DVD-43C

Lead Free Hand Soldering for Through-Hole Components

Below is a copy of the narration for DVD-43C. 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.

Preparation

In this video we'll be discussing the tools, materials, and *hand soldering techniques* that are used to attach *through-hole components* onto printed circuit boards – using lead free solder. IPC also offers a similar video for tin-lead solder.

The most important part of the hand soldering process is the person that does the job. Your commitment to doing the job *right* is the first step. But you'll also need to have proper training… then your experience and skill will bring it all together.

There will be a lot of people depending on the quality of the work you perform… Even *one* bad solder connection can cause an entire electronic system to fail, either completely or occasionally. A solder joint that opens up *occasionally* is called an *intermittent failure*. In some products this can be annoying. In others, an intermittent failure can be dangerous, or even fatal.

Let's begin by looking at a hand soldering *workstation.* Your workstation, and the area around it**,** should always be kept clean, well lit, and uncluttered. Any dirt, grease, solder splatter, insulation cuttings, and other debris should be cleaned away often. It's a good idea to use a rag or a brush to do this so you don't hurt your hand. Any of these materials can *contaminate* the assemblies you'll be working on.

Food residues on your hands… and certain types of hand creams or skin lotions can also contaminate component leads, lands, and solder joints.

One safety issue for lead free soldering involves the *fumes* given off during the hand soldering process. Some people are allergic to the *flux fumes* that are released when the solder is melted. A *fume extractor* can help remove these vapors. We'll be talking a lot more about *flux composition* a little later.

One of the *invisible problems* around your workstation that we need to protect against is called "Electro-Static Discharge" or *ESD.* Static electricity is created whenever two *dissimilar* materials *rub* against each other. For example, when your shoes *separate* from the floor, an electrical charge is generated and stored in your body. This build up of *static electricity* will be *discharged* whenever you touch, or come near an electrically conductive object…

Some electronic components are extremely sensitive and can be damaged by even a tiny electro-static discharge. That's why your workstation should be cleared of all non-essential items that can generate a static charge. In addition to wrist straps, the use of *grounding mats* on the floor and *anti-static mats* on the work bench surface will also help remove or *discharge* these static buildups.

The wrist strap is the primary and most important *grounding device* - and should always be worn - *regardless* of any other methods being used. Foot grounding straps, grounding shoes and smocks can also help eliminate built up static charges. These need to be checked on a regular basis to make sure they are working properly, and the operator is properly *grounded*.

Now let's discuss soldering irons… There are essentially two types of hand soldering irons: *controlled* output and *uncontrolled* output. The *uncontrolled output* irons range from 20 to 250 watts of *power* or *heat output.* These types of irons are rarely used in modern electronics assembly, because of the need for *different temperatures* for different *types* of work.

Today, almost all production soldering is done with *controlled output* irons. Controlled output irons will *maintain* the selected tip temperature during soldering operations - no matter what the *load* is. Some controlled output irons operate at a specific temperature that is *preset* by the manufacturer. Others are *temperature variable* – using an analog or digital control.

There is no "ideal" tip temperature, since that will depend on what you're soldering, and how thick the board is. In general, a tip temperature of 315 degrees C is a good *starting place* for soldering *through-hole* components.

Selecting a soldering iron *tip* of the proper shape and size is very important. The amount of heat that is transferred to the parts being soldered depends not only on the *temperature* of the tip, but also on how *much* of the tip *touches* the parts being connected.

Pointed tips, such as the *conical tip,* are used to transfer heat into a small area. These tips should be used with small lands and components that need very little solder.

A *screwdriver* tip, or *chisel tip,* will transfer more heat, because *more of the tip* contacts the parts to be soldered. As a general guideline, the *width* of the tip should be approximately equal to the diameter of the *land* that's being soldered.

Every solder connection should be completed in the *shortest possible time* to prevent excess heat from spreading to nearby areas of the board and causing thermal damage. Three seconds should be the *average* time to complete a hand soldered joint. If it takes more time than that, you *may* be causing *heat damage* to the board - or the component. Heat damage can *sometimes* be visible on the *surface* of the board. It can also exist on innerlayers – where it can appear as *isolated white spots* – called *measles*. M*easles* will probably not be cause for rejection of the assembly, but they are *definitely* not desirable.

Heat damage can also cause *delamination* of the base material. Internal delamination is like a small cavern or *hole* inside the board. If there happen to be any *internal conductors* within this delaminated area, there will be little or no electrical insulation between them. In high humidity environments, this can result in electrical problems. Excess heat can also *separate or lift* the land from the base material. The *worst* type of thermal damage will not even be visible on the surface of the board.

This is a microscopic *cross section* of a plated through-hole that has been damaged by excessive heat. When this area was *overheated,* different *expansion rates* for the metal and the base material caused this crack in the plating. This type of *barrel crack* can prevent the electronic signal from traveling *through* the hole, and result in signal failure. This particular problem *would not be visible* during final inspection… but it will cause reliability problems in the end product.

As you can see, *heat transfer* may be the most *critical* issue in hand soldering… *and* there are quite a number of factors that can affect it, including: the wattage or power of the soldering iron, the amount of time the iron takes to make up for any heat that is lost in the soldering process, the size and shape of the soldering tip, and the amount of time the connection is *contacted.*

All of these variables will be determined by the *type* and *size* of the connections you'll be soldering. You'll learn how to make the right decisions from the information in this video, and by experience - as you perfect your soldering skills.

<u>*Materials*</u>

There are *many* different types of lead free solders available today. The most common lead free alloy for hand soldering applications is tin-silver-copper. The melting point for this alloy can be up to forty degrees C higher than tin-lead – which becomes liquid at 183 degrees.

This **particular lead free** alloy typically contains 96.5% tin, 3% silver and .5% copper. Tin-silver-copper has a melting point of about 217 degrees C. Your company will have already selected the specific lead free soldering alloy it will be using for hand soldering applications. It's important to become familiar with its characteristics.

Lead-free solder alloys tend to have a stronger surface tension – meaning they are more difficult to spread along the surface of the connection than their tin-lead counterparts. Although studies have indicated that lead free solder joints can be as reliable as tin-lead, there are definitely challenges to implementing the process. Here are some things to be aware of.

Components and circuit boards need to be able to withstand potentially higher soldering temperatures. Solder defects may increase due to poor wetting, and may create more rework. Fluxes will need to clean surfaces more aggressively and will need to function properly at higher temperatures. That's because there's more possibility of oxidation, and potentially longer soldering times because of the higher melting temperature. The more active fluxes, in turn, may **also** require a more thorough cleaning process to remove the more aggressive (and possibly still active) **flux** residues.

Finally, the solder joints may have a different appearance depending on the lead free alloy used. The appearance of the connection may be **visually** disturbing to inspectors, but solder joint *graininess* has never been a problem or a reliability issue. Just because it looks different doesn't make it bad.

In addition, the amount of time solder takes to *harden* can also affect the strength of the solder joint. If a solder joint is cooling and the solder is not yet solidified… any bump or vibration can break, loosen or otherwise damage the electrical and physical properties of the solder connection. The result is often called a *disturbed* solder joint. If the solder appears *wrinkled* or *distressed* – this usually indicates a mechanical weakness – which can eventually cause electrical failure.

Another variable is the **flux** contained *inside* the solder wire. Most of the solder that we use for hand soldering has a *core* of liquid flux. Flux cored solder is like a *tube* that releases liquid flux, similar to a garden hose full of water. Flux has 3 main purposes…

Its first and most important job is to *remove light oxides* or *contamination* from the metal surfaces to be soldered. The metals to be soldered may *look* perfectly clean … but most metals will quickly *oxidize* whenever they are exposed to oxygen in the air. You might think of *flux* as a special kind of *soap* that removes *oxidation* or *cleans metal* **-** so that it can *bond* properly.

The second job of the flux is to prevent the freshly cleaned metals from being *re-exposed* to oxygen in the air – in order to keep the surfaces from *re-oxidizing*. The liquid flux will cover or *protect* the freshly cleaned metal – until the flux is displaced by the solder.

The third job of the flux is to assist in the *transfer of heat* from the tip of the iron to the metals being soldered. As an example, if you were to touch your hand to a hot frying pan, you might get away with it **-** if you touched it very quickly. But if you were to add some *oil* or liquid to this pan, the transfer of heat would be much faster. This should explain how the flux helps to spread or *transfer the heat* from the tip of the iron into all of the metals that it touches.

The hand soldering operation usually happens very quickly, and it's impossible to *see* everything that's going on, since the parts are very small. So let's examine an *animated* hand soldering operation to observe how everything works.

First… the tip of the iron is applied to the *junction* of the land and the lead to be soldered. This starts the heat flowing. Next, a *heat bridge* is formed by touching the solder wire to this same *junction*. This starts the *flow* of the *flux* and the initial melting of the solder. The flux *moves away* from the heat and ahead of the solder **-** over all of the metal surfaces. The heated flux removes oxidation or contamination from the metal surfaces. Everywhere the flux touches, it helps to *heat up* the metals. All of the metal surfaces need to be at the proper temperature or the solder wont bond properly.

Now the solder wire is moved over to the *opposite* side of the land, while the solder and flux continue to melt. Liquid solder will move *toward* the heat. That's why we want the solder to flow from the opposite side of the heat source… otherwise we might not get enough solder to flow over onto the *unheated* side. The flux is pushed along by the solder, as it performs its *cleaning job*. As it moves in front of the solder, it also *floats away* the loose contaminants. The flux and oxides will end up *pooled* around the edges of the land - after the soldering operation is completed. Now the solder is *chemically bonded* or *wetted* to the land and lead - just below the surface of the metals. The tin, lead and copper actually form a new type of metal in the area where they bond - which is called the *intermetallic layer*.

Wetting is a term we use to describe the *adhesion* of the solder to the base metals. *Properly wetted solder* typically *feathers out* to a smooth edge. Nonwetting is where the solder clumps like a *ball* on top of the metal. One way to think of *wetting* is to observe a sheet of copper with water flowing over the surface. If the copper is oxidized or contaminated, the water will *bead up* on the surface – into little balls. After we *clean* the copper and remove the oxidation, notice the difference? In this case we could say that the water *wets* the surface of the copper - rather than beading up into drops. We'll be talking a lot more about *wetting* later in this video… but for now, let's get back to the flux - and learn more about the different *types* of fluxes that you may be using in various situations.

The different types of fluxes used in soldering electrical connections are described in the IPC-J Standard 004. The J-STD-004 separates all fluxes into one of *three Classes.* These *classes* are based on the *activity level* of the flux - which essentially defines how *strong* of a cleaner they are - *and* how *corrosive* they are to metal. Type L stands for Low… Type M indicates medium strength, and H is for -- well… you guessed it.

Type H fluxes may occasionally be used. Type H flux cleans very well but has an extremely *active* or *corrosive residue* that *must* be completely removed from the board. Type H fluxes are used in situations where it is difficult to remove oxidation from the base metals.

Type M fluxes are less *chemically active* than Type H and are also less *corrosive.* Type M fluxes, *must* be thoroughly cleaned off the board to prevent metal corrosion and electrical failure.

Generally speaking, *type L fluxes* are relatively weak cleaning agents, and are practically *noncorrosive* if they are left on the board.

In most cases, *your company* will select the *type* of flux you'll be using - in order to be compatible with their cleaning systems. But it's important for you to understand that *there is a reason* to use only designated flux types - and to follow your company's standard operating procedures for flux usage and cleaning procedures.

The next consideration is the *amount or percentage* of flux contained i*nside* the solder wire. The J-STD-006 has a *table* that lists the *percentage* of flux that different thicknesses or diameters of solder wire may contain. Generally speaking (once again)… the higher the percentage of flux that a solder wire contains, the greater the *cleaning action…* but there will also be *more residue* to clean off the board. As you can see, there are quite a few options in flux selection. *Your company* will decide the specific *type* of flux - and the flux core *percentage* to use for each application.

Flux residue can also be *sticky*… If these residues are not cleaned off of the board right after the soldering operation, they can allow dust and other contaminants to *stick* to them. Some contaminants can *be* electrically conductive. If they are, this can create *electrical leakage* or even a *short circuit.* Flux cleaning techniques will be explained in section 4 of this program.

Now, let's discuss the *size* of the *solder wire.* Solder wire comes in different diameters… which is usually stamped on the end of the roll. Selection of the right diameter is an important part of the hand soldering process. For example, if you were to use a very *thin* solder wire for a *large* connection, it would take a long time to melt the right amount of solder. Keep in mind that after 3 seconds you run the risk of damaging the component or the circuit board. And if you were to use excessively *large* solder wire for a very *small* connection, you might not be able to control the amount of solder that ends up in the joint.

Selecting the correct diameter is something you'll learn from experience. Our recommendation is to pick a diameter that is slightly less than *half the size of the land* that you'll be soldering.

Solder Procedures

Now that you're familiar with soldering tools, solder types and fluxes, let's discuss the nuts and bolts of how to hand solder *through-hole components* onto printed circuit boards. Most *production* soldering is done with automated machines that can make *hundreds* of solder connections all at once. But there are some *heat sensitive components* that can't handle the higher temperatures during *wave soldering. Defective* components may also need to be removed from the board after wave soldering, and a new component hand soldered back in its place. Regardless of the reason for soldering *by hand,* we need to be able to make a strong physical and electrical solder connection that will *last.*

The hand soldering process should always begin by preparing or *tinning the tip* of the soldering iron. We explained earlier how *oxidation* forms on the surfaces of the metals to be soldered. This oxidation will *also* form on the *tip* of your soldering iron. Oxidation acts as a *barrier* or an *insulator,* which means that it can slow down the transfer of heat. An oxidized tip will prevent the rapid transfer of heat into the metals to be soldered. Lead free solder is even more sensitive to a dirty tip than tin-lead solder. Notice the time difference between the *properly tinned tip* and an *oxidized tip* – melting a similar solder connection.

To begin the *tinning process* we'll take the hot soldering iron and wipe the tip 2 or 3 times across a *damp* sponge. This will remove impurities and oxidation but it shouldn't *cool* the tip too much. If the tip is wiped excessively -- if it's gouged around in the sponge -- or if the sponge is too wet, the tip could become too cold to use for soldering *or* tinning.

Now let's apply some *flux cored solder* onto the tip. The flux inside the solder will flow first, and *chemically reduce* the oxides from the tip. Then the solder will flow over the tip and form a *shiny coating.* This tip is now *properly tinned.* Tinning is especially important on *brand new* soldering iron tips. Every time you install a *new tip*… it's important to tin it right away - or it may become un-tinnable and unusable. Tinning should be *repeated* as often as necessary.

Whenever you can see that the tip is no longer clean and shiny, you've waited too long to re-tin. Heat can cause soldering iron tips to become *so oxidized* that they become unusable. It's a good practice to melt some solder onto the tip - whenever you plan to let the iron sit for any length of time. This solder coating will keep oxygen from reaching the metal tip - to protect it from severe oxidation. It's also a good practice to turn the iron off when it won't be used for an extended period.

On some irons, oxidation can also form on the *barrel,* which is the area between the tip and the handle. If it's not removed, the oxidation on the barrel can *also* slow the transfer of heat to the tip - and keep it from quickly reaching the soldering temperature. Oxidation can be removed from the barrel with fine abrasive or a wire brush. Brushing should be done *away from the workstation surface* to avoid contaminating your work area.

After we've prepared the tip of the soldering iron, we should be ready to start the soldering operation. We'll be using a *temperature controlled* soldering iron with a *chisel tip*. The temperature of the tip will be set at 315 degrees C. Our solder will be 96.5 percent tin, 3 percent silver and .5 percent copper - with a 0.79 mm diameter. The flux in the core of the solder will be Type M - or *medium activity.*

To demonstrate the basic technique, we'll be soldering a *round component lead* into a *plated through-hole.* Normally this type of soldering operation would only take a few seconds to complete… But we'll be *stopping* the process in order to explain everything that happens as we go along…

We begin by *gently* placing the cleaned and tinned soldering iron tip against the lead and the land. This will transfer heat into both of these parts. Now the solder wire should quickly touch the tip of the iron - to melt *just enough* solder and flux to form a *heat bridge* between the metals. Then we'll move the solder wire over to the *opposite* side of the joint - still touching both the lead and the land. When there's enough solder melted into the connection, the solder wire is removed – followed by the soldering iron tip.

At this point, it's important to clean the connection if required. Then we'll *inspect* the joint to make sure it looks right. A *preferred* or *target* connection is where all of the metals are covered by solder and the *outline of the lead* remains visible within the solder connection. Notice that the tin-silver-copper alloy is *grainier* in appearance than the tin-lead solder joints you're used to seeing. This graininess is caused by the higher melting temperatures and is generally considered a cosmetic issue.
Here's what that same operation would look like at normal speed. Notice how quickly this all happens…Let's review the process once more - to highlight some of the problems to *avoid* during hand soldering.

The tip should *lightly* contact both parts to be soldered. Pressing down firmly with the tip will *not* transfer the heat faster… but it may damage the *land* or the base material. Only a *small* amount of solder should be melted against the tip of the iron. If you melt *all* the solder by touching it directly to the tip, you may not get enough solder to flow onto the *other side* of the connection. Remember that solder flows *toward* the heat – *flux* flows away.

Another problem is melting too much or too little solder into the connection. If you don't remove the solder wire at the right time, you could end up with something that looks like this. This time we removed the iron tip *before* the solder wire… now we'll have to *reheat* the joint in order to remove the solder wire.

Notice what happens when we *reheat* a solder joint? It looks even grainier than it did before. Now let's see what happens when you reheat a solder joint *using flux*… In this case, the solder appears the same as it did before. Whenever you melt solder, you always need to *add flux* - either through the core of the solder wire - or with an external applicator.

Now let's look at the *correct technique* one more time…There's a lot happening in just a few seconds. The parts to be soldered are heated, cleaned by the flux and joined together to form a *physical* and *electrical* connection. You probably noticed that we soldered on the *solder source* or *secondary side* of the board - away from the electronic components. This is done to minimize the amount of heat that reaches the components.

If there is a particular component that is especially heat sensitive, a *heat sink* or *thermal shunt* should be used to help absorb the heat. This *thermal shunt* is attached to the lead – right near the land - to prevent excessive heat from damaging the component.

On *multilayer* boards that are extremely thick - or have heavy internal *ground or power planes* - it may be necessary to *preheat* the entire assembly *before* hand soldering. Preheating brings the base material and the parts to be soldered up to a temperature *closer* to soldering temperature. This helps to make the soldering operation go a little faster… and it also reduces the *temperature shock* to the *base material*.

Another way to speed up difficult soldering operations is to apply heat to *both* sides of the hole at the same time. This can help transfer the heat all the way through the hole much faster. During this procedure, the solder should only be applied to *one* side of the connection.

Cleaning

Let's begin this next section with a discussion about removing or *cleaning flux residues.* Earlier in the video we mentioned that flux residues can be both *sticky and corrosive* if they're not removed from the board.

Before we discuss *any* flux cleaning techniques, it's important to note that there are *special fluxes* that are designed to be *left on* the board. The idea here is to eliminate the time and expense of the flux cleaning process, and reduce the usage of various chemicals that can degrade our environment. IPC has an entire video devoted to the specific hand soldering techniques associated with these *No-Clean* or *low residue* fluxes. If you're using *low residue fluxes*, you can safely skip the flux cleaning process.

On fluxes that *require* cleaning, the general idea is to remove the flux residue *right after* the hand soldering operation - by *brushing* the area with the appropriate cleaning solution. *Your company* will select the right cleaning fluids… which may be *water* based - or *solvent* based - depending on the *type* of flux being used. This cleaning operation should always be performed *immediately* after the hand soldering operation. If it's not done right away, the flux residue will harden and become very difficult - if not impossible to remove.

An absorbent - lint free – and ESD safe tissue is often used to remove the solvent - so the residue doesn't just spread around the board. Even after this type of cleaning process, some of the flux may be trapped underneath the components – and some may remain as an invisible film. If a *high level* of cleanliness is required, additional *machine cleaning* will be necessary. There are *water based* and *solvent* cleaning machines to *re-clean* the entire assembly. Again, your company will select a cleaning system that is compatible with your flux.

There are some assemblies and specific component types that can be damaged by cleaning fluids. Always make sure that the assembly is completely safe before sending it through any type of cleaner. Because each company sets its own procedures based on customer needs and the particular flux they use, there are many variations in cleaning methods, tools and materials. You may want to pause this video now to discuss your company's policy for removing flux residues from electronic assemblies.

Acceptance Standards

In this final section we'll be examining the qualities of a typical lead free hand soldered connection - for a through-hole component. Then we'll look at some of the *variations* that may or may not be acceptable.

Remember, earlier in the video we discussed the concept of "wetting". Notice how the solder *feathers smoothly* onto the land… and up onto the lead. The solder fillet is curved inward - or *concave.* The solder *covers* all of the land, and the lead. The *texture* is a little bit *grainy*. The outline of the lead is visible beneath the solder. The amount of solder here is just about perfect. This is good example of a *preferred* or *target* through-hole solder joint.

Here's one now - with a little *less* solder… You can see that the *wetting* is still good… and the coverage is even. The fillet is concave. This solder joint is perfectly acceptable - even though there is less solder in the connection. Now here's another one – with *quite* a bit more solder. The important thing to notice is the *angle of contact* between the solder and the metal.

Proper wetting is indicated by a solder contact angle of *less than 90 degrees* – which is a *square* or *right angle.* The *lower* the contact angle, the better the *wetting.* As you can see, there is a *range* of acceptable solder joints. You *will* be expected to know an acceptable solder joint from a defective one – before you begin soldering. This video will introduce you to the basic concepts about what to look for… but a more detailed study is recommended *before* you begin working as a soldering technician. There *is* a lot to learn… but the basics are pretty easy to understand.

Now let's look at some solder joints that are considerably less than *ideal*…

This is a *cold* solder joint. Notice that the surface of the solder is even duller and grainier than a typical lead free joint. This is usually caused by insufficient heat.

This is a *disturbed joint.* You can see that the solder shows *stress lines*, similar to the foothills in a mountain range. *Movement* during the cooling process can cause this condition.

This is a *fractured joint.* The lead may have been moved after the solder solidified. Clipping the lead too close to the solder can sometimes fracture the joint.

Here we have a *burned board.* This was caused by contact with a hot soldering iron, or too long a dwell time at the proper temperature. *Dwell time* is the length of time the soldering iron is in contact with the connection. These are some additional examples of thermal damage.

And this is a *lifted land*. Lifting can be caused by pushing or pressing down with the hot iron. Failure to allow cooling between heat applications can also result in a lifted land. Lifting can also indicate that the iron was left on the board for too long, or that too high of a temperature was used.

This joint has *excessive solder.* The fillet is not concave and there is solder flowing over the edge of the land. Excessive solder can also be detected when solder touches the component body or violates electrical clearance.

This condition is called *solder bridging.* A bridge is an *electrical path* that was not intended.

Here is a *solder projection,* also known as an *icicle,* or a *peak.* These are typically caused by excessive solder or insufficient flux, and by the iron being too cool… or being removed too quickly.

These are *solder balls.* They can create electrical *shorts* - by lodging in between conductors or component leads.

Here's an example of *non-wetting*. The solder does *not* feather to a thin edge… and some of the base metal is partially exposed.

Another type of imperfection is the *blowhole.* These are usually caused by gas escaping through the solder as it solidifies. If there is any moisture or solvent inside the hole - or excess flux - this can create a *blowhole* as the gas expands and escapes.

There are several types of cosmetic imperfections – such as *fillet lifting* and *tears* that are more likely to occur in a lead free process. It's important to understand that these types of conditions typically won't affect the strength of the mechanical and electrical connection of the solder joint. Although some of these conditions are *always* unacceptable - many of these imperfections could be allowed - in various degrees - depending on what type of product they might be used in. For example, we'd all expect that *any* aircraft or medical electronics would be highly reliable… but we may be able to live with some minor *cosmetic imperfections* in a portable CD player - as long as the product works. Tighter requirements generally mean higher prices. For consumer products

- where the idea is to keep the *price* down - the solder joints can tolerate a bit more variation from the ideal.

The J-Standard 001 has three *classes* of requirements, based on the final use of the end product. Class 1 is for *consumer* products, Class 2 is for *business* and *computer* products, and Class 3 is for high reliability electronics - where failure is *not* an option. The *specification* and the *class* of requirements that your company uses to inspect lead free solder joints will be clearly explained to you.

Some companies build a wide range of products with different requirements. Other companies build only *one* class of product. Part of your job is to make sure to always apply the *right* criteria to each assembly.

Although we've covered a lot of information in this video, a good through-hole solder joint is fairly simple to make. Now it's time to put this knowledge to work - to begin developing *your* hand soldering skills.