DVD-47C
Wave Soldering

Below is a copy of the narration for DVD-47C. The contents for this script were developed by a review group of industry experts and were based on the best available knowledge at the time of development. The narration may be helpful for translation and technical reference.

Section 1

NARRATOR
The ocean's so beautiful -- especially on the island of Maui. Whether smooth or choppy, every wave seems perfectly formed. There's nothing like it.

SURFER
Fer sure! It's incredible. Like dude -- when I'm really riding that wave -- I feel such a connection. Awesome!

NARRATOR
There's another kind of wave we have in the electronics industry. You see it on wave soldering machines. This wave's also about making connections. And it's pretty awesome too. This solder wave makes the mechanical and electrical connections of components onto a printed circuit board.

In this video we'll be introducing you to the key elements of the wave soldering process -- fluxing, preheating and soldering. We'll also be describing the conveyor system that moves the assembly through each section of the wave soldering machine. Once you've been introduced to these elements, we'll explain the steps required for the set up and operation of some typical wave soldering machines. Our program will conclude with preventive maintenance procedures and some tips on what to do if something goes wrong.

Let's start with a brief explanation of the wave soldering operation. As we just mentioned, wave soldering consists of three basic parts -- fluxing, preheating and soldering. Fluxing is the process of applying flux to the underside of the assembly. Flux is made up of a combination of chemicals. The purpose of these chemicals is to remove *oxides* from the surfaces of the parts to be soldered. Fluxing also protects these surfaces from further oxidation during pre-heat. We'll talk about why in a few moments.

After fluxing, the conveyor moves the assembly into the preheating section. The entire assembly is slowly heated to a temperature that will *activate* the flux. This enables the flux to react with and condition the metals for the soldering operation.

Molten solder is then delivered to the underside of the assembly in the form of a wave. The assembly then cools down and the solder solidifies making the mechanical and electrical connections. As you've observed, each of these process steps occurs in a different section of the machine -- all connected by a conveyor system.

There may also be a computer and other front panel controls that allow the process to be adjusted for the particular assembly to be soldered. When each part of the operation is properly regulated, thousands of perfectly formed solder joints can be made in a very short time. But if just one part of the process is out of adjustment, we can end up with a whole batch of unacceptable or defective assemblies.

Now, let's examine each element in more detail so you can have a better understanding of the entire wave soldering operation. We'll begin with the conveyor system. Depending on its size, the assembly may be loaded directly onto the conveyor fingers... ...or may be attached to a pallet which carries the assembly along the conveyor. Many conveyors are fitted with alternate "L" and "V" fingers. When pallets are used, they rest on the "L" fingers. Assemblies that are loaded directly onto the conveyor rest on the "V" fingers. These fingers exert *side thrust* which hold the assemblies in place. The critical adjustments for the conveyor system are the width and parallelism of the rails; the speed of the conveyor; and the perpendicularity of the rails to the solder pot.

Now, let's take a look at fluxing. Oxides begin to form on the component leads and through hole lands whenever these metals come in contact with air. If these oxides or contaminants are not removed, the solder won't form a reliable bond between the leads and through-hole lands. As the flux contacts the exposed metals on the heated assembly, it chemically removes the oxides, allowing them to be carried away by the molten solder. Flux also prevents further oxidation during preheat.

Your company will have determined the appropriate flux to be used on its assemblies based on testing and the machine's flux application process. There are many types of fluxes -- but they generally fall into one of three categories. The first is rosin-based fluxes which contain varying quantities of rosin, halide activators and a solvent carrier. The second is water soluble fluxes that contain solvent with organic acid activators. The last category is low residue fluxes which are mostly solvent with a weak organic acid activator.

The more active fluxes promote better surface preparation, but their residues are usually more corrosive and conductive. When residues from these active fluxes are exposed to water in the form of humidity, vapor or liquid, they can form corrosive acids that will attack metals on the assembly and reduce reliability. These flux residues can also be conductive and cause electrical problems such as short circuits.

Because of these problems, these flux residues must be cleaned off the assembly as soon as possible after wave soldering. Some companies have no-clean processes where low residue fluxes are used. These fluxes are much less active. This means that the residues can be left on the assembly after soldering without causing deterioration. Low residue fluxes require that the surfaces to be soldered exhibit good solderability characteristics.

Many companies that use low residue fluxes use a soldering machine equipped with a nitrogen blanket. This blanket reduces the oxygen concentration to a very low level. Without oxygen, there will be minimal oxidation or corrosion. This then reduces the need for higher activity fluxes in the process. Now that you have a better understanding of fluxing, let’s take a look at three different ways of applying flux. There are spray fluxers, foam fluxers and wave fluxers. The type of wave soldering system and method of flux application your company uses is probably based on the type of assemblies being manufactured.

Spray fluxing systems employ either reciprocating spray nozzles or fixed spray nozzle technology. Both systems are controlled by a computer programmed to deliver flux fairly accurately to the width and length of the board. In either application, the computer will sense the board speed using fiber optics or proximity switches -- and from this information calculate the coverage required.

Another method of applying flux is the foam fluxer. Here, a porous stone is submerged into a flux reservoir. Clean dry air is forced through the stone to create small bubbles. The bubbles are forced upwards through a wide chimney that ends just under the conveyor. As the assembly passes over this chimney, the flux is spread evenly across the underside of the board, the component leads and into the holes. The height of this foam head above the chimney is limited. If greater height is required, brushes can be added to create a supported foam head. This would allow components with long leads to go through the foam fluxer.

The final method of applying flux is the simplest system to operate and maintain. In the wave fluxing system a pump forces the flux up through a nozzle where the liquid spills over the top. An assembly passing over this wave has its bottom covered with liquid flux, as well as some of the insides of the through-holes. Wave fluxing often results in the application of more flux than is required.

Regardless of the method of fluxing, many systems employ an air knife immediately following the fluxer in order to remove excess solvent and flux from the bottom surface of the assembly. The air is directed at a slight angle, back toward the fluxer with a carefully adjusted low flow that does not drive off all the liquid. The air knife helps spread the flux and pushes it up into the holes. If excess flux is not removed, there’s the possibility of the flux dripping on the preheater and possibly causing a fire.

Speaking of the preheater, let’s take a look at why we need to preheat the assembly. There are five reasons. The first reason for preheating is to activate the flux. The fluxes used are not active at room temperature, and some only work at high temperatures. Preheating also helps some fluxes to rise up through the holes in the assembly.

Second -- faster soldering speeds are made possible by raising the temperature of the assembly closer to soldering temperature. If there was no preheating, all of the required heat would have to come from the solder wave. This means the assembly would have to spend more time in the wave, or the solder would have to be at a very high temperature. The extreme temperature spike from room temperature to the soldering temperature could also damage the component.

Reason number three has to do with thermal shock. If the temperature of the assembly is raised very quickly from room temperature to wave soldering temperature, the circuit board may bow. This can damage the integrity of the interconnections on the board. Also, some components are sensitive to quick heat-up. These components would be damaged if they went from room temperature directly into the wave. Therefore, both the board and components need to have the heat slowly ramp up before being exposed to final soldering temperatures.

The fourth reason for preheating is to evaporate the flux solvents. Any solvent left in the flux, upon entering the wave, will be heated to its boiling point and can cause blow holes, splatter and solder balls. Excessive splattering can actually ruin a solder joint.

Finally, proper preheating can assist top side hole fill on the assembly. Now that we've discussed the reasons for preheating, let's look at how the assembly is preheated.

All wave soldering machines have preheaters that heat the bottom of the assembly. Preheat systems can be either convection or radiation based. There is usually some heating by each heat transfer mechanism in all wave soldering systems.

Convection preheaters deliver hot air or gas through holes in a heated platen. A platen is similar to a hot plate used for cooking. Radiation preheaters deliver infrared radiation through quartz tubes, or wires, or platens heated by electrical resistance. Some wave soldering systems also incorporate top side preheaters. This can enable faster soldering of high thermal mass assemblies. Top side preheaters also allow greater control of the preheating process.

Preheating is an important part of the "thermal profile." A thermal profile can be represented by a chart or graph. This chart includes the ramp up of the preheat temperature up to soldering temperature as related to time. Each assembly will have an optimum heating cycle that is related to the mass of the circuit board and the types of components being used. The preferred temperature profile is affected by the specific flux being used. Let's examine how this thermal profile is developed.

Temperature recording devices such as thermocouples are attached to the surface of a test assembly during process development. A recording device is placed in a heat barrier envelope on a pallet or spare board just behind the assembly being studied.

As the assembly travels through the wave soldering machine, the recorder follows and logs the temperature of each thermocouple at specific intervals. After exiting the machine, the assembly is inspected for proper solder connections. The software in the computer then converts the recorded data into a graph that compares temperature and time. This becomes the thermal profile for that assembly. As you can see, the graph shows where each element of the wave soldering process registered for time and temperature. If the results of the soldering operation were not acceptable, elements of the process can be adjusted until the correct thermal profile for the assembly is determined.

Now that you have an understanding of preheating and thermal profiles, let's discuss the solder wave section of the wave soldering machine. The wave has two basic functions -- to carry and transfer heat to the component leads, the lands and plated through holes; and to deliver the solder that makes the mechanical and electrical connections.

First, let's look at the solder. The solder is typically eutectic tin-lead alloy made up of 63% tin and 37% lead. The temperature of the solder in the solder pot should be sufficiently above the liquidous, or molten temperature of the solder -- which is 183 degrees Celsius. Common solder pot temperatures are in the range of 240 to 260 degrees C. For some special purposes, a different solder alloy may be used. If this occurs, the solder pot temperature may have to be adjusted.

Now we'll examine the wave itself. A commonly used wave form is the adjustable laminar wave. With the use of extender plates, or a wide nozzle, most of the solder is directed toward the oncoming board. The board is used to push the solder over the exit end of the wave. This results in beneficial wave dynamics as the assembly exits the wave. Increased drainage of solder from the leads results in reduced bridging. Wave height may not accommodate long leads without nozzle or pot height adjustment.

Many wave soldering systems use both *laminar* and *turbulent*, or chip waves. Turbulent waves are almost always *symmetrical* and are used to ensure that all metal surfaces are wet by solder. This is especially important for soldering small chip components such as resistors and capacitors on the bottom of assemblies.

In either case, as the bottom of the assembly passes over the crest of the wave, solder touches the parts to be joined. Although the solder also touches the base, or laminate material of the board, it won't stick to these non-metallic materials if they are properly cured.

Systems may have a hot air knife at the exit of the wave. By directing a jet of hot air at an angle to the underside of the assembly, any excess solder can be blown off and find its way back to the solder pot. Excess solder can cause bridging, especially where joints are closely spaced. This tool is used to accomplish "debridging."

The last stage of the process is *cool down* -- where the solder solidifies. Many machines have fans that blow cool air onto the assembly. This cool down must be controlled to avoid *thermal shock* to the components.

Section 2

Now that you have an understanding of each part of the wave soldering machine, let's look at the set-up and operation of some typical systems. It's pretty common to feel overwhelmed by a machine this big -- that uses chemicals and lots of heat, but -- not to worry...

OPERATOR (V.O.)
When I first started working here I was concerned about being burned by the hot materials, or hurt by the chemicals. But after being trained and getting some experience working with the other operators, I feel pretty comfortable. The main thing is to follow the safety precautions. That means wearing gloves, safety glasses and a face shield when looking into the cabinet with the door open. And no open toed shoes, rings, jewelry or loose fitting clothes -- common sense stuff. I ask questions when I'm not sure of something, and I keep trying to learn more. It's a challenge, but it's really satisfying to know you're able to make a big complex machine turn out a high quality product.

NARRATOR
We'll divide the set-up procedures into what needs to be done at the beginning of each shift and what specific adjustments are required for the particular assembly being run. Let's start with the beginning of the shift. Most companies have a set-up instruction sheet attached to the front panel of the wave soldering machine. You should always follow this procedure exactly.

Let's go through a typical set-up sequence. The first step is to check that the exhaust vents are open and there is adequate ventilation. Now, we turn on the system. This is either done at the computer or front panel, or possibly both places. In-plant safety procedures should be followed to avoid injury to personnel, or damage to equipment. Depending on the size of the solder pot, the system may take several hours to come up to temperature. For this reason, many wave solder machines are on a timer which turns the machine on at a programmed time.

Once the solder pot is up to temperature, skim the pot. Then remove the flux tank cover and turn on the hood lights. Also, turn on the conveyor and the preheater. Verify that the convection blower is turning. Allow the temperature to stabilize. Then inspect the fingers on the conveyor system. Make sure they are in good mechanical condition and free of flux residue.. Also, check the level of solution in the finger cleaner tank. Then turn on the finger cleaner pump.

At this point, check that the flux reservoir is filled. The purity of the flux should also be checked. Purity can be measured by the turbidity, or clarity of the liquid, as well as a color change. In addition, check the specific gravity of the flux. Specific gravity is the way we measure the percentage of solvent in the flux. You could think of it as the viscosity, or thickness of the liquid flux. With spray fluxers, the flux is kept in a closed container and therefore don't require specific gravity checks.

Now, we make sure that the flux air knife is set at the correct angle. That's because the air knife is removed during cleaning and may not have been returned to its proper position. You should also check the air pressure.

Next, turn on the fluxer. Regardless of whether your machine is equipped with spray, foam or a wave, it is important to verify that there is even coverage of the flux application. This can be done by visually observing a glass plate riding on the conveyor.

There are also electronic measurement systems that can verify all of the set-up parameters for the entire wave soldering operation. They pass through the system in the same manner as the thermocoupled assemblies we discussed earlier. In addition to verifying parameters, these instrumentation systems print out statistical process control charts that indicate variations in the process. They may even indicate when preventive maintenance is required. These devices should be used after all systems are set up.

At this point, check the solder in the solder pot. The solder level is usually kept between a half inch to three quarters of an inch below the tank rim. If it is needed, add one bar of solder at a time to obtain the proper level. Don't forget to wear gloves and a face shield in case of solder splash.

Check that the temperature of the solder is within the recommended range -- usually 240 to 260 degrees C for eutectic tin-lead. Note that temperatures shouldn't vary more than plus or minus 5 degrees C from nominal temperature regardless of the alloy. Also, if your system has a hot air knife in line after the solder wave, check for correct angle, air pressure and temperature.

Now, we'll complete the set-up of the machine by adjusting certain parameters for the specific run of assemblies to be soldered. These assemblies are accompanied by a document called a traveler, or router. The router contains the assembly part number and revision letter; the size; the correct assembly loading orientation; and specific machine settings required for soldering the assemblies.

First, set the conveyor width based on the board size or pallet size. The fit of the board should be loose enough to allow the board or pallet to slide in the conveyor. Tight fits can result in bowing or distortion at higher temperatures. This can cause unsoldered areas where the bottom surface of the board does not touch the wave.

Next, turn on the conveyor. Set the speed as required for this particular assembly. Now, we select the predetermined temperature settings for the assembly. Preheater zones and solder wave temperatures may be set manually; or may be set automatically by the computer.

Finally, turn on the pump. If there is a nitrogen blanket, it should also be turned on. The nitrogen flow rate should be adjusted to provide the desired reduction of oxygen in the atmosphere. Now observe the wave. Your documentation will let you know whether there is simply a laminar wave, or whether the assembly requires an additional turbulent wave. The height of the solder pot and the waves must be set so there will be proper solder coverage. The height of the wave where the assembly exits should be referenced to the conveyor fingers. As we said earlier, there is also instrumentation available for measuring solder coverage.

At this point, the wave soldering machine is set-up and ready for production. But just to make sure that everything's working properly, we run from one to three assemblies through the machine to make sure we're achieving the desired thermal profile.

These assemblies are now loaded onto the conveyor and run through the machine. It's critical that the assembly is loaded with correct component and lead orientation as determined by board layout. Spacing between assemblies should be controlled to assure no overflow on trailing boards.

We follow the assemblies through fluxing, preheating, soldering and cool down. Then we carefully inspect each assembly. If the soldering has been done properly, then the entire production run can be started. If there’s a problem, adjust the settings as required. If the next run is not satisfactory, then notify your supervisor or process engineer.

Now, we’ll do the production run. A particular assembly may require additional hardware such as solder plows or stiffeners. These should be attached to the assemblies before they’re loaded onto the conveyor. This hardware keeps solder from flooding the top of the board on certain types of assemblies.

When manually loading assemblies, place them gently on the conveyor fingers. It is important to periodically monitor the conveyor for any changes in speed; for smoothness of travel; for scummy fingers; and for finger cleaner level. As the assembly passes over the fluxer, make sure that a thin layer of flux is applied to the underside of the board and that excess flux is being removed by the air knife.

Foam fluxers should be monitored periodically for reservoir level, turbidity, foam height and specific gravity. Specific gravity should be monitored more frequently. When a machine uses flux over and over, some of the solvent will be constantly evaporating as the foam is exposed to air. Spray fluxers can be monitored for spray pressure and total volume applied.

For preheating, we make sure that the preheater zones maintain the relationship to the thermal profile within the tolerances set by your company.

The solder wave should also be monitored periodically for wave height, the level of the solder pot, pump speed and dross build-up. Dross is the scum that forms on the top of the molten solder. The primary components of dross are tin and lead oxides. These are created when the solder comes in contact with air. Dross also contains sulfides, burned flux and residues, and other contaminants and metals that have entered the solder from the assemblies being soldered.

Excess dross must be removed or otherwise dealt with. Too much dross can cause erratic solder waves and can even damage the pumps. It can also contaminate the solder joints. The use of a nitrogen blanket significantly reduces the amount of dross formed. We’ll discuss the removal of dross in more detail in the next section dealing with preventive maintenance.

If your wave soldering system has a hot air knife following the wave, it should be occasionally monitored for proper temperature and pressure. Staying alert assures that the soldering process remains on track and that problems are remedied quickly if something starts to change.

After the assemblies leave the wave soldering machine, they are usually loaded in a cleaning system to remove any flux residues. Cleaning should be done as soon as possible after soldering, at least within 30 minutes. If low residue no-clean fluxes have been used, this step is generally omitted.

Section 3

This final section deals with preventive maintenance and troubleshooting. Let's begin with preventive maintenance. A good preventive maintenance program is one of the keys to assuring that the wave soldering machine performs the way it's supposed to. Your company will probably have a preventive maintenance schedule that's based on the recommendations of the manufacturer, and its own internal process control program. Let's take a look at some typical preventive maintenance procedures.

Some companies require removing dross from the solder pot once per shift. Other companies do this only every twenty four hours. There are wave soldering machines that use an enclosed nitrogen blanket to reduce the formation of dross. Removing dross from the solder pot in these systems is required even less often. A common way of removing dross is to skim it off the surface of the solder pot, moving it away from the nozzles. Remember to wear the required safety clothing, which may include a respirator, when performing this task. The removed dross is then sealed in a container and properly recycled.

It's important to clean the sides of the solder pot. This keeps any foreign matter in the pot from contaminating the solder. After doing this maintenance, make sure the solder pot is still level. Good manufacturing practices and specifications require periodic analysis of the solder in the solder pot to prevent solder defects.

The conveyor should be checked to make sure that the rails are aligned and parallel. The whole conveyor can become skewed and will result in uneven coverage of both flux and solder. The conveyor should also be checked for reproducible speed. Conveyor fingers should be inspected regularly for good mechanical condition. Make sure they are free of solder, dross or flux build-up. Pallets should also be inspected to determine any twist or bow -- and they should be cleaned.

The preheating section is generally cleaned once per shift. Remove any flux drippings with a soft cloth and alcohol. Needless to say, make sure the preheater has cooled down before doing this cleaning. During each shift, the entire machine also needs to be cleaned of all flux and solder residues.

There will also be specific calibration procedures, as well as other maintenance work -- such as changing belts -- that will need to be done on a regularly scheduled basis. Most companies have checklists that track when preventive maintenance has been accomplished, and when the next required maintenance needs to occur. As we said earlier, use of instrumentation that measures solder coverage can be an advantage in determining when preventive maintenance needs to be performed.

Now, let's turn to our last topic -- troubleshooting -- what we do when we don't get the results we expect. Common wave soldering defects includes pinholes and blowholes; solder voids; solder balls and splattering; dewetting and poor wetting; bridging and webbing; icicles and spikes; unacceptable fillet appearance; and excess solder.

These types of defects may or may not be related to the operation of the wave soldering machine. For example, poorly designed circuit boards; boards with undetected drilling problems; and boards and/or components with poor solderability can cause defective solder joints.

But for the purposes of this program, we’ll be focusing on machine controllable solutions. We’ll be looking at how to approach the troubleshooting process for several of these defects. IPC-TR-460A contains detailed troubleshooting charts for most of the wave soldering defects.

Pinholes and blowholes can be caused by volatiles in alcohol based fluxes not being evaporated during preheating. Improper preheating of water based fluxes can result in spattering. A possible solution is to adjust the thermal profile. Other causes may be excessive conveyor speed; low solder temperature; low specific gravity of the flux; or contaminated flux. Troubleshooting means checking out each of these possibilities against the proper set-up procedure. It’s important to notify your supervisor when a problem starts to occur.

Dewetting and poor wetting is almost always caused by inadequate fluxing. Check for complete flux coverage; check the level of the flux reservoir; check specific gravity; and check for contamination. Another possibility is to use a more active flux. Poor wetting can also be caused by preheat and/or solder temperatures being too low; conveyor speed being too fast; or the solder level in the solder pot being too low.

Bridging and webbing are most frequently related to a rough solder wave; incorrect wave height; or the solder temperature being too low. In addition, these defects can also be caused by improper fluxing or incorrect conveyor speed.

When the solder fillet appears rough, dull and grainy, discolored, or contains cracks, it is almost always related to solder composition or contamination. Time and temperature of the solder wave contact can also negatively affect the appearance of the solder joint. In addition, make sure that assemblies are not bumping or shaking on the conveyor after the assembly leaves the wave. If this occurs before the solder becomes solid, the joint will appear disturbed.

As you can see, the solutions to these defects come from a systematic approach of looking at all of the machine variables -- the quality and coverage of the flux; the proper ramp up of the preheater; the operation of the solder wave; and the speed and mechanical condition of the conveyor that carries the assemblies through the wave soldering machine. The more you work with a particular system and different types of assemblies, the more you’ll become aware of the particular problem areas -- and how to work with them.

This program has examined the details of the wave soldering operation. You were introduced to the key elements of wave soldering -- fluxing, preheating and soldering, as well as the conveyor system. Then we described typical set-up procedures -- to be done both at the beginning of your shift and for the individual types of assemblies to be run. You also saw exactly how typical wave soldering machines do their jobs and what aspects require monitoring during production. Finally, you were given some general preventive maintenance procedures, and some tips on how to approach troubleshooting.

Wave soldering is one of the most critical jobs in the assembly process. The quality of every solder joint determines the reliability of each assembly that’s manufactured. Your performance can make the difference in the continued success of your company.