Hazardous Material Minimization for Radar Assembly

Federal Manufacturing & Technologies

P. M. Biggs

KCP-613-5900

Published March 1997

Final Report

Approved for public release; distribution is unlimited.

RECEIVED

MAY 12 1997

OSTI

MASTER

DISTRIBUTION OF THIS DOCUMENT IS UNLIMITED

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

AlliedSignal
AEROSPACE

DISCLAIMER

This report was prepared as an account of work sponsored by an agency of the United States Government. Neither the United States Government nor any agency thereof, nor any of their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by trade names, trademark, manufacturer, or otherwise, does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof.

All data prepared, analyzed and presented has been developed in a specific context of work and was prepared for internal evaluation and use pursuant to that work authorized under the referenced contract. Reference herein to any specific commercial product, process or service by trade name, trademark, manufacturer, or otherwise, does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government, any agency thereof or AlliedSignal Inc.

Printed in the United States of America.

This report has been reproduced from the best available copy.

Available to DOE and DOE contractors from the Office of Scientific and Technical Information, P. O. Box 62, Oak Ridge, Tennessee 37831; prices available from (615) 576-8401, FTS 626-8401.

Available to the public from the National Technical Information Service, U. S. Department of Commerce, 5285 Port Royal Rd., Springfield, Virginia 22161.

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

AlliedSignal Inc.
Federal Manufacturing
& Technologies
P. O. Box 419159
Kansas City, Missouri
64141-6159

KCP-613-5900
Distribution Category UC-706

Approved for public release; distribution is unlimited.

HAZARDOUS MATERIAL MINIMIZATION FOR RADAR ASSEMBLY

P. M. Biggs

Published March 1997

Final Report
P. M. Biggs, Project Leader

Project Team:
G. A. Becka
J. W. Davis
M. L. Kindall
S. Landers
C. R. Saunders
S. S. Yerganian

HH
DISTRIBUTION OF THIS DOCUMENT IS UNLIMITED

AlliedSignal
AEROSPACE

DISCLAIMER

This report was prepared as an account of work sponsored by an agency of the United States Government. Neither the United States Government nor any agency thereof, nor any of their employees, make any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof.

DISCLAIMER

Portions of this document may be illegible in electronic image products. Images are produced from the best available original document.

Contents

<i>Section</i>	<i>Page</i>
Abstract	1
Summary	1
Discussion	3
Scope and Purpose	3
Activity	3
Laser Soldering	3
Near Zero Emission Electronic Assembly Solvent Cleaning System HC500SL.....	9
Trichloroethylene Replacement for Antenna Bonding	12
Alternative Soldering Technology	14
Spill Control System	15
Accomplishments	19
Future Work.....	21
References	22
Appendix.....	23

Illustrations

<i>Figure</i>	<i>Page</i>
1 Common Radar RF Assembly.....	4
2 HMC-M Hybrid Microcircuit Module	4
3 Ideal Cover Attachment Solder Joint.....	5
4 Cover and Backing Plate Assembly Cross Section	6
5 HC500SL Near Zero Emission Solvent Cleaning System	11
6 Spill Control System Logic.....	16
7 Satellite Storage in Spill Control Carriage	17
8 Spill Control System Control Panel	18
9 Spill Control System Pneumatic Routing.....	20
10 Control Panel Logic Pneumatic Routing.....	21
A-1 80X View of Sample 2-1 Cross Section.....	24
A-2 Cross Section 2-1 Elemental Scan Sampling Areas A and B.....	24
A-3 Cross Section 2-1 Plot Site B-1, 390X.....	25
A-4 Cross Section 2-1 Plot Site A-1, 220X.....	25
A-5 Plot A-1 Elemental Scan, Sample 2-1	26
A-6 Plot B-1 Elemental Scan, Sample 2-1	26
A-7 100X View of Sample 7-23 Cross Section.....	27
A-8 Crack in Solder Joint of Sample 7-23 Near Inside of Cover	27
A-9 Elemental Plot Sites 1 and 2 Near Sample 7-23 Solder Joint Crack ...	28
A-10 Sample 7-23 Cross Section Near Outside of Cover at 300X.....	28

A-11 Site of Plots A-1 and A-2 Near Outside of Cover	29
A-12 Plot A-1 Elemental Scan, Sample 7-23	29
A-13 Plot A-2 Elemental Scan, Sample 7-23.....	30
A-14 Crack Plot 1 Elemental Scan, Sample 7-23.....	30
A-15 Crack Plot 2 Elemental Scan, Sample 8-1	31
A-16 90X View of Sample 8-1 Cross Section	31
A-17 Site of Plots 1, 2, and 3 in Cross Section 8-1	32
A-18 Plot Site A-1 Near Outside of Sample 8-1 Cover	32
A-19 Plot Sites B-1 and B-2 Near Outside of Sample 8-1 Cover.....	33
A-20 500X View of Sample 8-1 Cross Section Near Inside of Cover	33
A-21 Plot A-1 Elemental Scan, Sample 8-1.....	34
A-22 Plot B-1 Elemental Scan, Sample 8-1.....	34
A-23 Plot B-2 Elemental Scan, Sample 8-1.....	35
A-24 Area Scan #1 Elemental Scan, Sample 8-1.....	35
A-25 Area Scan #2 Elemental Scan, Sample 8-1.....	36
A-26 Area Scan #3 Elemental Scan, Sample 8-1.....	36

Tables

<i>Number</i>	<i>Page</i>
1 Laser Soldering Evaluation Variables.....	7
2 Cleaning Variables for First Evaluation.....	12
3 Cleaning Variables for Second Evaluation	13

Abstract

The Clean Air Act Amendment, enacted in November 1990, empowered the Environmental Protection Agency (EPA) to completely eliminate the production and usage of chlorofluorocarbons (CFCs) by January 2000. A reduction schedule for methyl chloroform beginning in 1993 with complete elimination by January 2002 was also mandated. In order to meet the mandates, the processes, equipment, and materials used to solder and clean electronic assemblies were investigated. A vapor-containing cleaning system was developed. The system can be used with trichloroethylene or d-Limonene. The solvent can be collected for recycling if desired. Fluxless and no-clean soldering were investigated, and the variables for a laser soldering process were identified.

Summary

Methods were investigated for reducing or eliminating the need for chlorofluorocarbon (CFC) and methyl chloroform for cleaning electronic assemblies at AlliedSignal Federal Manufacturing & Technologies (FM&T) in order to contribute to an international commitment to eliminating the use of ozone-depleting chemicals such as CFCs and methyl chloroform. Work was conducted in three main areas: laser soldering, cleaning, and alternative soldering technology.

Laser soldering had been addressed at Sandia National Laboratories/New Mexico (SNL/NM) for the purpose of attaching lids to hybrid backing plates used on the Common Radar. Laser soldering presented the possibility of soldering without flux, eliminating the cleaning process and negative effects of residual solder. SNL/NM demonstrated a working set of parameters that would produce a solder joint utilizing an Nd:YAG laser capable of 200 watts output. The parameters were used as a baseline to establish laser power output, beam travel, preheat conditions, and lens size. The travel speed was used to establish the specification requirements for a motion control system needed to manipulate the hybrid assembly during the soldering process.

Most electronic assemblies were cleaned with chlorofluorocarbon (CFC) or chlorinated hydrocarbon (CHC) solvents. It was necessary to replace CFC and CHC usage or control the emissions from CHC solvents to meet the national commitment as described in the Clean Air Act. Continuing the use of CFC, a significant contributor to ozone depletion, was not an option since it would not be produced in the near future. Methyl chloroform, which depletes the ozone layer to a lesser extent, would also be banned. Trichloroethylene, a CHC, was a suspected human carcinogen.

Typically, parts were cleaned by spraying the part to be cleaned with solvent. The spraying operation was conducted in a spray booth. Solvent vapors were vented to the outside atmosphere. A vapor-containing cleaning system has been developed to contain the vapors during the cleaning process. Methyl chloroform, trichloroethylene, d-Limonene, and alcohol can be used in this system. The process is conducted in a closed chamber that is evacuated and back-filled with nitrogen before the chamber door is open. Evacuated vapors are collected in a carbon filter in line between the exhaust and the system cleaning system. Solvent used to clean parts is collected in satellite containers. The solvent can be recycled through the system until it is no longer suitable for cleaning.

The antenna sealing process required the use of trichloroethylene for cleaning the antenna housing and dielectric prior to sealing. An investigation was initiated to replace trichloroethylene. A replacement must result in a reliable seal and a repeatable process. The process was engineered to include alcohol as a replacement for trichloroethylene.

Fluxless soldering and no clean soldering were investigated. Fluxless soldering was considered premature for assembly processes at FM&T. Low solids flux was investigated, and it was determined that such a flux could be used without cleaning.

Solvent spray booths are exhausted and equipped with drainage to satellite storage for collection of solvent used during cleaning processes. A solvent-spill prevention apparatus was developed to prevent accidental overflow of satellite storage containers. In addition, the system reduces the evaporation and exhaust of vapors from the satellite when cleaning processes are not being conducted.

Discussion

Scope and Purpose

The purpose of this endeavor was to replace, reduce, or eliminate the use of chlorofluorocarbons (CFCs) and chlorinated hydrocarbons (CHCs) wherever possible in the production of electronic assemblies manufactured by Radar Operations at AlliedSignal Federal Manufacturing & Technologies (FM&T).

Activity

The Clean Air Act Amendment, enacted in November 1990, empowered the Environmental Protection Agency (EPA) to establish programs to completely eliminate the production and usage of CFCs by January 2000. Methyl chloroform would also be eliminated by January 2002. Officials at AlliedSignal, Sandia National Laboratories/New Mexico, and the Department of Energy signed an agreement that all CFCs and CHCs would be eliminated wherever possible by the end of 1994.

Radar Operations typically used one or both of these solvent families to clean electronic assemblies. Alternatives would require investigation. There would be instances when the solvents could not be replaced. It would, therefore, be necessary to contain solvent vapors. The tasks in this endeavor were arranged in the following categories.

- Laser Soldering - A process for attaching hybrid covers to backing plates.
- Cleaning - The replacement and vapor containment.
- Alternative Soldering Technology.
- Other opportunities to reduce vapor emissions.

Laser Soldering

The Common Radar RF Assembly contains seven lidded hybrids. The hybrid electronics assembly is attached to a backing plate. A cover is then attached to the backing plate to provide an RF shield and protective cover. Six of the hybrids are a common size and the seventh is somewhat larger. Figure 1 is a photograph of the RF assembly with the lidded hybrids fastened to a mounting plate. Figure 2 is a picture of an individual hybrid with lid attached.

The solder joints pictured were created by an electronic assembler with a soldering iron. The process requires the use of flux. Flux is minimized to prevent migration of the flux onto the hybrid within the module. It is preferable that flux not be used in the process.

Figure 1. Common Radar RF Assembly

Figure 2. HMC-M Hybrid Microcircuit Module

Engineers at Sandia National Laboratories/New Mexico (SNL/NM) established the feasibility of joining Ni-Au plated Fe-Ni-Co alloy backing plates with 80In-15Pb-5Ag solder using laser heating. The process used a hydrogen-argon cover gas to eliminate the need for flux. This project was established to transfer the technology to FM&T for joining lids to backing plates of hybrid modules.

In order to establish the process it would be necessary to

- Identify specific variable values that apply to equipment available at FM&T, and
- Establish equipment modifications necessary for manipulating the hybrid modules during the soldering operation.

The laser utilized at SNL/NM was a continuous wave (CW) neodymium doped yttrium aluminum garnet (Nd:YAG) laser capable of delivering 100 watts. The Nd:YAG laser at FM&T, in comparison, was capable of delivering only 50 watts. The SNL/NM study showed that it was necessary to have the 100-watt capability to achieve adequate wetting. A laser with 200-watt capability was ordered from U.S. Laser Corporation, Wycoff, NJ. U.S. Laser was also contracted to conduct a series of tests with a laser powered similarly to the one being ordered. Of particular interest from the evaluation was the speed at which the joint should move in front of the laser for optimum soldering results. The speed would then be used to specify motion control requirements.

The material supplied for the evaluation was

- Backing plates as specified by the design definition,
- Lid as specified by the design definition, and
- 80In-15Pb-5Ag solder ribbon 0.010" thick by 0.030" wide.

Figure 3 is a sketch representing the ideal solder joint. The solder flow is into the joint area at both the edge of the cover and between the inside of the cover and edge of the backing plate. A cross-sectional sketch of a cover attachment to a backing plate is shown in Figure 4.

Figure 3. Ideal Cover Attachment Solder Joint

Figure 4. Cover and Backing Plate Assembly Cross Section

Table 1 shows the data from tests conducted at U.S. Laser. The power capabilities available at U.S. Laser were higher than those at FM&T, so a bold approach to the evaluation was possible. As a result, some samples demonstrated some melting of the Kovar base material. The comments section of Table 1 lists process parameters and describes the visual appearance of the resultant joint exterior. Sample Numbers 2-1, 3-1 (7-15), 3-2 (7-15), 3-4 (7-15), 3-2 (7-23), 8-1, and 8-2 visually appeared to have penetration of solder into the joint area. The appendix contains pictures of cross-sectioned joints 3-2 (7-23) and 8-1 soldered with laser power set at 200 watts. In addition, sample 2-1 was cross-sectioned since it was soldered with the highest power setting, 500 watts.

Photographs of a cross section of sample 2-1 are included in the appendix. In addition, two elemental analysis charts are included. Observe the cross section in Figure A-1. The edge of the backing plate has been melted during the soldering process. It appears that the energy from the laser beam was concentrated on the edge of the backing plate, causing the back plate to melt. Although the extreme high soldering temperature excursion was encountered, solder wetting still occurred. Good solder reflow was achieved at the outside base of the lid. The fillet at the inside base of the lid was Au-In rich. Apparently the gold plating flowed to the inside of the lid surface during the soldering process. A feathered fillet was achieved on the inside backing plate surface. Figure A-2 shows two areas where elemental analyses were performed. These areas are magnified in Figures A-3 and A-4. The elemental analysis plot A-1 (Figure A-5) shows that the melted Fe-Ni-Co alloy has been entrapped in the In-Pb-Ag solder. Plot B-1 (Figure A-6) shows the presence of In-Pb, two of the solder elements, and Ni, probably from the back plate plating. There is also finely dispersed intermetallic throughout the bulk of the solder fillet. The solder joint is probably brittle. The lack of flow along the side of the lid appears to be a lack of solder volume available to fill the joint ideally.

Table 1. Laser Soldering Evaluation Variables

Sample No.	Atmosphere	Power (watts)	Travel (ips)	Preheat (C)	Focal Length (mm)	Preform Placement	Comments
1	Argon Box	75	1	110	87	On end	Joint dark, fell apart when assembly sectioned.
2-1	Tube (10cfm)	500	1	Ambient	75	On end	Solder reflowed, Joint filled, dark.
2-2	Tube (10cfm)	500	0.5	Ambient	75	On end	Melted the cover last 40% of joint.
2-3	Tube (10cfm)	400	0.5	Ambient	75	On end	Discolored, voids, some welding possible.
3-1(7-15)	Tube (10cfm)	500	5	Ambient	75	On end	Good joint except dark
3-2(7-15)	Tube (10cfm)	300	5	Ambient	75	On end	Good joint except localized voids.
3-3(7-15)	Tube (10cfm)	250	0.25	Ambient	75	On end	Solder melted but void visible.
3-4(7-15)	Tube (10cfm)	300	0.25	Ambient	75	On end	Good joint except dark
3-1(7-23)	Ambient	400	0.6	Ambient	75	On end	Solder melted, not uniform
3-2(7-23)	Ambient	200	0.3	Ambient	75	Flat	Solder flow good except some voids
3-3(7-23)	Ambient	200	0.2	Part 85	75	On end	Solder flow uneven
4-1	Argon Box	100	1	110	87	On end	Joint dark, voids
4-2	Tube (10cfm)	500	1	Ambient	87	On end	Joint dark and some evidence of welding.
6-1	Tube (10cfm)	300	0.3	110	75	On end	Excess heat, voids.
6-2	Tube (10cfm)	300	0.6	110	75	On end	Good beginning, then voids, good at end.
6-3	Tube (10cfm)	350	0.6	110	75	On end	Good appearance and even flow.
6-4	Tube (10cfm)	200	0.2	110	75	On end	First half joint very good, melted cover last 1/3.
8-1	Ambient	200	0.3	86	75	In joint	Joint looks excellent
8-2	Ambient	200	0.3	Ambient	75	In joint	Flow not even, some non-wetting
8-3	Ambient	200	0.3	110	75	Flat	Cable interrupts heat, joint appearance changes
8-4	Ambient	200	0.3	87	75	On end	Joint good some areas, voids others.

Referring to photographs of the cross sections in the appendix, it can be seen in Figure A-7 (sample 7-23) that the solder flowed well. The wetting on the interior surfaces is evident but the area is gold rich. A crack has propagated in the gold-rich area. Figures A-8 and A-9 show the crack in the intermetallic. Figures A-14 and A-15 (crack Plots 1 and 2) show Pb/In and Au/In rich areas. It appears that the crack propagates between the dendritic areas of the Au/In intermetallic. The propagation ends as it leaves the gold-rich area. The gold was leached from the gold-plated lid and backing plate during the soldering process. Figure A-10 shows the area near the outside of the lid. It appears that the lid was overheated where the laser beam impinged on the surface of the cover. No delamination of the plating was observed. The area is enriched with elements from the Fe-Ni-Co lid. Figure A-11 is a magnified view of the Fe-Ni-Co area. Figures A-12 and A-13 (plots A-1 and A-2) show the elemental makeup in the overheated area. Each plot shows that Ni is present but no Fe or Co. It is likely that the Ni is from the base plating, but the Fe-Ni-Co base metal was probably not melted during the soldering process. The internal solder joint microstructure of sample 7-23 has finely divided phases of In and Pb. This joint appears overheated but it has characteristics that make it a good starting point for refining the process variables.

The cross section of a sample 8-1 solder joint (Figure A-16 in the appendix) shows good wetting and adhesion of the exterior solder fillet. The interior fillet also had good wetting as evidenced by the small feathered fillet at the backing plate. The fillet on the interior of the lid appears to be Au-In enriched intermetallic. Elemental scans were taken in the three regions identified in Figure A-17. The plots (Figures A-24, A-25, and A-26) all show In-Pb-Ag, the solder. The Au is an intermetallic from the gold-plated surface of the cover or backing plate. The Au could be reduced by reducing the Au plating thickness. Reducing the Au may also have improved the joint strength.

Figure A-18 shows an area of the solder joint at the outside of the cover. There is a gold-rich area that is better shown in Figure A-19. Elemental scans (Figures A-22 and A-23) show the area is rich in gold. The scanned area B-2 is gold only. It is possible that thermal processing could cause peeling in these areas but only in the intermetallic-enriched zone.

Reviewing pictures of cross sections of samples 7-23 and 8-1 shows two solder joints with desirable solder flow. The processing parameters of the two sections were similar; however, the change in the orientation of the preform in the solder joint had an apparent effect on the temperature of the joint as it formed. This is evidenced by the amount of gold at the base of the joint in sample 7-23. The gold has flowed and accumulated ahead of the flowing solder. It could be expected that the greatest heat would have accumulated in sample 8-1 since the preheat temperature is 16 degrees C higher. The preform is, however, positioned so that the laser shined on the 0.010" thickness in the 8-1 process. The 7-23 process had the preform positioned flat or in a way that the laser shined on the 0.030" width. The laser energy is reflected by gold more than by the solder; therefore, the greater surface area in sample 7-23 absorbs more energy, causing more heat during the joint formation. As in sample 2-1, 7-23, and 8-1, intermetallic disbursed throughout the solder fillet. A reduction in heat input would be appropriate.

The evaluation conducted at U.S. Laser reaffirmed the feasibility of soldering the hybrid module covers to backing plates with a laser as the source of heat. The parameters used to solder sample 8-1 were judged to be the best starting point for establishing a production process. The velocity of the beam travel (0.03 ips) and beam power (200 watts) were used as baselines for specifying a new laser and a new motion control system. Other process parameters can be further optimized without exceeding the capabilities of the laser and motion system.

Identifying the velocity and acceleration characteristics to be used in specifying the motion control system was a mathematical evaluation verified with CADSI DADS dynamic simulation software.

Near Zero Emission Electronic Assembly Solvent Cleaning System HC500SL

The purpose of this project was to investigate the practicality of developing a self-contained cleaning system that could utilize a variety of solvents and very significantly reduce or virtually eliminate solvent vapor emissions to the environment. A second objective was to establish machine control of various process parameters and thus eliminate operator variables that invariably produce cleaning results that are less than uniform from unit to unit. This effort was conducted with the assistance of a commercial supplier of cleaning equipment. Several modifications were made to the design of an existing cleaning machine in order for it to be approved to handle a wide range of solvents including but not limited to trichloroethylene, isopropyl alcohol, d-Limonene, or even water. The result was the development of a system that met the major requirements and one that is commercially available and in use by several manufacturers in the United States, including installations in California, which has the most restrictive limits on the use of solvents of all types.

The background for this effort was the ever-increasing restrictions on both the type and quantity of solvent emissions allowed for use in cleaning of sensitive electronic assemblies used in a wide variety of military applications. Similar restrictions and needs for cleanliness apply to both commercial and military products.

Existing solvent cleaning processes included dipping, rinsing, wiping, spraying, bubble tanks, and conveyor cleaners. Each of these processes involved the evaporation of a significant amount of the cleaning solvent into the environment, both to the area in which the cleaning process was conducted and to the atmosphere outside the factory involved. For example, tests indicated that up to 80% of the solvent used to spray clean electronic assemblies was evaporated and exhausted from the cleaning hood to the outside environment. This protected the operator from excessive exposure but at the same time released potentially harmful solvent fumes to the environment.

Existing cleaning practices included as a minimum a four-step cleaning process which included a spray clean in trichloroethylene, trichloroethane, or trichlorotrifluoroethane followed immediately by a spray clean using isopropyl alcohol, dry nitrogen blow dry, and finally a vacuum bake to remove most residual solvent. The preferred solvent combination has been trichloroethylene and isopropyl alcohol. This combination was found in other studies to be the most effective cleaning process available.

The use of trichloroethylene and isopropyl alcohol was a particularly difficult combination for which to build a cleaning system. The presence of the alcohol created the requirement that any machine developed be explosion proof as required by NFPA Standards. The trichloroethylene necessitated that Viton or metallic seals be used for all connections. Additionally, mechanical pumps were found to be a problem because of electrical requirements in an explosive environment and because of the effects of the solvents on the pump seals. For example, an explosion-proof pump was found to be inoperative after the machine had not been used for two days. The pump seals had been damaged by the trichloroethylene.

Another complicating factor was the introduction of a replacement solvent for the CHC and CFC solvents listed above. A more environmentally friendly solvent, d-Limonene, was added as a replacement for the chlorinated and fluorinated solvents. Isopropyl alcohol was continued in use. In the future, consideration was to be given to water as a cleaning solvent. Consequently, the machine was required to handle both flammable and nonflammable solvents with aggressive cleaning characteristics that often degrade the systems in which they are contained.

Other concerns for the project included the collection of the used solvent for recycling or filtering and reuse within the process machine and the minimization of both fugitive vapor escape and exhaust to the atmosphere.

As a result of this project, a chemical cleaning system, shown in Figure 5, that meets all the major criteria was developed and is currently available for purchase. Several machines have been placed in use in commercial industry, including a machine in California. One machine has been installed in the Department of Energy's Kansas City Plant and is to be used for further process development activities. The machine as configured is capable of all of the subject solvents. The machine was engineered to be explosion proof so that flammable solvents can be utilized. The pumping mechanism was changed from mechanical pumps to nitrogen pressurized tanks. Solvent recovery tanks were provided to collect used solvent in a closed loop environment. The only emissions from the machine were from the small amount of residual solvent that remained on the board after cleaning and drying and the solvent vapor carried out with the nitrogen gas used to dry the units. The nitrogen gas used to dry the units was routed through a 55-gallon charcoal filter media before being exhausted from the plant. The cost of this system was less than \$30,000. Tests indicated solvent recovery/reuse to be greater than 95% compared to 80% loss with the existing process. This type process has not yet seen widespread application because of the cost of equipment involved and because additional engineering time is required to develop unique tooling and to determine process parameters for various assemblies. Clearly, with additional efforts, incremental improvements can be realized in the solvent emission levels from these cleaning processes.

Figure 5. HC500SL Near Zero Emission Solvent Cleaning System

Trichloroethylene Replacement for Antenna Bonding

The antenna sealing process required the use of trichloroethylene for cleaning the antenna housing and dielectric prior to sealing. The sealing process is very sensitive to the cleanliness of the two parts to be sealed; therefore, any change to the cleaning process required extensive evaluation. Several factors had to be considered when evaluating the elimination of trichloroethylene from the cleaning process. These factors included finding an acceptable replacement solvent, development of a repeatable process, and the reliability of the seal. With these factors in mind, an evaluation plan was developed.

Ten scrapped antenna housings and dielectrics were acquired from manufacturing. Temperature sensing equipment, which was compatible with the plasma cleaning equipment, was set up to monitor the plasma cleaning process. Trichloroethylene, toluene, acetone, and alcohol were selected for evaluation, with trichloroethylene being the control solvent. Because of factors other than their cleaning ability, toluene and acetone were eliminated from consideration. This left only alcohol and variations in the plasma cleaning process to be considered in the evaluation.

Two control samples were prepared using trichloroethylene as required in the cleaning process (sample 1). Two samples were prepared using alcohol and the plasma cleaner set at the same settings used with the trichloroethylene cleaning process (sample 2). Two samples were prepared using alcohol and the plasma cleaner rf power set at 600 watts (sample 3). Two samples were prepared using alcohol and pure oxygen as the plasma cleaning gas (sample 4). Two samples were prepared using alcohol and zero air (dry air) as the plasma cleaning gas (sample 5). All of the samples were purged and backfilled with helium, the purge tubes were then pinched-off and welded, and a leak rate was determined for each sample. Table 2 shows all of the plasma cleaner settings and gases used for each set of samples that were prepared for the evaluation.

Table 2. Cleaning Variables for First Evaluation

Sample Number	Cleaning Solvent	Process Time (Mins)	RF Power Setting (Watts)	Argon Pressure (Torr)	Oxygen Pressure (Torr)	Zero Air Pressure (Torr)
1	Trichlor	60	400	0.4	0.1	
2	Alcohol	60	400	0.4	0.1	
3	Alcohol	60	600	0.4	0.1	
4	Alcohol	60	400		0.5	
5	Alcohol	60	400			0.5

The ten sample assemblies were then subjected to 50 temperature cycles. Each cycle was defined as ambient temperature to -55°C to +70°C to ambient with each cycle requiring 72 minutes to complete. After the temperature cycles each sample assembly was again tested for leak rate. The before and after temperature cycling leak rates for each sample were compared. Any significant changes in the leak rates were noted. Three of the samples showed significant degradation in the leak rate after temperature cycling. One assembly from sample #1 and both assemblies from sample #2 were degraded. The remaining seven sample assemblies were again subjected to 50 temperature cycles. Some degradation of their leak rates was noted in all of the remaining samples after the second set of temperature cycles.

After completing the temperature cycle portion of the evaluation, the possibility of replacing trichloroethylene with alcohol as the cleaning solvent did not appear to be good. The integrity of the seals produced with the alcohol cleaning process did not appear to be as good as seals produced with trichloroethylene. Although the seals produced with trichloroethylene did degrade, they did not degrade to the same extent as those produced with alcohol.

At the same time as this evaluation was being performed, troubles with the production sealing process were encountered. A separate evaluation of the production sealing process was performed. During that evaluation, it was determined that a change in the primer formulation had caused the production sealing process to degrade. Based on the production evaluation findings, a second evaluation of the cleaning process was performed.

For the second cleaning evaluation 20 rejected production assemblies which required the removal of the dielectric from the housing and the installation of a new dielectric were used. Trichloroethylene was used to remove the original RTV sealer from 10 of the assemblies; alcohol was used for the remaining 10 assemblies. Alcohol was not successful in removing the original RTV sealer from the housings, so mechanical methods (rubbing, scraping, etc.) were used. Two of the assemblies used the prescribed cleaning technique (trichloroethylene) to create a control sample (sample 1), while the remaining 18 were cleaned using alcohol and zero air (sample 2). The zero air was chosen over the argon-oxygen mix because it was a more effective cleaning agent. It was also chosen over pure oxygen because it was nearly as effective a cleaning agent and was considerably less degrading to the surface of the dielectrics. The 20 assemblies were backfilled and leak tested as before. Table 3 shows all of the plasma cleaner settings and gases used for each set of samples that was prepared for the second evaluation.

Table 3. Cleaning Variables for Second Evaluation

Sample Number	Cleaning Solvent	Process Time (Mins)	RF Power Setting (Watts)	Argon Pressure (Torr)	Oxygen Pressure (Torr)	Zero Air Pressure (Torr)
1	Trichlor	*120	400	0.4	0.1	
2	Alcohol	*120	400			0.5

* The specification requires the plasma cleaning time be doubled for rework assemblies.

Temperature cycles as described earlier were performed on the 20 assemblies. This time there were no significant changes in the tested leak rate; therefore, replacing trichloroethylene with alcohol appeared to be technically feasible. An advance change order (ACO) was prepared that changed the specification. This ACO replaced trichloroethylene with alcohol and the argon-oxygen gas mix with zero air. The 20 sample assemblies were reworked in accordance with the new process and returned to production.

The changes to the cleaning process significantly reduced cycle time of the process as well as the generation of large quantities of hazardous wastes (trichloroethylene).

Alternative Soldering Technology

Low Residue Fluxes

Fluxless soldering process was sought as an extension in the development of laser soldering lid to back plate hardware. At the time, fluxless soldering was an emerging technology, but the development of low residue fluxes was nearing maturity. The flux manufacturers were settling on particular low residue (LR) flux formulations. LR fluxes are, in part, designed for flux application technique and need for or ease of cleaning.

Materials Engineering partnered with SNL/NM on a Cooperative Research and Development Agreement (CRADA) to evaluate LR fluxes. The CRADA was successful in establishing good processing practices with the new LR fluxes. The results are in a publication, *Evaluation of Low Residue Soldering for Military and Commercial Applications: A Report From the Low Residue Soldering Task Force*, dated June 1995, issued by SNL/NM.¹ Low residue fluxes are a possibility for the lid-to-base laser soldering process. These fluxes are supplied in either liquid, paste, or core-in-wire form. The flux can be dried before the solder operation, and, dependent upon the application, only traces amounts of residue may remain.

Fluxless Soldering

Fluxless soldering of electrical hardware is still an emerging technology. Joint surfaces still need to be cleaned to promote good wetting. Thus some cleaning or flux to strip away tarnish and to break down oxide layers is needed. Even the fluxless soldering processes need some chemical activation of the joint surface to promote solder wetting.

In industry, there are three touted fluxless soldering techniques at various stages of development and success. They are

- PADS -- Plasma Assisted Dry Soldering,
- ROSA -- Reduced Oxide Solder Analysis, and
- Controlled Atmosphere or Reactive Gas.

PADS and controlled atmosphere have replaced liquid flux with an activated gas(es). With PADS, plasma is used to ionize fluorine gas which then reacts with tin oxides. The ionized gas passes over the assembly and reacts with tin oxides. The tin-oxygen-fluorine compound breaks down at soldering temperatures and fluorine carries off the oxygen. The assembly is then soldered over a wave without liquid flux or fusing fluids. In the U.S., military agencies and institutions are evaluating this technique as a batch process. A German company (Novastar) has combined a plasma chamber with a wave soldering machine. The plasma gas is passed over the assembly before it reaches the solder wave.

Controlled atmosphere soldering has low level of hot gases pass over the assembly to strip away oxides. Some of these gases include hydrogen, dissociated methanol, dissociated ammonia, or weak organic acid vapors (i.e.; formic and acetic acid). In brazing, hydrogen is an effective reaction atmosphere. For soldering, hydrogen needs to be at 600°C to strip away tin oxides. Moisture in the chamber also needs to be controlled. Too much water vapor will cause oxidation.

ROSA has the assembly cleaned in an electrolyte solution and then soldered in an inerted chamber. Some companies, institutions, and agencies are interested, but the process is still in development.

Truly, the closest fluxless soldering techniques under evaluation use lasers. Laser wavelength and pulse/energy duration have been shown to restore solderability. Eximer lasers have restored solderability to IMC loaded coupons and some component leads. The YAG laser is being developed as a fluxless soldering technique, too. A fast Q-switch pulse provides enough energy to evaporate or break down tarnish and oxides, but the fast switch limits the energy in the pulse. The Q-switched pulse energy is dissipated into the substrate. Consequently, by programming the pulses, fluxless laser soldering is possible. Research in this area is being performed by Sandia National Laboratories/New Mexico.

Spill Control System

The primary objective of efforts to reduce or eliminate the use of CFC and CHC solvents is to eliminate or reduce the emission of the solvent vapors into the atmosphere. Exhausted spray booths are designed to protect operators from vapors by exhausting the vapors to the atmosphere. The exhausting of vapors can continue after the solvent spraying process is complete by drawing vapors from the waste collection tank. Vapors can also be emitted into the workplace if a solvent waste collection tank is allowed to overflow, a potential hazard to the health of individuals in the workplace.

A control system was developed for use in Telemetry Engineering that had many of the same requirements as the Radar Manufacturing application. The fact that the system was composed of pneumatic controls availed it for use around flammable solvents such as the alcohol. This system used by Telemetry was used as the basis for the system developed for Radar Manufacturing to avoid emission to the atmosphere from spills and the waste collection tank.

Two operations in particular were conducted in Radar Manufacturing departments that required an exhausted operation, spray cleaning and potting removal. In both cases it is necessary to have a drain path to a waste storage tank and exhaust to remove solvent fumes. It was also necessary to prevent solvent entering the storage tank drain when the storage tank is full. Figure 6 is a diagram that represents the logic sequencing of the controls. This is all triggered when an operator presses a start button located next to the spray or depot booth. The following then occurs:

1. The system senses if a can is present. Figure 7 is a picture of the storage can in place for the spray operation. When it is in place, it closes a switch.
2. The system then senses if the can is full. The platform on which the can is located is held above a switch by a spring. The spring is depressed as the can fills. When the can is full, the spring is depressed sufficiently to allow the platform to close a switch. Tubes leading to the switch can be seen to the right of the can in Figure 7.

Figure 6. Spill Control System Logic

If the can is full or not in place, the system will not actuate the spray or depot/bubble system. If the can is in place and not full, the following occurs:

- Nitrogen is supplied to the spray gun.
- The drain is opened. The drain control device can be seen in Figure 7 at the upper left of the picture.
- The spray timer is started. This timer is intended to limit the amount of time the spray system is active. A liberal amount of time can be allowed.
- The exhaust is started.
- Nitrogen is supplied to the bubble and depot systems.
- The bubble and depot systems timer is activated. This timer is intended to assist as a process control variable.

Figure 7. Satellite Storage in Spill Control Carriage

The timers are located in a control box and are preset. Figure 8 is a picture of the control box. As the timers expire, the system begins the shutdown process. Spray cleaning is the most frequent use for the system. For this application the depot/bubble timer is set to zero time. When the spray timer has expired, the nitrogen supply to the spray gun is interrupted. The drain valve remains (open) actuated. It is not desirable for the drain to close when the spray gun is deactivated. Some time interval is necessary before solvent in the booth sump can drain into the waste storage can. The valve timer is set to allow that additional time. The drain timer is also shown in Figure 8. When the drain time expires, the drain valve is closed and the exhaust is stopped.

The only event that will interrupt the timing sequence is when the waste storage container becomes full. When this happens, the drain valve is immediately closed and the spray gun is deactivated. The exhaust is not stopped. The waste storage container must be removed and replaced with an empty container before operation can continue.

The depot/bubble timer operates similarly except the exhaust is not stopped and the drain is not closed when the time expires.

Figure 8. Spill Control System Control Panel

A sump full warning device has been included in the controls. When a float senses that the spray booth sump is full, an audible warning device can be sounded. Should the volume of the depotting reservoir exceed that of the waste storage and sump capacity, this warning would sound. The float would be set to sound in advance of a spill situation.

Figures 9 and 10 are pictures of the control panel and surrounding pneumatics. Figure 10 shows the internal routing of pneumatic tubes. Figure 8 shows the signal tubes from the control panel leading to control devices such as valves in the nitrogen lines. The controls are operated by air pressurized to 80 psig.

Development of the spill control system has resulted in installation of such controls on four solvent spray hoods in three manufacturing departments.

Accomplishments

The laser soldering process was proven to be feasible for the attachment of covers to HMC backing plates used in the Common Radar. A study was completed that identified a set of process variables that were used to specify a new laser and motion controls that will be used to automate the soldering process. A metallurgical analysis was conducted on solder joints created during the study. The solder joints selected because of their appearance had a well-formed joint with the exception that the solder quantity was not sufficient to fill the joint area as desired. The solder joints also appeared to have been overheated during the soldering process. Soldering process variables were established during the study as beginning points for establishing a manufacturing process. Overheating and solder fill were identified as areas to be addressed.

The variables established for the laser soldering process were used to simulate the motion that would be needed and establish the capabilities of a motion control system needed for the soldering process. The dynamic simulation revealed that the movement around the corners of the hybrid module would require a significantly abrupt change of speed in the x movement axis. The movement capabilities were not readily apparent without the dynamic simulation. As a result, the proper motion controls were acquired for implementation into the laser system. The end result of this activity is to move to a fluxless soldering system. Cleaning with solvents would not be required.

Cleaning of electronic assemblies requires some solvent to remove flux required for most component attachment. In cases where solvents are necessary it is the goal to prevent the solvent vapors from escaping into the manufacturing facility's environment or the outside atmosphere. Two devices were developed to contain solvent vapors. A near-zero emissions spray cleaning system was developed and its use implemented at FM&T. The cleaning system is capable of being used with trichloroethylene, isopropyl alcohol, d-Limonene, and water. Solvent loss due to vaporization is 5% as opposed to 80% in a conventional spray booth. Solvent can be collected for recycling where applicable, reducing the cost of disposing of used solvents.

The process for cleaning bonding surfaces for the sealing operation was changed by replacing trichloroethylene with a combination of alcohol and zero air plasma cleaning. The process was implemented for hardware.

Refinements for a spill containment system available at FM&T were developed to prevent solvent vapor escape and chemical spills. The system is pneumatically operated, making it suitable for spray systems using alcohol. The system is equipped with automatic drain valve closure in the event that a solvent storage can is full or the spray operation is complete. The spray booth exhaust system is automatically turned off when liquid solvent has drained from the booth sump. The system has been installed in several manufacturing areas at FM&T.

Figure 9. Spill Control System Pneumatic Routing

Figure 10. Control Panel Logic Pneumatic Routing

An investigation into alternative soldering materials was conducted with the intention of identifying the feasibility of eliminating cleaning completely. Two alternatives were investigated, fluxless soldering and low solids flux. These technologies had not matured sufficiently to make them usable on the Common Radar, a new radar in development. Data gathered during this development activity was used in further investigations for demonstration programs conducted at FM&T.

Future Work

Laser soldering development will continue toward developing a production process for the Common Radar. The major area of development will be concentrated in efforts to develop an integrated laser soldering system utilizing a laser and motion control systems that are separate system entities. Development of software that will make the system user friendly for the operators in the manufacturing area will be involved.

References

¹*Evaluation of Low Residue Soldering for Military and Commercial Applications: A Report From the Low Residue Soldering Task Force.* Albuquerque: Sandia National Laboratories/New Mexico, June 1995.

Appendix

Selected samples from the laser soldering variables characterization were cross-sectioned to examine the configuration and metallurgy of the solder joint. The pictures and elemental plots are from the solder joints that showed the best overall outer joint appearance.

Figure A-1. 80X View of Sample 2-1 Cross Section

Figure A-2. Cross Section 2-1 Elemental Scan Sampling Areas A and B

Figure A-3. Cross Section 2-1 Plot Site B-1, 390X

Figure A-4. Cross Section 2-1 Plot Site A-1, 220X

Figure A-5. Plot A-1 Elemental Scan, Sample 2-1

Figure A-6. Plot B-1 Elemental Scan, Sample 2-1

Figure A-7. 100X View of Sample 7-23 Cross Section

Figure A-8. Crack in Solder Joint of Sample 7-23 Near Inside of Cover

Figure A-9. Elemental Plot Sites 1 and 2 Near Sample 7-23 Solder Joint Crack

Figure A-10. Sample 7-23 Cross Section Near Outside of Cover at 300X

Figure A-11. Site of Plots A-1 and A-2 Near Outside of Cover

Figure A-12. Plot A-1 Elemental Scan, Sample 7-23

Figure A-13. Plot A-2 Elemental Scan, Sample 7-23

Figure A-14. Crack Plot 1 Elemental Scan, Sample 7-23

Figure A-15. Crack Plot 2 Elemental Scan, Sample 8-1

Figure A-16. 90X View of Sample 8-1 Cross Section

Figure A-17. Site of Plots 1, 2, and 3 in Cross Section 8-1

Figure A-18. Plot Site A-1 Near Outside of Sample 8-1 Cover

Figure A-19. Plot Sites B-1 and B-2 Near Outside of Sample 8-1 Cover

Figure A-20. 500X View of Sample 8-1 Cross Section Near Inside of Cover

Figure A-21. Plot A-1 Elemental Scan, Sample 8-1

Figure A-22. Plot B-1 Elemental Scan, Sample 8-1

Figure A-23. Plot B-2 Elemental Scan, Sample 8-1

Figure A-24. Area Scan #1 Elemental Scan, Sample 8-1

Figure A-25. Area Scan #2 Elemental Scan, Sample 8-1

Figure A-26. Area Scan #3 Elemental Scan, Sample 8-1