in exposed glass fibers or
measling. Strong acid water soluble fluxes or aqueous alkaline
flux removers can also attack this resin. The smallest amount
of chloride in the flux, even RMA fluxes, can pull the bromine
out of the board and result in leaving lead bromide which
cannot be removed by solvent or aqueous cleaning. A lowering of
insulation resistance between circuits may be the result, then,
of the soldering process. Therefore it is a solderability

consideration. Solder mask is not always completely cured,
especially the ultraviolet-curable type. Solder can stick
to this mask, resulting in a web effect of solder on the
mask. Incompletely cured solder mask can be smeared over
surfaces which are to be soldered if brush cleaning of the
pads is done after trying unsuccessfully to cure the mask.
An overall circuit board solderability test has to be run
prior to assembly to see if any of these problems occur,not
after stuffing components into the board when corrective
action is difficult if not impossible. A simple inspection
procedure for boards with plated through holes -- and people
don't even do this -- is to hold the board up to the light and
see if there is any etch residue in the holes.If there is,
clean it out or the result will be unfilled holes or residue
that cannot be removed in the solder joint at the top of the
board.

Nickel-iron or kovar component leads will not solder with a
mildly activated rosin flux. Tinning of the leads has to be
done with acid flux prior to putting the components on the
assembly line. Be suspicious of those steel leads that have
been only plated with tin, solder, silver or gold. Make
certain that the metal under the plating is solderable since
the plated metals will be coming off in the solder pot. A hot
solder dipped lead is usually reliable and has indefinite
storage life. However, ultrasonic tinning without flux may only
put a sleeve of solder on the steel lead. Always check
solderability even if by only dipping the lead in flux and then

into molten solder to observe if solder fully wets the surface.

Conclusion - The only way to obtain reliability and to assure quality soldered connections is to begin with the parts to be soldered and build in solderability. Incoming inspection, component prep operators and assemblers should be trained to recognize the source of soldering problems and steps should be taken to correct the defects in material or process prior to wave soldering. The touchup operator with the hot soldering iron in his or her hand should not be the determining factor in producing reliably soldered assemblies.

9 January 1980

Mr. Jim D. Raby
Soldering Technology Branch
Code 3681
Naval Weapons Center
China Lake, CA   93555
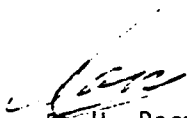
Dear Jim:

In response to your letter of 3 December 1979, I am enclosing the presentation paper and abstract information requested that George Reagan and myself will present on 20 February titled "Continuous Performance Evaluation of Solder Workmanship". Part 1 of the presentation package is my introduction and the remainder is George Reagan's package.

Both George and I intend to attend the Speaker's Meeting on the evening of the 19th at 7:00 p.m. in your Soldering Technology Branch conference room.

Please call if there are any concerns regarding the enclosed material. Looking forward to seeing you on 19 February.

Sincerely,

D. H. Rasmussen
Harpoon Quality Assurance Mgr.

DHR:kpr

I APPRECIATE THE OPPORTUNITY TO BE A SPEAKER IN THIS YEAR'S

SEMINAR. I HAVE HAD THE PLEASURE OF ATTENDING THE LAST TWO

SEMINARS AND FELT IT WAS ABOUT TIME TO PARTICIPATE IN A MORE

DIRECT MANNER. TRUTHFULLY, JIM RABY CAN BE VERY PERSUASIVE

IN THESE MATTERS AND THIS IS MY WAY OF GETTING EVEN.

I AM GOING TO COVER ONLY SOME OF THE BACKGROUND OF THE EVOLUTION

OF SOLDER REQUIREMENTS FOR THE HARPOON PROGRAM AND OUR OBJECTIVES

AND CURRENT STATUS BY WAY OF INTRODUCING TO YOU MY CO-SPEAKER,

MR. GEORGE REAGAN, MANAGER OF PRODUCT ASSURANCE AT THE NORTHROP

CORPORATION, NORWOOD, MASS, WHO WILL ADDRESS THE TOPIC "CONTINUOUS

PERFORMANCE EVALUATION OF SOLDER WORKMANSHIP." NORTHROP IS

PRODUCING THE ATTITUDE REFERENCE ASSEMBLY WHICH IS A CRITICAL

ELEMENT OF THE MID COURSE GUIDANCE UNIT.

IN THE PROCESS OF IMPLEMENTING THE HARPOON UPGRADED PROGRAM

REQUIREMENTS FOR SOLDERING, NORTHROP HAS ESTABLISHED AN EXCELLENT

EXAMPLE FOR A SYSTEM OF INSPECTION AND DOCUMENTATION FOR DEFECTS

WHICH PERMITS MANAGEMENT VISIBILITY OF THRUPUT YIELDS, IDENTIFICATION

OF PROBLEM AREAS, AND TIMELY CORRECTIVE ACTION.

VUGRAPH NO. 1 - BACKGROUND

THE HARPOON PILOT PRODUCTION PROGRAM STARTED IN 1975 WITH NO

SPECIFIC CONTRACT CRITERIA FOR SOLDERING REQUIREMENTS. THE

ENGINEERING REQUIREMENTS DEFINED IN THE VARIOUS EQUIPMENT :

SPECIFICATIONS CALLED FOR COMPLIANCE WITH MIL-STD-454, LEVEL 5

OR 9 AS APPROPRIATE.

WITH THE ADVENT OF FLEET TESTING AND SUBSEQUENT CONCERN RELATED

TO THE RELIABILITY OF THE MISSILE SYSTEM, EXTENSIVE REVIEWS BY

BOTH THE CUSTOMER AND MCDONNELL DOUGLAS EVOLVED A COMPLETELY

REVISED CONTRACTUAL PRODUCT ASSURANCE REQUIREMENTS BASELINE FOR

HARPOON PRODUCTION. INCLUDED IN THIS BASELINE WAS THE ADDED

REQUIREMENT FOR COMPLIANCE WITH WS6536C.

AFTER CONSIDERABLE EXCHANGE BETWEEN MDAC-STL, OUR RESPECTIVE MAJOR

SUBCONTRACTORS AND THE NAVY, THE WS6536C SPECIFICATION WAS TAILORED

TO ACHIEVE A MINIMUM COST IMPACT. EVERY EFFORT WAS MADE TO MAINTAIN

EXISTING PROCEDURES AND PRACTICES TO THE EXTENT FEASIBLE. CERTAIN

PRODUCTS, SUCH AS SWITCHES, RELAYS AND BATTERIES, WERE ESTABLISHED

AS "EXEMPT" IN THE TRADE-OFF AND DESIGN CRITERIA WAS AGREED TO BE

VUGRAPH NO. 1 - BACKGROUND (CONT'D)

"NOT APPLICABLE" SINCE THE HARPOON DESIGN BASELINE WAS ALREADY

ESTABLISHED. NO ALTERATION WAS MADE TO THE WORKMANSHIP STANDARDS;

HOWEVER SOME CONCESSIONS WERE ALLOWED AS TO "HOW" AND TO THE EXTENT

OF PERSONNEL TRAINING AND RECERTIFICATION REQUIREMENTS.

IN A COMPLIMENTARY MANNER, TIME PHASED RELIABILITY FAILURE REPORTING,

TEST THRUPUT AND TREND ANALYSES, AND MAJOR EQUIPMENT END-ITEM DATA

REPORTING REQUIREMENTS WERE ESTABLISHED WHICH PROVIDES A DATA BASE

FOR MANAGEMENT VISIBILITY AND ASSESSMENT TO ASSURE TIMELY AND

ADEQUATE FOLLOW-UP OF PROBLEM AREAS.

HARPOON

SOLDER REQUIREMENTS FOR THE PRODUCTION HARPOON

BACKGROUND

- PRODUCTION CONTRACT BASELINE UPDATED

- INCLUDED WS 6536C SOLDER SPECIFICATION

  - CONTRACTOR/SUBCONTRACTOR/NAVY REVIEWS

  - RELIABILITY REPORTS AND END ITEM DATA ANALYSES

  - MANAGEMENT REPORTING AND FOLLOW-UP

MCDONNELL DOUGLAS CORPORATION

DHR: 1

VUGRAPH NO. 2 - OBJECTIVES

THE PREDOMINANT OBJECTIVE WAS, OF COURSE, TO EFFECT AN OVERALL

IMPROVEMENT IN THE HARPOON MISSILE SYSTEM QUALITY AND RELIABILITY

WHICH IS BEING ACCOMPLISHED THRU INCREASED PERSONNEL TRAINING,

THE EXPANSION AND IMPROVEMENT OF PROCESS DOCUMENTATION AND CONTROLS,

THE STANDARDIZATION OF WORKMANSHIP REQUIREMENTS, AND PERFORMANCE

REPORTING.

THE ESTABLISHMENT OF MINIMUM TRAINING LEVELS PROVIDES THE NECESSARY

KNOWLEDGE AND MOTIVATION FOR THE EMPLOYEE TO PERFORM THE WORK TO

THE BEST OF HIS ABILITY.

THE IMPROVED DOCUMENTATION PROVIDES AUDITABLE CRITERIA FOR MEASURING

THE ADEQUACY OF IMPLEMENTATION AND PERFORMANCE.

THE ESTABLISHMENT OF UNIFORM QUALITY LEVELS AND CATEGORIZATION OF

DEFECTS CORRESPONDINGLY PERMITS A PREDICTABLE QUALITY LEVEL FOR

ESTABLISHING THRESHOLDS AND MINIMIZES REWORK/REPAIR ACTIONS.

THE USE OF PRODUCTION AND TEST TREND REPORTING PERMITS MEASUREMENT

VUGRAPH NO. 2 - OBJECTIVES - (CONTINUED)

OF PERFORMANCE AGAINST ESTABLISHED THRESHOLD GOALS WHICH ARE

ASSIGNED TO ACCOUNTABLE AND RESPONSIBLE DISCIPLINES FOR

ACCOMPLISHMENT.

HARPOON

SOLDER REQUIREMENTS FOR THE PRODUCTION HARPOON

OBJECTIVES

- IMPROVED SYSTEM QUALITY AND RELIABILITY THROUGH

  - INCREASED PERSONNEL TRAINING/MOTIVATION

  - IMPROVED PROCESS DOCUMENTATION AND CONTROLS

  - STANDARDIZATION OF WORKMANSHIP LEVELS

  - MANAGEMENT VISIBILITY OF PERFORMANCE TRENDS

MCDONNELL DOUGLAS

VUGRAPH NO. 3 - STATUS

IMPROVED PRODUCTIVITY TRENDS ARE BEGINNING TO REFLECT THE

COLLECTIVE RESULTS OF TREND ANALYSIS AND REPORTING, PERSONNEL

AND MANAGEMENT AWARENESS AND MOTIVATION AND THE IMPROVED AND

STANDARDIZED PROCEDURES AND PRACTICES.

SOLDER REWORK IS BEING REDUCED AS A DIRECT RESULT OF IMPROVED SKILL

AND WORKMANSHIP AND BY THE CLASSIFICATION OF DEFECTS TO AVOID

UNNECESSARY REPAIR OF CONNECTIONS.

WITH THE FLOWDOWN OF SOLDER REQUIREMENTS TO THE MAJOR SUBCONTRACTORS

AS REQUIRED BY CONTRACT, THE CRITICAL FLIGHT EQUIPMENT IS BEING

PRODUCED TO COMMON HIGH RELIABILITY SOLDER STANDARDS IN A UNIFORM

MANNER.

AS THE RESULT OF THESE ACTIONS IN PARALLEL WITH OTHER ADDED PRODUCT

ASSURANCE INITIATIVES, I.E., TIGHTENED QUALITY AND RELIABILITY PROGRAM

REQUIREMENTS AND ELECTRONIC PARTS TESTING BELOW THE LEVEL OF THE ALL

UP ROUND, THE HARPOON MISSILE SYSTEMS OUTSTANDING PERFORMANCE IS

PROVING THAT HIGH QUALITY AND RELIABILITY IS ATTAINABLE WITH DEDICATED

EFFORT AND DISCIPLINED REQUIREMENTS AND PROCESS CONTROLS.

SOLDER REQUIREMENTS FOR THE PRODUCTION HARPOON

STATUS

- IMPROVED PRODUCTIVITY TRENDS

- SOLDER REWORK REDUCED

- MAJOR SUBCONTRACTOR ACTIVITY IS STANDARDIZED

- THE HARPOON MISSILE SYSTEM HAS BENEFITED

HARPOON

MCDONNELL DOUGLAS

LET ME NOW TURN OVER THE DISCUSSION TO GEORGE REAGAN WHO WILL

TALK TO YOU IN MORE DETAIL AS TO HOW NORTHROP HAS PROVIDED FOR

AN IMPROVED SOLDER PROGRAM.

FOURTH ANNUAL

NAVAL WEAPONS CENTER

SOLDER TECHNOLOGY SEMINAR

20 - 21 FEBRUARY 1980

PRESENTATION ON:

"CONTINUOUS PERFORMANCE EVALUATION OF SOLDER WORKMANSHIP"

PRESENTED BY: GEORGE REAGAN, NORTHROP CORPORATION
                              PRECISION PRODUCTS DIVISION
                              NORWOOD, MASSACHUSETTS

CONTENTS: ABSTRACT

            TEXT

            VU-GRAFS INDEX

            VU-GRAFS

ABSTRACT

"Continuous Performance Evaluation of Solder Workmanship"

This presentation summarizes the implementation of WS-6536 at the
Northrop Precision Products Division in order to achieve high reliability solder
workmanship on the Attitude Reference Assembly used in the Mid-course Guidance
Unit for the Harpoon missile system; it identifies the utilization of existing
quality performance tracking techniques, and the development of a new format to
provide a finer assessment of personnel performance; and how this new format
helped identify the major contributors to solder workmanship rejections, and the
necessary corrective actions. It describes contract data reporting requirements
leading to plotting of quality performance that shows practical elimination of
system failures for solder workmanship related causes. This has been accom-
plished through a well organized, well disciplined, well controlled, and well
documented solder workmanship program. By virtually eliminating solder workman-
ship related test failures, we know that the design is better able to perform to
its limits, and that when there is a failure, we know the cause is not being
masked by deficient workmanship.

-- CONTINUOUS PERFORMANCE EVALUATION OF SOLDER WORKMANSHIP --

I want to thank Jim Raby and the Naval Weapons Center here at China
Lake, and the McDonnell Douglas Astronautics Company in St. Louis for the
opportunity to participate in this seminar. I want to pass on to you our
experiences related to upgrading our solder workmanship program to the level
required by the Harpoon missile program to produce high reliability soldering.
I will be providing evidence that we at the Northrop Precision Products
Division feel is proof that a well organized, well disciplined, well controlled
solder workmanship program will reduce hardware performance failures during
in-house testing, and result in improved performance in the system and in the
missile.

It is always interesting to note the reaction when something new or
different is proposed or imposed on a program. There is an immediate knee jerk,
a tightening of the face muscles, a raising of the hair on the back of the neck,
and a loud expelling of air, either with or without words. This was probably
our reaction when we at the Northrop Precision Products Division were first
asked to look at WS-6536C in the spring of 1976, shortly after we started the
development of the Attitude Reference Assembly for the Harpoon missile Mid-
course Guidance Unit.

While this solder specification contained much of the same material as
other solder specifications, material that was already integrated into our
in-house specifications, it did have some very significant differences,
especially when compared to MIL-STD-454, requirement 5. Our initial review of
WS-6536C identified that the most significant differences between our internal
practices at that time, and the WS-6536C requirements related to:

a. Certification of personnel

b. Contractor performance evaluation

c. Facilities

d. Quality Assurance provisions

(VU-GRAF #1)

In the area of personnel certification, WS-6536C contains the most specific requirements related to solder workmanship since our experience on the Saturn/Apollo program for NASA six to seven years earlier. Since the majority of our work force associated with electronic assembly had been trained and certified to the NASA requirements at that time, our annual recertification of personnel was based on their quality record, and an examination of recent work samples. This method provided satisfactory results, better than "best commercial practice," and satisfied the solder workmanship requirements that had been imposed by our various customers and Government agencies.

(VU-GRAF #2)

Contractor performance evaluation requires preparation of printed wiring board assembly samples that show the workmanship and quality of hardware that is to be delivered, with the samples requiring procuring activity approval prior to production; the establishment of a program for evaluating and recording certified personnel performance; the preparation and implementation of workmanship standards which clearly illustrate the quality of the various solder connections for the applicable deliverable hardware, identifying the difference between acceptable and unacceptable workmanship which shall be used for inspection criteria and evaluation of personnel performance; and implementation of continuous in-process inspection.

(VU-GRAF #3)

As for the requirements related to facilities, we had just upgraded our electronic systems assembly area for the production work on the Harpoon ARA

and other electronic systems programs. Because these requirements are related to the "Minimum Working Area Environments" requirement that is also imposed on the Harpoon program, we have included an ongoing monitoring of our facility to assure continuing satisfactory compliance.

(VU-GRAF #4)

In the Quality Assurance Provisions, in addition to some very specific requirements related to inspection of material, preparation for soldering, soldering processes, and inspection tools and equipment, the paragraphs and Table (VU-GRAF #5) regarding inspection method, reworkable defects, and acceptable defects were major departures from our normal method of operation, as I guess they were for most companies. Starting in the fall of 1977, we proceeded with the implementation of WS-6536C. The NWC trained and certified our Category C Instructor/Examiner Quality Engineer in a two-week session here at China Lake. The solder process specification and the training program outline were prepared and approved, and the actual training and certification of Manufacturing Assemblers and Quality Assurance Inspectors was completed. We also included training and certification of the Manufacturing and Quality Engineers and Supervisors who would be involved in the Harpoon ARA program to assure everybody was on the same track. The workmanship standards were prepared, and the new criteria was included in the Manufacturing work instructions and Quality check lists. At this time we realized that our Quality Performance Report technique was not going to be adequate for tracking individual quality performance.

Our standard practice already included in-process inspection points where the new workmanship standards criteria would be implemented. These in-process inspection points provided for a recording of inspection results which could be reviewed for a determination of certified personnel proficiency. However, it was determined that we would need a different technique that would provide a finer look at overall program performance.

For several years we have used the Discrepancy Report (Squawk Control Record)(VU-GRAF #6) for the reporting of deficiencies, and subsequent rework and reinspection acceptance. The Inspector, upon the completion of the initial inspection, or the reinspection after acceptance of squawk rework, would enter the results on the Inspection Evidence Record (VU-GRAF #7) with a simple "accept" or "reject" and a summary of the "reason for rejection." Therefore, a unit that was submitted for inspection that was rejected, along with one that was accepted, would show up as a 50% yield. Quality Engineering would then analyze the Inspection Evidence Records, identifying quantity accepted, quantity rejected, percent yield, and major rejects at assembly. The results of this analysis would then be published monthly as the Quality Performance Record (VU-GRAF #8) for distribution to Manufacturing and Quality supervision and management. While this technique has provided satisfactory results for many years in identifying major assembly problems and an indication of the Manufacturing quality, it did not provide the specific Assembly Operator performance that we needed.

As a part of implementing the workmanship standard and the Table II, Group I/Group II defects, we were developing visual aids for use in inspecting the Printed Wiring Board assemblies and the ARA wiring harness. We decided to tie these visual aids in with the Table II information in what we now call the Inspection Verification Record (VU-GRAF #9). We also used the NWC letter 3681/JDR of 18 January 1978 which clarified the use of the word "characteristic" in paragraph 4.7.2 of WS-6536C as referring to the "features" of an assembly, to provide a total "characteristic" count for each PWBA and the ARA. This NWC letter of clarification was issued to resolve when Group II defects from Table II required rework and when they could be accepted without rework.

(VU-GRAF #10, page 1 of NWC LETTER)

(VU-GRAF #11, page 2 of NWC LETTER)

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In the initial versions of the Inspection Verification Records, the total characteristic value for each assembly was shown (VU-GRAF #12), and the Group I defect characteristics were separated from the Group II. The current version does not include total characteristic values, and separates the Group I and Group II defects by number only. This (VU-GRAF #13) illustrates how the Inspector will identify and record defects on an actual Inspection Verification Record. Manufacturing supervision is aware that the Instructor/Examiner Quality Engineer must be called before any rework of Group II defects.

In the course of implementing WS-6536C, we found that, in order to accomplish one of the major objectives of WS-6536C, that is to eliminate unnecessary reworks, we would have to change our method of inspecting PWBA's, which are all wave soldered. Rather than having Manufacturing perform solder touch up of the PWBA's before presentation to Inspection, the PWBA's are now presented to Inspection after wave soldering and flux cleanup. The inspection results are recorded on the Inspection Verification Record. This has provided visibility of Manufacturing operator performance, control of the wave soldering processes, and identification of the true causes of the observed defects.

The Instructor/Examiner Quality Engineer collects all of the Inspection Verification Records from a run of PWBA's and summarizes on the IVR Defect Tally Sheet (VU-GRAF #14) for each PWBA type. He will then use the Defect Analysis Sheet (VU-GRAF #15) to summarize performance on all PWBA's run for that report period.

By the summer of 1978, we had all of the elements for implementing WS-6536C in place, and we could start assessing our performance. By this time our knee jerks had ceased, our eyes had quit popping, our breathing was back to normal and we could determine what benefits all this activity was going to provide. As so often happens, the benefits were not necessarily in the areas

expected. It is always incumbent on Quality Assurance management to be alert
for peripheral circumstances that may be preventing accomplishment of the
primary objectives. Although the primary intent of continuous performance
evaluation is to monitor the performance of the certified personnel to ensure
consistent quality is built into the hardware, our experience has shown that
the main contributors to inconsistent quality have been: (VU-GRAF #16)

    a. inadequate work instructions

    b. inadequate check lists

    c. process control problems, or

    d. incorrect work flow

    At this time we were using for ARA final inspection a check list that
described in general terms what the Inspector was to check for. The inspections
resulted in a high number of squawks, which after rework would result in more
squawks during the reinspection. Once the ARA was accepted by Inspection, it
would then proceed to customer and Government Source Inspection, where it was
invariably rejected for workmanship deficiencies. The Instructor/Examiner
Quality Engineer then did an analysis that identified over 300 inspection points
that we were expecting the Inspectors to consistently check using the 10-point
check list. A "laundry list" check list was developed identifying the 300 plus
points that had to be checked on each final IRA. This "laundry list" check list
(VU-GRAF #17) was subsequently divided into five check lists and incorporated at
the proper in-process work operations and inspection points(VU-GRAF #18). This
has resulted in identifying the operations responsible for the majority of
defects, improvement of the work instructions when required, further training
of the Manufacturing Operators when necessary, and a ten to fifteen fold reduc-
tion in workmanship deficiencies. There has also been a considerable benefit
resulting from less handling of the ARA.

For the Printed Wiring Board Assemblies, the initial implementation of WS-6536C caused a significant increase in the rejection level for workmanship defects. This Quality Performance Record (VU-GRAF #19) for the Wheel Supply Board for this time period was typical of all of the PWBA's. It became apparent that this form of quality performance reporting was not going to provide the specific details to zero us in on problem causes, to determine actual rework rates, and to help establish a rework rate goal. It was at this time we started implementing the previously described Inspection Verification Records, the IVR Defect Tally Sheets, and the Defect Analysis Sheets.

The initial analysis identified an unsatisfactory rework rate of between 11 to 15%, with the major reason for rejection being blow holes in the solder (VU-GRAF #20). Investigation showed these blow holes were caused by substandard or questionable plating in the PWB plated through holes, and possibly by incomplete cured PWB's. Quality Assurance instituted source inspection and surveillance at the PWB suppliers, and a test of incoming PWB's, at Receiving Inspection. Manufacturing implemented a temperature bake of all PWB's, and storage in dry nitrogen boxes. This eliminated 25% to 50% of the rejection of PWB's, with rejections for blow holes being practically eliminated.

The next major reasons for rejections were associated with component lead lengths through the PWB being too long or too short on the bottom side, and improper component clearance on the top side of the PWB (VU-GRAF #20A). Most of these defects were caused by the solvent soluble component spacers either crumbling or being displaced, permitting the components to cock. There was some adjustment of the lead forming and cutting equipment, but the major improvements were realized from the change over to permanent spacers. This eliminated another 20% of the rejections of PWB's.

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The next major reason for rejection was poor solderability of some component leads (VU-GRAF 20B). The Instructor/Examiner Quality Engineer was able, through the use of the Inspection Verification Record, to determine that the major contributors to poor wetting were those components with kovar leads, specifically certain transistors and capacitors. Our investigations and contacts with the suppliers of these parts disclosed that the manufacturers were not meeting the lead solderability requirements. In order to eliminate this cause for rejection, we are now cleaning and tinning all kovar lead parts, and packaging for stores in static-free, airtight bags. This eliminated another 10% of the reasons for rejection being detected in the July to December 1978 time frame.

By this time, in the early spring of 1979, we realized that using this technique had helped us zero in on some major problems that were not people oriented, and that it was going to be worthwhile to provide a tracking chart of the PWBA Rework Rate (VU-GRAF #21). As can be seen, we were able to show that our efforts in late 1978, early 1979, had resulted in a much more acceptable rework rate, and in the ensuing nine months we have been able to improve on that by a further 33% reduction in the reject rate. We know that the majority of the causes of the remaining defects are design related; i.e., component density on some PWBA's, rectangular lead components in round PWB holes, close spacing of leads on some components, parts location relationship, components lead material, etc.

I mentioned earlier that the Facilities requirements of WS-6536A are closely related to the "Minimum Standards for Working Environments" that have been imposed on the Harpoon program. In order to assure continuing compliance with these requirements, we have included the checking and the reporting in our Process Control work schedule (VU-GRAF #22). This identifies the elements that are checked on a regular scheduled basis in each work area that is involved with the Harpoon ARA production.

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For the Harpoon ARA program, in addition to our in-house quality
performance tracking scheme that I have described, the contract requires the
preparation and submittal for each ARA shipped of an End Item Data Package
(EIDP) (VU-GRAF #23 and #23A), and a weekly submittal of the Failure Free Test
Status Report (VU-GRAF #24) for all ARA's shipped during the week. These are
required as the result of DCRL items R-118 (VU-GRAF #25) and P-019A (VU-GRAF
#26). The data for P-019A is obtained from the Factory Test History and Failure
History portions of R-118. MDAC, as stated in the purpose of P-019A, uses this
data to identify trends in Harpoon hardware throughput, at the suppliers, but
also at systems integration at MDAC, and at missile testing at MDAC and the
Navy. MDAC started providing in the spring of 1978, the results of their track-
ing of Northrop ARA's at our acceptance testing (VU-GRAF #27). While I have
removed information pertaining to exact failure rates and number of units
processed, this chart identifies our performance over a thirteen month period,
eleven months prior to implementing WS-6536C, as well as the other Product
Assurance initiatives, and the first two months after initiating the implementa-
tion. The chart shows that we were at a pretty low level of performance. At
this point in time, we realized that, although there was no contract requirement
that we plot the "Failure Free Thruput", it was going to be necessary that we do
so, in order to know what our performance was, where our problems were, what
corrective actions we would have to take, and how effective these actions were,
in advance of any report from MDAC which may be six to eight weeks after ship-
ment of ARA's. In October 1978, we instituted our own plotting of the Failure
Free Tests for the same time period as the MDAC plot (VU-GRAF #28). As can be
seen, there is good agreement on the overall profile, and we were able to dem-
onstrate improved test yields, which we considered were at least due to improved
solder workmanship, especially in the early stage of improvement. This we know
because the implementation of WS-6536C was in advance of the other Product
Assurance initiatives.

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At this time we decided to start tracking another element from the EIDP, that of Quality History, since the Thruput Report only covered Test History and Failure History. The Quality History identifies rework history relating to component removals/replacements, solder reworks, contamination, and Material Review Board actions. Since there was a change in the mill in the method of counting quality events, our initial plot of removals/replacements and quality events was not that meaningful.

(VU-GRAF #29)

Using the contents of DID R-118, we prepared a Quality Assurance Job Instruction that categorized the individual rework events into what we now plot as Removals/Replacements (VU-GRAF #30) and Workmanship Quality Events (VU-GRAF #31). Starting in March 1979, we again started plotting Workmanship Quality Events in addition to Component Removals/Replacements (VU-GRAF #32). This decrease in defects or Workmanship Quality Events clearly shows the improvement in workmanship quality that is the result of corrective actions that I previously described, and continued improvement has been mainly a result of increased Manufacturing Operator experience and confidence. This improvement is also illustrated in our in-house Quality Performance Record (QPR) for Harpoon Assembly Yields (VU-GRAF #33). The QPR provides a detailed summary of the major reasons for rejects, but, like the plotting of workmanship quality events, it is after the fact. This is why we have found it to be extremely important to do an immediate assessment of the inspection results on each lot of PWBA's, and for each ARA, to be able to stay on top of problems, or potential problems.

Well, what has been the payoff of all this effort.

(VU-GRAF #34)

This chart covers the period from late 1977, when MDAC started their Thruput Report, until the end of 1979. The initial implementation of WS-6536C had much to do with the improvement seen in the spring and early summer of 1978,

and continuing satisfactory failure-free thruput test results since that time. This continuing satisfactory performance is also illustrated in our QPR for Harpoon ARA Final Test.

Another big payoff area has been the reduction in ARA's being returned from MDAC. In the period prior to the spring of 1978, the ARA's being returned by MDAC because of failures in system integration were predominantly for workmanship-related causes; i.e., broken wires, solder particles, shorts, unsoldered connections, etc. These MDAC returns were the major reason for early implementation of WS-6536C solder workmanship. There has not been a single ARA returned from MDAC for solder workmanship related failures since WS-6536C was implemented, and our in-house experience for ARA failures has been practically nill during this period for solder workmanship-related causes.

In summarizing our implementation of WS-6536C (VU-GRAF #35), we have accomplished a major upgrading of our solder workmanship program from "best commercial practice" to the high reliability level required by WS-6536C. This upgrading has come about by well organizing the program through a tailored solder specification; a thorough training program outline; the training and certifying of all personnel who have responsibility for hardware quality; tailoring the workmanship standards to our Harpoon ARA needs; and upgrading the details in the manufacturing work instructions and the inspection check lists to incorporate the solder specification and workmanship standards. The elimination of unnecessary rework and handling of the hardware by limiting rework to Group I defects, and only those Group II defects that cumulatively exceed the specification limits; the immediate assessment of inspection results and implementation of the continuous performance tracking scheme has provided the means for timely identification of problem areas, sorting out the people problems from the process problems; and the institution of the required corrective actions.

The results speak for themselves (VU-GRAF #35A), where we have achieved a major reduction in reject and rework rate, which cannot but help the reliability of the ARA. We have identified areas of the design that require change in order to further improve the workmanship quality. These are being reviewed for benefits to the ARA reliability, and also for cost effectiveness. By virtually eliminating solder workmanship-related test failures, both in-house and at MDAC, we know that the design is better able to perform to its limits, and that when there are failures, the cause is not being masked by deficient workmanship.

In taking a combined look (VU-GRAF #36) at Failure Free Thruput and Quality History, we realize we have come a long way in the past two years. We realize the challenge, to maintain this achieved high level of quality and to work to eliminate the remaining obstacles to further improvement.

Again, I thank Jim Raby, the NWC, and MDAC for the opportunity to present our experiences to you today.

-- VU-GRAF INDEX --

WS-6536C, PARAGRAPH 3.7 HIGHLIGHTS

CERTIFICATION OF PERSONNEL

- CERTIFICATION

- VISUAL ACUITY

- ACHIEVEMENT OF CERTIFIED STATUS

    CERTIFICATE CATEGORIES:

        A - SENIOR EXAMINER (Government)
        B - OPERATOR/INSPECTOR (Government)
        C - INSTRUCTOR/EXAMINER (Contractor)
        D - INSPECTOR (Contractor)
        E - OPERATOR (Contactor)
        R - RESTRICTED OPERATOR/INSPECTOR (Contractor)

- CONTRACTOR TRAINING PROGRAM

    . GENERAL
    . TRAINING RECORDS
    . PROGRAM EVALUATION

- MAINTENANCE OF CERTIFIED STATUS

    . GENERAL
    . CONTINUOUS PERFORMANCE EVALUATION

- RECERTIFICATION

    . REQUIREMENTS
    . PROCEDURES
    . REVOCATION OF CERTIFIED STATUS

WS-6536C, PARAGRAPH 3.8 HIGHLIGHTS

CONTRACTOR PERFORMANCE EVALUATION:

- SUBMISSION OF WORKMANSHIP SAMPLES

- PROGRAM EVALUATION

- WORKMANSHIP STANDARDS

- CONTINUOUS IN-PROCESS INSPECTION PLAN

WS-6536C, PARAGRAPH 3.9 HIGHLIGHTS

FACILITIES:

- GENERAL REQUIREMENTS

  . WORK AREA AND BENCHES

    CLEAN AND ORDERLY

- ENVIRONMENTAL CONDITIONS

  . TEMPERATURE

  . RELATIVE HUMIDITY

- DESIGN FACTORS

  . INTERIOR FINISH

  . LIGHTING REQUIREMENTS

WS-6536C, PARAGRAPH 4, HIGHLIGHTS

QUALITY ASSURANCE PROVISIONS:

- RESPONSIBILITY FOR INSPECTION

- INSPECTION OF MATERIAL

    SOLDER - FLUX - SOLVENTS - TUBING - TERMINALS - WIRE -

    PWB's - FLEXIBLE PW's - MODULES - COMPONENT EXTERNAL

    LEADS FOR SOLDERABILITY - CONFORMAL COATING

- SURVEILLANCE INSPECTION OF PREPARATION FOR SOLDERING

- SURVEILLANCE INSPECTION OF SOLDERING PROCESSES

    SOLDER PURITY - MACHINE - HAND - FLUX RESIDUE - FOAM OR

    WAVE FLUXING - APPLICATION OF SOLDER - COOLING - CONVEYOR -

    CLEANING OF PWBA's AFTER SOLDERING - DIP TANKS - VAPOR

    DEGREASING - VISUAL APPEARANCE - REWORKING UNSATISFACTORY

    CONNECTIONS - REHEAT METHOD OF REWORK - RESOLDER METHOD -

    WICKING - REPAIRS - PWBA COATING

- INSPECTION OF SOLDERED CONNECTIONS AND ASSEMBLIES

    INSPECTION TOOLS AND EQUIPMENT

        . MAGNIFICATION AID

        . WORKMANSHIP STANDARDS

    INSPECTION METHOD

        . REWORKABLE DEFECTS

        . ACCEPTABLE DEFECTS

WS-6536C

Table II. Defects

Type of defect	Reference paragraph	Group I	II
1. Unsoldered connections	4.7.2.4k	X	
2. Bridging	4.7.2.4x	X	
3. Damage to wire or strands	3.4.2.3.2	X	
4. Metal encased components mounted over circuit path (not insulated)	3.4.7.2	X	
5. Uninsulated wires or component leads routed over the circuit path where shorting is possible	3.4.5.3	X	
6. Charring, burning, or damage to insulation (not affecting electrical operation)	3.4.2.3.1		X
7. Charring, burning or damage to insulation (affecting electrical operation)	3.4.2.3.1	X	
8. Burned, scorched PWB or parts	3.5.5d	X	
Solder connections			
9. Rosin	4.7.2.4a	X	
10. Cold	4.7.2.4b	X	
11. Fractured or disturbed	4.7.2.4c	X	
12. Insufficient solder	4.7.2.4d	X	
13. Excessive solder	4.7.2.4e		X
14. Poor wetting	4.7.2.4q	X	
15. Overheating or splattering	4.7.2.4s	X	
16. Pits, holes or voids	4.7.2.4i		X
17. Birdcaged leads	4.7.2.4l	X	
18. Cut or nicked leads or wires	4.7.2.4m	X	
19. Stretched or scraped leads or wires	4.7.2.4n	X	
20. Unclean connection	4.7.2.4o		X
21. Pattern delaminated	4.7.2.4w	X	
22. Gold plating not removed	3.4.2.5	X	
23. Improper stress relief	3.4.4.3		X
24. Glass encased components not protected by buffer material	3.4.7.1	X	
25. Dewetting on areas not to be soldered	3.3.7.1.2.2		X
26. Dewetting of solder area	3.3.7.1.2.2	X	
27. Slivers on circuit path	3.3.7.1.2.2	X	
28. No wire or component lead in plated-through hole	3.4.5.5		X
29. Lead clinched beyond allowable limits	3.4.5.3.1	X	
30. Solder not smooth and shiny	3.5.5.a		X
31. Solder points, peaks, or icicles	4.7.2.4h	X	
32. Excessive wicking	3.4.5.5.2.1	X	
33. Visible bare copper or base metal in solder connection	4.7.2.4p		X
34. Excessive lead length	3.4.5.3	X	
35. Insufficient lead length	3.4.5.3	X	
36. Insufficient lead clinch	3.4.5.3.1		X
37. Flux residues, oils, greases on assembly	4.7.2.4y	X	
38. Improper tinning of stranded wire	3.4.2.4	X	
39. Stranded wire lay disturbed	3.4.2.3a		X
40. Improper lead wrap	3.4.4		X
41. Improper insulation clearance	3.4.4.7		X
42. Excessive terminal fill	3.4.4.2		X
43. Improper lead bends, radius	3.4.4.3		X
44. Improper lead bend clearance	3.4.4.3		X
45. Improper transmission of stress	3.4.4.9	X	
46. Component not centered	3.4.5.3a		X
47. Component has improper clearance	3.4.5.3b and e	X	
48. Component not supported	3.4.5.3e	X	
49. Component has improper clearance between the PWB	3.4.5.3d		X
50. Component not sufficiently supported	3.4.5.3c		X
51. Component markings not visible or correctly oriented	3.4.5.3q		X
52. Component less than 1/16 inch to edge of PWB causing interference	3.4.5.3f	X	
53. Component less than 1/16 inch to edge of PWB not causing interference	3.4.5.3f		X
54. Possible component damage	3.4.5.3i		X
55. Component obscures termination of another component	3.4.5.3k		X
56. Component improperly mounted	3.4.5.k		X
57. Component improperly bonded	3.4.5.3b	X	
58. Improper termination causing PWB	3.4.5.3		X
59. Excessive wire or solder	3.3.7.1.2.4	X	
60. Improper solder contour	3.3.7.1.2.3		X
61. Improper hole size	3.3.7.1.2.3		X
62. Pits, scratches, or inclusions	3.4.5.13		X
63. Blisters in conductor	3.4.5.13	X	
64. Delamination of base material	3.4.5.13	X	
65. Warped PWB in cluster pattern	3.4.5.13	X	

VU-GRAF #6 P&P N-390A

DISCREPANCY REPORT (SQUAWK CONTROL RECORD)

N-390A(12-64)

SQK NO	DISCREPANCY — LEGIBLE(PRINT) – BRIEF but SPECIFIC – RECORD serial numbers	REJECTED			N-34 NO	REWORKED			INSPECTED				SECONDARY REJ OR N-34
		BY	DATE	QTY		BY	DATE	QTY	BY	DATE	QTY ACC(REJ)		
1													
2													
3													
4													
5													
6													
7													

NOTES & COMMENTS

NAME: _____

STAMP: _____

DATE: _____

INSPECTION
EVIDENCE
RECORD

PROGRAM: _____

AREA: _____

HOURS: _____

PART NO.	OP. NO.	SALES ORDER	SER. NO. LOT NO.	QTY.		REASON FOR REJECTION
				A	R	

N-621

QUALITY PERFORMANCE RECORD

VU-GRAF #8

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	JAN
PART													
QTY REJECTED													
% YIELD													

Date _____

Prepared By _____

MAJOR REJECTS AT ASSEMBLY

DEPARTMENT OF THE NAVY
NAVAL WEAPONS CENTER
CHINA LAKE, CALIFORNIA 93555

IN REPLY REFER TO:

3681/JDR:ej
Reg 3681-113-77
18 JAN 1978

MEMORANDUM

From: Head, Soldering Technology Branch (Code 3681)
To: All Hands (Code 368)

Subj: Corrective interpretation WS-6536C, paragraphs 4.7.2.1 and 4.7.2.2

1. In the past there has been some misunderstanding by not only contractors, but government personnel as to the proper interpretation of WS-6536C paragraphs 4.7.2, 4.7.2.1, and 4.7.2.2. The intent of WS-6536C is clarified by this memorandum, and the above referenced paragraphs will be enforced in accordance with this clarification.

2. Paragraph 4.7.2 use of the word "characteristic" refers to the "features" of an assembly and has nothing to do with any type of defect. Each feature (prominent part or characteristic) represents a chance or possibility to have one or more defects. Example: an assembly has characteristics such as component bodies, component leads, wires, terminals, board material, and solder connections.

3. Paragraph 4.7.2.1 uses the word "characteristics" (unnecessarily) pertaining to types of defects. In the first sentence of 4.7.2.1, strike the words "that exhibit any of the characteristics", making the sentence read, "Defects listed as Group I of Table II shall be rejected."

4. In paragraph 4.7.2.2 the word "characteristics" is again used in reference to features of the assembly, and each feature or characteristic represents a chance for defect. Thus, to determine the number of Group II defects to be accepted without rework, the number of chances for defect must first be determined. Example: an assembly has 20 components and each component has two leads. The number of chances are:

> 20 component bodies
> 40 component leads
> 40 solder connections*
> 1 printed wiring board

> 101 total chances

  * On plated-thru-hole printed wiring boards the top and bottom
     connection is one integral connection.

The above assembly may have as many as 10 Group II defects and be accepted without rework. The defects might all be one type such as excessive solder, or they might be 10 different types.

5. It should be noted that it is not the intent of WS-6536C paragraph 4.7.2.2 to in any way release a contractor from his/her responsibility for 100 percent inspection. A contractor who chooses to take advantage of this paragraph must have supporting data for each assembly so accepted. The data may be in the form of an inspection record that gives the number of chances for the assembly and shows the location and type for each defect accepted. The purpose of permitting a small number of minor defects is to reduce rework and the damage that often results. The contractor must have a controlled process and be able to effectively demonstrate and/or prove adequate conformance. Without defect data, the contractor does not assure compliance with paragraphs 3.7.5.2 and 3.8.2.2 of WS-6536C.

JIM D. RABY
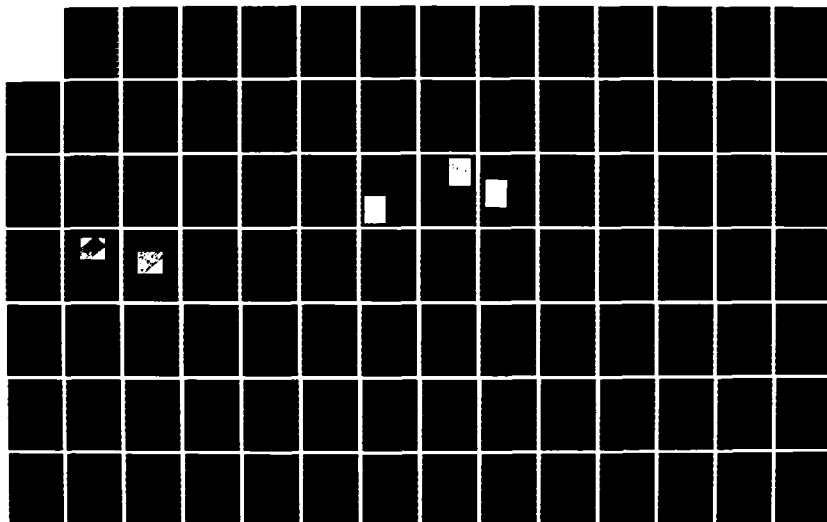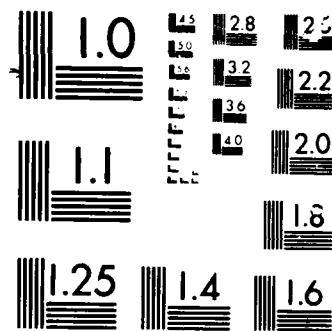
Board #2		Operator No.
Serial No.	Part No.	Inspector No.
Date Inspected		Inspection Operation No.
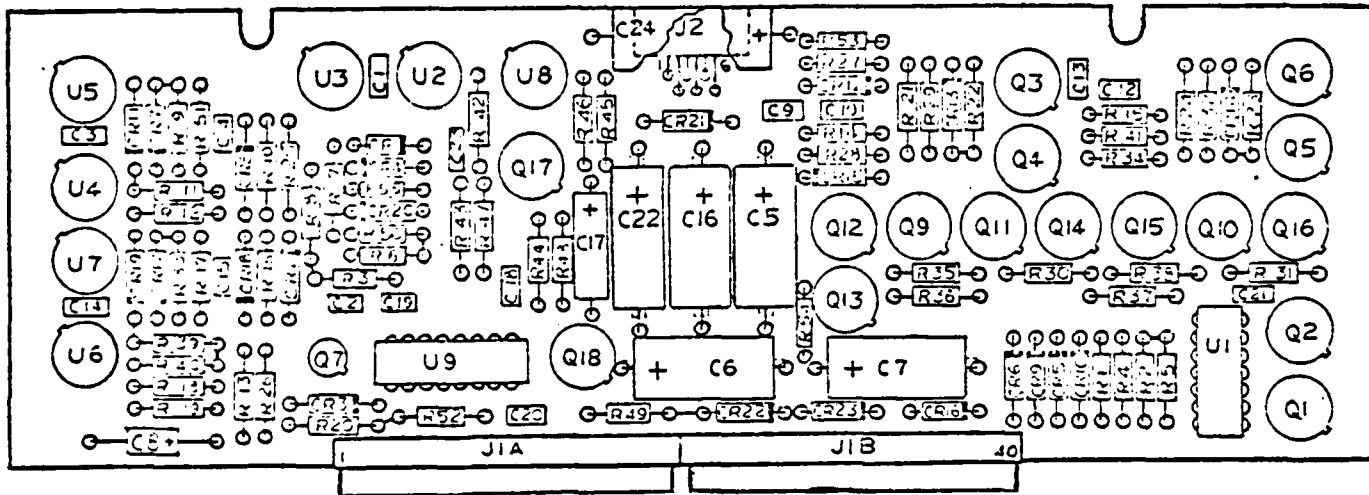
INSPECTION CHARACTERISTIC	QUANTITY	REWORK	REINSPECT
1. INSUFFICIENT SOLDER			
UNSOLDERED CONNECTION			
2. BRIDGING			
4. DAMAGE TO WIRE STRANDS			
5. DAMAGE TO INSULATION – MAJOR			
6. DAMAGE TO PWB – PARTS			
7. ROSIN SOLDER CONNECTION			
8. COLD SOLDER CONNECTION			
9. FRACTURED/DISTURBED SOLDER			
10. POOR WETTING			
11. OVERHEAT SPLATTER			
12. DELAMINATED PATTERN			
13. Missing Component			
14. SOLDER POINTS, PEAKS, CYCLES			
15. EXCESSIVE LEAD LENGTH			
16. INSUFFICIENT LEAD LENGTH			
17. IMPROPER TRANSMISSION OF STRESS			
18. IMPROPER COMPONENT CLEARANCE (A)			
19. BLOWHOLES			
20. POTENTIAL SHORT			
21. BIRDCAGED LEADS			
22. GOLD PLATE NOT REMOVED			
23. SOLDER NOT SMOOTH & SHINY			
24. EXCESSIVE WICKING			
25. FLUX RESIDUE OIL, GREASE			
26. EXCESSIVE WARP OR TWIST			
27. BASE MATERIAL DELAMINATION			
28. INCORRECT COMPONENT VALUE			
29. INCORRECT COMPONENT POLARITY			
30. VISIBLE BARE COPPER BASE METAL			
31. DAMAGE TO INSULATION – MINOR			
32. EXCESSIVE SOLDER			
PITS, HOLES, VOIDS			
IMPROPER STRESS RELIEF			
35. INSUFFICIENT LEAD CLINCH			
36. DISTURBED WIRE LAY			
37. IMPROPER LEAD WRAP			
38. IMPROPER TERMINATION CLEARANCE			
39. IMPROPER COMPONENT CLEARANCE (B)			
40. UNCLEAN CONNECTION			

PART NO. _____   DESCRIPTION   **Board #2**

SER NO

SERIAL NO. _____   PROCESS SPEC. NO. _____

INSP. OPER. NO. _____   PROCESS SPEC. REV. _____

INSPECTOR NO. _____   ASS'Y OPERATOR NO. _____

NOTE: Inspect assembly for applicable inspection characteristics denoted on defect tables.
Record quantity of each characteristic observed in assigned space of defect table. Note
location of defect on applicable assembly illustration. Defects designated as Group II
type, may be accepted if total quantity of Group II defects accumulated from all sides
of assembly. Do not exceed 10% of total characteristic value. The total characteristic
value for this assembly is:

INSPECTION CHARACTERISTIC GROUP I	QUANTITY	REWORK	DATE	REINSPECT	DATE
1. Unsoldered Conn.					
2. Bridging					
3. P.W.B. Damage/Delamination					
4. Fractured/Disturbed Solder					
5. Insufficient Solder					
6. Cold/Poor Wetting					
7. Overheat/Splatter					
8. Pattern Delamination					
9. Gold Contamination					
10. Points, Peaks, Icicles					
11. Flux, Oil, Grease					
12. Improper Component Clear.					
13. Damage To Component/Lead					
14. Incorrect Value/Polarity					
15. Excessive Warp/Twist					
21. Potential Short					
24. Miscellaneous					
SUBTOTAL GROUP I		GROUP I TOTAL-ALL SIDES			
GROUP II					
25. Excess Solder					
26.					
27. Improper Lead Solder Clear.					
28. Improper Fillet, Clearance					
29. Visible Base Copper					
34. Component Marking					

VU-GRAF #13A

INSPECTION VERIFICATION RECORD

VU-GRAF #13

INSPECTION VERIFICATION RECORD

Board #2

I.V.R. DEFECT TALLY

P.W.A. TYPE _____   DATE INSPECTED _____

LOT NO. _____   UNIT QUANTITY _____

INSPECTION CHARACTERISTIC	COMPONENT SIDE		SOLDER SIDE	
INSUFFICIENT SOLDER				
UNSOLDERED CONNECTION				
BRIDGING				
DAMAGE TO WIRE STRANDS				
DAMAGE TO INSULATION				
DAMAGE TO PWB / PARTS				
ROSIN SOLDER CONNECTION				
COLD SOLDER CONNECTION				
FRACTURED / DISTURBED SOLD.				
POOR WETTING				
OVERHEAT / SPLATTER				
DELAMINATED PATTERN				
IMPROPER LEAD CLINCH				
SOLDER PEAKS, ICYCLES				
EXCESSIVE LEAD LENGTH				
INSUFFICIENT LEAD LENGTH				
REVERSE LEAD STRESS				
IMPROPER COMP. CLEARANCE				
BLOWHOLES				
POTENTIAL SHORT				
BIRDCAGED LEADS				
GOLD CONTAMINATION				
SOLDER NOT SMOOTH / SHINY				
EXCESSIVE WICKING				
FLUX RESIDUE, OIL, GREASE				
EXCESSIVE WARP / TWIST				
BASE MATL. DELAMINATION				
INCORRECT COMP. VALUE				
INCORRECT COMP. POLARITY				
VISIBLE BASE METAL				
MISSING COMPONENT				
GROUP II DEFECTS				

Summary:

DEFECT ANALYSIS   PWA's Reviewed:

P.W.A. TYPE	No. Units Insp.	Total Defects	Char. Per Unit	Total Char.	Rework Rate %	Defect Per Unit
Board #1						
Board #2						
Board #3						
Board #4						
Board #5						
Board #6						
Board #7						
TOTAL						

$$\text{Rework Rate} = \frac{\text{Total No. of Actual Defects}}{\text{Total No. of Potential Defects}} = \underline{\qquad} =$$

Defect Category	Board #1	Board #2	Board #3	Board #4	Board #5	Board #6 & 7	TOTAL
Poor Wetting							
Improper Comp. Clear.							
Excess. Lead Length							
Insuff. Lead Length							
Bridging							
Missing Component							
Fract./Dist. Solder							
Unsoldered Conn.							
Solder Peaks, Icicles							

PRIMARY CONTRIBUTORS TO INCONSISTENT HARDWARE WORKMANSHIP QUALITY

- INQDEQUATE WORK INSTRUCTIONS

- INADEQUATE INSPECTION CHECK LISTS

- PROCESS CONTROL PROBLEMS

- INCORRECT WORK FLOW

ARA S/N _____ INSPECTED BY _____

DATE _____ OPERATION NO. _115_____

REVISION _____ REVISION DATE _____

HARPOON VERIFICATION CHECK LIST

SUPPLEMENT TO PROCESS ROUTE CARD 101874

	ACC.	REJ.
A. Harness Lacing and Tying		
1. Running lace has proper starting and ending knots.		
2. Running lace is Lock-Stitched		
3. Pigtail length is not excessive, less than ½".		
4. Pigtails have been properly burnt off leaving clean unfrayed tail with no solder residue.		
5. Wire bundles are firmly laced and will not distort with slight finger pressure.		
6. Leads outside of Harness Trunks are Spot-Tied or laced to prevent movement.		
7. Lacing and ties are tight and will not move along Harness with slight touch.		
8. Spot-Ties are square knots.		
9. There is no cutting or other damage to lacing.		

HARPOON VERIFICATION CHECK LISTS

INCLUDES INSPECTION VERIFICATION CRITERIA FOR:

- MARKINGS

- HARDWARE INSTALLATION

- CABLE CLAMPS

- CONNECTORS

- HARNESS LAYOUT AND ROUTING

- INSULATION DAMAGE

- SOLDER SLEEVES

- WIRING/SOLDERING

- HARNESS LACING AND TYING

- TRIM COMPONENTS INSTALLATION

- CLEANLINESS

- CONFORMAL COATING

QUALITY PERFORMANCE RECORD

HARPOON ARA
BOARD #2 ASSEMBLY YIELDS

VU-GRAF #19

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	JAN

NOV 1978
Date

P. D. Zasadny
Prepared By

Approved By

(Month) _____ Yield

MONTH:
QTY INSPECTED
QTY REJECTED
% YIELD
REJECT REASON:
MAJOR REJECTS AT TEST

REJECT REASON												
SOLDER	2	—	—	—	—	1	3	43	59	60	36	—
CONTAMINATION	—	—	—	—	—	1	3	11	2	4	2	—
DAMAGED CKTY/PAD	—	—	—	—	—	1	—	2	16	—	10	—
DAMAGED COMPONENT	—	—	—	—	1	1	3	1	1	1	1	—
MISSING COMPONENT	—	—	—	—	—	—	1	1	1	3	2	—
WRONG COMPONENT	—	—	—	9	—	—	—	—	—	1	1	—
COMPONENT POSITION	—	—	—	25	2	—	—	—	2	—	5	—
CONFORMAL COATING	—	—	1	1	1	2	—	1	3	1	—	—
	—	—	—	—	2	—	—	1	2	2	2	—

MISC

MAJOR REASONS AND CAUSES IN JULY-DECEMBER PWBA REJECTIONS
AFTER WAVE SOLDERING, AND ASSOCIATED CORRECTIVE ACTIONS

REASONS FOR REJECTION:

- BLOW HOLES IN SOLDER

CAUSES:

- PWB'S PLATED-THROUGH HOLES

- PWB'S NOT COMPLETELY CURED

CORRECTIVE ACTIONS:

- SOURCE INSPECTION/SURVEILLANCE AT PWB SUPPLIERS

- PWB TESTING AT RECEIVING INSPECTION

- TEMPERATURE BAKE OF ALL PWB'S

- DRY ATMOSPHERE STORAGE

RESULTS:

- ELIMINATION OF 25% TO 50% OF REJECTIONS

REASONS FOR REJECTION:

- INSUFFICIENT COMPONENT LEAD LENGTH - CIRCUITRY SIDE

- EXCESSIVE COMPONENT LEAD LENGTH - CIRCUITRY SIDE

- IMPROPER COMPONENT CLEARANCE - COMPONENT SIDE

CAUSES:

- COMPONENT LEAD FORMING AND CUTTING OPERATIONS

- SOLVENT SOLUBLE COMPONENT SPACERS

CORRECTIVE ACTIONS:

- TIGHTENED CONTROLS ON LEAD FORMING AND CUTTING EQUIPMENT

- CHANGE TO PERMANENT TYPE COMPONENT SPACERS (TRANSI-PADS)

RESULTS:

- ELIMINATION OF 20% OF REJECTIONS

NOTE: DENSITY OF COMPONENTS ON SOME PWBA'S DUE TO DESIGN NEGATE FURTHER IMPROVEMENT

REASONS FOR REJECTION:

- POOR WETTING OF KOVAR LEADS ON TRANSISTORS AND CAPACITORS

CAUSE:

- COMPONENT MANUFACTURERS WERE NOT PROVIDING SATISFACTORY COMPONENTS
TO MEET LEAD SOLDERABILITY REQUIREMENT

CORRECTIVE ACTIONS:

- IDENTIFIED PROBLEM PARTS

- SUBJECTED THESE PARTS TO SPECIAL CLEANING AND TINNING,
AND PACKAGING IN STATIC-FREE, AIRTIGHT BAGS

RESULTS:

- ELIMINATION OF 10% OF REJECTIONS

PERCENT CHARACTERISTICS
REWORKED

WKLY. •————•

CUM. •——•——•

PRINTED WIRING ASSEMBLY REWORK RATE
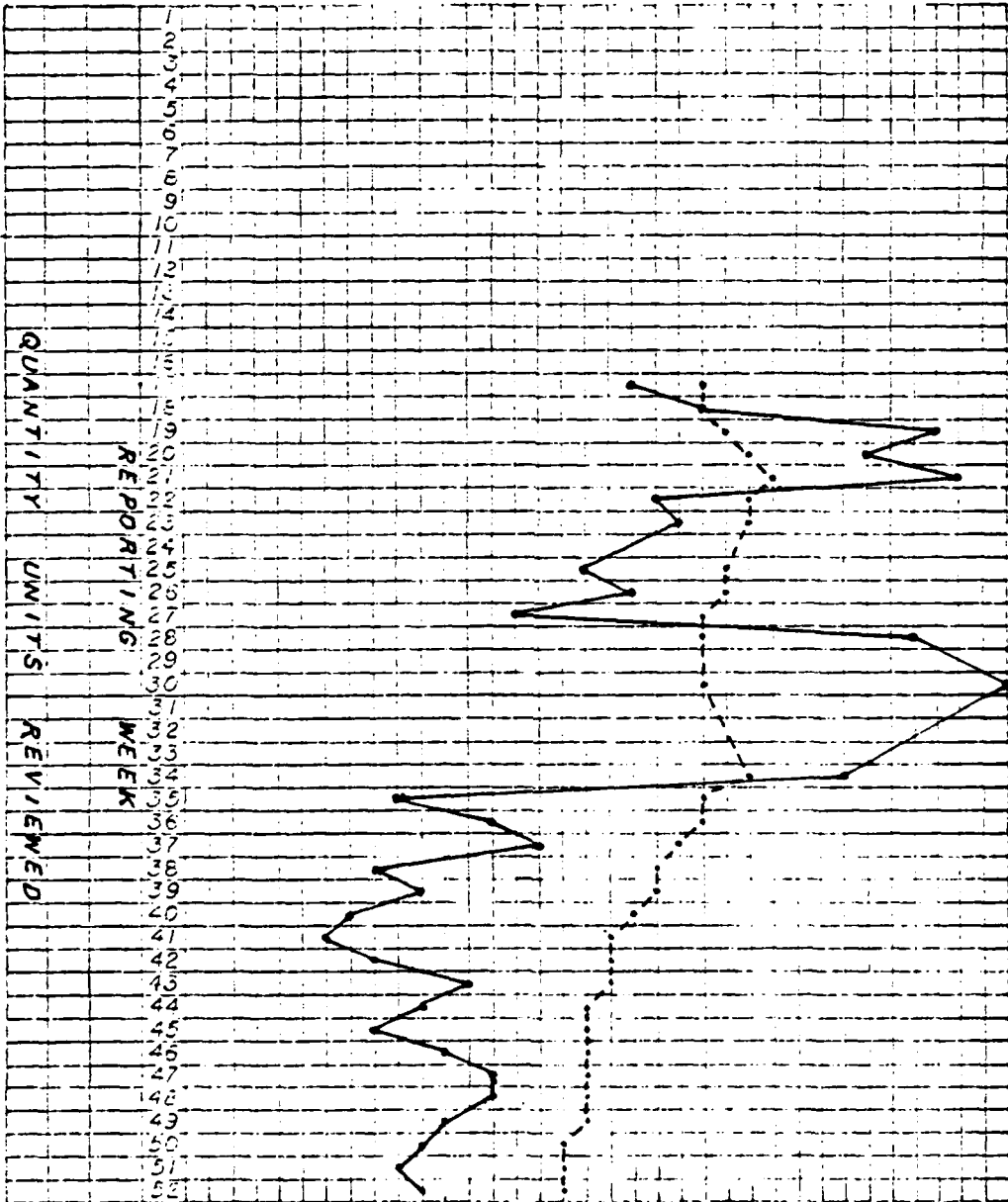
Harpoon ARA
Spec. Ident. AS4080
PPD Process Control
Work Record

ACTIVITY & LIMITS	WORK AREA						
	Machine Shop	Precision Inspection	Potting	ARA Assembly	ARA Inspection	Gyro Assembly	Gyro Inspection
Cleanliness (1) Prompt clean-up of spills, dirt, debris (Class B) (2) Fed Std 209 Class 100,000 (Class A)	(1) X	(1) X	(1) *	(1) *	(1) *	(2) *	(2) *
Lighting (1) 100 ft. Candles (2) 200 ft. Candles	(2) X	(2) X	(1) X	(1) X	(1) X	(1) X	(1) X
Air Temperature (1) 65 to 80°F (2) 65 to 85°F (3) 65 to 95°F	(1) X	(1) X	(3) X	(2) X	(2) X	(2) X	(2) X
Relative Humidity (1) 30 to 70% (2) 35 to 55% (3) 60% maximum	(1) X	(2) X	(3) X	(1) X	(1) X	(2) X	(2) X
Airborne Contaminants (1) Fed Std 209 Class 100,000 (Class A) (2) Air handling 10 μ filtration (Class B) (3) Filter type unspecified	(3) X	(1) X	(3) X	(2) X	(2) X	(1) X	(1) X
Ventilation Forced ventilation or exhaust as required for comfort.	X	X	X	X	X	X	X
Noise (maximum) (1) 70 dba (2) 75 dba (3) 80 dba	(3) X	(1) X	(3) X	(2) X	(2) X	(1) X	(1) X
Habitat No food, drink, smoking, or personal grooming allowed in work area.	X	X	X	X	X	X	X

* Out of spec. conditions

WRA NAME   Attitude Reference Assembly (Northrop)

WRA S/N   025011   REVISION LETTER V   REWORK EVENTS

ASSEMBLY NAME	DRAWING NUMBER	MSN	REV LTR	REMOVE REPLACE	SOLDER REWORK	CONTAM- INATION	MRB	TOTAL	COMMENTS
Accelerometer (X) U1 Roll	67079-301	21624	E						
Accelerometer (Y) U2 Pitch	67079-301	21522	E						
Accelerometer (Z) U3 Yaw	67079-301	21639	E						
Gyro, Rate (X) MT1 Roll	67663-303/304	21000	G						
Gyro, Rate (Y) MT2 Pitch	67663-303/304	21002	G						
Gyro, Rate (Z) MT3 Yaw	67663-303	20848	G						
Board #1	102130-302	3269	D		10			10	
Board #2	69503-302	3439	M		5			5	
Board #3	69504-303	3619	R	1	11			12	
Board #4	102150-302	3777	B	1	10			11	
Board #5	102153-302	3793	B		18			18	
Board #6	102153-302	3998	B		1			1	
Board #7	101888-304	5039	E						
Attitude Reference Assembly	642A51213	025011	Y	1			1	2	
TOTALS				3	55	1		59	

WRA TEST HISTORY
ATTITUDE REFERENCE ASSEMBLY   MFC NORTHROP

Serial No. GCU   025011
Part No. 642A51217-2
Test Time   22.6

VU-GRAF #23A

DATE	EVENT	EST. TIME (HRS)	DESCRIPTION	DISPOSITION/CAUSE	ANOMALY RPT	F.A.R. #
10/26/79	CAL		TS. 3179 - FAILED	Y GYRO ANALOG REPLACE U2 W/U3		
10/26/79	CAL		6 POSITION TEST			
10/26/79	B.T.		B.E. (45~)			
10/29/79	VIB		R) VIBRATION			
10/30/79	CAL		T/P - 3312 - FAIL	Y GYRO BIAS. COULD NOT CONFIRM.		
10/31/79	CAL		T/P - 3312 - OK			
11/1/79	PRE E.T.P.		PRE-E.T.P. - OK			
11/1/79	B.T.		B.E. (3) ~			
11/2/79	E.T.P.		E.T.P. - ACCEPTABLE	SHIPPED TO MARC-E		

SIGNED   T. LOSSER
DATE   11-5-79

Northrop Corporation
Precision Products Division

Week Ending ____ December 14, 1979

Total Shipped ____ 5 ____

FAILURE FREE TEST STATUS

DETAILED HISTORY

SERIAL NO.	DATE STARTED	DATE PASSED	NO. REPAIRS DURING TEST	FAILURE REPORT NO.	
025030	12/7/79	12/8/79	0	--	
025027	11/30/79	12/10/79	1	399	
025028	12/11/79	12/12/79	0	--	
025029	12/11/79	12/12/79	0	--	
025031	12/11/79	12/12/79	0	--	

115

DATA ITEM DESCRIPTION SUMMARY R-118

TITLE: END ITEM DATA PACKAGE (EIDP)

PURPOSE: TO PROVIDE MDAC-ST. LOUIS AN END ITEM DATA PACKAGE FOR EACH
DELIVERABLE UNIT THAT ADDRESSES THE FOLLOWING SUBJECT AREAS:

- WRA IDENTIFICATION

- CONFIGURATION STATUS

- QUALITY HISTORY

- FACTORY TEST HISTORY

- FAILURES AND CORRECTIVE ACTION HISTORY

EIDP AMENDMENT FOLLOWING INITIAL ACCEPTANCE.

ANY END ITEMS RETURNED FOR ANY REASON (FAILURES, CHANGE

INCORPORATION, ETC.) SHALL HAVE EIDP'S AMMENDED TO REFLECT

FULLY ANY ADDITIONS OR CHANGES TO THE DATA AS A RESULT OF

ACTIONS TAKEN BY THE SUPPLIER.

DATA IEM DESCRIPTION SUMMARY P-019

TITLE: WEEKLY HARDWARE THRUPUT REPORT

PURPOSE: THIS DATA IS USED BY MDAC HARPOON PROGRAM

MANAGEMENT TO IDENTIFY TRENDS IN HARPOON

HARDWARE THRUPUT. AS EXPERIENCE IS GAINED IN

USING THE DATA, THRESHOLDS CAN BE IDENTIFIED

WHERE PRODUCTION PROBLEMS CAN BE ANTICIPATED

UNLESS CORRECTIVE ACTION IS INITIATED.

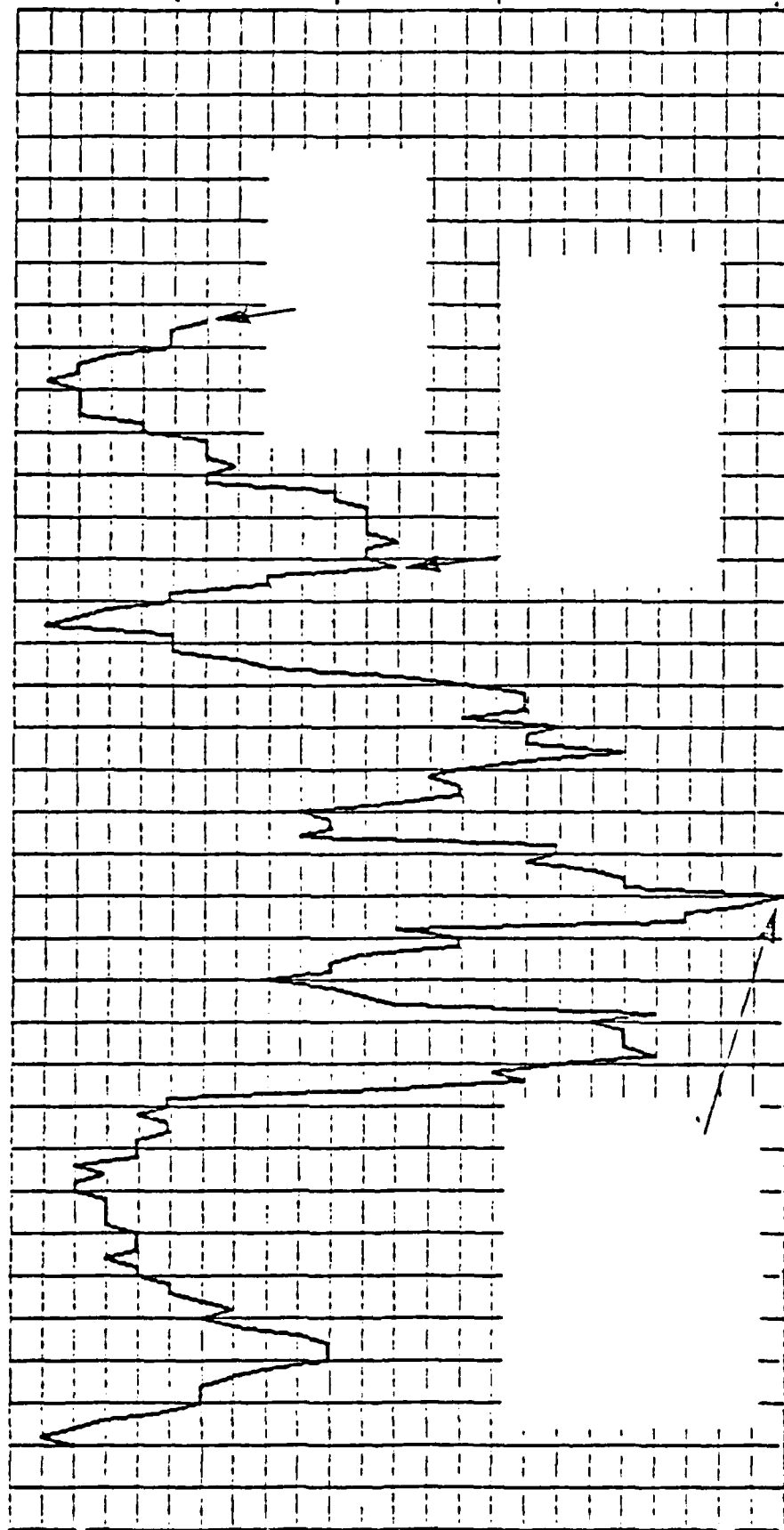AIM HARDWARE THRUPUT - NORTHROP

FAILURE FREE TESTS

10 UNIT

MOVING AVERAGE

VU-GRAF #27

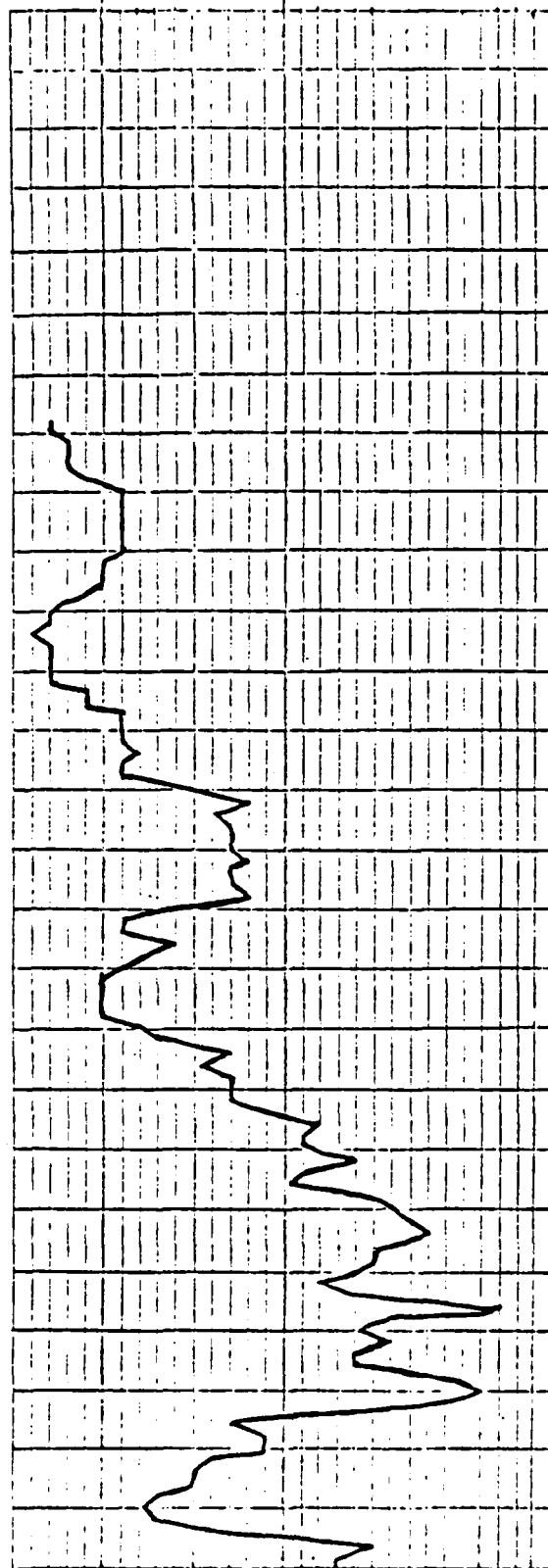VU-GRAF #27

091178

081177

UNITS PASSED

UNITS PASSED + TOTAL REPAIRS

UNITS PASSED

AVERAGE THRUPUT =

ARA THRU-PUT PANEL CU DATE PASSED TEST
TEN UNIT MOVING AVERAGE

UNITS PASSED
UNITS PASSED & TOTAL RETURNS

12/30/77
1/27/78
2/4/78
3/31/78
4/28/78
6/2/78
7/2/78
7/28/78
9/1/78
9/28/78

UNITS SHIPPED

HARDWARE LIFE TRENDS, 12 UNIT AVERAGE
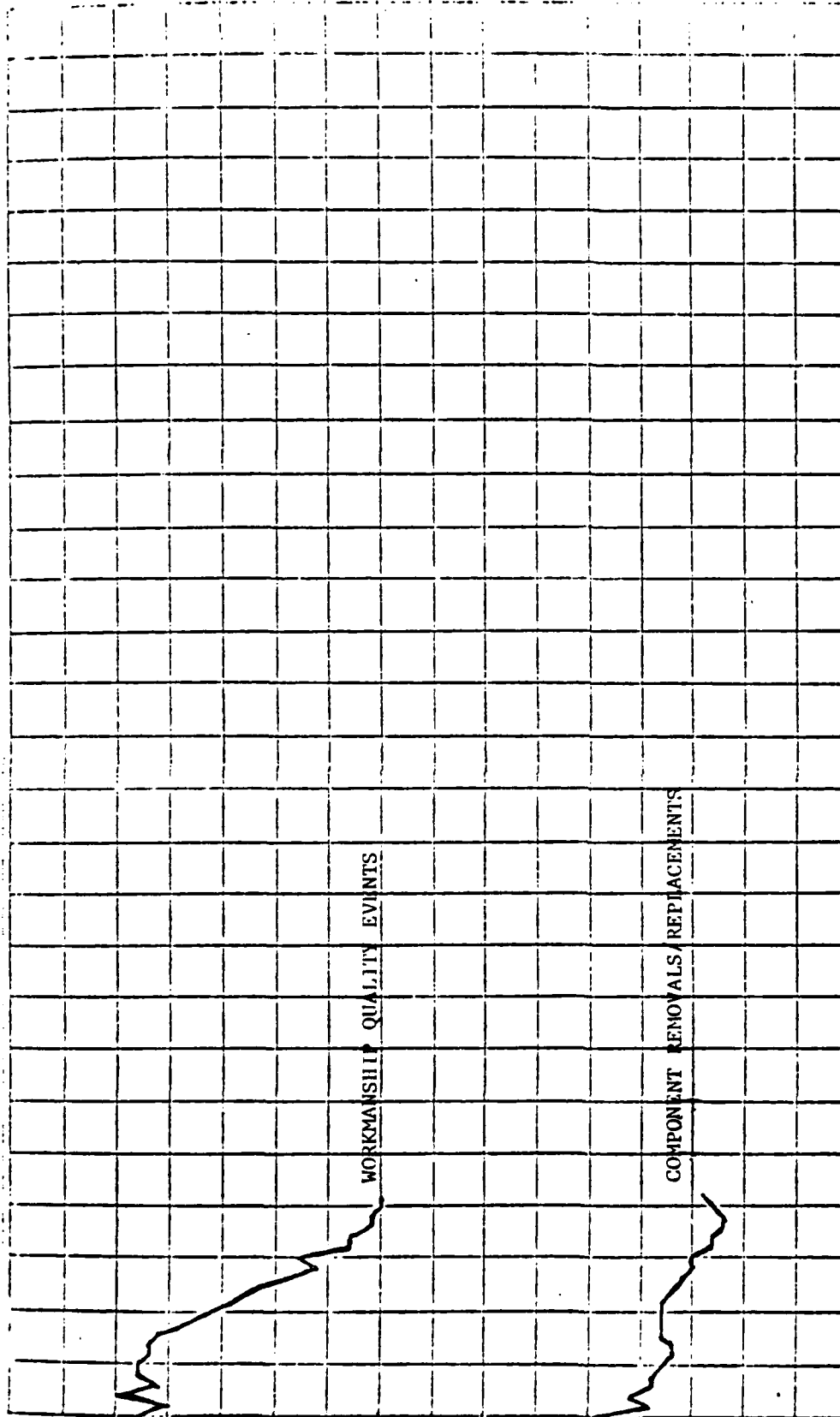
WORKMANSHIP QUALITY EVENTS

COMPONENT REMOVALS/REPLACEMENTS

UNITS SHIPPED

9/28/78

9/1/78

7/2/75

EIDP CATEGORIZATION OF REWORK HISTORY:

COMPONENT REMOVAL REPLACEMENT

1. REMOVAL, REINSTALLATION, AND REPLACEMENT OF PARTS DURING TESTING AND TROUBLESHOOTING.

2. REMOVAL OF INCORRECT, REVERSED POLARITY, DAMAGED OR DEFECTIVE PARTS, AND CORRECT INSTALLATION.

3. REMOVAL OF PARTS FOR ACCESS TO OTHER PARTS AND THEIR INSTALLATION.

4. INSTALLATION OF A MISSING PART.

5. REMOVAL AND REPLACEMENT OF PARTS FOR INCORPORATING CHANGES OR FOR ENGINEERING PURPOSES.

EACH REMOVAL AND SUBSEQUENT REINSTALLATION OR REPLACEMENT OF A PART WILL BE COUNTED AS A SINGLE REWORK EVENT.

SUBDIVIDE COMPONENT REMOVAL/REPLACEMENT TO REFLECT THE FOLLOWING SUB-CATEGORIES:

1. PARTS/COMPONENTS REMOVED AND REPLACED BECAUSE OF ACTUAL OR SUSPECTED FAILURE.

2. ALL OTHER REMOVALS INCLUDING WRONG PART INSTALLED, PART IMPROPERLY INSTALLED, AND PARTS/COMPONENTS/ASSEMBLIES REMOVED TO OBTAIN ACCESS TO THE FAILED PART(S).

ENTRIES IN THE SUBMITTED EIDP SHALL BE CLEARLY IDENTIFIED AS TO SUB-CATEOGRY.

ADDITIONAL INFORMATION: THIS CHANGE DOES NOT CHANGE THE TOTAL
                          "REMOVE/REPLACE" COUNT HERETOFORE ESTAB-
                          LISHED, BUT DIFFERENTIATES THAT TOTAL
                          INTO THE TWO SUBCATEGORIES DEFINED ABOVE.

EIDP CATEGORIZATION OF REWORK HISTORY WORKMANSHIP QUALITY EVENTS
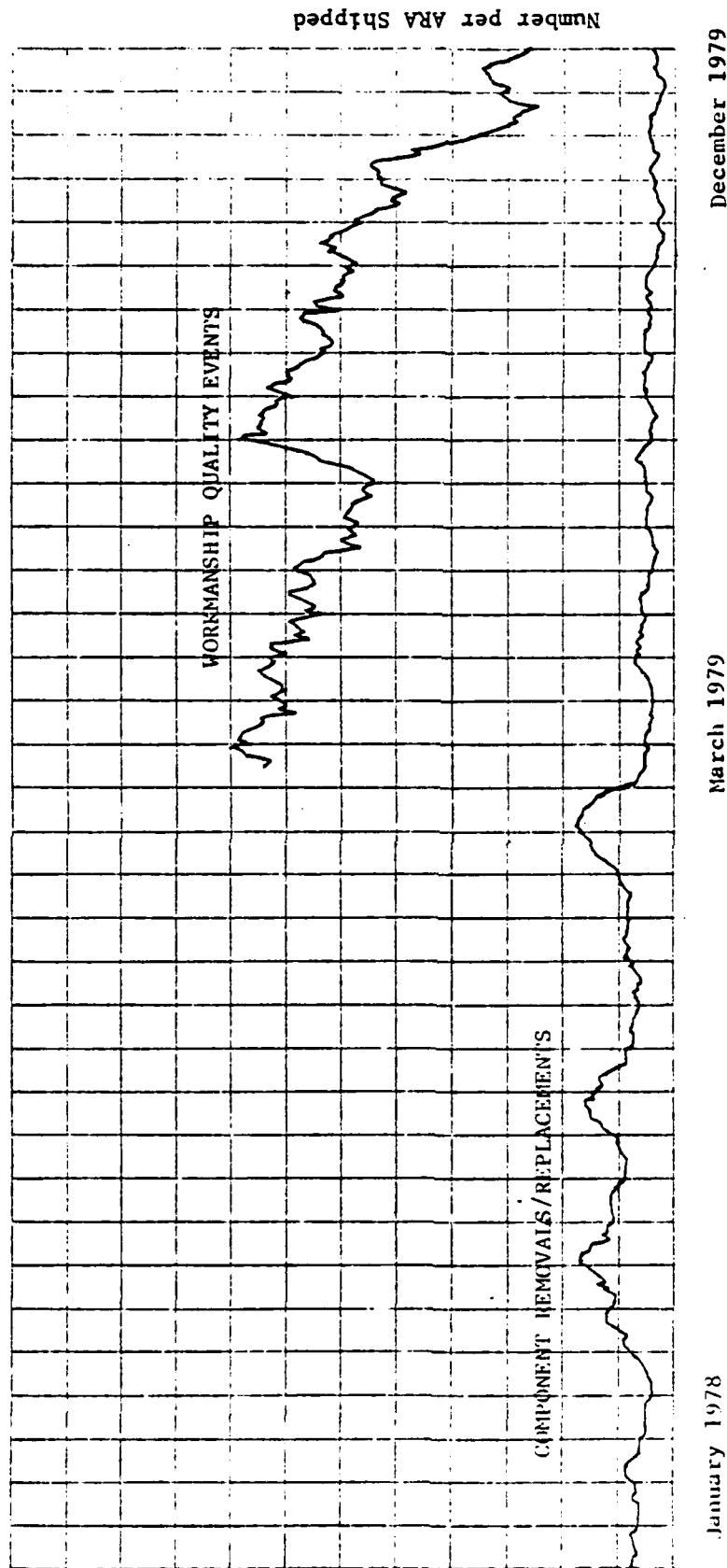
SOLDER REWORK:

1. CORRECTION OF DEFECTIVE SOLDERING, SUCH AS EXCESS SOLDER, SOLDER DEWET, COLD SOLDER JOINT, AND INSUFFICIENT SOLDER.

2. UNSOLDERING AND RESOLDERING A JOINT FOR ANY REASON EXCEPT COMPONENT REMOVAL AND REPLACEMENT (CORRECTION OF REVERSED WIRING WOULD ENTAIL TWO SOLDER REWORK EVENTS).

3. SOLDERING/UNSOLDERING TEST LEADS WHEN NOT PART OF THE NORMAL TEST SEQUENCE.

4. RESOLDERING OF LEADS BECAUSE OF BIRDCAGING OF WIRE OR EXCESSIVE WIRE LENGTH.

CONTAMINATION:

1. EXCESSIVE OR RESIDUAL SOLDER FLUX.

2. WIRE CLIPPINGS OR OTHER FOREIGN MATERIAL IMBEDDED IN SOLDERING ON CONFORMAL COATING AREAS.

3. FOREIGN MATERIAL OF ANY KIND REQUIRING ADDITIONAL CLEANING.

VU-GRAF #32

HARPOON ARA QUALITY HISTORY
TEN UNIT MOVING AVERAGE
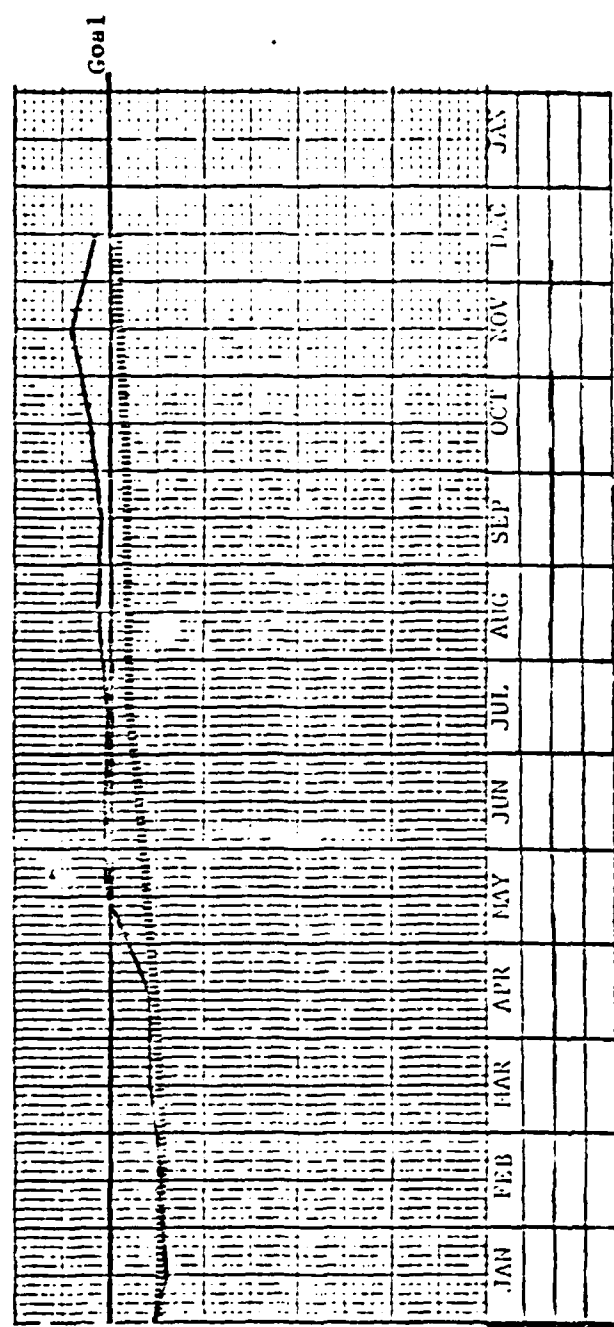
Number per ARA Shipped

WORKMANSHIP QUALITY EVENTS

COMPONENT REMOVALS/REPLACEMENTS

January 1978

March 1979

December 1979

HARPOON ASSEMBLY YIELDS

Date: 1979
Prepared By: P. Zasadny

YIELD ———
CUM ——————

Q'TY INSPECTED
Q'TY REJECTED
% YIELD

MAJOR REJECTS AT ASSEMBLY

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
	118/18	230/5	235/0	174/10	235/15	224/1	172/1	45/4	200/2	219/6	162/3	182/5
Solder Workmanship Wave/Hand	26	14	39	13	14	5	6	2	9	6	4	3
Wire-damage/Broken	78	166	19	38	6	17	21	5	23	11	10	4
Cable Lacing/Dress	54	19	136	102	19	60	39	35	61	43	61	35
Component-Damage/Placement	36	6	7	7	12	9	7	–	7	16	5	4
Hardware - General	23	11	35	37	14	11	5	6	10	15	4	5
Coating/Adhesives	63	113	57	65	61	66	30	13	22	12	17	54
Contamination	68	55	60	30	15	34	33	18	28	9	11	5
Misc. Problems												

VU-GRAF #34

HARPOON ARA THRUPUT
FAILURE FREE TESTS

TEN UNIT MOVING AVERAGE

$$\frac{\text{Units Passed}}{\text{Units Passed} + \text{Total Repairs}}$$

December 1979

January 1978

PERCENT YIELD

UNITS SHIPPED

125
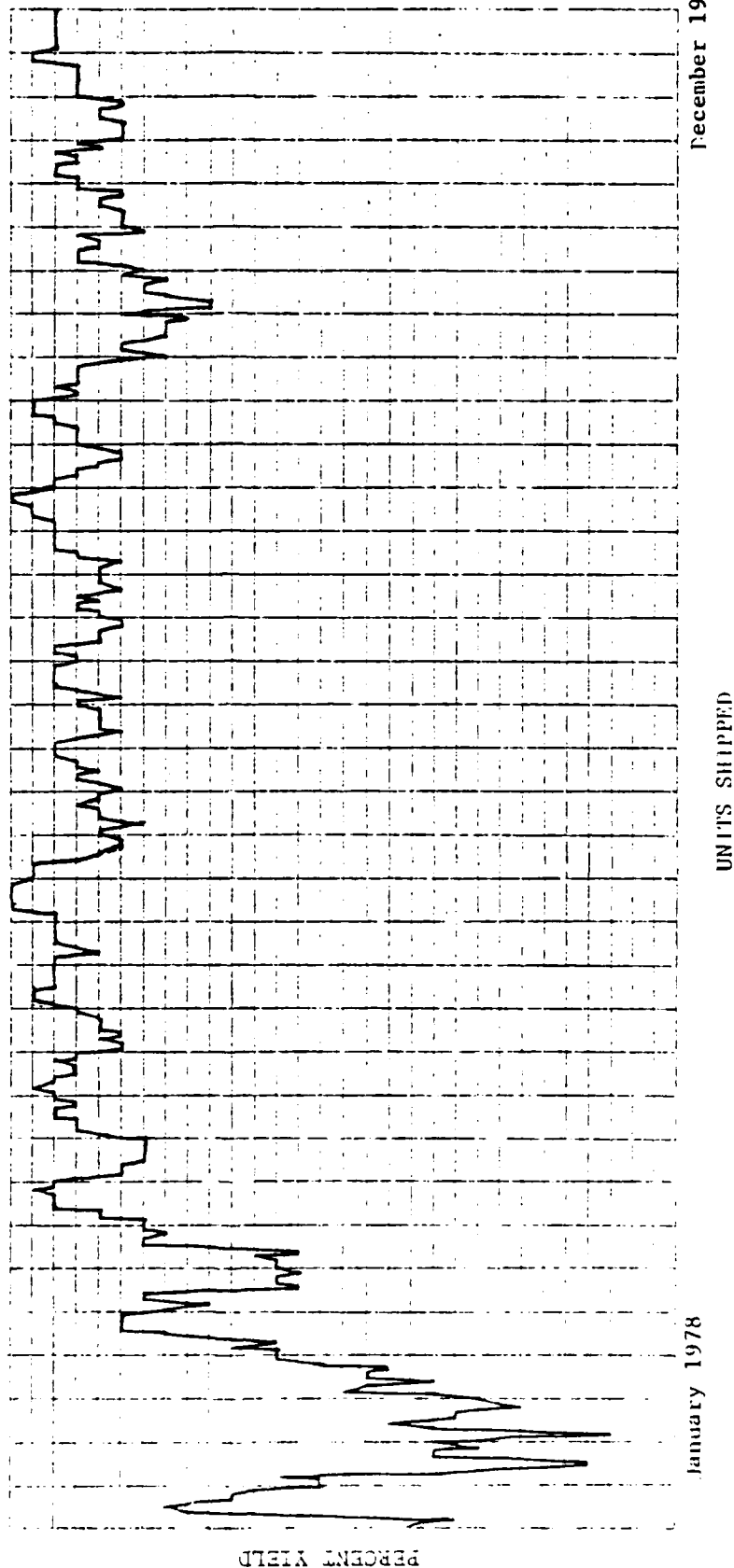
WS-6536C SOLDER WORKMANSHIP PROGRAM ACCOMPLISHMENTS

UPGRADED SOLDER WORKMANSHIP FROM "BEST COMMERCIAL PRACTICE" TO HIGH RELIABILITY LEVEL.

IMPLEMENTED A WELL ORGANIZED, WELL DISCIPLINED, WELL CONTROLLED SOLDER WORKMANSHIP PROGRAM.

- TAILORED SOLDER PROCESS SPECIFICATION

- TRAINING PROGRAM OUTLINE

- TRAINING AND CERTIFICATION OF:

    MANUFACTURING ASSEMBLERS
    QUALITY ASSURANCE INSPECTORS
    MANUFACTURING ENGINEERS
    QUALITY ASSURANCE ENGINEERS
    MANUFACTURING SUPERVISORS
    QUALITY ASSURANCE SUPERVISORS

- TAILORED WORKMANSHIP STANDARDS

- DETAILED MANUFACTURING WORK INSTRUCTIONS

- DETAILED INSPECTION CHECK LISTS

- INSPECTION VERIFICATION RECORDS

- GROUP I/GROUP II DEFECTS REWORK

- ELIMINATION OF UNNECESSARY REWORK/HARDWARE HANDLING

- IMMEDIATE ASSESSMENT OF INSPECTION RESULTS

- IMPLEMENTED A CONTINUOUS PERFORMANCE TRACKING SCHEME

- INSTITUTION OF CORRECTIVE ACTIONS

RESULTS:

- ACHIEVEMENT OF AN 30 TO 90% REDUCTION IN REJECT/REWORK RATE.

- ACHIEVEMENT OF A LEVEL OF WORKMANSHIP QUALITY THAT IS LIMITED BY DESIGN

- VIRTUAL ELIMINATION OF TEST FAILURES FOR SOLDER WORKMANSHIP RELATED CAUSES.

- ELIMINATION OF FAILURES AT MDAC SYSTEM INTEGRATION FOR SOLDER WORKMAN-SHIP CAUSES.
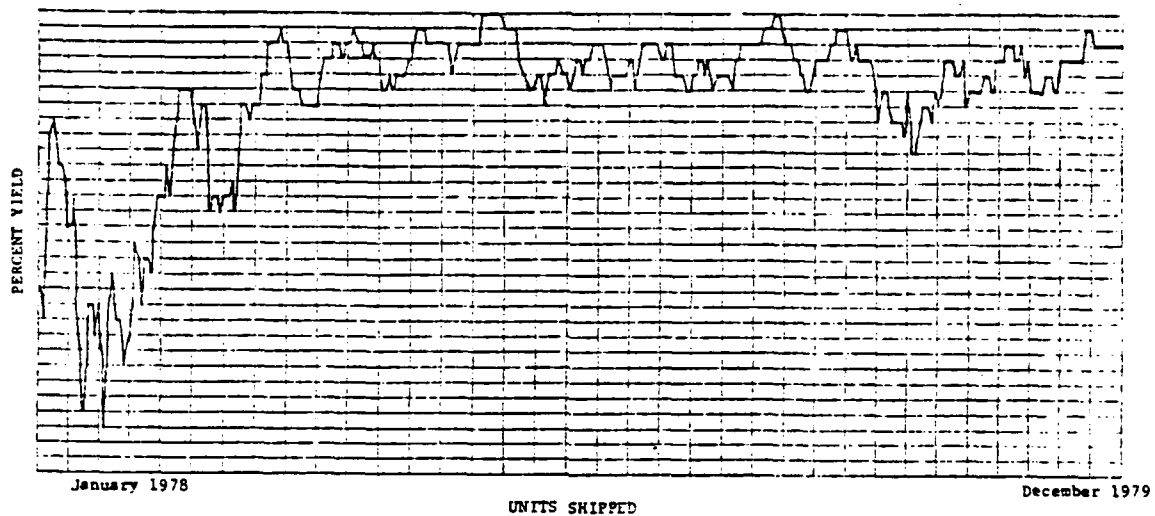
GRAPHIC ILLUSTRATION OF RESULTS OF
IMPROVED SOLDER WORKMANSHIP SINCE
WS6536C IMPLEMENTATION

VU-GRAF #34

Units Passed
—————————————————
Units Passed + Total Repairs

HARPOON ARA THRUPUT
FAILURE FREE TESTS

TEN UNIT MOVING AVERAGE

January 1978

UNITS SHIPPED

December 1979

VU-GRAF #32

HARPOON ARA QUALITY HISTORY
TEN UNIT MOVING AVERAGE

WORKMANSHIP QUALITY EVENTS

COMPONENT REMOVALS/REPLACEMENTS

January 1978

March 1979

December 1979
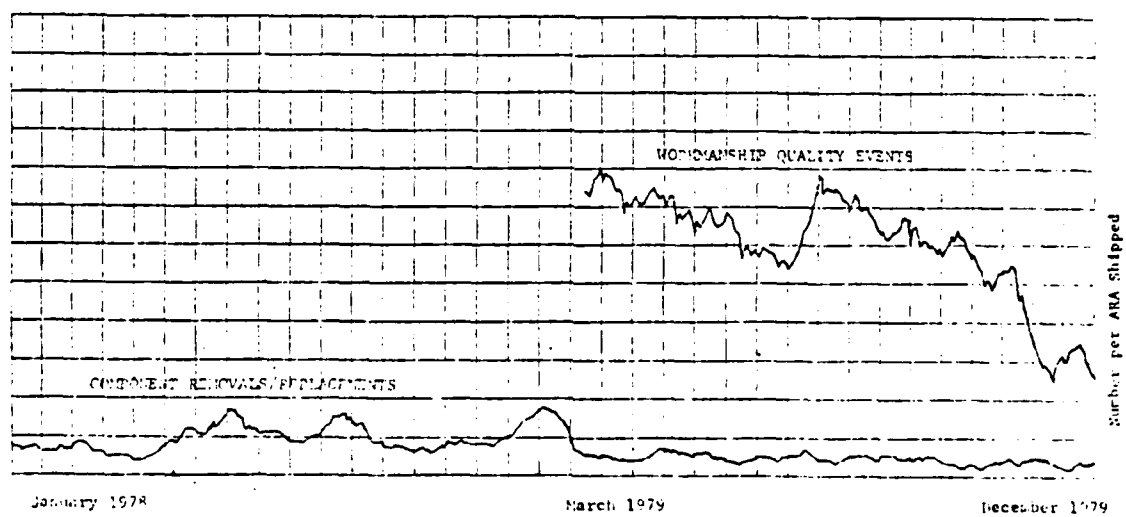
Bendix

**Electrodynamics
Division**

Jim Raby
Soldering Technology Branch
China Lake Naval Weapons Center
China Lake, California 93555
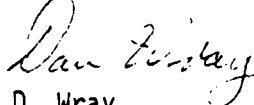
14 January 1980

Reference: QE:80:018:DW

Dear Sir:

Enclosed is the original of the paper to be presented at the Soldering
Seminar. We have included half-tones of the figures for higher quality
photo copies. If you have any questions, please feel free to call.

Sincerely,

D. Wray

DW/cl

Enclosure

AN EFFECT OF AGING ON TIN LEAD SURFACES

A TECHNICAL PAPER BY:

D. WRAY, QUALITY ENGINEER

BENDIX

ELECTRODYNAMICS DIVISION

Sylmar, California

As the electronic systems being produced by our industry increase in complexity, the requirements of system reliability and the processes that impact this reliability during manufacturing operations will become critical. The problems associated with producing these systems in a cost effective manner revolve around process control. These controls will enhance reliability and reduce cost by minimizing the degrading effects of rework.

Both military and commerical houses have learned that control of copper quality in plated-through holes, hole diameter/lead diameter relationships and minimizing both organic and ionic contaminates dramatically reduces the need for rework of solder joints. In many cases, new contractual requirements have been designed to require and insure the control of processing during the entire fabrication cycle. At Bendix, Electrodynamics Division, this concept has been evaluated and found to be helpful in improving system reliability by significantly reducing required rework.

After several experiments it was decided that control of independent operations was unsatisfactory and that elimination of major problems would only occur if the entire system was controlled. Efforts were initiated to extend control of work instructions, factory disiplines, tools, and each process affecting the assemblies during the manufacturing cycle. Currently, contamination by physical contact with boards or component leads has been reduced by the required use of gloves by all assembly personnel prior to the flow solder operation. Additional cleaning steps prior to soldering provided added assurance that organic contamination has been minimized.

Requirements in excess of Military Standards on current contracts for copper plating have been imposed including increases in copper thickness, and thermal stress testing. An on going program to revise drill hole tolerancing for lead diameter/hole diameter relationships has been initiated. As a result of this effort a dramatic decrease in flow soldered defects has occured.

However, as we gain a better understanding of the problems associated with our process, the tendency of component leads and printed circuit boards to decrease in solderability as a function of time appears to be a significant problem in terms of impact on system reliability and rework costs. The current available literature dismisses this problem as a build up of metal oxides or as a result of sulfur or halogen contamination. Careful evaluation of this aging phenomena indicates that the decrease of solderability may be more precisely defined.

Characteristically, a component or printed circuit board is subjected to
solderability testing during receiving inspection. Although the conditions
are not representative of the actual flow solder environment, when the same
test is performed again after six months storage, a high percentage of the
time the units fail this test. The failure to satisfactorily meet this
solderability requirement does not appear to be of function of the method
of packaging, or handling. Even the incorporation of oxidation inhibitors
appears to have minor impact on this aging process.

In an effort to gain a better understanding of this problem, samples of
printed circuit boards and component leads that had originally passed solderability
testing and after a period of time were no longer solderable were subjected to
scanning electron microprobe analysis. The first micrograph (Figure 1)
revealed the presence of a contaminate growth on the surface of the track.
Upon close examination (Figure 2) the crystals appear to grow from a base
identified by arrow C, into the larger protruding columns at B. We elected to
identify the cation in these crystals. The graph (Figure 3) represents emission
intensity as a function of frequency. Areas A, B, and C were mapped and the
presence of excessive amounts of lead in the crystals was demonstrated.

FIGURE 1

First view of affected track area. The
dark areas are more conductive than the
lighter areas. Note the widespread
variations in surface appearance.

FIGURE 2

A closer view of the less conductive
columnar crystals. Arrows A, B, and
C indicate areas used for cation
emission comparision in Figure 3.

FIGURE 3
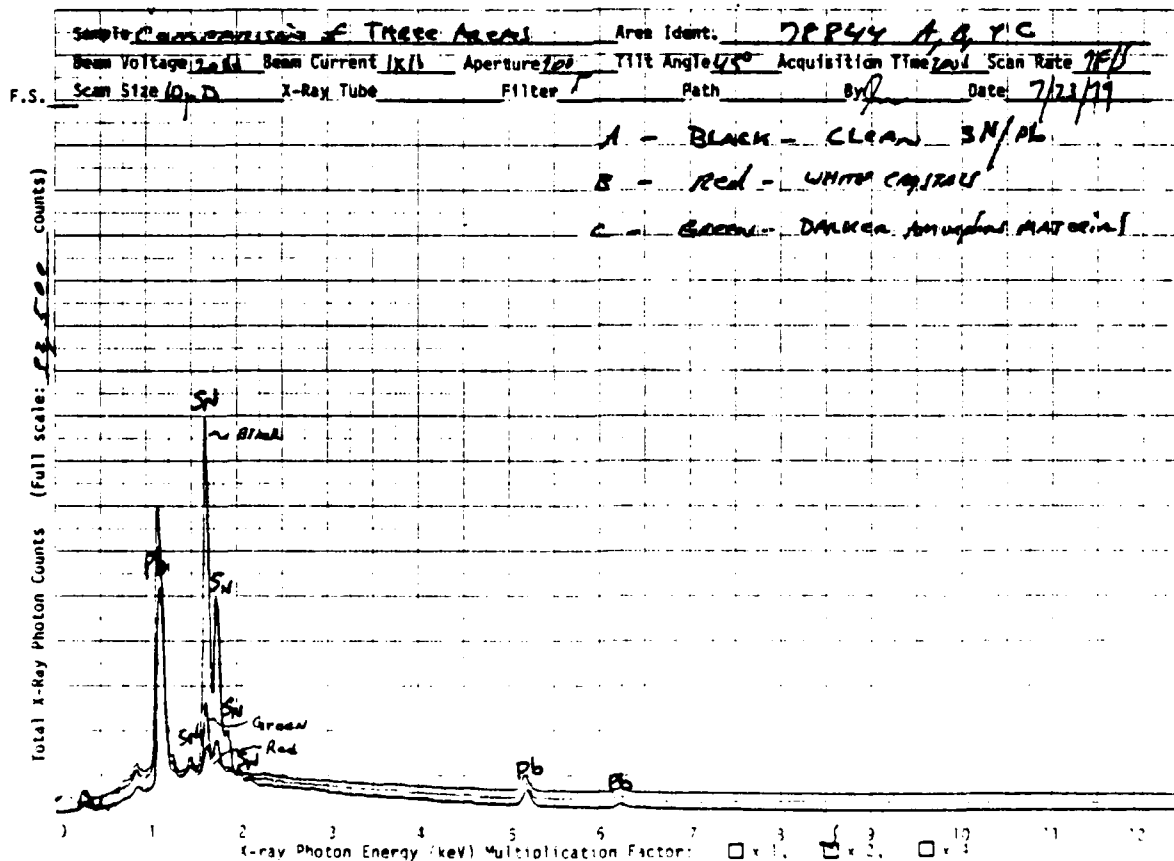
The determination of the anion in the crystal was a more difficult task. Emission intensity of atoms of lower atomic weights is significantly less than that of heavy metals, such as tin or lead, the resolution of the emissions from light atomic weight species is less than desirable. Furthermore, several of these atomic emission lines, such as that for oxygen would be readily adsorbed by lead.

With these limitations in mind, scans for halogens, sulfur and oxygen revealed insignificant amounts of these materials. However, the area map for carbon (Figure 4) when superimposed on the Figure 2 micrograph establishes an important relationship. Evidently the carbon is present in definable amounts at the initial growth point of the protruding crystal.

FIGURE 4

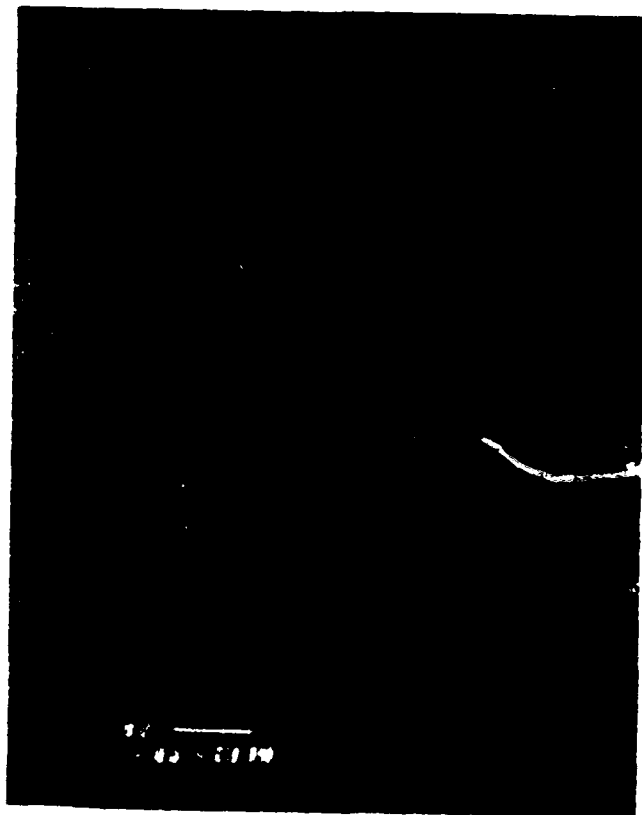Carbon map of the area of Figure 2. Note the concentration pattern near the growth sites of Figure 2.

We believe that the anionic material in the protruding crystal is a carbonate. This theory provides an explaination for degradation in solderability, the inability for oxidation inhibitors to effectively control this problem, the observable and the presently available data. It is proposed that the reaction

proceeds in a sequential manner of two steps. This reaction would occur as follows:

1. $2Pb + O_2 \longrightarrow 2PbO$

2. $PbO + CO_2 \longrightarrow PbCO_3$
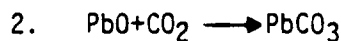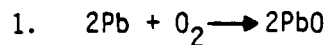
We are not prepared to speculate on the exact mechanism of this reaction at this time. However, the presence of halogens or sulfur appears to increase the rate of this reaction. While the presense of an oxidation inhibitor may compete with the first step in the reaction at the available active sites, the carbonate reaction appears to be nearly irreversible and hence little affect is noted by the presence of these inhibitors.

The proposed two step reaction offers an acceptable explanation for the degradation of solderability. We have observed the solderability of a printed circuit board or components is fairly consistent for about 120 - 180 days, this period is followed by a rapid deterioration in solderability. We will speculate that during the first time period the slower of the two reactions take place followed by a more rapid irreversible step. This material is not removed by the fluxing operation, hence poor solderability results.

The presence of detectable amounts of carbon on the surface of the initial crystal growth indicates a high probability that carbon is a part of the anionic portion of the crystal. When consideration is given to the available material capable of providing carbon at the growth site, we have concluded that carbon dioxide may be the reacting material and that these crystals are of lead carbonate. Further evaluation is required before positive demonstration of the chemical composition of this material can be made.

Some consideration must be given to the physical boundaries provided by these 10 micron crystals and their probable role in retarding solderability. During the soldering operation the molten solder must become totally intimate with solder plate on the printed circuit board and the component lead and form a continuous metal bond. If any material exists between the solder plate and the molten solder that is not removed during the fluxing operation poor solderability will result. In the case of the crystals, this intimate contact cannot occur until this material is displaced. Flux does not appear to effectively remove or reduce this material in the time between application and exposure to the solder wave. Yet, in order to control the solderability this condition must be severly restricted.

Several options for control may prove effective. Chemical or physical removal of this material prior to loading should be considered. At Bendix, we have found that physical abrasion and cleaning with soap and water prior to loading helps but the contaminate material in plated through holes is not removed. Other similar methods may prove more useful.

A second method would prevent the growth of this material from occuring. Before such a system can be developed a better understanding of the exact mechanism of this reaction must be developed.

In conclusion, we have found that controls on copper plating quality and lead diameter/hole diameters relationships will resolve many problems at flow solder. However, as these controls go into effect the decreasing solderability of tin lead plate as a function of time will become a major manufacturing concern.

We encourage efforts to eliminate this problem and in light of the cost and impact on system reliability we will extend our cooperation in any effort to control this degradation.

FATIGUE PROPERTIES
OF
SOLDER JOINTS

By

JOHN A. DeVORE
General Electric Company
Electronics Laboratory
Syracuse, NY

1. Introduction

In recent years, there has been an increased incidence of "cracked solder joints." Investigations in the late 1960's and early 1970's related much of the cracking to conformal coatings under components. This work addressed the source of a problem but did not cover the actual metallurgical mechanism of failure. Shortly after this, in 1972, Roger Wild of IBM defined the actual fatigue mechanism of solder joint fatigue in metallurgical terms. This was the first significant work based on printed wiring assembly solder joints. Also in the same period, IPC published work in conjunction with the component mounting manual (IPC-CM-770) in recognition of the cracked solder joint problem.

Today we are more than ever concerned about solder joint fatigue. The environments that new equipments operate in are more extreme, in terms of fatigue, than has ever been seen before. This includes both commercial and military equipments.

The problem of solder joint fatigue is an insidious one. In 90% of the cases, the failure is a field failure. Therefore the fatigue failure is a true reliability hazard. In addition, if the equipment is of the commercial type, there is the question of product liability.

2. Contributing Environment

In order to produce a cracked solder joint, certain types of stresses must be applied. A heavy, sustained load will produce a stress rupture fracture due to creep. An impact load will produce fast fracture at a single or at least very few applications. Cyclical loadings will produce fatigue fractures. The most common source of cyclical loadings in solder joints are mechanical vibration and thermal cycling. The former is rarely encountered in practice. Design engineers have good awareness to the effects of mechanical vibration and provide good isolation or restraint features in their products. The latter is least understood and therefore given much less attention in product design. Nearly all of the cracked joint failures analyzed by the author over the past 20 years have been thermally induced, low cycle fatigue failures.
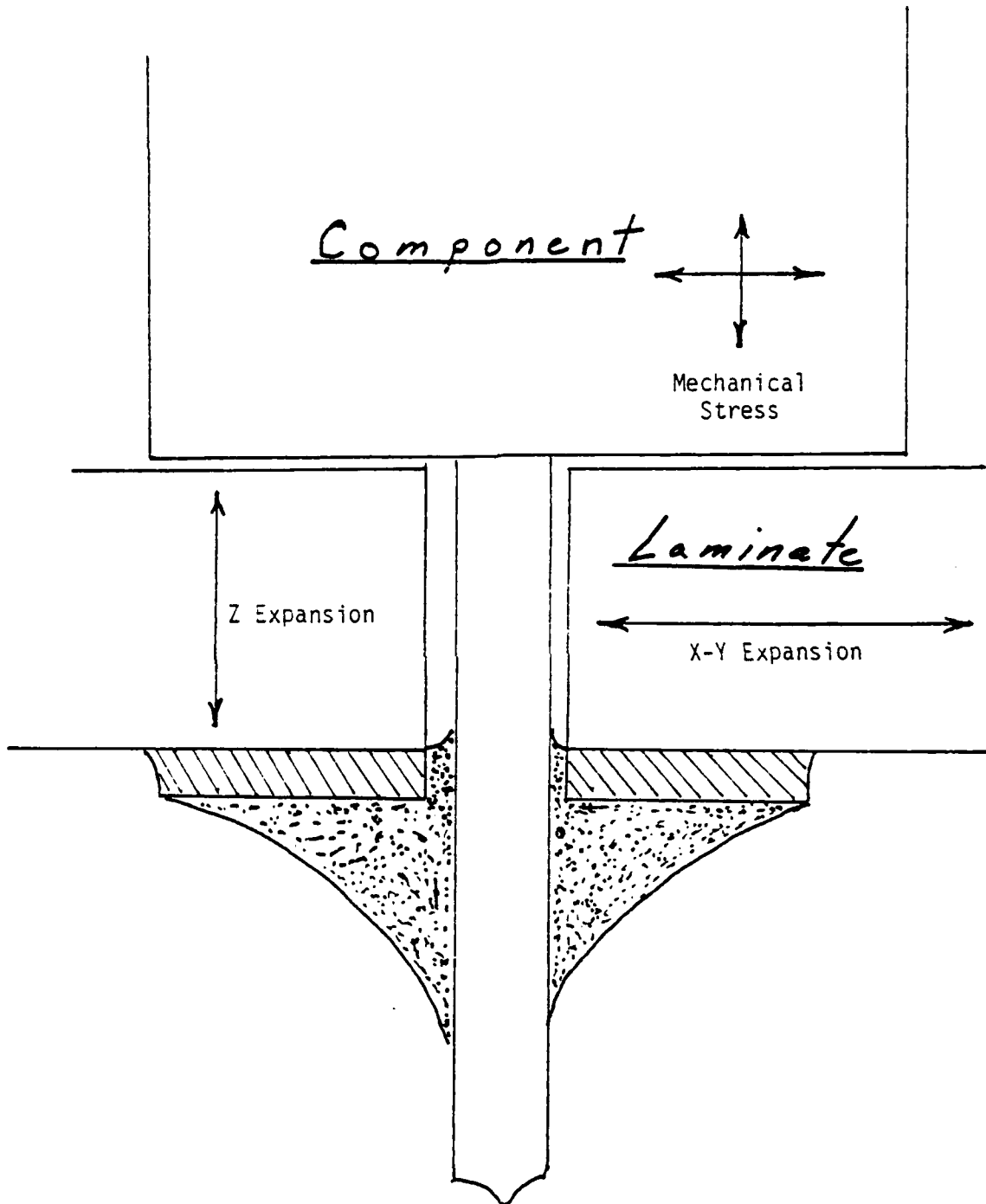
Figure 1 - Solder Joint and Stress Sources

The environment producing the failures is one of thermal cycles. The number of cycles producing a failure range from a very few to tens of thousands of cycles. As will be shown in this paper, all components of the solder joint system have an affect on the longevity of the joint.

In the case of fatigue failures, the actual failure must be defined in terms of the electronic system in which the solder joints are used. Some systems will fail if only a small crack is present if the system is sensitive to small changes in resistance. Other systems will fail only if there is a complete loss of contact in the solder joint after a full fracture has occurred. Therefore, a system which is sensitive to a small crack will fail at a significantly lower number of cycles than one in which a full fracture is required even though all of the stress factors are the same.

3. Fatigue Mechanism

The mechanism of fatigue in solder joints is one of alternating stress application to the solder joint. Figure 1 shows a typical solder joint with the major contributing stress sources shown. The application of these stresses in a cyclical mode to the solder causes metallurgical changes to occur.

The first change is caused by plastic flow in the solder which results in work hardening. This is followed by recrystallization. This is followed by extensive grain growth. Figure 2 shows this effect. The maximum stress plane is usually 1-2 mils out in the solder from the major stress contributing component.

/2

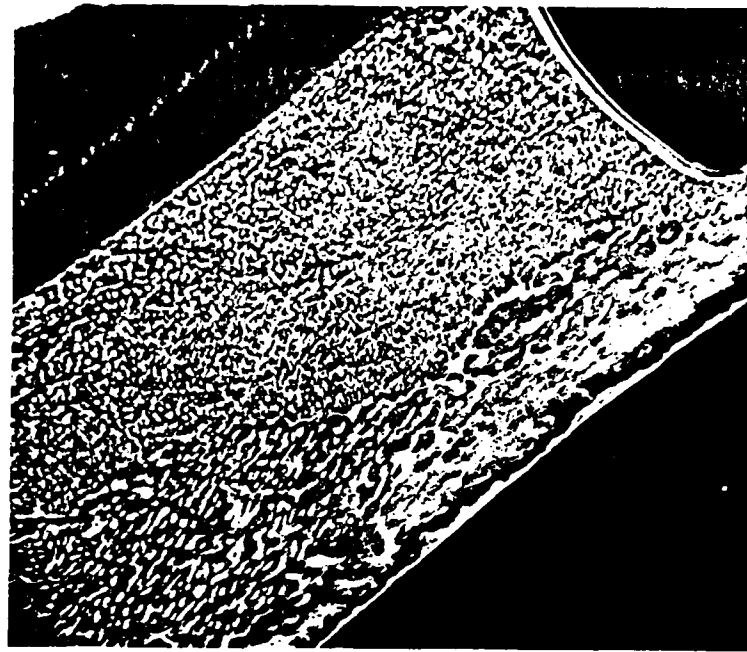Figure 2 - Solder joint subject to fatigue stresses.

Due to the very low creep strength of solders, this plastic flow is maxi-
mized by relaxation. Also, the slower the stress rate, the more complete
will be the relaxation and the greater the total plastic flow. Figure 3
shows a graphical representation of the relaxation characteristic. The
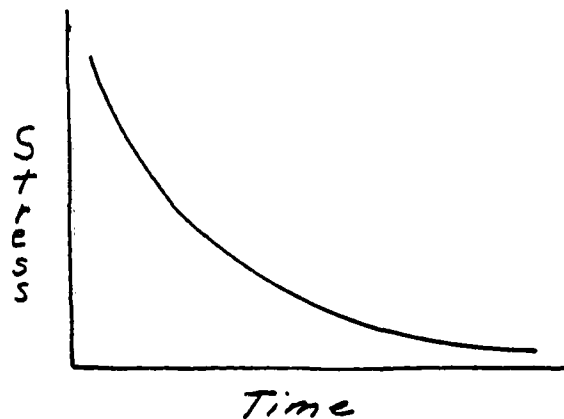
Figure 3 - Solder joint relaxation characteristic.

greater the stress, the faster the relaxation. The maximum relaxation usually occurs between 30 min and 1 hour. This rate is very often the thermal cycle rate of many of the electronic equipments we see in operation daily.

The second metallurgical change is a loss of grain or phase boundary integrity. This is shown in Figure 4. After extensive grain growth, a crack
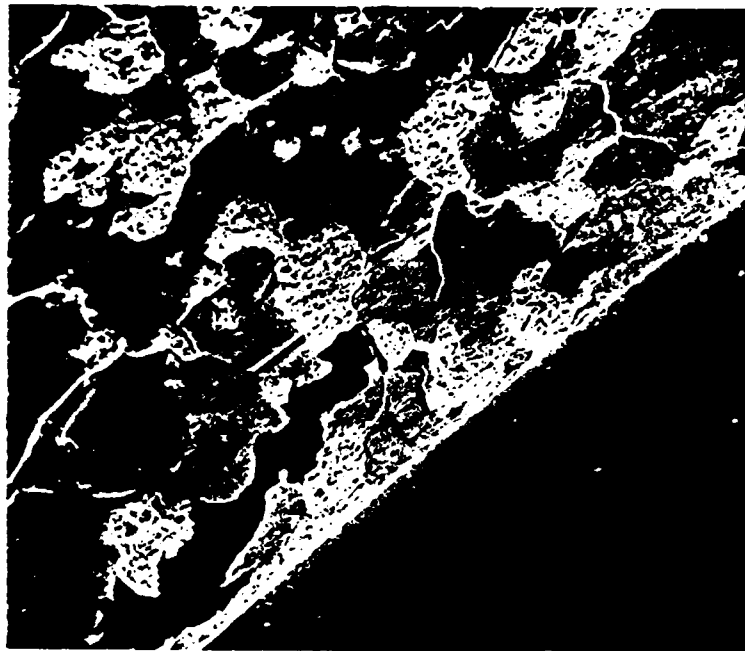
Figure 4 - Fatigue crack characteristic

will form at a grain (phase) boundary in the fillet near the maximum stress. It will then propagate through the solder joint along the grain (phase) boundaries.

Eutectic solders are two phase materials. One is high lead and the other is high tin. The properties of these two phases are significantly different. During plastic flow, the tin rich phase becomes hard and brittle. The fatigue crack will occasionally crack across this phase. The lead rich phase remains soft and ductile and will not crack transgranularly. Therefore, the fatigue crack propagation is mainly by cracking between phases with occasional transgranular cracking of the tin rich phase.

A further note to the fatigue mechanism is that any solder joint subjected to cyclycal stress will fatigue. There appears to be no stress level which will not eventually cause a failure. It is merely a matter of time and number of cycles. Therefore, all solder joints can be considered to have a finite life when subjected to cyclical stress environment.

4. Fatigue Failure Prevention

There are three major areas of design which can be controlled to reduce the possibility of fatigue failure and are shown below.

     1) Component selection and mounting
     2) Solder joint design
     3) Materials selection

A fourth possibility is, of course, control of the thermal environment under which the equipment operates. However, in practice, this is often dictated by the equipment use. Therefore, there is seldom a chance to alter the operating environment.

Prevention by component selection and mounting is an item needed to be factored in early in the design cycle. The recommendations found in IPC-CM-770 are a good starting point. Table I, taken from the introduction, lists some of the points to consider in mounting of parts.

TABLE I

AGGRAVATING CIRCUMSTANCES	MINIMIZING CIRCUMSTANCES
A component (such as a power transistor or module) mounted flat on the surface of a board with non-plated holes. In this, the differential is coefficient of expansion between the board material and the lead material acts directly on the solder joint.	The use of supported holes (plated, etc.) increase the volume and total area of solder attachment in the joint and greatly improves resistance to cracking.
Unsupported holes that are much larger than the component leads cause the solder fillet to thin-out on one side of the hole to around 0.0005-inch (5 mils) or less. This situation is particularly noticeable when clinched leads are used.	Proper sizing of holes to leads tends to increase the fillet bridging from the pad to the lead.

Table I (cont'd)

AGGRAVATING CIRCUMSTANCES	MINIMIZING CIRCUMSTANCES
Copper burrs around non-plated holes cause stress concentrating points that can initiate cracking.	Careful attention to reduction of burrs around holes.
The use of eyelets in interfacial holes (lands both sides) cause a thermal coefficient mismatch between the board material and the eyelet.	
The use of a component lead or "Z" wire for an unsupported interfacial connection.	
Axial component leads that do not enter approximately perpendicular to the hole, this reduces the available stress relief in the bend.	Proper attention to lead forming (stress relief) of axial-lead component leads.
Parts which generate heat, if mounted directly on the board, can cause locally severe thermal coefficient mismatches and attendant cracking.	Design component mountings that tend to maintain as uniform a board temperature as possible. High-heat components should be mounted off of the board wherever possible.
Lack of stress relief bends in component leads.	Use of adequate stress relief bends.

It can be seen that all thermal problems involve coefficient of expansion mismatches which are the source of stress. More will be said of this later.

In most designs, it is almost impossible to eliminate stresses when severe thermal environments are encountered. In order to minimize the effects of these stresses, their amplitude and direction must be known. If known, they will aid in the design of the solder joint.

There are various solder joint designs which can be employed in PWB assemblies. Figure 5 shows several of these. The most common are types 1 and 2 with type 3 used occasionally. Type 4 is the common flatpack joint. Type 5 is a variation of type 1 and has similar characteristics.
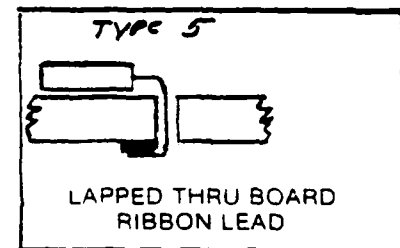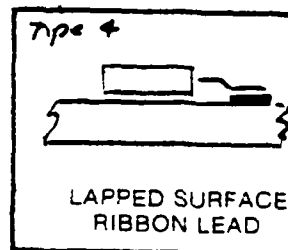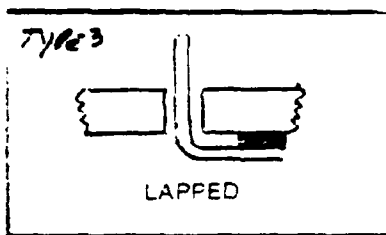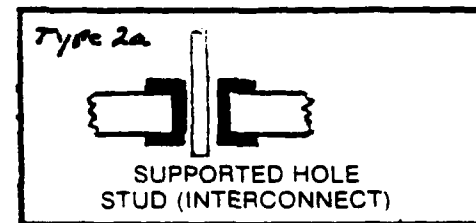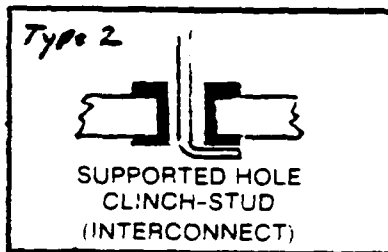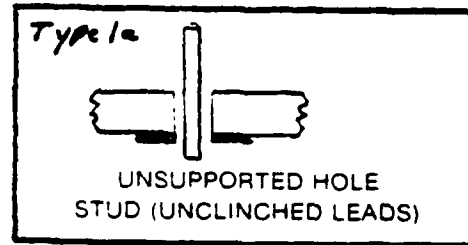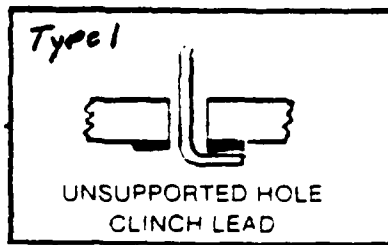
Figure 5 - Solder Joint Designs

Type 1 also is very similar in terms of fatigue life to a type 2 joint if the hole remains unfilled with solder.

One of the major controversies in our industry is the case of filled or unfilled holes. One of the considerations rarely taken into account in these arguments is fatigue life. At this point, one must also discriminate between a hole with or without a lead. If the hole has a lead in it, the fatigue life will vary considerably between filled and unfilled. Depending on stress direction, the filled hole will have 5 (in bending) to 50 (axial load) times the life of the unfilled. Also, any degree of unfilling will reduce the fatigue life. This shows that the life of a solder joint is directly related to the soldered length all other factors being the same.

Based on the above, it has been shown that anything which reduces the soldered length in a joint will reduce the life. We have found that voids,for example, drastically reduce the life. Voids appear to have a dual role in this respect. First is the simple reduction in soldered length. Second, and equally or more important, is the stress concentration factor of the void. Examination of fatigued solder joints show the cracks preferentially propagating through voids.

From this, it can be seen that solder joint designs and component mounting procedures should be such as to eliminate gas entrapment in the solder joint. Also, outgassing of the PWB should be carefully watched.

Any poor solderability problem, especially with component leads, will reduce the life of a solder joint in fatigue. Again, poor solderability reduces the effective soldered length and may introduce a stress concentration factor.

In high fatigue environments, clinched leads should always be used to increase the soldered length. Straight through leads seem to have 25% or less life compared to clinched leads.

In many applications, the type 3 solder joint can be used effectively. This joint style is a stress-relief design. However, it is more costly to manufacture as the lead dress against the pad is important. It also requires greater board area as the actual joint is removed from the hole.

Lead sizes also are a factor in the fatigue life of a solder joint. Large lead diameters transmit more stress in certain stress directions (i.e., bending) than do small lead diameters. If a component is available in more than one lead size, thought should be given to the smaller diameter.

In many applications, significant lead stress relief can be given in the lead forming operation. Many styles of stress relief forms are snown in IPC-CM-770. It will be found that not all components in a PWB assembly require extensive stress relief to prevent fatigue. A stress analysis will show which component may be critical. Therefore, the added cost can be kept to a minimum.

One cautionary note should be made about lead stress relief. That is when a fully potted module type of assembly is used. In some cases, the potting will fully negate a stress relief configuration.

5. Materials Considerations

Since the major stress forming elements in a PWB design are the materials used, thought must be given to minimizing the mismatch of thermal coefficients. The PWB laminate material is the first to consider. In the laminate, the most serious property is "Z" expansion. The use of polyimide, for example, instead of epoxy glass will minimize this.

Reduction of board thickness to reduce the total expansion is not a straight-forward solution. Since reduction of board thickness reduces also the soldered length, care and a full analysis are needed to justify the approach.

Lead materials should also be considered. Copper leads will match the system better than, for example, nickel-iron leads.

In the case of soldering materials 63/37 Sn/Pb is very poor in fatigue. Little data is available on other solder systems. Limited testing has shown promise in other systems. However, in looking at other systems, one must take care that the data fits the application.

Summary

Most solder joint fatigue problems can be reduced by careful design. Both mechanical and metallurgical designs must be evaluated. Careful materials selection is also a key in reducing fatigue problems.

In many cases, the problem of fatigue cannot be entirely eliminated. Therefore, the best approach is to design for a finite life. This may be the most practical and cost effective approach. The major problem is determining the life. Work is going on now to provide mathematical models which would aid in this process.

/mvg

TROUBLESHOOTING THE WAVE SOLDERING SYSTEM

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ABSTRACT

The wave soldering system is capable of producing thousands of discrepant solder joints per minute which could make it the most non-productive and costly system to operate. However, when properly operated and maintained, it can become a most profitable, high yield soldering system capable of consistently producing good quality connections. When troubleshooting is required, it should be performed in a systematic manner using the "process of elimination" concept to analyze each segment of the system. In addition, it must be pointed out that a successful and cost effective wave soldering operation is contingent upon a thorough understanding of the entire wave soldering process and system and a willingness to put that understanding to work with an emphasis on "paying attention to details." The time/cost factors of a careful troubleshooting effort will be infinitesimal when compared with the savings of a high yield, high quality, low touch-up wave soldering process.

Improved quality solder connections through proper troubleshooting of the wave soldering process will overcome any attempts needed to lower quality standards, to justify the "half filled hole" concept, or to expend countless hours of costly touch-up.

TROUBLESHOOTING TOPICS

1. ### The Inclined Conveyor

   Inclined conveyor rails assist in solder drain-back, minimizing the formation of icicles, bridges and/or nodulation. An incline of $5^{o}-7^{o}$ is the generally accepted angle.

2. ### Printed Wiring Board Carrier Frames/Fixtures and Immersion Depth

   During transporting, the frame's four (4) corners should contact the conveyor rails. A raised corner could result in partially filled holes, skip soldered connections, poor solder wetting and solder bridging. In addition, for consistency in hole filling, it is vital that all of the board carrier frames are dimensionally consistent so that each board enters the solder wave with the same immersion depth.

   A combination problem such as an unstable wave height condition coupled with dimensional variance of board carrier frames (due to wear) could result in countless solder defects.

TROUBLESHOOTING TOPICS (Continued)

3. **The Foam Fluxing System**

    Finding the right flux/thinner combination and the best specific gravity
    range can be a chore.

    To arbitrarily pick a flux, a thinner or an S.G. range can spell disaster.

    The following is a list of recommendations:

    a. Develop a solderability spread test system to enable visual examina-
        tion of solder spread rates between various flux/solvent combinations.

    b. Determine best S.G. range .... high S.G. can result in solder
        bridging low S.G. will promote solder voids solder spatter, etc.

    c. Determine best discard frequency of the flux. Flux tends to coagulate
        when over exposed to air. This condition has only slight effect on
        S.G. Therefore, do not depend on S.G. alone for the determination of
        good flux. The solderability spread rate test could be helpful in
        determining discard frequency.

    The flux must penetrate into the plated-through holes, and the brushes
    adjusted to leave a thin flux film. Some problems associated with flux
    are bridging, icicles, and partially filled holes.

4. **Preheater System**

    The preheater drives-off flux solvents, conditions the board for soldering
    and minimizes heat sinking (temperature loss) from the solder.

    Normally, preheat temperatures are about $160^{\circ}F$ - $180^{\circ}F$ on the component
    side. However, the best temperature would be that which would leave the
    flux in a tacky state just prior to entering the solder wave.

    Insufficient preheat temperature will promote solder spatter and trapped
    gas resulting in pinholes/voids.

    Excessive preheat temperature reduces mobility of the flux (dries the flux)
    and increases the surface tension of the solder and surfaces to be soldered.
    This condition will result in excessive solder (bridging, webbing, nodula-
    tion) and poor solder filleting.

5. **Solder Wave Stability**

    Momentary drops of the wave height could indicate possible problems in the
    solder pump. This condition could result in skip soldering, partially
    filled holes, bridging, nodulation and poor solder wetting. It is imperative
    that the solder pump be subject to proper maintenance and lubrication.

TROUBLESHOOTING TOPICS (Continued)

6. Soldering Oil and Injection

It is imperative that the oil be injected into the wave to form a mist sufficient to relieve surface tension of the solder and surfaces to be soldered.

It is important to see that the droplets of oil mist is breaking at zero velocity and falling in a straight fall plane and not skewing. Skewing indicates problems with the sump baffling or excessive pumping force.

It is also imperative that the right brand of oil be used. Oil with excessive wetting agents can be as detrimental to hole filling and solder quality as a brand with less agents.

Wetting agent in the oil decomposes when subjected to solder bath temperature. Therefore, fresh oil should be added two (2) or more times daily.

Solder bridging, insufficient hole filling and blowholes are but a few of the defects associated with insufficient or excessive oil injection; decomposed oil and/or use of the wrong brand.

7. Solder Bath and Analysis

Establishing proper intervals for solder bath analysis is extremely important for the maintenance of solder quality.

Using a matrix to track the rate of degradation from each analysis will assist in determining when tin adds are necessary and the expected expiration of bath life. In addition, the matrix will provide visibility in plotting the rate of the most bothersome contaminate(s) for corrective action purposes, i.e., if silver was found to shorten bath life, then pre-tinning of the silver leaded components should be considered to protect bath life.

Tin plays a major role in assuring quality soldering. Tin in the solder alloys with contaminants (copper, gold, etc.) and these alloys no longer serve the solder bath. This tin should be periodically replaced if the benefits of a eutectic solder is to be realized.

Selecting the proper soldering temperature and maintaining that temperature closely is vital for consistent quality. Day-to-day temperature variations of 15° - $20^\circ F$ could result in excessive solder touch-up.

8. **Conveyor Speed**

    The conveyor must be set as a speed which allows for the effects of heat
    sinking from component leads and ground planes. The basic claim of 3-4
    seconds in solder is not reasonable; what is reasonable is that the time
    in solder is contingent upon the time needed to effect <u>good wetting action</u>
    and the formation of an intermetallic compound (bond).

9. **Troubleshooting Procedure**

    1. Document all operating parameters:

        Exact Flux S.G., Pre-Heat and Solder Temp,
        Conveyor speed, etc.

    2. Run 5 cards - personally examine the cards and document the type,
        size and quantity of defects.

    3. Make an adjustment to the segment under study and none other.

    4. Run 5 more cards (same part number) - personally evaluate the type,
        size and quantity of defects and compare with the initial 5 cards.

    5. Increase or decrease adjustment setting according to the results of
        the run.

    6. Continue running cards until the segment under study has been
        optimized.... The optimized setting will now replace the initial
        "Documented" setting.

    NOTES:

    1. Repeat the above procedure until all segments of the wave soldering
        system has been optimized, i.e., the fluxer, preheater, solder bath
        temperature, oil selection, conveyor speed, etc.

    2. Troubleshooting should be done using the card assembly having the
        most defects.

    3. Don't depend on someone else to troubleshoot the system for you....
        Do it yourself or personally supervise it.

    4. Judge your progress by personally examining the cards.... Use an
        8-10 X magnifier.

Many wave soldering problems could be eliminated if proper flux/thinner
combination and proper wave oil selections were made.

QUALITY ASSURANCE

USE OF

INSPECTION BEFORE TOUCH-UP DATA

PREPARED BY
JAMES G. PARK, MANAGER
PROCESS QUALITY ASSURANCE
GENERAL DYNAMICS
POMONA, CA.

AND

FRED R. LEE, DIRECTOR
OFFSITE OPERATIONS
GENERAL DYNAMICS
CAMDEN, ARKANSAS

ABSTRACT

THIS PAPER IS OFFERED SPECIFICALLY FOR THOSE UTILIZING AUTO-
MATIC MACHINE SOLDERING PROCESSES. IT IS ALSO OFFERED FOR THOSE LIKE
OURSELVES, WHO FELT CONFIDENT WITH AN ESTABLISHED SYSTEM OF TOUCH-UP
IMMEDIATELY FOLLOWING WAVE SOLDER, PRIOR TO INSPECTION, NOT REALIZING
HOW EFFICIENT THE MACHINE SOLDERING PROCESS CAN BECOME, WITH CERTAIN
REFINEMENTS AND PROCESS CONTROL TECHNIQUES.

THE PAPER CONCLUDES THAT BY ESTABLISHING THE WAVE SOLDER
MACHINE AS A "PROCESS CONTROL CENTER", AND UTILIZING INSPECTION BEFORE
TOUCH-UP DATA, A VIRTUALLY NO TOUCH-UP, DEFECT-FREE, MACHINE SOLDERING
PROCESS CAN BE ACHIEVED.

QUALITY ASSURANCE USE OF INSPECTION BEFORE TOUCH-UP DATA

THE PRIMARY OBJECTIVE OF PROCESS CONTROL IS TO MAKE THE PRODUCTION PRO-
CESS AS REPEATABLE AS POSSIBLE, TO INCREASE THE CONSISTENCY OF THE YIELD. EXPERIENCE
HAS PROVEN TO US TIME AND AGAIN THAT PROCESS CONTROL IS THE MOST ESSENTIAL INGREDIENT,
FOR CONSISTENTLY PRODUCING RELIABLE PRINTED CIRCUITS, AS OUR REQUIREMENTS ARE FOR THE
PRODUCT WHICH MUST OPERATE RELIABLY IN: SHIPBOARD, TACTICAL AND AVIONICS APPLICATIONS,
MEETING MILITARY SPECIFICATION REQUIREMENTS FOR QUALITY.

TO QUOTE A PHRASE OF JIM RABY'S, "IT IS EVERYONE'S RESPONSIBILITY TO GET
THE MOST FOR OUR TAX DOLLAR, AND PROCESS CONTROL IS A MEANS OF OBTAINING THIS GOAL".

IN THE PAST YEARS, SOLDERING TECHNOLOGY WAS PRIMARILY CONCERNED IN THE
BUILDING OF ONE OF A KIND HARDWARE THAT WAS NOT PARTICULARLY COMPLICATED OR COMPLEX.
TODAY, PRODUCTION REQUIREMENTS HAVE DRASTICALLY CHANGED; THE ENVIRONMENT NOW IS ONE
OF UNEQUALLED VOLUME AND COMPLEXITY. STATE OF THE ART IS CHANGING RAPIDLY WITH NEW
PARTS TECHNOLOGY, PRINTED WIRING BOARD TECHNOLOGY, AND MANUFACTURING EQUIPMENT
TECHNOLOGY. OUR PRODUCTION LINES ARE NOW MOVING FASTER AND WITH GREATER VOLUME THAN
EVER BEFORE. THE WEAPONS SYSTEMS THAT WE BUILD DEMAND HIGH RELIABILITY. WE MUST BE-
COME CAPABLE OF ACHIEVING HIGH RELIABILITY IN A MANNER WHICH IS JUST AS COST EFFECTIVE
AS HARDWARE BUILT WITH LESS QUALITY. THIS CAN BE ACHIEVED BY ADOPTING A BASIC, SIMPLE
PROCESS CONTROL PHILOSOPHY BY FIRST PROCESSING A PART THROUGH THE PROCESS, THEN
MEASURING FOR DEFECTS AND THEN READJUSTING THE PROCESS TO ELIMINATE THE DEFECTS.

DUE TO THE REQUIREMENT OF GOVERNMENT SPECIFICATIONS FOR THE PRODUCTION OF
HIGH RELIABILITY SOLDERED CONNECTIONS, INTERJECTED WITH CERTAIN COSMETIC REQUIREMENTS,
VIRTUALLY EVERY HIGH VOLUME PRODUCER OF SOLDERED ELECTRONIC COMPONENTS OR PRINTED

WIRING BOARDS IS INVOLVED IN TOUCH-UP OPERATIONS OF VARYING DEGREES. THE PHRASE TOUCH-UP HAS A BAD CONNOTATION AND WE ARE CONVINCED THAT IT HAS AN EVEN WORSE CONNOTATION TO OUR CUSTOMER. THE QUESTION THAT ALWAYS COMES TO MIND IS, "WHY DIDN'T YOU BUILD IT RIGHT THE FIRST TIME?" - BUT WHAT IS EVEN WORSE, IS WHEN WE REALIZE THAT WE NEVER EXPECTED TOUCH-UP FREE SOLDERED CONNECTIONS FROM OUR SOPHISTICATED, VIRTUALLY AUTOMATIC WAVE SOLDER SYSTEMS.

PRIOR TO THE RECEIPT OF THE WAVE SOLDERING MACHINE, WE PLANNED FOR A TOUCH-UP AREA SO THAT PRODUCTION FLOW WOULD BE ENHANCED. WE SPENT LOTS OF MONEY ON THE EQUIPMENT AND THEN, GREATER SUMS OF MONEY STAFFING AN OPERATION TO TOUCH-UP THE HARDWARE THAT OUR PIECE OF EXPENSIVE EQUIPMENT PRODUCED. THIS APPROACH, WE BELIEVE, CAN BE SEEN AS COMMON THROUGHOUT THE INDUSTRY AND THANKS TO THE EFFORTS AND ENCOURAGEMENT OF THE PEOPLE AT CHINA LAKE SOLDERING TECHNOLOGY, WE CAME TO THE REALIZATION THAT THERE COULD BE A MORE EFFECTIVE SYSTEM FOR ASSURING THE DELIVERY OF HARDWARE WITHIN SPECIFICATION LIMITS AND AT A LOWER COST. (SEE FIGURE 1).

WE DON'T BELIEVE THERE IS SUCH A THING AS A STRICTLY CONTROLLED TOUCH-UP OPERATION - THERE ARE TOO MANY SUBJECTIVE, PEOPLE VARIABLES. THEREFORE, IN MANY CASES SOLDERED CONNECTIONS ARE UNNECESSARILY TOUCHED UP BY REFLOWING THE SOLDER, REMOVING THE SOLDER AND REAPPLYING NEW SOLDER, ETC., BASED ON AN OPERATOR'S OPINION THAT TOUCH-UP IS REQUIRED.

THE WORST THING THAT CAN HAPPEN IN THE TOUCH-UP OPERATION, IS THE DAMAGE THAT CAN OCCUR TO THE PRINTED WIRING BOARD AND COMPONENTS, CAUSED BY INADVERTENT UNNECESSARY TOUCH-UP. BUT, IN ADDITION, A TOUCH-UP OPERATION OF THE MAGNITUDE THAT MANY OF US HAVE EMPLOYED IN THE PAST, IS A TREMENDOUS ADDED MANPOWER EXPENSE AND ESPECIALLY AGGRAVATING WHEN IT WOULD ALMOST APPEAR THAT THE SIX OR EIGHT SOLDER TOUCH-UP OPERATORS WHO ARE SUPPORTING ONE AUTOMATIC MACHINE COULD POSSIBLY PRODUCE AS MUCH HARDWARE WITHOUT THE AUTOMATIC SOLDERING MACHINE. (SEE FIGURE 2).

FIG. 1

WAVE SOLDER PROCESS FLOW

ORIGINAL SYSTEM

GENERAL DYNAMICS
Pomona Division

FIG. 2

WAVE SOLDER PROCESS FLOW

DATA COLLECTION IMPLEMENTED

GENERAL DYNAMICS
Pomona Division

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┌──────────┐     ┌────────┐     ┌────────────┐     ┌─────────┐     ┌──────────────────┐
│   WAVE   │     │  WAVE  │     │   DEFECT   │     │         │     │  IDENTIFICATION  │
│ SOLDER / │────▶│ SOLDER │────▶│    DATA    │────▶│ TOUCH-UP│────▶│       AND        │
│   PREP   │     │        │     │ COLLECTION │     │         │     │  SERIALIZATION   │
└──────────┘     └────────┘     └────────────┘     └─────────┘     └──────────────────┘
                                                         ▲                    │
                                                         │ RE-INSPECT         │
                                                         │                    ▼
                                                    REJECT          ┌─────────────┐
                                                         ◀──────────│ INSPECTION  │
                                                                    └─────────────┘
                                                    ACCEPT                 
                                                      │
                                                      ▼
                                                   TO TEST
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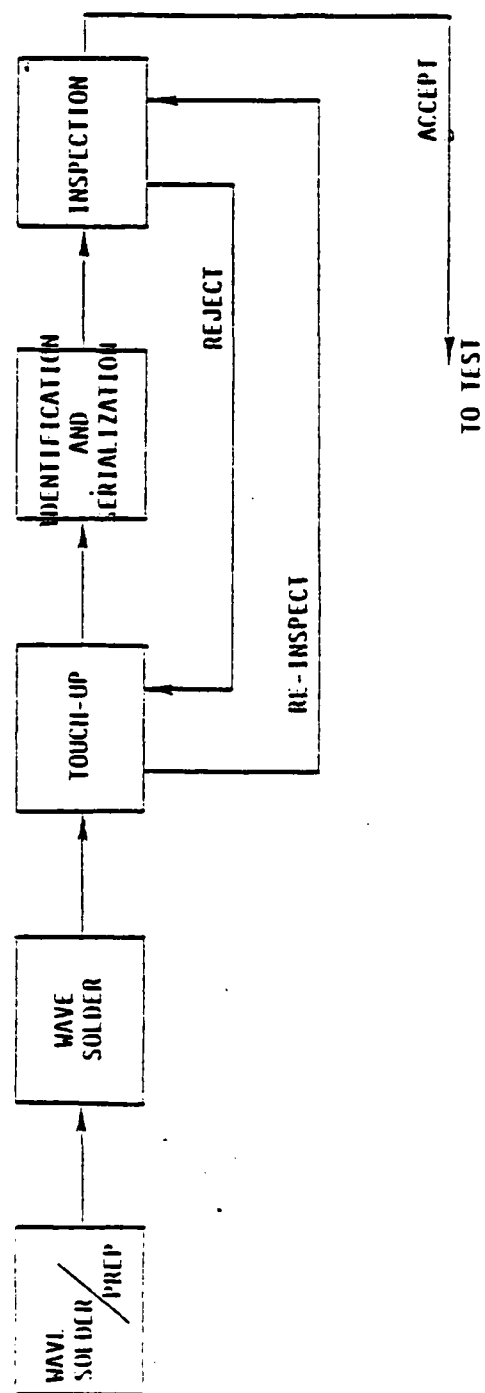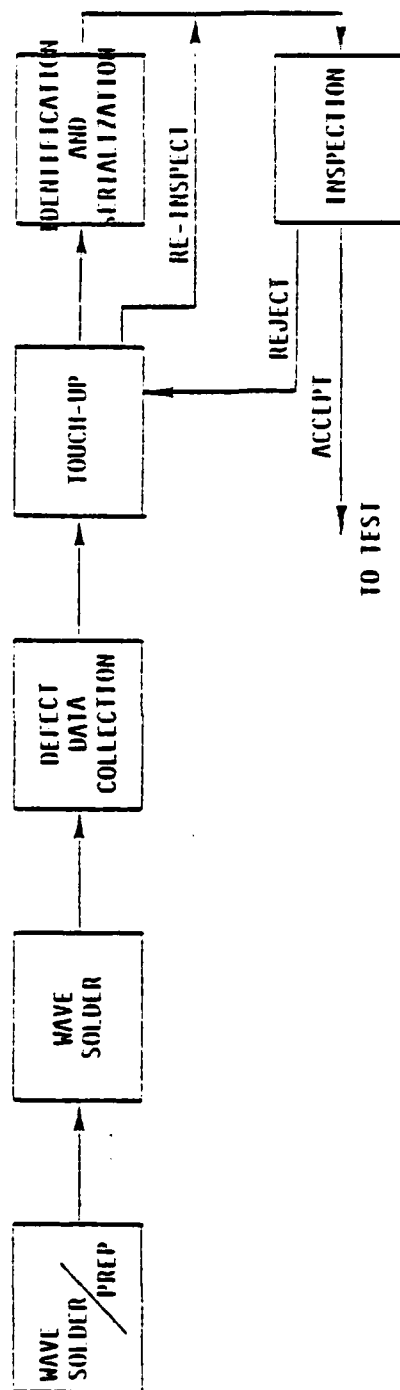
IN THE MEANTIME, OUR AUTOMATIC MACHINE KEEPS POURING OUT HARDWARE OF VARIOUS CONFIGURATIONS PROBABLY ALL OF WHICH RECEIVE SOME TOUCH-UP.

WE REALIZED THAT WE NEEDED SOME MEANS OF TELLING OUR MACHINE WHEN IT WAS DOING A GOOD JOB AND ALSO TO TELL OUR MACHINE WHAT KIND OF A JOB IT WAS SUPPOSED TO DO FOR EACH OF THE VARIOUS TYPES OF HARDWARE THAT IT WOULD BE SOLDERING. OUR PROCESSES HAD BEEN ESTABLISHED IN GENERALITIES WHICH DID NOT TAKE INTO CONSIDERATION MANY OF THE OTHER VARIABLES THAT AFFECT THE SOLDER PROCESS. FOR EXAMPLE, COMPONENT DENSITY, GROUND PLANES, HEAT SINKS, ETC. WHAT WE ALSO NEEDED WAS A FEEDBACK SYSTEM TO THE MACHINE AND THE MACHINE OPERATOR WHICH WOULD ASSURE THAT THE SOLDERING PROCESS WAS CORRECT FOR EACH PART NUMBER OR CONFIGURATION OF HARDWARE. WE NEEDED TO STOP TOUCHING UP THE SOLDERED CONNECTIONS AS A "WAY OF LIFE", AND TO START INSPECTING THE CONNECTIONS IMMEDIATELY AFTER THEY CROSSED THE WAVE SOLDER MACHINE SO THAT WE WOULD HAVE DATA TO CORRECT AND CONTROL THE MACHINE PROCESS.

OUR FIRST STEP TO ELIMINATE THE TOUCH-UP ACTIVITY AND TO CONTROL THE SOLDERING PROCESS WAS TO INSURE THAT THE WAVE SOLDER MACHINE WAS CORRECT AND CAPABLE OF MAINTAINING THAT CORRECTNESS FOR EACH PART NUMBER. WE DEVELOPED WHAT WE CALL "PROGRAM SHEETS" OR SOLDER SET-UP INSTRUCTIONS FOR EACH PART CONFIGURATION, WHICH STIPULATED THE CORRECT ADJUSTMENTS AND SETTINGS THAT THE MACHINE OPERATOR WOULD USE BEFORE SOLDERING THE PART ON THE MACHINE. (SEE FIGURE 3). THIS WAS DONE FOR THE PURPOSE OF ELIMINATING DEFECTS ASSOCIATED WITH THE PROCESS.

STEPS HAD ALREADY BEEN TAKEN TO ELIMINATE PRE-SOLDER PROCESS DEFECTS SUCH AS PWB CONTAMINATION, COMPONENT CONTAMINATION, INSUFFICIENT OR IMPROPER LEAD TINNING, INCORRECT ASSEMBLIES ETC. PROPER CLEANING, TINNING, AND ASSEMBLY VIRTUALLY ELIMINATES THIS TYPE OF DEFECT PRIOR TO THE SOLDER PROCESS. BY ELIMINATION OF PRE-SOLDER PROCESS DEFECTS OF WHICH OUR BIGGEST PROBLEM WAS SOLVED BY 100% TIN-DIPPING OF COMPONENT LEADS, AND NOW THE ELIMINATION OF SOLDER PROCESS DEFECTS, TOUCH-UP OPERATIONS COULD BE VIRTUALLY ELIMINATED.

A. J. Branno
Manufacturing Engineer

Bill Clinocca
Process Control Engineer
QUALITY ASSURANCE

PROGRAM:

PART #:

PART NAME ___ AMPLIFIER

PWB THICKNESS ___ .030

PART DIMENSION ___ 3D

SOLDER SET UP

FLUX S.G.: ___ .850 TO .890

PREHEAT SETTING: ___ 7.5 ___ 175°C

COMPONENT SIDE TEMP: ___ 180°F

CONVEYOR SPEED: ___ 3.2 ___ SOLDER DWELL: ___ 4.3

CONVEYOR ANGLE: ___ 6 to 9°

D.I. INJECT VALVE: NONE □ ___ MEDIUM ☒
___ TRACE □ ___ FULL □

SOLDER TEMP: ___ 516°F - 521°F

IMMERSION DEPTH: SOLDER ___ .015 medium
___ FLUX ___ Thin cover component side

FLUX: ALPHA 611

THINNER: ALPHA 113

DROSS INHIBITOR: EPA FLOW

SOLDER: SN 63/37

HOLDING FIXTURE: 1ST SIDE: ___ 933-477
___ 2ND SIDE: ___ 933-477

SPECIAL INSTRUCTIONS: ___ Insure proper wicking
on all transistors. If not, slow speed to
___ 3.0

THE FIRST STEP TOWARDS THE ELIMINATION OF TOUCH-UP WAS TO ASSURE A PHILOSOPHY OF PERFORMANCE IN THE MINDS OF THE SOLDER OPERATOR AND THE SUPERVISOR, REQUIRING THAT THEY HAVE THE RESPONSIBILITY TO INSURE HARDWARE IS READY FOR SOLDERING AND THAT THE HARDWARE BEING PROCESSED ON THE MACHINE IS ACCOMPLISHED IN ACCORD WITH THE DETAILED STANDARDS ESTABLISHED FOR EACH PART. WE THEN ESTABLISHED A WAVE SOLDER ACCEPTANCE STATION (PRE-INSPECTION) WITH THE SCOPE TO ASSIST THE WAVE SOLDER OPERATOR IN DETERMINING THAT THE CONNECTIONS HAD BEEN SOLDERED PROPERLY. THE ACCEPTANCE STATION OPERATOR, WHO IS A CERTIFIED INSPECTOR, PERFORMS A VERY QUICK VISUAL INSPECTION ON THE FIRST PIECE RUN ACROSS THE MACHINE TO DETERMINE THE DEFECTS. IF THE FIRST PIECE MEETS ACCEPTANCE CRITERIA, THEN PRODUCTION CONTINUES — IF NOT, THE WAVE SOLDER SUPERVISOR AND OPERATOR ARE REQUIRED TO CORRECT THE PROCESS PRIOR TO RELEASING THE REMAINING HARDWARE FOR SOLDERING. (SEE FIGURE 4).

ONCE A PARTICULAR WORKING LOT OR WHAT WE CALL A "BOND" OF HARDWARE, GENERALLY 30 PIECES, HAS BEEN SOLDERED THE ACCEPTANCE OPERATOR SCANS ALL MODULES FOR ANY DEFECTS. DEFECTS ARE DOCUMENTED AND REMOVED TO A REWORK STATION AND THEN TO AN IDENTIFICATION STATION; IF THERE IS NO REWORK REQUIRED, THE BOND MOVES TO IDENTIFICATION, THEN TO INSPECTION.

THE RESPONSIBILITY FOR WAVE SOLDER QUALITY WAS PLACED ON SUPERVISION AND THE PEOPLE PERFORMING THE MANUFACTURING OPERATIONS AND IN THAT ORDER. THE REASON FOR THIS IS THAT EVEN THOUGH WE STILL CONDUCT 100% INSPECTION, IT WAS REALIZED THAT INSPECTION WAS NO MORE RESPONSIBLE FOR PRODUCT QUALITY THAN THE WEATHERMAN IS RESPONSIBLE FOR THE WEATHER. IT IS UNDERSTOOD THAT INSPECTION IS AN INTEGRAL PART OF THE MANUFACTURING SYSTEM — THE PART WHICH EVALUATES PRODUCTION AND FEEDS BACK THE APPROPRIATE STATUS SO THAT MANAGEMENT CAN MAINTAIN CONTROL OF THE MANUFACTURING PROCESS.

FIG. 4

GENERAL DYNAMICS
Pomona Division

WAVE SOLDER PROCESS FLOW

PRESENT SYSTEM

WAVE SOLDER PREP

WAVE SOLDER

1ST PIECE "NO GO"

* (ACCEPT STATION) DEFECT DATA COLLECTION

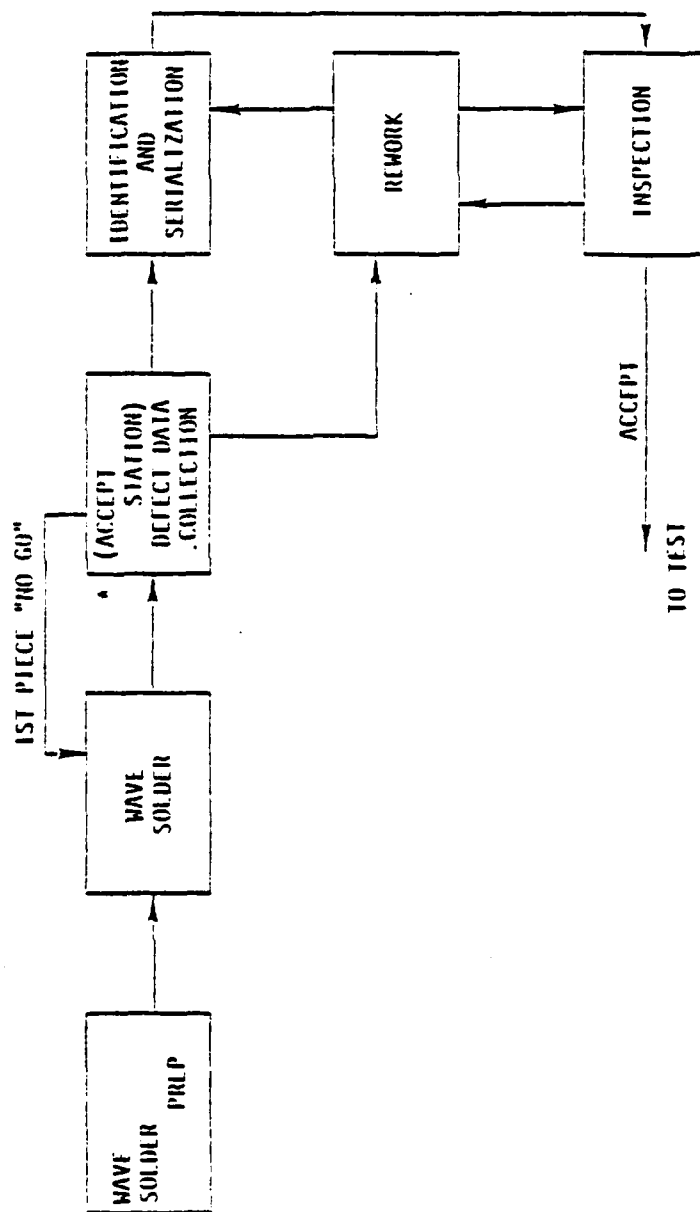IDENTIFICATION AND SERIALIZATION

REWORK

INSPECTION

ACCEPT

TO TEST

*1ST PIECE SCREENED - "GO" - W/S OPERATOR RELEASES OTHER 29.

THE OPERATOR AND SUPERVISOR HAVE THE RESPONSIBILITY OF INSURING THAT THE HARDWARE IS READY FOR MACHINE SOLDERING, THE RESPONSIBILITY TO READ THE SET-UP SHEET BEFORE SOLDERING HARDWARE AND MAKE THE APPROPRIATE ADJUSTMENTS TO THE WAVE SOLDER MACHINE, THEN RUN ONE PIECE OF HARDWARE PER THESE ESTABLISHED SETTINGS. THE HARDWARE IS THEN CLEANED AND DELIVERED TO THE ACCEPTANCE STATION FOR REVIEW OF THE SOLDERED CONNECTIONS. THE HARDWARE IS THEN RETURNED TO THE OPERATOR WITH EITHER A "GO" OR A "NO-GO". IF THIS IS A "GO" STATUS, THE OPERATOR PROCEEDS TO SOLDER THE REMAINING PIECES OF HARDWARE IN THE BOND. IF THERE IS A "NO-GO" CONDITION, AND CAUSE IS DETERMINED, AND CAN BE CORRECTED, THE OPERATOR MAKES THE APPROPRIATE ADJUSTMENT AND RERUNS THE HARDWARE AND SUBMITS TO THE ACCEPTANCE STATION TO ACHIEVE A "GO" SITUATION. IF THE OPERATOR CANNOT DETERMINE THE CAUSE OF THE PROBLEM, SUPERVISION AND APPROPRIATE MANUFACTURING ENGINEERING PERSONNEL ARE CONTACTED. IF IT IS DETERMINED THAT A FIX WILL TAKE AN INORDINATE AMOUNT OF TIME, THE BOND IS PUT ASIDE AND THE OPERATOR PROCEEDS TO THE NEXT PART NUMBER OR HARDWARE CONFIGURATION. WHEN A SOLUTION OR FIX IS DETERMINED, THE OPERATOR PROCESSES AN ADDITIONAL PIECE OF HARDWARE, CLEANS IT AND DELIVERS IT TO THE ACCEPTANCE STATION FOR A "GO" SITUATION. WHEN THE OPERATOR COMPLETES THE REMAINING HARDWARE IN THE BOND, ALL PARTS ARE THOROUGHLY CLEANED, MOLD SEAL, SUPPORTS REMOVED, ETC. AND THE HARDWARE IS SENT TO THE ACCEPTANCE STATION. UPON ARRIVING AT THE ACCEPTANCE STATION THE ACCEPTANCE OPERATOR VISUALLY SCANS EACH PIECE OF HARDWARE TO DETERMINE IF THE PROCESS REMAINED CONSISTENT OR WAS BEGINNING TO DROP OUT.

THE ACCEPTANCE STATION OPERATOR WHO PERFORMS THE VISUAL SCAN AND REPORTS "GO" AND "NO-GO" SITUATIONS TO THE MACHINE OPERATOR HAS THE RESPONSIBILITY TO IMMEDIATELY REVIEW THE FIRST PIECE OF HARDWARE, AND DETERMINE IF ALL CONNECTIONS AND COMPONENTS ARE PROPERLY SOLDERED, CHECKS FOR DEWETTING, UNSOLDERED CONNECTIONS, PITS, HOLES, VOIDS, ETC. IF SOLDERED CONNECTIONS APPEAR SOUND, THE ACCEPTANCE OPERATOR

ADVISES THE WAVE SOLDER OPERATOR TO RELEASE THE REMAINING HARDWARE IN THE BOND WHICH CONSTITUTES THE "GO". IN THE EVENT SOLDER DEFECTS OCCUR ON THE FIRST RUN, THE ACCEPTANCE STATION OPERATOR ADVISES THE WAVE SOLDER OPERATOR IMMEDIATELY THAT A "NO-GO" SITUATION IS IN EFFECT UNTIL A FIX HAS BEEN MADE BY SUPERVISION AND MANUFACTURING ENGINEERING AT WHICH TIME A SECOND SAMPLE WILL BE CHECKED. THIS WILL BE REPEATED UNTIL A "GO" SITUATION IS REACHED OR IT IS DETERMINED BY MANUFACTURING ENGINEERING AND SUPERVISION THAT THIS IS A "NO FIX SITUATION".

UPON RECEIPT OF THE ENTIRE BOND OF HARDWARE FROM WAVE SOLDER FOLLOWING A "GO" SITUATION, A QUICK ACCEPTANCE CHECK IS MADE BY THE ACCEPTANCE OPERATOR TO DETERMINE IF THERE ARE ANY OBVIOUS SOLDER DEFECTS SUCH AS: IMPROPER ASSEMBLIES AND MISSING COMPONENTS. THIS TYPE OF DEFECT IS DOCUMENTED AND MARKED WITH A RED ARROW. WHEN THERE ARE NO DEFECTS, THE BOND OF HARDWARE IS FORWARDED TO AN IDENTIFICATION STATION, THEN TO 100% INSPECTION. SHOULD ANY REWORK BE REQUIRED FOR OBVIOUS SOLDER DEFECTS WHICH WERE PREVIOUSLY IDENTIFIED WITH THE RED ARROW, THE BOND IS FORWARDED TO REWORK FOR CORRECTION OF THE SPECIFIC DEFECTS. WHEN THE HARDWARE REACHES THE REWORK STATION, THE REWORK OPERATOR CORRECTS ONLY THOSE DEFECTS MARKED WITH RED ARROWS. UPON CORRECTION, THE BOND IS FORWARDED TO IDENTIFICATION. FOLLOWING IDEN- TIFICATION, THE HARDWARE IS SUBMITTED FOR 100% VISUAL INSPECTION AND ANY REQUIRED TOUCH-UP IS DOCUMENTED AND IDENTIFIED WITH RED ARROWS AND SENT BACK TO THE REWORK STATION AT WHICH TIME THESE DEFECTS WILL BE CORRECTED AND RETURNED TO INSPECTION.

THE OBVIOUS ADVANTAGES OF THIS SYSTEM ARE THAT POST SOLDER DEFECT DATA CAN BE ACCUMULATED FROM INSPECTION CLEAN-UP SHEETS; AN IMMEDIATE NET RESULT OF THIS SYSTEM PROVIDED FOR THE REDUCTION OF FOUR OPERATORS PREVIOUSLY REQUIRED FOR TOUCH-UP.

OUR DEFECT RATE HAS DROPPED DRASTICALLY AND OUR TOUCH-UP REQUIREMENTS HAVE BEEN SIGNIFICANTLY REDUCED. THIS CAN GREATLY REDUCE THE POSSIBILITY OF ANY ADDITIONAL DAMAGE CREATED BY UNNECESSARY TOUCH-UP TO PRODUCTION HARDWARE BY OPERATORS WHO ARE PROBABLY NOT INSPECTORS, FROM PLACING A SOLDERING IRON ON CONNECTIONS THEY BELIEVE TO HAVE DEFECTS. (SEE FIGURE 5).

FIG. 5

WAVE SOLDER ACCEPTANCE

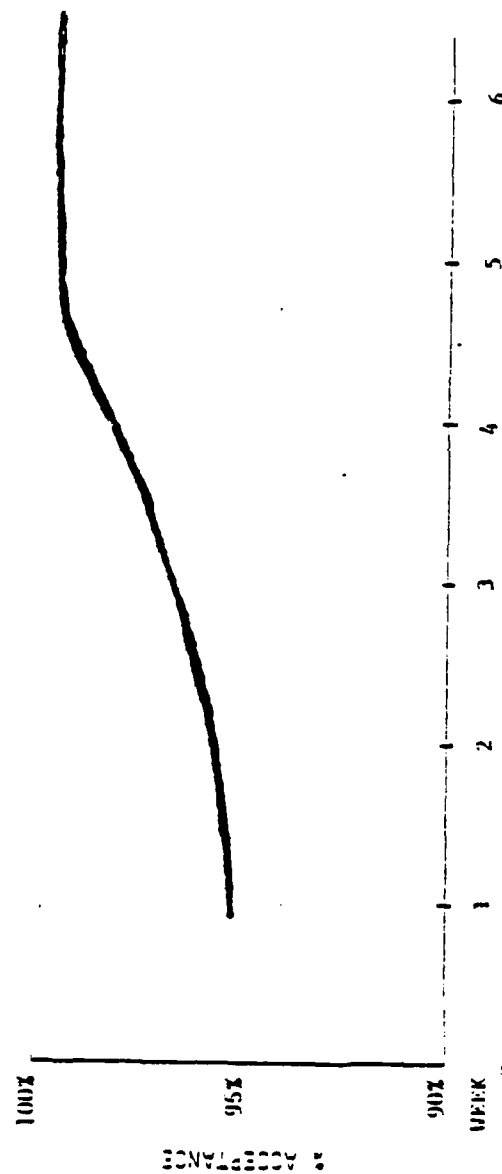ACCEPTANCE TRENDS AFTER NEW SYSTEM

GENERAL DYNAMICS
Pomona Division

THIS SYSTEM ASSURES THAT SOLDERING PROCEDURES ARE FOLLOWED IN DETAIL FOR EVERY PART NUMBER. AS THIS WAS OUR PILOT RUN ON ONE WAVE SOLDER SYSTEM, IT HAS LAID THE GROUND WORK FOR EXPANSION OF THIS PROGRAM OF ELIMINATING TOUCH-UP TO OUR OTHER WAVE SOLDER MACHINES. IN ADDITION TO THESE BENEFITS, IS THE KEY FACTOR THAT OUR CUSTOMER WILL BE ASSURED THAT WE ARE NOW PROVIDING HIM THE BEST HARDWARE THAT CAN BE PRODUCED FROM A HIGH VOLUME FACILITY UTILIZING AND CONTROLLING A VIRTUALLY "DEFECT FREE" PROCESS. A GOAL FOR THE FUTURE WILL BE TO CONTINUE TO REFINE THIS SYSTEM WHERE THE PROCESS RELIABILITY ITSELF WILL BECOME OF SUCH CONFIDENCE, THAT A REDUCTION IN THE 100% FINAL INSPECTION OF EACH SOLDERED CONNECTION WOULD BE APPROPRIATE. THIS PROCESS CONTROL SYSTEM CAN PROVIDE THE ELIMINATION OF ALL TOUCH-UP FOLLOWING AUTO-MATIC MACHINE SOLDERING.

ESSENTIALLY, IN REVIEW, THE SYSTEM IS TO ESTABLISH DETAIL MACHINE PARAMETERS FOR EACH BOARD CONFIGURATION, RUN A SAMPLE FROM EACH BOND FOR ANALYSIS, TO ALLOW ADJUSTMENT OF THE MACHINE OR PROCESS, TO CORRECT FOR PROBLEMS AND THEN TO RUN A BOND. THIS SYSTEM ESTABLISHES THE WAVE SOLDERING MACHINE, THE MACHINE'S OPERATOR AND OPERATOR'S SUPERVISION AS THE PROCESS CONTROL CENTER. WE FEEL THAT THIS SYSTEM HAS TREMENDOUS POTENTIAL IF ADHERED TO, AS WE ARE NOW OPERATING WITH VIRTUALLY NO TOUCH-UP.

ANY PROCESS OR SYSTEM THAT REMOVES OR REDUCES THE NEED FOR TOUCH-UP AND REWORK IS DESIRABLE AS IT GREATLY ENHANCES THE QUALITY AND RELIABILITY OF THE PRODUCT; MOREOVER, IT SAVES MANY OF THOSE HARD-EARNED TAX DOLLARS.

A STUDY PROGRAM

ON

WATER SOLUBLES AND THEIR CLEANING

by

Carl W. Buchanan, Jr.

Jim D. Raby

The current position of the Naval Weapons Center is not to allow the use of water soluble flux (WSF)/organic acid flux (OA) on the fabrication of electronic assemblies.

Before that position is changed, there must be data accumulated to include, as a minimum:

a. The activity of the WSF and how that activity is maintained. Preliminary data indicates that the WSF activity level ranges from equivalent to water white rosin (R) to pure acid flux. This data is required for the procurement and process controls of the WSF.

b. There is conflicting data for: time between the soldering operation (fluxing) and the cleanliness stage, the system of aqueous cleaning necessary to remove the WSF, and the testing necessary to verify the WSF has been removed from the electronic assemblies. This data is necessary for the implementation of process controls.

Currently the resistivity of solvent extract test is a requirement in most military specifications. This requirement gives both the government and the contractor assurance that the electronic assemblies are free from water soluble ionic contamination. It is a valid test for the cleanliness using a rosin-based/solvent-cleaned process. There is controversy that the cleanliness test, as stated in the current military specifications, is not a valid test for rosin-based/aqueous cleaned process. The data to substantiate or disprove (with an acceptable alternate method) will be generated by NWC, Code 3681.

The resistivity of solvent extract test is currently being used throughout industry and will still be a requirement until an acceptable alternate method is generated. The test is the most cost-effective and reliable measurement of the cleanliness of the electronic assemblies.

Current Specifications and the Cleanliness Testing Requirement

MIL-STD-275D   dated 26 April 1978

Purpose. This standard establishes design requirements governing rigid, single-sided printed wiring boards, double-sided boards, multilayer boards and design considerations for the mounting of parts and assemblies thereon.

MIL-P-55110C   dates 26 April 1978

Scope. This specification covers the certification and performance requirements for rigid single-sided printed-wiring boards, rigid double-sided printed wiring boards, and rigid multilayer printed wiring boards with plated-through holes.

Para. 3.17, 4.6, 4.7.1.3, 4.8.12 - Cleanliness requirements, description of cleanliness test and sampling details for printed wiring boards.

MIL-STD-454F Requirement 5   dated 15 March 1978

Purpose. This requirement establishes procedures for making soldered electrical and electronic connections. RA flux may be used on assemblies which will subsequently be tested for and conform to cleanliness requirement of MIL-P-28809.

MIL-P-28809   dated 21 March 1975

Scope. This specification covers printed wiring assemblies (circuit cards) consisting of rigid printed wiring boards on which separately manufactured parts have been added.

Para. 3.7, 4.8.3, 6.4, 6.5, 6.6, 6.7 - Resistivity of solvent extracted shall not be less than $2M\Omega$-cm.

MIL-S-45743E dated 15 October 1976

Scope. This specification covers soldering, high reliability electrical and electronic connections with manual soldering apparatus as applicable to guided missile and certain aerospace equipment requiring extraordinary control of soldering environment and techniques. It is not applicable to general soldering requirements.

Para. 3.6.3, 4.2.2, 4.3.2 - Cleanliness test and sampling test.

MIL-P-46843D dated 25 February 1976

Scope. This specification covers the production of printed wiring assemblies consisting of printed wiring boards on which separately manufactured component parts have been added.

Para. 3.6.6, 4.5.1.2 - Description of cleanliness test and sampling details for printed wiring assemblies.

WS 6536D

Scope. This specification defines the approved materials, methods, and inspection standards for producing the quality of electrical soldering workmanship necessary for use on guided missiles, aircraft, shipboard, weapons, ground vehicle equipment and program critical ground support equipment.

WATER SOLUBLE FLUXES
CAN THE MILITARY USE THEM?

STEVE STACH - TEXAS INSTRUMENTS

Water soluble organic acid fluxes have been used in the electronics industry now for about 10 years with limited success. Recent developments in the flux/cleaning technology have greatly improved both short term and long term reliability of hardware processed via aqueous techniques.

This article examines how these recent developments have affected aqueous soldering of printed wiring boards for military applications.

It includes a physical and chemical evaluation of several water soluble organic acid fluxes and associated cleaning processes and will specifically address such problems as corrosion, cleaning, glycol absorption, and insulation resistance break-down and how these problems relate to extended shelf life and latent defects.

With the ever increasing pressure to restrict or eliminate the use of organic solvents in the post-soldering cleaning process, the stage is now set for new innovations. The question to be addressed here is - can water soluble fluxes fit the bill without compromising quality or reliability?

INTRODUCTION

In order to better understand organic acid fluxes, let us first look at fluxes in gerneral. MIL-STD-454 defines a flux as a chemically active compound that is capable of promoting the wetting of metals with solder. The term chemically active refers to the fact that the flux or specific agents in the flux chemically attack the oxide film on a component lead or PWB conductor, thereby removing it from the surface and rendering the exposed metal solderable.

Rosin fluxes

Rosin fluxes were the first to be utilized by the growing electronics industry because they were relatively forgiving if left uncleaned, were non-toxic and could be readily derived from naturally occurring products (tree sap). The active species in a pure rosin flux is abietic acid. Abietic acid is such a weak acid that at room temperature it essentially is not an acid at all, and not until it reaches a temperature of above 200°F does it gain enough activity to begin to remove any oxides. Because of its inherently weak nature, moderate to heavy oxidation may prove to be too much for rosin alone. Because of this, it became necessary to add small amounts of stronger activators to increase the oxide removal capaibility of the rosin flux.

With the advent of post soldering cleaning, it became more practical to use this stronger rosin flux. Today rosin fluxes are divided into 3 classes based mainly on the final resistivity of a 1-500 flux to water solution. These 3 classes of rosin fluxes are divided as shown in Table 1.

Table I. Major Divisions of Rosin Fluxes

Class	Designator*	Activators	Water Extract	Resistivity
1	R	Rosin		
2	RMA	Rosin - Bromide Salt	>100,000	Ω cm
3	RA	Rosin - Chloride Salt	> 50,000	Ω cm

*R — Rosin, RMA — mildly activated rosin, RA — fully activated rosin

Table II. Chemical Comparison of Fluxes

Component in Flux	Type of Flux	Rosin	Rosin Mildly Activated	Rosin Fully Activated	Organic Acid Fluxes
Abietic Acid		12-55%	12-55%	12-55%	—
Water Soluble Organic Acid		—	—	—	5-20%
Halide Activator		—	0.1-1.0%	0.5-1.5%	0-8%

Rosin as an activator is not water soluble and is primarily cleaned with both polar and non-polar organic solvents. Rosin, however, can be cleaned in a water cleaner using a saponifying agent. A saponifying agent is a special chemical or mixture of chemicals capable of reacting with the rosin and turning the rosin into a soap which is water soluble. These saponifying agents have only recently been introduced, and until now organic cleaning solvents have primarily been used. The major drawback to using organic solvents as a cleaning material is that their non-polar nature tends to leave the more polar halide activators behind as a whitish film on the surface of the PWB. This residue could eventually lead to a resistance breakdown or possibly give rise to an area of corrosion.

The early industries used no post soldering cleaning. They were successful because of rosin's ability to crystallize on freshly soldered printed wiring boards when left to dry. In doing so, it locks the ionic activators in a rigid crystalline lattice. Even though the activators were still present, they presented little danger because of their isolated position. In addition, the crystallized rosin protected the conductors from further oxidation. This symbiotic relationship worked fairly well, provided the electronic assembly encountered no extreme environmental conditions, i.e. temperature, humidity, salt spray, etc.

Modern electronic equipment must be able to survive the most extreme of environmental conditions. It is because of this that flux residues must be removed or rendered totally inactive.

O.A. Fluxes

Organic acid fluxes are similar to rosin fluxes in that they utilize an organic acid dissolved in a carrier and can be found in the mildly activated and fully activated rosin fluxes. Organic acid fluxes (sometimes refered to as water

soluble fluxes), differ in composition from rosin fluxes in 2 major areas.

• A water soluble organic acid is substituted, for the non-water soluble organic acid found in rosin. (Abietic acid)

• If found, the halide activators are usually found in larger concentrations.

These differences are summarized in Table II.

Activators

An activator can be defined as a chemically active species, which when found in a flux, increases the oxide removing capabilities of the flux in excess of that of the base organic acid by itself. Activators are usually found as Hydro halide salts of amines during the solder process. Not all rosin and water soluble organic acid fluxes contain activators, but meniscograph data indicates that the addition of these activators greatly improve the wetting characteristics of the base metal being fluxed.

Figure 1 compares the meniscograph data of a rosin mildly activated flux and a rosin fully activated flux as well as a water soluble organic acid flux with and without activators on a heavily oxidized copper coupon.

As you can see in Figure 1, activators do significantly add to the wetting power of either a rosin or water soluble organic acid flux. The major problem in using activators in either rosin or in water soluble organic acid fluxes is that if the activators or activator residues are left on the PWB they may lead to insulation resistance breakdown or possible corrosion or both. Since either rosin or water solubl fluxes can contain halide activators, both are confronted with this problem, but each in its own unique way. For example, as previously stated, rosin fluxes may seal activators in the polymerizing rosin lattice, thereby rendering the compounds inactive. This will remain true as long as the PWB sees no extreme environmental conditions such as high humidity and temperature. Water soluble organic acid fluxes, on the other hand, would leave any activators in the exposed active form. This form does prove to be more readily cleanable, but on the other hand, if improperly cleaned, these residues would certainly be much less forgiving.

Cleaning Post-soldering residues

In cleaning post-soldering residues, the electronics industry has in the past relied heavily upon organic solvents to do the job. With ever increasing environmenta and economic pressures to eliminate the use of organic solvents, the electronic indust has begun to turn to aqueous techniques to remove residues associated with the solderi process. Several recent developments have brought about a wide spread usage of aqueou cleaning.

• Development and use of components that can tolerate aqueous cleaning
• Development and use of effective water cleaning systems
• Formulation of new flux types which improve cleanability (water soluble fluxes)
• Formulation of saponifying agents which aid in removal of rosin fluxes
• Development of reliable equipment and methods to test the final cleanliness of PWB's
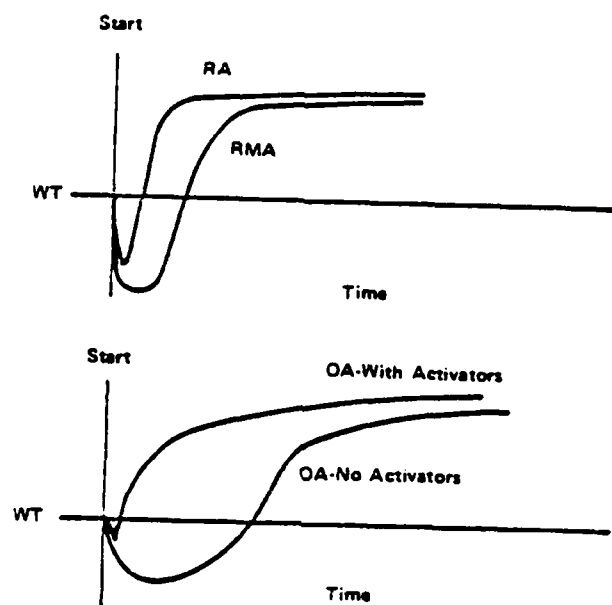
Figure 1. Meniscograph Data for Various Activation Levels

Both rosin and water soluble fluxes can be cleaned with aqueous methods, but because of rosin's uncanny ability to form a semi-impervious crystal, it still may be necessary to include organic solvents in cleaning post-soldering residues from a rosin flux.

Water soluble fluxes are designed to be cleaned with water.

Vehicles for water soluble fluxes

Vehicles for carrying the active ingredients of water soluble fluxes should be capable of maintaining the oxide removing materials in the active form throughgout the soldering process. In the rosin flux, the abietic acid itself provides a media to keep activators in the active or ionic form. With water soluble fluxes, the carrier is usually a moderate molecular weight poly-alcohol. The O-H groups are necessary to provide needed solvent polarity to keep active ingredients in the ionic or working form. One potential problem to be addressed in the following test section is-can moderate to high molecular weight poly-alcohols, used as carrier vehicles, be surface absorbed to the point that they cannot be removed and thus possibly give rise to insulation resistance breakdown under proper environmental conditions?

Testing

In order to answer the question posed in the title of this article, two phases of tests were performed upon water soluble fluxes. The goal of Phase I was to select the best water soluble organic acid flux/cleaning system, and the approach used was to compare the results of the following tests:

1. Specific gravity
2. Percent solids
3. Acid number
4. Weight percent chlorides
5. Meniscograph
6. Insulation Resistance Breakdown
7. Cleanability

The best cleaning system was selected by comparing the cleanliness of fluxed/soldered printed wiring assemblies as measured per MIL-P-28809, using the flux which exhibited the most desirable characteristics as compared in tests 1 through 7, using hot tap and deionized water with and without rinse aids.

The goal of Phase II was to prove that the long term reliability of properly designed printed wiring assemblies would not in any way be affected or degraded by the use of properly selected water soluble organic acid/aqueous cleaning system. The approach used was to prove that cleanliness levels can meet acceptable limits per current MIL-P-28809 and to show that assemblies process in this matter can perform as well as assemblies soldered with conventional activated rosin fluxes. (Phase II will be reported in a future issue.)

Tables III and IV are keys to flux and rinse aid identification.

Table III. Flux Identification Key

Flux Identification Number	Type of Flux
1	OA Flux 23% solids
2	OA Flux 30% solids
3	OA Flux 12% solids
4	OA Flux 16% solids
5	OA Flux 18% solids (low halide)
6	RMA Flux
7	RA Flux
8	No Flux control

Table IV. Rinse Aid Identification Key

| Rinse Aid Identification Number	Type of Rinse Aid
1	None
2	Alkaline
3	Alkaline
4	Alkaline
5	Alkaline

PHASE I

The goal of this phase of testing was to evaluate and select the best water soluble flux/cleaning system based on physical properties, chemical properties, chemical compatibility, wetting rates, insulation resistance breakdown and cleanability.

Test 1: Specific Gravity

The purpose of this test was to gain insight as to relative types of carrier solvents and to establish baseline data for further test. Specific gravity was determined by use of calibrated 60/60 hydrometers at $60^\circ F$. The specific gravity of each flux should be a good indication of the relative positioning of a particular flux, based on average molecular weight, because the lower molecular weight compounds are generally less dense that the higher molecular weight compounds. For test results, see Table V; for rankings, see Figure 2.

Table V. Specific Gravity of OA Fluxes

| | Specific Gravity | |
Flux	(Measured)	(Reported by Vendor)
1	0.883	0.879 @ $77^\circ F$
2	0.914	0.909 @ $77^\circ F$
3	0.846	0.840
4	0.948	No value given
5	0.938	0.956 @ $75^\circ F$
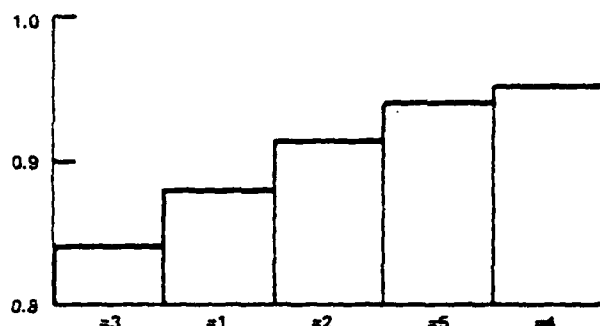
Figure 2. Specific Gravity Test Results

Test 2: Percent Solids

The purpose of this test was to establish the relative amounts of nonvolatile compounds in various water soluble fluxes. This was determined on 3 samples per flux by weighing approximately a 6 gram sample of the flux to the nearest 0.001 gram and evaporating the volatiles at $105^\circ C$ for 2 hours in a forced circulation oven.

Test results from Test 2 indicate significant differences in formulation of the OA fluxes tested. Results from Tests 1 and 2 would indicate that Flux #3 is the lowest in high molecular weight compounds. These tests would indicate that the relative amounts of residues left after soldering would follow this order. See Table VI and Figure 3.

Table VI. Percent Solids of OA Fluxes

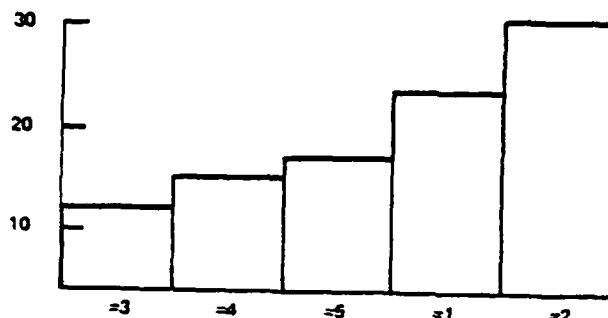| Flux	Percent Solids (Avg. of 3)
1	22.98%
2	30.27%
3	11.62%
4	16.19%
5	17.80%

Figure 3. Percent Solids of Various Water Soluble
Organic Acid Fluxes

Test 3: Acid Number

The purpose of this test was to establish the relative amounts of total acidity for each OA flux. The acid number was determined by the following method utilizing 3 test samples per flux. The results in Table VII represent the average value.

1.   Weight in the analytical balance approximately 10 grams samples using a 250 ml beaker.

2.   Dilute to 100 ml with distilled water.

3.   Add 3-4 drops of phenolphthalein indicator solution.

4.   Titrate with a standardized 1.0 normal sodium hydroxide solution to the first pink color change.

5.   Calculate the acid number using the equation:

$$\text{Acid number} = \frac{\text{ml-NAOH} \times \text{Normality} \times 56.11}{\text{grams sample}}$$

Preparation of the indicator solution was achieved by dissolving 1 gram of phenolphtalein in 100 ml of isopropyl alcohol (99).

-7-

Table VII. Relative Total Acidity

Flux	ml NAOH	Acid Number
1	3.76	21.13
2	5.00	28.05
3	2.06	11.56
4	10.94	61.35
5	20.93	117.46

The acid number differed significantly from flux to flux varying from 11.56 for flux number 3 to 117.45 for flux number 5. Flux number 5 was nearly double the acid number of the nearest flux tested. This can be attributed to the fact that number 5 is the only flux in the test group which is halide free and depends solely on the water soluble organic to provide fluxing action. Of the remaining fluxes which use halide activators, flux number 4 was again double the acid number for the nearest flux. No apparent reason can be given for this variation, but it must arise from differences in formulations.

It must be pointed out that this test gives total acidity available and does not necessarily infer activity levels seen under soldering conditions. This correlation between active and available acid would probably follow a similar trend.

Test 4: Weight Percent Chlorides (Cl)

The purpose of this test was to determine the weight percent chlorides in each water soluble organic acid flux, to establish relative amounts of chloride activators used in each flux. The weight percent chlorides for 3 samples per flux was determined by the following method. The averaged results are given in Table VII.

1. Pipette 10.0 ml of a representative sample @ 25^OC (77^OF) into a 500 ml volumetric flask.

2. Add distilled water to the mark at the calibration temperature of the flask and shake well to mix thoroughly.

3. Pipette a 100 ml aliquot of the above solution into a clean dry 250 ml beaker.

4. While agitating, measure the pH and adjust it, if necessary to 7.0 $\pm$ 0.10 with (Cl free) 0.1 N KOH solution.

5. Add 3.0 to 4.0 ml of potassium chromate solution and, while stirring well, titrate with a standardized 0.1 N Ag NO_3 solution to the first brown endpoint that persists 30 seconds.

NOTE: In the case of materials containing less that 1.5% Chlorides, a micro burette with subdivisions of 0.02 ml should be used to deliver the 0.1 N Ag No$_3$ solution with greater accuracy.

The calculation used was:

$$\frac{\text{ml Ag No}_3 \text{ used x normality x 1.7729}}{\text{Sp Grav. @ 77}^{\text{O}} \text{ of flux sample}} = \frac{\text{Chlorides}}{\text{as \% Cl}^-}$$

All glassware used in the above procedure must be chloride-free.

Table VIII. Results of Percent Chloride Test

Flux	Weight Percent Chlorides (expressed as Cl⁻)	Weight Percent Chlorides (expressed as dimethylamine hydrochloride)
1	1.40%	3.21%
2	1.82%	4.18%
3	1.40%	3.21%
4	3.18%	7.30%
5	<0.65%	<1.5%

Again, flux number 5 finished with lowest chlorides because it is a chloride free flux using only water soluble organic acide to provide the fluxing action. Of the water soluble organic acid fluxes containing chloride activators, flux number 4 contained the largest percentages coming in at 3.18. The weight percent chlorides is also expressed as dimethylamine hydrochloride because this is the way in which chloride is usually found in fluxes.

Test 5: Meniscograph

The purpose of this test was to determine relative wetting rate of water soluble organic acid fluxes being evaluated. This test was performed using a Hollis meniscograph, using the following procedure.

1. Cut rectangular test coupons 4.0 ± 0.1 cm X 1.0 ± .5 cm from a heavily oxidized piece of 15 mil 2 ounce copper PWB laminate.

2. Clean coupons by wiping with isopropyl alcohol. Touch coupon along edge from this point on.

3. Flux one end of coupon by immersion of 1/3 of the coupon in the test flux.

4. Insert opposite end into holder as far as possible. Tightening holding clamp.

5. Possition holder and sample on meniscograph.

6.   Activate meniscograph and strip chart recorder.

7.   Remove and invert coupon.

8.   Flux unsoldered end of coupon using a fully activated rosin flux.

9.   Repeat 4 through 6.

10.   Run minimum of two (2) tests per flux.

Figures 5 through 14 are reductions of the original meniscographs of the various water soluble organic acids overlayed with the fully activated rosin flux standard. The folowing measurements were taken from the meniscograph curves.
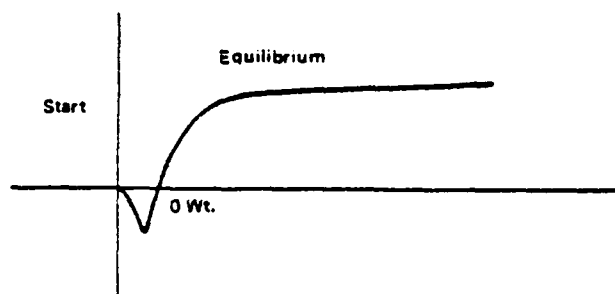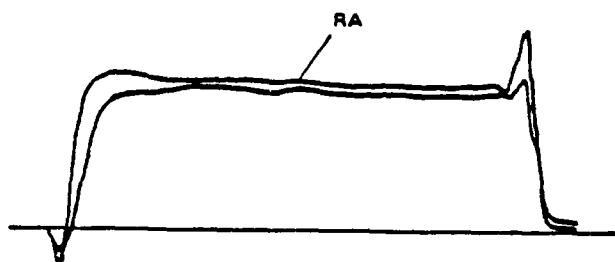

Figure 4. Generalized Meniscograph
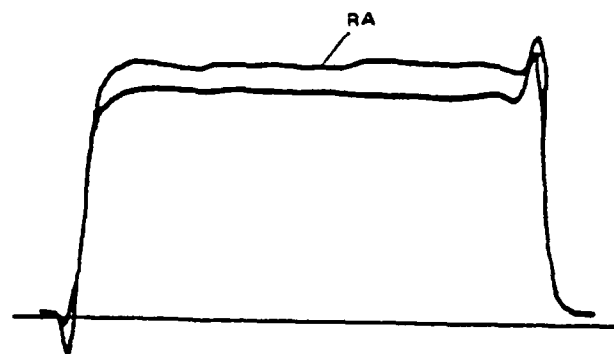

Figure 5. Flux 1, Test 1
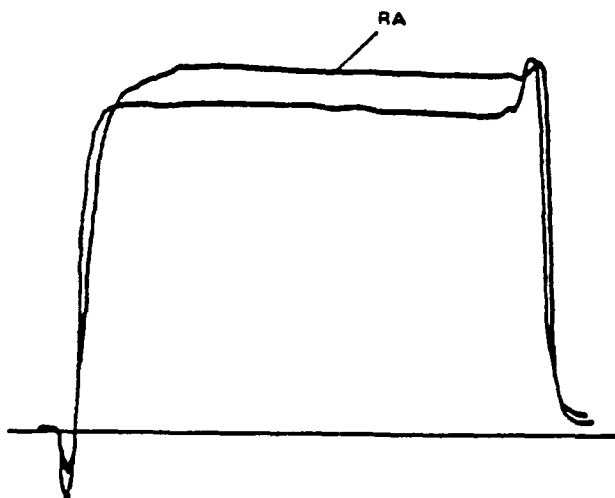

Figure 7. Flux 2, Test 1
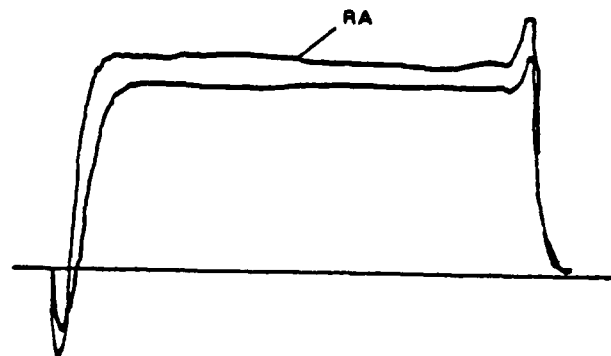

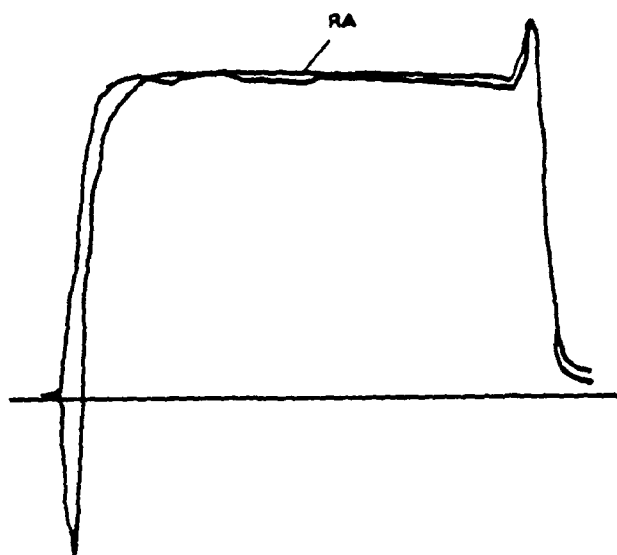Figure 6. Flux 1, Test 2

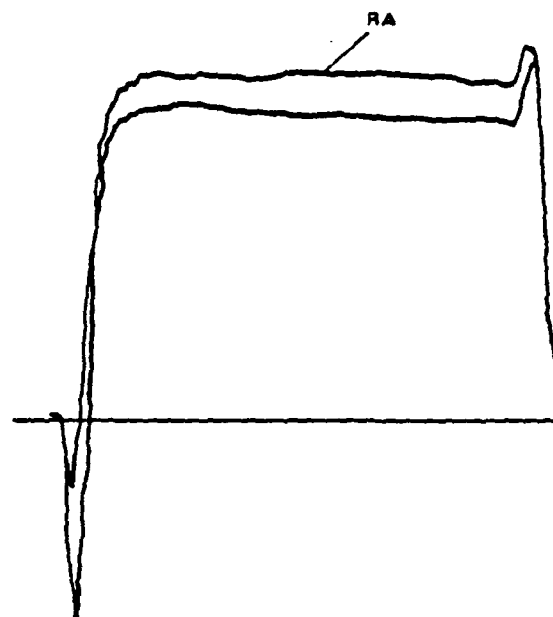Figure 8. Flux 2, Test 2

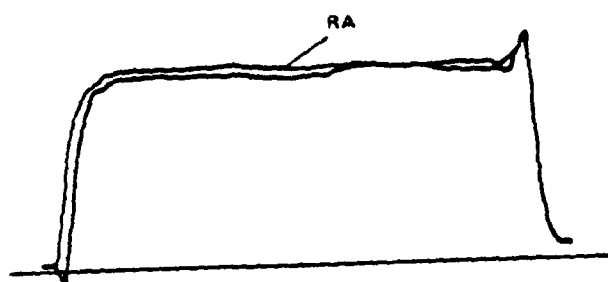Figure 9. Flux 3, Test 1

Figure 12. Flux 4, Test 2
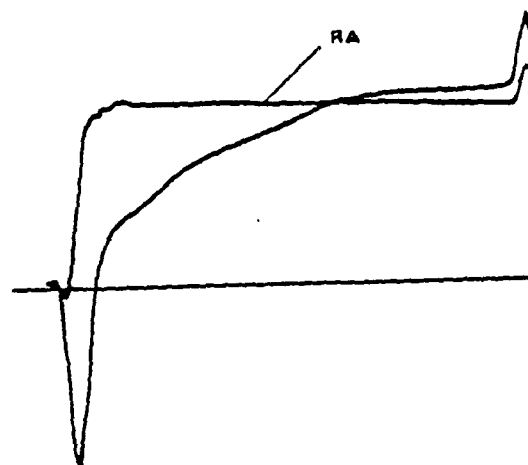

Figure 10. Flux 3, Test 2
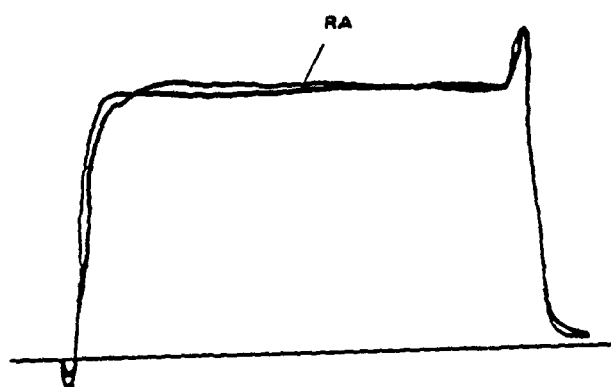

Figure 13. Flux 5, Test 1
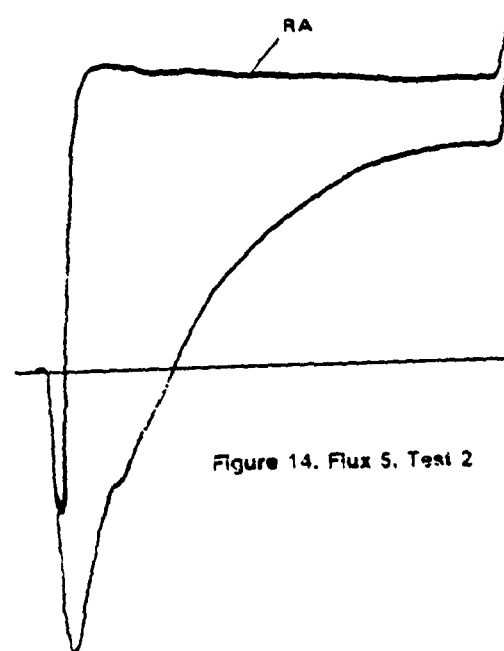

Figure 11. Flux 4, Test 1

Figure 14. Flux 5, Test 2

Based on meniscograph data, the fluxes tested would rank the following order as to activity:

Most   #3 - #2 and #4 - #1 - #5 and #6   Least

Active   Active

Flux number 5 is the halide free organic acid flux, and as you can see, it performed very poorly with a wetting action approximately equal to that of the RMA flux.

Table IX. Summary of Meniscograph Data

Flux	Oxidation State	OA 0 wt.	RA 0 wt.	OA Equilibrium	RA Equilibrium
1	heavy	0.60 cm	0.45 cm	2.10 cm	1.40 cm
1	heavy	0.55 cm	0.55 cm	2.90 cm	1.75 cm
2	heavy	1.0 cm	0.60 cm	2.55 cm	1.55 cm
2	heavy	0.35 cm	0.55 cm	1.60 cm	2.25 cm
3	heavy	0.50 cm	0.80 cm	2.40 cm	2.10 cm
3	heavy	0.10 cm	0.80 cm	2.20 cm	3.00 cm
4	heavy	0.50 cm	0.35 cm	2.90 cm	1.60 cm
4	heavy	0.60 cm	0.95 cm	2.30 cm	3.20 cm
5	heavy	4.30 cm	0.75 cm	14.70 cm	1.90 cm
5	heavy	1.30 cm	0.30 cm	12.00 cm	1.60 cm
5	heavy	4.00 cm	1.00 cm	14.70 cm	2.20 cm

Test 6: Insulation Resistance Breakdown

The purpose of this test was to determine if printed wiring assemblies, flow soldered using various water soluble organic acid fluxes and properly cleaned to at least 15 megohm cleanliness, would show any signs of insulation resistance breakdown when compared to a standard RA flux. The testing was performed per the following procedure:

1. Obtain enough coupon E test cards (10 layer multilayer) to run 5 samples per flux to be tested.

2. Preclean test coupons following this sequence: (a) degrease using vapor and spray with 1,1,1 trichloroethane, and (b) water wash in Dee Model 301 water wash.

NOTE: Use finger cots to handle all samples from this point on.

3. Wire test coupon with buswire in an alternating shoe lace pattern. See figure 15. Leave 1/4 inch minimum clearance between wire and etch.

4. Flux test coupon by 100% clip immersion into unthinned flux to be tested.

5. Flow solder within 5 minutes of fluxing operation. Preheaters should provide a presoldering top side coupon temperature of 190-200°F at a rate of 3 feet per minute.

6. Clean coupons in a water wash having the following characteristics:

wash	rinse	rinse	dry	dry
close tap water at 150°C		cascade de-ionized water @ 150°F		forced air @ 260°F

7. Measure and record cleanliness per MIL-P-28809. If test coupons do not meet 14 megohm-centimeters or greater, clean again and repeat step 7 until cleanliness meets 14 megohm-centimeters or greater. Record number of cleaning cycles.

8. Conformal coat test coupons with an acrylic conformal coating to a thickness of no greater than 5 mils.

9. Measure insulation resistance of 500 volts DC for a minimum of 1 minute, meeting the requirement of paragraph 4.7.11 of MIL-P-55640A.

10. Perform moisture resistance test in accordance with MIL-STD-202, meeting all requirements.
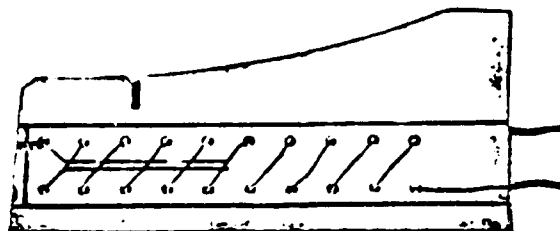
11. Record final insulation resistance.

Figure 15. Top View of Wired Coupon

Table X. Averaged Results of Insulation Resistance Test

Flux	Initial Resistivity (Ω)	Final Resistivity (Ω)	Number Cleaning Cycles	Final Cleanliness Level Mohonm-cm
1	4.60×10^{13}	2.5×10^9	2	> 20
2	3.4×10^{13}	2.4×10^9	2	> 20
3	3.6×10^{13}	1.0×10^9	2	16.5
4	3.8×10^{13}	2.7×10^9	2	14.9
5	3.8×10^{13}	3.9×10^9	3	15.7
6	5.6×10^{13}	2.8×10^9	2	14.4
8	3.5×10^{13}	6.5×10^9	2	17.7
9	3.7×10^{13}	14.0×10^9	1	17.6

Samples 1-5 were all water soluble organic acid fluxes. Sample 6 was an experimental modified rosin water soluble organic acid flux. Sample 8 was a standard RA flux and Sample 9 saw no flux and no soldering operation and was intended as a control.

In all cases, the final resistivity of the OA flux samples was lower than that of the RA flux and no flux controls, but nevertheless, all the OA samples did meet the minimum requirement of 5.0×10^8 Ω minimum on the insulation resistance.

These results indicate that if water soluble organic acid fluxes are used and cleaned to a cleanliness level of fourteen (14) megohm-cm or greater, that there should be little chance of long term insulation resistance breakdown.

It has been suggested by several authorities in the field that the use of high molecular weight poly-alcohols/poly-glycols in the water soluble organic acid fluxes as carrier vehicles can be surface absorbed by the epoxy/glass laminate. It is contended that this absorption phenomena is permanent and can result in the eventual breakdown of the insulation resistance. In checking with the flux vendors, no direct correlation could be established between the use or non-use of these high molecular weight poly-alcohols and the variances found between the OA fluxes tested. This would seem to indicate that other phenomena could play significant roles in the apparent lowering of the insulation resistance, such as the possible formation of the relatively insoluble tin and lead oxyhalides due to a relative increase in the amounts of the halide activators used in most OA fluxes. If this was the case, this formation could be reduced by the use of chelating agents which would tie up the tin and lead ion formed during the soldering process prior to formation of the insoluble products.
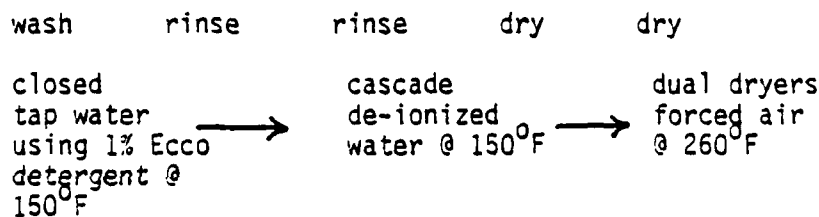
Test 7: Cleanability

The purpose of this test was to establish the relative cleanability of the water soluble organic acid fluxes tested and to gain insight into the effects of varying amounts of process heats upon it. The test procedure was as follows:

-14-

1.   Obtain raw un-stuffed PWB's scrapped for cosmetic defects (six per flux).

2.   Pre-clean by manual hand, scrub in fresh 1,1,1 trichlorethane.

NOTE: Do no handle with bare fingers from this point on.

3.   Stuff axial lead components into cleaned PWB's. (Two per square inch of PWB).

4.   Flux PWB by 100% dip immersion into flux to be tested.

5.   Flow solder within five (5) minutes of fluxing according to the following
        conditions.
        Preheat - constant level. Should provide minimum $180^{\circ}F$ top side heat at six (6)
        feet per minute.
        Solder temperature - $480 \pm 5^{\circ}F$.
        Conveyor speed - run three (3) of the six (6) samples at 3 ft/min and the
        remainder at 6 ft/min.

6.   Clean the PWB's within 5 minutes of the flow solder operation in a water wash
        of the following configuration:

        wash   rinse   rinse   dry   dry

        closed   cascade   dual dryers
        tap water   ─────▶   de-ionized   ─────▶   forced air
        using 1% Ecco   water @ $150^{\circ}F$ @ $260^{\circ}F$
        detergent @
        $150^{\circ}F$

        NOTE: Rosin flux samples were cleaned in perchloroethlene wave cleaner and
        then degrease in a 1,1,1 trichloroethane degreaser prior to water wash.

7.   Measure and record cleanliness per MIL-P-28809.

        Fluxes 1,2 and 7 are easier to clean when soldered at a higher speed. This is
what one would expect since at lower conveyor speeds, the PWB would be exposed to
the wave heat longer thereby increasing the chance that flux components designed to be
water soluble could break down via thermal decomposition into a less soluble, more
difficult to remove compound.

        Samples 3,4,5 and 6 exhibit the opposite properties, proving to be more cleanable
at the lower conveyor speeds. If follows that the amount of process heat that a
PWB will see is very important in choosing a water soluble organic acid flux.

Table XI. Averaged Results of Cleanability Test

Flux	Conveyor Speed	Cleanliness (Megohm-cm)	Average Cleanliness at both speeds (Megohm-cm)
1	3 ft/min	3.07	3.91
	6 ft/min	4.45	
2	3 ft/min	2.83	3.16
	6 ft/min	3.50	
3	3 ft/min	3.33	3.23
	6 ft/min	3.13	
4	3 ft/min	2.83	2.48
	6 ft/min	2.13	
5	3 ft/min	4.70	4.41
	6 ft/min	4.13	
6	3 ft/min	2.53	2.33
	6 ft/min	2.13	
7*	3 ft/min	4.70	4.88
	6 ft/min	4.08	
8	N/A	8.5	8.5
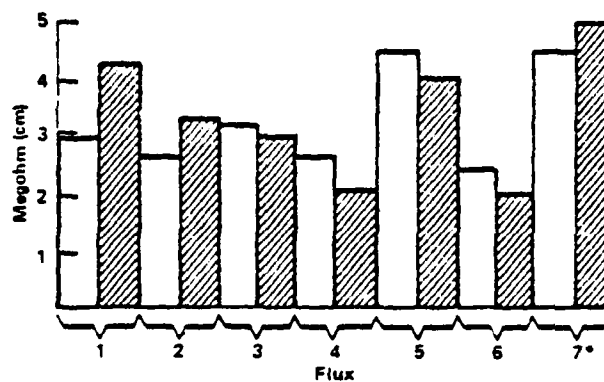
*See Note in Part 6 of Procedure

Figure 16. Flux Cleanliness Comparison

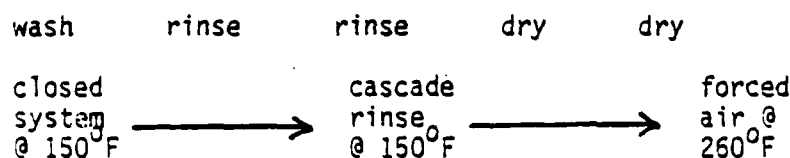## Table XII. Final Cleanliness (MegOhm-CM)

Rinse aid used

	#1	#2	#3	#4	#5
De-ionized water	4.75	5.15	5.15	6.8	4.25
Tap water	5.25	5.05	5.25	7.5	3.80

Test 8: Selection of Cleaning Process

The purpose of this test was to establish the most efficient method of neutralizing PWB's wave soldered using a water soluble organic acid flux. The test procedure was as follows:

1. Obtain raw un-stuffed PWB's scrapped for cosmetic defects (6 per test).

2. Pre-clean by manual hand, scrub in fresh 1,1,1 trichloroethane.

3. Stuff axial lead components into cleaned PWB's. (Two per square inch of PWB).

4. Flux PWB by 100% immersion.

5. Flow solder within 5 minutes of fluxing according to the following conditions. Preheat - constant level. Should provide minimum $180^{\circ}F$ top side heat at 6 feet per minute.

6. Clean the PWB's within 5 minutes in a water cleaner of the following configuration.

wash	rinse	rinse	dry	dry
closed system @ $150^{\circ}F$ $\longrightarrow$		cascade rinse @ $150^{\circ}F$ $\longrightarrow$		forced air @ $260^{\circ}F$

Clean 3 test PWB's using tap water wash and 3 other PWB's in the same system using de-ionized water in the wash section with the following rise aids in the wash section only. All rinse aids concentration is 102/gal.: (1) None; (2) Rinse aid #1, (3) Rinse aid #2, (4) Rinse aid #3; (5) Rinse aid #4.

7. Check cleanliness per MIL-P-23809.

In an evaluation very similar to that of test 8, Fred Boriack and Floyd Cline designed a series of tests to determine the best flux/cleaning system using water soluble fluxes. This evaluation was performed for TIVAT calculator program by said personnel of Texas Instruments and the results were taken from a memorandum issued 21 November 1972. In this series of tests, it was demonstrated that if the PWB was properly designed and cleaned, it could survive an accelerated age cycle.

In test 8, the water cleaner used (see section 6 of test procedure) was not designed for a one pass removal of water soluble flux residues to acceptable MIL-P-28809 acceptable levels.

With this in mind, it is very encouraging to note that the level of cleanliness obtained using rinse aid #4 did meet the minimum cleanliness requirement.

The tap water used in this test was relatively soft water, having a total hardness of less than 10 ppm. No real differences could be detected between using tap water in the wash section and using de-ionized water in the wash section.

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Conclusions of Phase I

Phase I was designed to select the best flux/cleaning system. The selection of the flux is one of great importance and should be based on specific project requirements such as PWB design, amount of thermal exposure in soldering process, expected environmental endurances, etc. Tests 1 through 7 were designed to give some insight into selecting a flux according to the needs of a project. These tests have shown that water soluble organic acid fluxes can vary greatly in both chemical and physical properties.

For example, the cleanibility test illustrated this point very well showing 2 of the 5 OA fluxes tested clean better when exposed to minimal process heat. The other 3, however, proved to be more cleanable when processed at a slower conveyor speed. OA fluxes should be picked to be compatible with process conditions.

The results of the insulation resistance breakdown test were quite significant and showed that neither surface or bulk resistivity lowered below acceptable levels. There was, however, a lowering in the realtive levels of insulation resistance for the OA fluxes versus that of the RA fluxes. In major correlation there seems to be one of activitiy of the flux since it can be observed that the most active flux corresponds to the largest loss of insulation resistance.

Activity

#3	-	#2	and	#4	-	#1	-	#5
#3	-	#2	-	#1	-	#4	-	#5

Final Insulation Resistance

The phenomema could be attributed to a surface mobility of surface residues which could lead to surface leakage. This data indicates that the level of activation of the flux is in some way related to the final insulation resistance after humidity. The correlation of activators expressed as percent chlorides versus final insulation resistance does not correlate as well as flux activity as measured per meniscograph.

Activators as Cl

#4	-	#3	and	#2	-	#1	-	#5
#4	-	#2	-	#1	-	#4	-	#5

This relationship does, however, suggest the use of halide activators and does give rise to a general lowering of insulation resistance since flux number 5 is the only halide free flux.

Final Insulation Resistance

Highest M. wt. #2 - #1 - #4 - #5 - #3 Lowest M.wt.

Lowest I.R. #3 - #2 - #1 - #4 - #5 Highest I.R.

Upon checking the relationship between use of higher molecular weight compounds in the OA fluxes, it was found that with the exception of flux #3, there did seem to be a correlation between high molecular weight carrier vehicles and a general lowering of insulation resistance. Again, all fluxes tested exhibited on Final I.R. at least double the minimum value.

Fluxes 1,2 and 7 are easier to clean when soldered at a higher speed. This is what one would expect, since at lower conveyor speeds the PWB would be exposed to that wave heat longer, thereby increasing the chance that flux components designed to be water soluble could break down via thermal decomposition into a less soluble, more difficult to remove compound. Samples 3,4,5 and 6 exhibit the opposite properties proving to be more cleanable at the lower conveyor speeds. It follows that the amount of process heat that a PWB will see is very important in choosing a water soluble organic acid flux.

IMPROVEMENTS OF FUTURE FORMULATION OF NEW FLUXES

Several possiblities exist that could give rise to improved fluxes.

Rosin Fluxes

There are numerous optically active isomers of abietic acid which vary significantly in acidity or activity. Presently, the only source of the abietic acid in rosin fluxes is in naturally occurring rosin. This rosin contains many isomers of the acid and can affect the performance of the flux if the source of type of rosin is changed. It may be possible to formulate rosin fluxes using synthetic isomers of abietic acid picked for the most desirable characteristics. This would surely increase the cost of the flux, but may provide a higher level of activity without sacrificing long term reliability.

OA Fluxes

It may be possible to modify the abietic acid molecule by adding hydroxy or carbonyl groups, or by adding ether or ether linkages to improve the water solubility of the rosin type fluxes. In addition, the incorporation of certain electronegative electron withdrawing groups in strictly active position could increase the acid disassociation constants, thereby increasing the activity of the parent molecule. The combined result would be a molecule with more activity and more water solubility.

Cleaning Process

The water cleaner used in test 8 was inadequate to furnish ample safety margin in the final cleanliness. It appears that it would be necessary to have a water cleaner meeting at least the following criteria.

1. A pre-wash section for gross residue removal. This could be a heated recirculating tank which had a standing drain and the make-up water would be added based on an internal resitivity monitor or the tank could be ambient tap water with a high volume low pressure spray which went directly to drain.

2. The pre-rinse should be followed by a recirculating wash section at a minimum of 150°F. This section would contain any rinse aids and would be periodically checked for rinse aid concentration.

3. The wash section should be followed by a minimum of three (3) cascading de-ionized water rinse tanks at a minimum temperature of 150°F.

4. The rinse sections should be followed by a drying section capable of completely drying the PWB's and should be designed to blow off rather than evaporate the water.

5. Each section should be separated by air knives to remove as much residue from the previous section as possible.

PHASE II

While Phase I was primarily concerned with the selection of a commerically available water-soluble flux and the laboratory testing of the cleaning process, Phase II was devoted to the implementation of the Phase I process on a production scale.

BUILDING THE AQUEOUS SOLDERING SYSTEM

The Aqueous soldering system was designed based on the results of Phase I testing and existing manufacturing flow. The present activated rosin system and the proposed aeueous system both consist of six basic steps as shown in Figure 1.

These six steps are outlined below:

Flow Solder: For all practical purposes, the two flow solder machines in Figure 1 are identical in design. Special consideration, however, was given to the corrosion-resistant material (polypropylene) used in the fluxer design of the aqueous system. All flow solder parameters such as conveyor speed, solder temperature, preheat settings, etc. were the same in both processes.

Post Soldering Cleaning: In the present activated rosin system the removal of post soldering residues is accomplished by the use of an in-line organic wave cleaner followed by a conveyorized vapor degreaser. This step in the aqueous system was accomplished by the use of a water cleaner designed for removal of the selected flux.

Touch-up: In both cases, a mildly activated rosin-cored touch-up wire was used to perform all touch-up operations. Since the start of these tests, several water-soluble cored touch-up wires have become commercially available and should be considered in any aqueous system. They were not included in these tests, however, because of the unavailability and relative newness.

Post-touch-up cleaning: In the aqueous process, the cleaning operation was accomplished using an existing aqueous rosin saponification system. This replaced a vapor degreasing in the parallel activated-rosin system.

Unit test: All visible flux residues must be removed prior to unit test or they will gun up and/or corrode tests points.

Final cleaning: This step was accomplished in the aqueous system with one pass through an existing water cleaner designed and maintained for rosin saponification. (Detergents used work effectively on both residues). In the rosin system, the circuit board is cleaned with a vapor degreaser and a water wash.

It is at this point, prior to conformal coating, that MIL-SPEC cleanliness must be met.

CLEANING CONSIDERATIONS

Using the cleaning configuration developed in Phase I, we approximated the system with our existing aqueous cleaning system as show in Figure 2.

The recommended system differs from the existing system in that it is preceeded by a prewash designed to flood the circuit card with a high-volume low-pressure spray of unheated water. This technique removes the majority of the water-soluble flux residues prior to entering the wash section and results in a two-fold advantage:

> The rate at which the closed loop of the wash tank is contaminated with flux residues is minimized. The majority of the flux residue is removed in the open-loop prewash allowing a minimum detergent concentration to be used in the wash section. This facilitates the removal of potentially harsh detergent residues in the rinse sections.

In addition to the prewash, testing indicates that the recommended system should have an additional deionized rinse and associated air knife. As a result, the system to clean water-soluble fluxes is constructed as shown in Figure 3.

Particular attention must be given to the air knives as they are often overlooked and are a key and integral part of an efficient aqueous cleaning system.

The air knives are present to avoid an unnecessary contamination of a particular section by the preceeding section. The air knives are critical to the dryer section as they strip the surface layer of water from the printed wiring boards. In some dry configuration, a second air knife follows the first bank of radiant heaters and is used as a flash dryer. Since this increases the efficiency of the drying section, it is the preferred method. The rinse sections are triple cascades with the last tank being the purest. A resistivity monitor to indicate water purity allows a water purity level of 0.1 megaohm-cm to be maintained in the final rinse tank. The dryers employ both forced convection and radiant heaters. These are used in an alternating series to maximize dryer efficiency by first using a heated air knife to remove bulk waster. This is followed by a radiant heat bank to heat the assembly and a final heated air knife to flush the remaining moisture.

In our approximation of the recommended aqueous system, we used one-pass through the existing water cleaner (with the wash section and the dryers off) to approximate the prewash. The wash tank was then charged with the recommended detergent and both the wash tank and the rinse tanks were heated to 150°F. The assemblies were then run through a second pass to complete the cleaning process. The resulting approximation of the recommended system is shown in Figure 4.

In testing this system with the flux selected in Phase I, it was possible to meet MIL-P-28809 cleanliness requirements based on sample size of five test printed wiring boards.

PHASE II TESTING

The goal of this phase was to gather preliminary data as to the effects of the selected aqueous soldering/cleaning processes on printed wiring assemblies (PWBs). This was evaluated both at the board and the system level (final electronic assembly).

SYSTEM LEVEL TESTING

Three tests were performed at the systems level. In test 1, hereafter referred to as Group I, four systems were subjected to temperature shock per MIL-STD-810B, Method 503, Procedure 1, followed by temperature altitude per MIL-STD-810B, Method 504, Procedure 1. Results showed no degradation in any of the four systems assembled using the selected aqueous method.

Group II consisted of two systems exposed to a humidity cycle per MIL-STD-810B, Method 507, Procedure 1. Test results indicate no degradation to the system which was attributable to the flux.

Group III consisted of four systems built from PWBs assembled using the previously selected water soluble flux procedure. In Group III, the systems were subjected to low temperature per MIL-STD-810B, Method 502, Procedure 1, followed by high temperature per MIL-STD-810B, Method 501, Procedure 1, followed by salt fog per MIL-STD-810B, Method 509, Procedure 1, Again, no degradation in these systems was attributed to the flux or cleaning procedures used.

BOARD LEVEL TESTING

Two tests were performed at the board level. In Group IV, 20 PWBs were processed through an existing system using a fully activated rosin flux and cleaning with both organic solvents and rosin saponification. Twenty additional PWBs were processed with the recommended aqueous soldering/cleaning system previously mentioned. The PWBs were then conformally coated with an acrylic coating to a dry film thickness of approximately 2 mils and subjected to temperature shock per MIL-STD-810B, Method 503, Procedure 1. The assemblies were then electrically tested and visually inspected for defects.

The results of these tests showed no signs of degradation in either control group or in the water soluble flux group.

Group II examined the effects of long-term storage on PWBs processed using selected aqueous techniques. In Group II, 20 PWBs were soldered and cleaned as recommended. They were then subjected to a high temperature storage test where they were stored in an oven at $125 \pm 2^{\circ}C$ for 1,000 hours. This approximated 100 years at room temperature ($25^{\circ}C$). Again, an additional 20 conventional rosin PWBs were run as a control group.

The PWBs were then checked periodically. About 600 hours into the test a bluish discoloration was noticed on both the test and control groups. This discoloration was spotty in nature and was confined to the etch side tin/lead. These residues were analyzed using an electron microprobe and it was determined that they contained some halide residues. This discoloration did not effect the electrical performance of the PWBs. The test was repeated, but this time, a new type of water soluble flux, which had recently been developed as a result of Phase I recommendations, was included. Again, the discoloration appeared at about 600 hours on the control and the original test group, but no discoloration appeared throughout the test on the samples fluxed with the water-soluble rosin flux. Further tests indicated this new flux is cleaned easier relative to conventional water-soluble fluxes. Because of these developments, this flux will be evaluated in parallel with the aqueous system previously recommended in Phase I during the third and final proving phase. These new fluxes are referred to as "surface active water-soluble rosin fluxes" and are described in the following section.

SURFACE ACTIVE WATER-SOLUBLE ROSIN FLUXES

One of the major problems facing the water soluble flux formulator of today is what to use as an antioxident. The compound or compounds must be thermally stable to $500°F$, noncorrosive, nontoxic, and be easily and thoroughly removed by water. In the case of rosin fluxes, the abietic acid acts as the antioxidant and meet all requirements except being easily soluble in water. Even with the use of rosin saponification, it is difficult to meet MIL-SPEC cleanliness with aqueous cleaners. Water-soluble fluxes have in the past typically used polyglycols as antoixidants. Polyglycols can easily penetrate organic polymer structures and are heavily employed in the plastics industry as plasticizers. It has been suggested that because of this property, the polyglycol would penetrate into the epoxy polymer and result in a retardation of the cleaning process.

In recent months, a new flux, based on a modified rosin, has been developed which may offer a solution to this controversial problem. This compound is used in formulating water-soluble fluxes and is analogus to abietic acid in rosin flux formulations.

The resulting water-soluble flux is referred to as a surface active water soluble flux.

A surface active water-soluble rosin flux is a rosin flux chemically modified to be water soluble. In addition, an amide, a nitrogen containing group, is added to the rosin molecule which has a high affinity for oxide free metallic surfaces such as tin, lead, or copper. The combination of these two transformations in the rosin flux, when used with conventional activation systems, is water soluble and has the unique ability to mask the fresh tin/lead surface with an inert molecular film of water-soluble rosin. This layer protects the fresh tin/lead until it is cleaned with water. The protective layer facilitates the removal of the active layer resting above it.

Surface active water-soluble fluxes are made by reacting rosin (abietic acid) with ammonia (NH_3) resulting in a rosin amide easily seperable from the remaining products in the rosin. The rosin amide is then dehydrogenerated and reacted with ethelene oxide which adds the watersolubling ether and alcohol groups. Because the flux is based on inexpensive, readily available materials, the resulting flux is economically competitive.

PHASE II CONCLUSIONS

Perhaps the most important single item gained from Phase II is that the total soldering system is only as good as its weakest link. That is, in the wave soldering process and subsequent touch-up/repair and cleaning processes, the soldering system can either directly or indirectly affect the final quality of the assemblies. Each portion of the process must be considered in designing an assembly line to produce high reliability military products using aqueous technology. As a direct result, a system approach must have a well defined set of process controls governing all processes.

Wave soldering

In the area of wave soldering, we will maintain our present controls including flux density, conveyor speed, preheat settings, solder temperature, and presoldering bake requirements. In addition to these requirements, it is necessary to maintain both a minimum and maximum time that the assemblies are cleaned following flow solder.

The minimum requirement is necessary to ensure proper cool down of the assembly and associated components to prevent thermal shock and/or sucking water into the sealed components upon entering the in-line prewash section of the aqueous cleaner. A maximum time limit will be incorporated to minimize chances of chemical damage to the PWB. Depending on the production rates and the type of flux used, it is necessary to incorporate varying degrees of age control on the flux used. For example, several water soluble fluxes tested contain activators which are somewhat volatile and, as a result, tend to lose strength over time.

If an oil injection system is used, special consideration must be given to the wave oil which must be water soluble. This water-soluble wave oil should be changed on regular predetermined intervals as it can break down with time into partially water soluble or non-water-soluble form on the hot solder wave.

Touch-up

At touch-up, there are two options: use rosin flux or use water-soluble flux. The preferred method is to use water soluble flux cored touch-up solder wire. Again, this requires a maximum time requirement in which a cleaning operation is performed. This will not, however, necessarily be the same maximum requirement set at flow solder since the water-soluble fluxes used to core touch-up wire are typically much less active than those used in the flow solder process. A similar maximum time limitation should be incorporated if rosin flux is used at touch-up as the rosin will crystalize, rendering it very difficult to remove using saponification.

Water Cleaner

It should be understood that the cleaning operations are in all probability the most critical operations affecting the final quality of the PWBs being produced. Some of the variables which should be verified on a regular basis include tank temperatures, neutralizer concentration (if used), conveyor speed, air knives and spray nozzles, resistivity of water in the final rinse, and a mandatory maintenance schedule.

Again, Phase II test data strongly indicates that our aqueous soldering/ cleaning system did not degrade the system we tested relative to present MIL-SPEC methods. We were able to meet MIL-P-28809 with one simulated pass through the aqueous cleaner recommended for water soluble fluxes. Finally, we did show that the new class of surface active water-soluble rosin fluxes, whose development was stimulated by Phase I, did offer superior corrosion protection found with either halide activated rosin or organic acid fluxes.

Conclusions Phase I and II

Two major conclusions were drawn after completing testing Phases I and II.

1. Cleanliness readings alone do not tell the full story of printed circuit board long term reliability. As a result of the tests conducted in Phases I and II, it has been shown that in order to fully understand and predict long term system reliability, one must look at both clean-liness results and insulation resistance degradation through environ-mental cycles, i.e. humidity.

2. Properly selected aqueous soldering technology can meet or exceed present reliability levels established by the military.

The question can now be asked, is it the activity level of the flux that needs to be controlled to insure a reliable system or is it the final condition of the assembly, i.e. cleanliness and insulation resistance breakdown, that needs to be controlled to assure a reliable system.

It is the opinion of this researcher that the emphasis needs to be placed on the final product. The path by which one obtains a reliable system should be less restricted as long as the final requirements are met.

An additional test phase is in progress to further evaluate these fluxes in a manufacturing environment. Final conclusions will be based on the results of these tests to be completed by mid-year 1980.
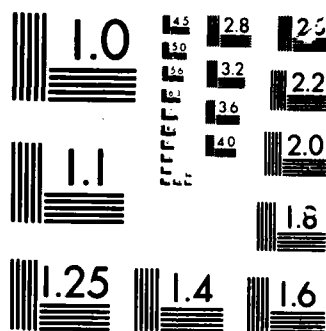
FIGURE I - PRESENT ROSIN PROCESS VERSUS PROPOSED AQUEOUS PROCESS

Activate Rosin

Flow Solder	Wave Clean	Degrease	Touch Up	Degrease	Unit Test	Degrease	Water* Wash	Conformal Coat

Water Soluble

Flow Solder	Water+ Wash	Touch Up	Water* Wash	Unit Test	Water* Wash	Conformal Coat

Steps   1   2   3   4   5   6

FIGURE II - EXISTING AQUEOUS CLEANER CONFIGURATION

Wash	Air Knife	D-I Rinse	Air Knife	D-I Rinse	Dry	Dry

FIGURE III - AQUEOUS CLEANER DESIGNED FOR WATER SOLUBLE FLUXES

Pre Wash	Air Knife	Wash	Air Knife	D-I Rinse	Air Knife	D-I Rinse	Air Knife	D-I Rinse	Dry	Dry

FIGURE IV - FUNCTIONAL APPROXIMATION OF RECOMMENDED SYSTEM

Rinse	Air Knife	Rinse	Air Knife	Wash	Air Knife	Rinse	Air Knife	Rinse	Dry	Dry

* Designed for rosin
\+ Designed for water soluble

END

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