6. Serviceable Design

Real pinball machines have numerous design elements that are there purely for the sake of serviceability - that is, to make the machines easier to repair, upgrade, and maintain. These features are often the products of a series of refinements that wouldn't have been obvious without experience, and a lot them are hidden, internal features that you wouldn't even realize are there when you're just playing the games.

It's not surprising that serviceability is such a high priority for the pinball manufacturers when you consider who their customer is. The thing to realize is that players are *not* their customer. Players are only the "end users". The *customer* is the commercial operator who buys the machines for their arcades and routes. The player mostly wants machines that are fun to play. An operator certainly cares about that, too, because an arcade game earns quarters by being fun to play. But what the operator cares even more about is high reliability and low repair costs. A machine that's down for repairs isn't earning quarters no matter how much fun it is.

Some of things that they do in real pinball machines to make them serviceable translate readily into the world of virtual cabs, where we can copy them to get the same benefits. But new virtual cab builders are often unaware of how the real machines work, so they don't know there's a good design they can copy - instead they make things up as they go. And of course the first time you build *anything*, you're likely to come up with quick-and-dirty ways to solve immediate problems without considering the longer-term costs. So I want to point out a few of the serviceability features in the real machines that we can leverage for virtual use, so that you're aware of them, and so you can keep them in mind as you plan your build.

What makes a machine serviceable

Before we get to implementation details, let's look at what serviceability really means in the abstract. These are what I consider the key goals of a serviceable design:

- Accessibility. You should be able to access everything in the machine easily, without having to destroy anything, without having to de-construct anything, and ideally without any tools.
- Modularity. You should be able to remove and replace most individual parts or subsystems without having to destroy anything, and with as little work as possible. Electrical connections should be pluggable, for example, rather than being hard-wired or soldered; parts should be secured with removable/reusable fasteners like screws, rather than permanently glued or nailed.

Specific recommendations

With the abstract goals above in mind, here are some concrete recommendations for how to achieve them, based in part on how the real machines accomplish the same ends. Things are different in a virtual cab, naturally, but some of the ideas from the real machines carry over surprisingly well.

Liftable playfield

The real machines are set up so that the playfield can be tilted up from the front and lifted all the way up to lean against the backbox. This lets you access the entire interior of the main cabinet and the entire underside of the playfield *without taking anything apart*. It's like popping the hood of a car to get to the engine. It lets you get in and out quickly. Minor jobs remain minor because it only takes a few seconds to open the machine up.

In my opinion, this is the ideal way to arrange a virtual cab as well. Accessing the interior of the main cabinet is at least as important in a virtual cab as a real machine, as that's where we typically install the PC motherboard and most of the feedback devices. In the virtual cab, it's the main TV (in place of the playfield) that needs to tilt up and out of the way like a car hood.

This is why I always advise against any design that involves the main TV being difficult or impossible to remove, such as installing the TV in routed grooves along

the side walls.

Removable TVs

On the real machines, the playfield not only tilts up and out of the way, but can also be removed entirely. They even make this fairly easy: the playfield isn't actually permanently attached, but is only resting on the pivots that let it tilt up, so remove it is just a matter of lifting it off the pivots.

In a virtual machine, it's equally important to make the TVs removable. They are of necessity at the very front of every part of the machine, so you need to get past them to get to anything else. If it's hard to remove any of the TVs, it's hard to service what's behind it.

For the playfield TV, the ideal as far as I'm concerned is to installed it analogously to a real playfield, with the same ability to tilt it up for smaller jobs and remove it entirely for larger jobs.

The backbox TV(s) should likewise be removable, and like the playfield TV, this should be possible without a lot of disassembly and certainly non-destructively (meaning you shouldn't have to rip off the sides or cut any new holes anywhere).

If you're using a separate DMD TV, that should of course be removable as well. This one is usually easy to make modular, at least, since it's so small.

Foldable backbox

On the real machines, the backbox is attached to the main body with a hinge that lets it fold forward, so that it lies flat on top of the main cabinet. This is a key feature to make it practical to transport the machine, since it's too tall, top-heavy, and fragile to move it with the backbox upright.

Some pin cab builders figure that they can just remove the backbox if they ever need to move the machine. Consider the amount of wiring that you'd have to disconnect to do that, and the risk of breaking something when redoing the wiring. If a folding backbox is impossible because of the geometry of your backbox TV, then at the very least, be sure that the wiring connectors are all modular, so that it's quick and reliable to reconnect the wiring.

Modular wiring connectors

Real pinball machines have lots of wiring internally, with many interconnections. (Stern Pinball has estimated that there's about half a mile of wire in a typical Stern machine from the 2000s. It might even be a bit higher in the 1990s machines, since they used lower-tech electronics to implement a similar feature complexity.) The real machines deal with their many connection points mostly by using plug-and-socket connectors.

In the 1990s machines, they made heavy use of a few different connector types made by Molex. You see the term "Molex connector" used almost generically as though it referred to some specific physical plug type, but it's actually a particularly unhelpful term when you're searching for parts. Molex the company makes a huge array of diverse connector types, so "Molex connector" can refer to all sorts of things. If you want to be helpful when describing a particular connector to someone, you need to give them a Molex part number or at least the Molex product line name.

Pluggable connectors of the sort used in the real machines have two important virtues:

- You can easily connect and disconnect them at any time
- You can't get a connection wrong when re-connecting something, because the plug only fits in the one place where it's supposed to go

Most virtual pin cab builders intuitively recognize the important of modular wiring - of using some kind of removable connectors rather than soldering everything together permanently. But many new pin cab builders gravitate towards screw-terminal blocks, and in my opinion, those don't quite achieve the full goal here. Terminal blocks do avoid the need for permanently soldered connections, so they address the first point above right, but they miss the mark on the second point. Consider what happens if you have a couple of terminal blocks for wiring a particular part, and you disconnect the wiring: where do the wires go when it's time to reconnect them?

Proper pluggable connectors of the sort we're talking about are definitely a bit more work to set up than screw terminals. But they're great once they're in place, because you can arrange things so it's practically impossible to plug things in the wrong way. These connectors can also be time-consuming to select during the design phase, because there are so many options available. I'm convinced you could build a nice engineering career on a solid knowledge of the Molex catalog and of which connector to use when. I've tried to make your job here a little easier via pointers to some good basic options in Chapter 80, Connectors.

There are three clever techniques used in the real machines to make the connections "idiot-proof", which are worth cribbing when you're wiring your virtual cab:

- Whenever possible, use a unique connector type. It's impossible to plug a nine-prong Molex .062" plug into an eight-prong socket. If there's only one nine-prong Molex .062" plug and one nine-prong socket in the whole build, that's one connection that you can't plug back in to the wrong place.
- Wherever you have to use the same connector type more than once, use a "keyed" connector. That means that you snip off one pin on the plug side, and block the corresponding socket on the receptacle side. If you try to plug the wrong 9-pin plug into the wrong 9-pin receptacle, that wrong plug won't have the right pin clipped, so it won't fit into the blocked socket.
- Use plug-and-socket connectors that only plug in one way, so that you can't accidentally plug something in backwards. You get this benefit automatically for connector types that have asymmetrical shapes. All of the Molex .062 and .093 connectors are inherently designed this way, for example.

7. Selecting a Playfield TV

For most cab builders, the playfield TV is the most important piece of hardware in the system. A pin cab is, after all, fundamentally a video game. The weight of this importance makes it tough to decide on the perfect TV, but it's even more complicated because of the physical constraints of a pin cab, and the special performance demands of video gaming.

I'd love to simplify this by offering a list of Amazon "buy it now" links for the best TVs for the job. Unfortunately, I really can't, because any such list would be out of date by the time you're reading this. TV product life cycles are only about six months these days.

In fact, even "real time" recommendations on the forums can go stale quickly. If you talk to someone who already finished their project, they probably bought their TV at least a few months ago, so their particular model might already be hard to find. Your best bet is usually to share notes with other people who are out shopping right now.

Since I can't give you a list of models to choose from, I'll instead try to offer some advice to help you figure out what to buy. This section attempts to answer the questions that new pin cab builders often have when looking for a TV (and maybe answer some questions you didn't know you should ask).

Note that this chapter is about *selecting* the playfield TV. We'll get into the details of actually installing it later, in Chapter 29, Playfield TV Mounting.

Size constraints

Whatever else you look for in a TV, it has to fit your cabinet. Obviously that means it can't be bigger than the available space. Most people want a TV that's as big as possible within that constraint, to minimize any "dead space" not covered by the TV image.

There are two ways to approach this problem of finding the ideal fit:

- Pick a TV that fits your cabinet
- Build a cabinet that fits your TV

Most people go with the first approach, because they've already decided to use the standard dimensions of a real pinball machine. Using standard dimensions is important if you want it to look authentic, since the real machines all come in about the same size and have recognizable proportions. Building to a standard size also lets you use off-the-shelf pinball parts for your cabinet hardware (lockdown bar, side rails, legs, and so on), which is another key part of making it look authentic.

Not everyone feels compelled to use standard dimensions, though. If you're doing your own woodworking, you can tailor the machine's dimensions for a custom fit to any TV of your choosing. This gives you more flexibility in picking out a TV. The tradeoff is that a non-standard size and proportions can harm the illusion that it's a real machine. You'll also need to buy custom parts for some of the cabinet hardware, since off-the-shelf parts are sized to fit the standard cabinet widths and lengths. Custom parts are almost always more expensive than standard parts and can be harder to find.

In either case, whether you're picking a TV to fit your cabinet or sizing your cabinet to fit a TV, the dimensions that matter are the **inside width** of the cabinet and the **exterior height** of the TV. You're going to turn the TV sideways to mimic the layout of a pinball playfield, so the height of the TV has to fit across the width of the cabinet.

Note that the **width** of the TV isn't a constraint in most cases. Normal pinball playfields are considerably more elongated than 16:9 TVs, so any TV that fits into the available cabinet width will easily fit front-to-back, with room to spare.

Leftover front-to-back space

As mentioned above, a 16:9 TV will fit front-to-back in a normally proportioned cab with room to spare, meaning there will be some extra space that the TV doesn't fill. Assuming you find a TV that's nearly as big as possible for the cabinet width, the extra space will amount to about 6" in a standard body cabinet, and about 7" in a widebody.

Some people are bothered by that leftover space, and some aren't.

Before you decide that it's a problem, consider that you can put the space to good use. If you're using a plunger, it will jut into the front of the cabinet by about 3", which might necessitate moving the TV back that far. You can fill the gap that creates with an "apron", similar to on a real pinball machine, with an instruction card and price sheet. A 3" apron at the front still leaves 3" to 4" at the back. This is an ideal place to put a row of flasher domes, for bright lighting effects during play.

Some new cab builders get very fixated on the idea of covering every available millimeter with video display, and especially hate the idea of any extra space at the front. They insist on having the TV start exactly zero millimeters from the lockbar. I understand this instinct; I had the same thoughts myself when I was first building my cab and discovered the space conflict between plunger and TV. I ultimately decided that the plunger was important enough to justify the space at the front. Once I had everything assembled, I found that it makes absolutely no difference when playing to have the TV set back a few inches. If you think about it, you'll see why: your brain pays attention to the parts of the visual field where the action is taking place, and essentially makes you blind to the rest. It's the same effect as when you're watching a movie: you really don't see the curtains around the screen, you just see what's on the screen. A few inches of "curtains" in the form of an apron won't even register visually during play.

If you're still absolutely certain you can't live with any leftover space front-to-back, there are a couple of options for eliminating it:

- Build your cab to a non-standard size, shortening it from the standard length to eliminate the excess space. This can make the proportions of the finished product look unusual or "wrong" if you're used to seeing the real machines, but that doesn't bother everyone, and some cab builders prefer that to the excess space. A non-standard length also means you can't use a standard pinball glass cover or side rails.
- Use an ultra-wide TV instead of a 16:9 set. A few TVs are available with 21:9 aspect ratios. That's actually even more oblong than standard playfields (which are about 18.7:9), so it goes too far the other direction, but you could tuck some of the extra TV length into the area under the backbox.

  This approach has some downsides. For one, it's hard to find ultra-wide TVs in our size range. The format never caught on with consumers, so there aren't very many models available. For another, you might be making things hard on

yourself when it comes time to setting up software. Almost everyone uses 16:9 TVs or monitors for playing pinball, so most of the software assumes that layout.

Picking a TV based on cabinet size

If you're basing your design on a pre-determined cabinet size, you need to pick a TV that fits the cabinet.

TV sizes are always stated in terms of the "diagonal" size, which is the distance between diagonal corners on the display area. However, recall that the relevant dimension for fitting to a pin cab is the TV's **height**. How do you translate between height and diagonal size? You can get a rough approximation using this formula:

$$D = 2.04 \times (W - 1)$$

W is the inside width of the cabinet in inches (the distance between the inside surfaces of the cabinet side walls), and **D** is the nominal diagonal size in inches of the biggest TV that will fit. This formula assumes a ½" bezel all around.

But that's only an approximation, because manufacturers always round the diagonal size up, and because the the size of the bezel varies from model to model. So use the formula as a guideline, not as an exact specification. Shop for TVs with a stated diagonal size within an inch (plus or minus) of the size you get out of the formula. Then check each TV's specifications to get its actual height.

When you're looking at the TV specs, the one to pay attention to is usually called "height without stand". Most flat-screen TVs come with a stand that you can choose to attach or not. In our case, we won't need it, since we're going to lay the TV on its back rather than stand it up on a tabletop.

Applying the formula, we get the following results for the standard cab dimensions:

Type	Cab inside width	Max. TV size (diagonal)
Standard body	20.5"	39.8"
Wide body	23.25"	45.4"

So if you're building a standard body cab, you should be able to fit most 39" TVs, and possibly a 40" TV, if it has a narrow enough bezel. For a widebody, you can fit about a 45" TV.

Building a cab around the TV

If you're willing to customize your cab dimensions to fit your TV, you're much less constrained in your TV options. You can go out and find the perfect TV first, then measure it and design your cabinet plans around the TV's dimensions.

I'd recommend adding ¼" to ½" to the exterior height you measure for the TV to get the cabinet inside width. This will give you a little extra room for getting the TV in and out of the cabinet.

Remember that the TV height determines the **inside** width of the cabinet, but most other dependencies are tied to the **outside** width. The width of your lockdown bar, front and back cabinet walls, and glass cover all depend on the outside width. If you're using standard ¾" plywood, the outside width will be 1.5" wider than the inside width.

Custom-width cabinet hardware

There are two main pieces of cabinet hardware that depend on the cabinet width: the lockdown bar and the glass cover.

You can buy a custom-made lockdown bar with a tailored width from VirtuaPin and others. Search for "custom lockdown bar". The prices on these are about twice the price of the standard lock bars, but it will let you create an authentic look for your custom cabinet.

You won't be able to find custom-width playfield glass from pinball vendors, but it should be easy to find locally from any window glass shop. Ask for 3/16" tempered glass. Window glass vendors should be able to cut this to any custom size for you. Alternatively, you can use acrylic (plexiglass), which you can buy in custom sizes from local vendors like TAP Plastics.

Squeezing in a too-big TV

The perennial question that new cab builders ask is: how do I cram in a TV that's slightly too big for my cabinet design?

Part of the reason this comes up so often is that you can't buy a TV in just any size. You can only buy a size they actually sell. It's unlikely that you'll find a TV for sale that's a perfect fit to any standard cabinet plans. So you have two options: (a) you can pick a TV that's slightly smaller than the ideal, which (being smaller) will easily fit, but which (being smaller) will leave an unsightly gap around the edges. Or (b) you can pick a TV that's slightly bigger than ideal, and find some "hack" to make it fit.

The other part of why this comes up so often is that most new cab builders hate option (a) and believe they won't be happy unless they find a way to cram in a too-big TV.

My advice is to suppress your knee-jerk reaction to option (a). When we were considering the related problem of the leftover front-to-back space earlier, I mentioned that you won't really notice the space while playing, because your brain tends to focus so much on the action and ignore the periphery. Well, the same thing applies to leftover space side-to-side. Despite what your instincts might tell you, it really won't make much of a difference during play if you leave a little blank space on each side of the screen. In fact, if you look closely at real pinball machines, you'll observe that they give up about half an inch on each side of the playfield for wood rails around the perimeter.

What you gain by going with the "next notch down" option is an easy fit, a simpler design, and the ability to maintain easy access to the cabinet interior after the TV is installed. I consider these to be important features.

Okay, I tried. I know some people just can't be convinced of this. So what if you have your heart set on a TV that's a little too big? Is there any way you can squeeze it in without redesigning the whole cab? Yes, there are some options.

De-case it

One approach is to "de-case" the TV - remove the outer plastic case and just use the internal LCD panel.

A few years ago, this was practically a standard practice among cab builders. At the time, the plastic cases were quite a lot larger than the panels inside, so the only way to get a reasonable fit was to take the cases off.

Times have changed, though, and most cab builders now leave their TVs intact. There are two main reasons for this. The first is that cases have shrunk to the point where they're practically no bigger than the panels inside, so de-casing doesn't offer a meaningful size reduction. The other is that many newer TVs simply can't be de-cased without damage. The way manufacturers have managed to make modern cases so svelte is that they've removed the internal supports that made older models bulkier. That means the cases themselves now have to serve as exoskeletons that hold everything together. There's a big risk of cracking the delicate glass panel that holds the LCD elements if you remove the structural support provided by the case.

I'd advise against de-casing for any newer set. If you want to attempt it despite the risk, I'd try to get advice first from someone who's disassembled the same model. The pin cab community is small enough that you probably won't find anyone there, so you might try casting a wider net. For example, perhaps look for someone who's successfully repaired the type of TV you have.

Route grooves for the TV

Another way to make a slightly-too-big TV fit is to make the cabinet a little wider on the inside, but only where the TV goes, by routing out grooves in the side walls wide enough for the TV. Here's how this might look:

I'm not a big fan of this approach for two reasons. First, it weakens the side walls. Second, it makes it much more difficult to remove the TV if you want to access the inside of the cabinet for repairs or upgrades. I see easy access to the interior as a top priority. If you use routed grooves, you'd have to remove either the front wall or the back wall of the cabinet to take out the TV, and to do that you'd have to take off the legs. That's enough to make me rule out this approach if it were my own cab.

A similar alternative is to route out grooves like this all the way to the top of the side walls. That would at least let you remove the TV from the top, but it would weaken the walls even more than simple grooves.

Despite my strong reservations, routed grooves like this are fairly popular among cab builders. But the tradeoffs are too onerous for me to recommend this approach.

Use thinner plywood

Rather than routing grooves, you could simply use thinner plywood for the walls. That would increase the inside width without changing the exterior dimensions. You'd still be able to use off-the-shelf hardware (like the lockbar), since that's all sized according to the exterior width.

One downside of this approach is that the cabinet would obviously be a little less sturdy. But that's probably okay for home use, since your cab won't have to stand up to the punishment a public arcade machine receives. The other downside, probably more important, is that flipper buttons and some other parts are sized for the plywood width, so you'll have some ill-fitting parts to deal with.

Also, keep in mind that you'll have to make adjustments to the carpentry if your plans call for miter joints or the like. Joint dimensions will depend on the plywood width.

TV features and performance

So far, we've been focused exclusively on picking the right size of TV. But that's hardly the only criterion. You also want a TV that displays a good image, and one that works well for games, which have somewhat different characteristics from ordinary video sources.

Let's look at some of the specific features to consider, and the performance metrics you should pay attention to.

1080p vs 4K vs 8K

1080p HD TVs were the standard for pin cab playfields for a long time, largely because that was the highest resolution we could get in this size range. Starting around 2017, though, the industry starting moving towards the "Ultra HD" standard, also known as "4K". And in mid 2019, an even newer generation known as "8K" has started to become available.

The difference between 1080p, 4K, and 8K is pixel resolution. In other words, the pixels on 4K sets are smaller than on 1080p sets, and the pixels on 8K sets are smaller still. A 4K set has four times the number of pixels per unit area as 1080p, and 8K has four times the pixels per unit area as 4K. The smaller the pixels are, the harder it is for the eye to discern individual pixels; smaller pixels blend together better to make a more realistic image.

Higher pixel resolution comes at a cost in performance, though (in addition to the higher dollar cost). More pixels means more work for the PC. The PC has to fill in every pixel on the display on every video frame, so the larger number of pixels means the PC has to do more computation on every frame. If you use a 4K TV, you'll need a more powerful CPU and graphics card to keep up with the higher computational load. So if you want to use 4K, you'll need a more powerful and thus more expensive computer rig. 8K likewise requires a more powerful computer than 4K.

Recommendations

If I were building a new cab right now, I'd go with 4K for the playfield TV. It's well supported by the operating system and pinball software, and the price premium for a 4K TV over a 1080p TV isn't that large. You will have to spend more for a 4K-capable video card, but even that is entering the mainstream, and enough options are available that the price doesn't have to go into the stratosphere.

I wouldn't go as far as 8K right now, though. It's much more expensive than 4K right now, and I'm skeptical that it will even make much of a visible difference in a pin cab application, since at this viewing distance, 4K is already approaching the limits of the human retina's ability to resolve pixels. (Although I'm sure some people will be able to see the difference.)

Finally, on the off chance you come across a 720p set, skip it. 720p used to be common in this size range; it's almost extinct at these sizes now, but you might still see a few on sale. They're cheap, but they're really not suitable for the playfield. 720p simply isn't adequate resolution for the viewing distance of a playfield TV. (720p *is* generally just fine for a backglass TV, though. That's a smaller TV at a greater distance, and the graphics it displays aren't as demanding.)

LCD, LED, QLED, OLED

There are currently two main display technologies available: LCD and OLED. There's also an older flat-panel technology called plasma that's not currently being manufactured, but you might still see used sets or remainders available. Here's a brief overview of each panel type.

LCD: This is currently the most common display type. An LCD panel uses liquid crystal pixels that can range between (almost) opaque and (almost) transparent. A backlight is placed behind these pixels. When the liquid crystal turns opaque, it looks black (or at least dark gray) because it's blocking the light from the backlight. When it turns transparent, it looks white because it lets (most of) the light from backlight through.

LED: This is really the same thing as an LCD TV, but it uses an LED-based backlight instead of the fluorescent backlights used on older LCD TVs. "LED" is a marketing term that the manufacturers use as an intentional bit of misdirection, because they know that consumers think of LCDs as an older, boring technology. But an LED TV actually is an LCD TV by a different name.

QLED: This is yet another marketing term for an LCD TV. In this case, it's an LCD panel with a special type of LED backlight called a QLED or quantum-dot LED. Quantum sounds even more cutting-edge than LED, doesn't it?

All of these LCD TV types, whether the manufacturers call them LCD, LED, or QLED, are fundamentally the same backlight-and-shutter design. The fundamental weakness shared by all LCD panels is that the shutters can't turn 100% opaque, so they can't display true blacks, just varying shades of dark gray. Some panels are better at this than others, and it's one of the big quality differentiators among LCD

models. LCD panels also have inherent limits on viewing angle because of the way light has to be funneled through the shutters. Again, some models are better at this than others.

The backlight type does make some difference. LED backlights generally produce better color fidelity than fluorescent tubes did, and they use less power and run cooler. All of that is great for a pin cab, so if you're considering an LCD TV, I'd definitely give priority to the LED models. But you'll hardly have to even think about that since practically all of the TVs in this size use LED backlights. QLED backlights supposedly have even better color fidelity than regular LEDs, according to the manufacturer's claims, but I haven't seen any independent testing confirming this.

OLED: This is a truly is a different display type, not just a variation on the LCD. An OLED panel is an array of small "organic LED" pixels, each of which can be turned on or off individually. There's no backlight, since the OLED pixels emit their own light directly. ("Organic" doesn't mean that they grow them without antibiotics and pesticides, but rather refers to the chemical components making up the emitter.)

On paper, OLED has big advantages over LCD. Producing light at the pixels rather than blocking light with a shutter allows for true blacks, which makes for higher contrast and better-looking images. Emitting light directly at the display surface (rather than blocking light from a backlight) allows for unlimited viewing angle. However, OLED is still a relatively immature technology, and reviews of current models are mixed. There are several potential drawbacks. The first is brightness: current OLED models are only about half as bright as LED-backlit LCDs. The second is display lag. Console gamers have reported substantial lag in many available OLED sets. A third is "burn in", where pixels get "stuck" if a static picture (like a pinball playfield!) stays on the screen for too long at a time. Early OLED models also had problems with pixel lifetime, which was particularly problematic in that the color components in the pixel can degrade over time at different rates, causing the color balance to change as the panel ages. Newer OLED panels will probably have better longevity and color stability, but I'm not sure the problem has been completely solved yet. In any case, don't dismiss OLED because of these concerns. These are just things you should dig into when you're researching models. These concerns might disappear entirely over the next few model years as the technology matures.

Plasma: There used to be yet another display technology known as plasma. These used gases trapped in tiny glass cells to generate light. As in an OLED, the individual pixels emitted light (rather than blocking light like in an LCD), so plasmas had many of the same virtues as OLEDs. But they were never as popular with consumers as LCDs, and never as cheap to manufacture, so the electronics companies eventually all stopped making them (the last ones were built around 2015). Plasmas generally had excellent picture quality, but they had a couple of drawbacks for virtual pin cab use. For one, they generated a lot of heat; for another, their glass panels were fragile and not meant to support their own weight when laid on their backs, as we need to do in a pin cab. I'd avoid them for pin cabs as a result. But it's really moot now given that you can't buy them anyway.

Recommendations: Most of your options in our size range will be LED-backlit LCD TVs. Fortunately, that also happens to be an excellent choice for our needs. It's a mature technology that the TV manufacturers have gotten very good at building, so many excellent TVs in our size range are available.

I'd also consider OLED if you can find a suitable model. I think OLED will eventually be a superior option, because the light-emitting pixels are inherently superior to the shutter-based LCD design for producing high contrast and for wide viewing angle. However, there aren't many OLED models available yet, so your options will be limited. They're also more expensive, and the technology might not be mature enough yet to be an ideal fit for gaming. Be sure to look carefully at the concerns mentioned above relating to OLED, particularly display lag and image retention. If you find an OLED you like, do some research on the Web to see if any console gamers have experience with it, since console gaming places the same demands on a TV as virtual pinball.

Flat vs. curved screens

It almost goes without saying, but a pinball playfield is best simulated with a flat-screen display.

This is generally an easy requirement to fill with current TVs, since most LCD and OLED models have perfectly flat screens. But some models are now available with a

convex curvature across the width of the panel. This is supposed to give you a wrap-around effect like in a large-format movie theater. Some people like the effect, others see it as little more than a sales gimmick. Whatever your feelings about it for a living room TV, though, I'd recommend against it for a virtual pinball playfield TV. A playfield TV is oriented in portrait mode, which defeats the purpose any wrap-around effect. The curvature will only serve to distort the geometry of the image.

Input lag

One of the really important differences between video gaming and regular TV viewing is that gaming is interactive. The animation on the screen responds to actions you take in the game. This exposes an element of TV performance that's not noticeable in normal passive viewing: "input lag". This is the amount of time that passes between the TV receiving the electronic signal for a video frame, and the video frame actually appearing optically on the display panel.

Input lag is important (in a bad way) to video gaming because it creates a time gap between when you press a button and when the resulting action appears on screen. If the time gap is long enough for you to perceive, it makes the gaming action feel leaden and unresponsive. You want the flipper to flip the instant you press the button, not a couple of seconds later after the ball has already rolled off the end!

Don't confuse input lag with "refresh rate", "response time", or "pixel cycle time". The refresh rate refers to how many times per second the TV draws a video frame. The response time or pixel cycle time refers to how quickly a physical pixel can change color. These times are important in their own right, because they affect how smooth motion looks on the display. But they're entirely different things unrelated to input lag.

Where to find input lag numbers

I've never seen a manufacturer list input lag in their spec sheets, so you have to dig a bit to find information on it. Manufacturers do often quote pixel cycle times, response times, and/or refresh times, but remember that input lag isn't in any way related to those.

Your best bet for finding concrete data on input lag is console gaming Web sites, since console gamers use regular TVs like we do. One good site is displaylag.com. They measure input lag with special equipment and post the numbers on their site. They have a large database of current models that they update regularly.

What's an acceptable input lag?

Short answer: 40ms or less.

You don't need a TV with zero input lag, and it's impossible to find such a thing anyway. As long as the actual lag time is below a certain threshold, you won't be able to perceive any lag time at all, so anything below that threshold might as well be zero.

Human time perception varies according to context, but for video gaming, the main thing that matters is action/reaction timing. An action/reaction sequence is something like this: You push a button. A light appears on screen. Did the light appear exactly when you pushed the button, slightly before, or slightly after? When researchers do this experiment, they find that time gaps of up to about 50ms are perceived as exactly simultaneous. In other words, humans can't tell the difference between truly simultaneous and about a 50ms delay. It's not a matter of how smart you are or how closely you're paying attention; it's simply a fact of human nervous system physiology. Our neurons can only move signals so quickly, and as a result our brains perceive events that are very close together in time as though they were perfectly simultaneous.

This doesn't mean a TV with a 50ms input lag time is automatically good enough. You don't perceive the TV's lag time in isolation, but rather in combination with all of the other sources of latency in the overall system: delays from the key encoder device, the USB connection, the Windows video drivers, the pinball software itself. The latency from these other components varies, but in a well-tuned system it might add up to around 10 to 20ms. So that leaves us with 30 to 40ms to work with for the TV.

What causes input lag?

Input lag is caused by the internal digital processing that the TV does to the image before realizing it on the display. Most of this is processing that enhances the picture in some way: resolution up-scaling, frame interpolation, sharpness enhancement, noise reduction, motion smoothing. Modern TVs all do these enhancements digitally, by putting the pixels into a memory buffer inside the TV and running some software algorithms over the pixels. The software processing takes time, just like on a PC, and that processing time is what causes the lag.

Note that input lag has nothing to do with the physical pixels, so you can't guess anything about input lag based on what type of panel technology the TV uses. LCD, LED, OLED, plasma - none of those are inherently faster or slower in terms of input lag. It's purely a function of the digital image processing going on inside the TV.

How can you minimize input lag?

The best way to minimize input lag is to buy a TV with low input lag. You can't generally find this information on manufacturer spec sheets, but you can check gamer Web sites like displaylag.com. As described above, you don't need a TV with zero input lag (such a thing doesn't exist), you just need a TV with input lag low enough to be imperceptible. I'd use a threshold of 30ms to 40ms, and rule out sets with much higher lag times.

Definitely stay away from sets with unusually high lag times. Some TVs currently on the market have lag times above 100ms, which will be maddeningly obvious during game play.

Even if your TV has great lag time numbers on paper, you'll still need to adjust its menu settings to get the best performance out of it. Even the fastest TVs can have bad lag times when all of their picture enhancement modes are enabled, and all of those modes are usually enabled by default when you first take your new TV out of the box. Every TV has its own menu settings that affect lag in different ways, so you might need to do a little Web research or experimentation, but here are a couple of rules of thumb applicable to most TVs:

- Turn on "Game Mode". Most TVs have a few master modes you can select from, with names like Movie, Pro, Vivid. One of these is usually a Game mode. If your set has such a mode, select it. In most cases, the main purpose of this mode is to minimize input lag, so it's the easiest way to go straight to the right settings on most sets.
- Turn off all picture and motion enhancement features: sharpness, noise reduction, high frame rates (120Hz or 240Hz, for example), and especially anything related to motion smoothing. Motion smoothing is the worst offender because it usually involves buffering up several frames for interpolation purposes, which deliberately delays the display by that many frames.

Effect of connector types on lag

In some cases, you might see different lag times with different connector types. Most newer TVs use HDMI connectors exclusively, so you might not have any other options. But if your TV has a mix of connector types (HDMI, DVI-D, DP), and you can't eliminate lag via mode settings, you might try different connector types to see if one type is better than the others.

There's nothing inherently good or bad about any of the connector types that affects input lag, so don't look for a rule like "DVI-D is fastest". Any such claims you see on the Web would only apply to a particular TV model, if they're even true. The only reason connectors would have any effect is that the internal electronics in some TVs have a faster path for some connectors than others.

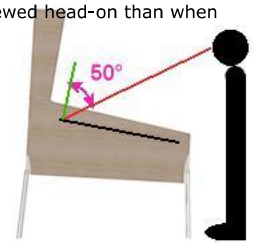
Picture quality

This is probably the easiest metric to find opinions on, since everyone buying a TV for any use cares about it. You can simply look at user reviews on Web stores that sell the TV to get an idea of what people think of different models. For professional reviews, you can check Web sites and magazines that specialize in consumer electronics.

Basic video picture quality is generally excellent for most newer TVs, so user reviews are more useful for ruling out the occasional problem model than for distinguishing among the best models.

Viewing angle

Some types of displays produce a better image when viewed head-on than when viewed at an angle. LCD panels tend to have this property. Viewing from a steep angle can make the picture look dimmer, washed out, or uneven.



The position of the playfield TV is in a full-sized cabinet creates an off-axis viewing angle of about 50° to 60°, depending on the height of the player, so it's important to find a TV that maintains its image quality when viewed from that kind of angle.

Unfortunately, the manufacturer claims for viewing angles in the specifications aren't usually helpful, because they only tell you the range where you can see any image at all. In fact, they usually quote the viewing angle as 180°, which is just the maximum for viewing a planar surface. We're really interested in the range of angles where the picture quality holds up without significant loss of brightness or uniformity. The best way to check is to look at the set in person and specifically try viewing it from about 60° off axis.

If you can't check your candidate models in person, you can at least check user reviews for any red flags about viewing angle. Viewing angles are generally excellent in newer 1080p and 4K LCD panels, and people have come to expect this, so other buyers will probably have noticed if a model has any problems with this.

Note that viewing angle is almost never an issue with OLED or plasma displays. These technologies have their light emitters located directly at the surface of the display, which makes them viewable from any angle.

Motion artifacts

Some TVs are better than others at displaying moving objects realistically. Pinball simulation obviously involves a bunch of rapidly moving objects, so motion rendering is an important element of the overall picture quality in a pin cab TV.

When a TV doesn't handle motion well, you'll perceive effects known as motion artifacts:

- Blur (a moving object looks fuzzy)
- Ghosting (a moving object looks washed out or partially transparent)
- Jitter or judder (objects jerk or vibrate rather than moving smoothly)

It's commonly understood that the "pixel refresh time", also known as "response time", tells you how well a TV renders motion. Yes and no; the refresh rate is important, but it doesn't tell the whole story. Don't get too attached to the idea that you can just look for a TV with the fastest pixel update speed and call it a day. One problem is that there's no standard way to measure these values, so manufacturers can pick whatever measurement is the most favorable; this makes it fairly meaningless to compare the numbers for different models. The other issue is that the apparent smoothness of motion depends on other factors besides the pixel response time. It's more complex than that because motion perception happens in the human visual system, not in the TV. Motion artifacts like those listed above are caused by the interactions between your visual system and the display technology. Faster refresh rates generally reduce these artifacts, but other factors contribute to the artifacts as well, so refresh rate isn't a perfect proxy for motion rendering quality.

The best way to determine a TV's motion handling is (as always) to view it in person with suitable content. If possible, watch the TV in action playing a pinball video game, or some other video game with small moving objects against a fixed background. If that's not possible, try ESPN - sports tend to have a lot of motion of the right sort.

If you can't check the TV in person and you can't find another pin cab builder using the same TV, try user reviews on Web stores. Motion rendering is important to regular TV viewers, especially sports fans, so you should at least be able to check for complaints about particular motion artifacts or problems.

Image retention

Some TVs suffer from a problem known as image retention, or "pixel burn-in", where pixels get "stuck" if you leave a static image on the screen for too long. This leaves a sort of ghost image stuck on the screen. This was a major problem in the ancient days of CRTs. This is, in fact, why they invented "screen saver" programs. The job of

the screen saver is to keep varying the image displayed so that no one pixel will ever be held on at the same color for long periods.

Image retention has always been a concern for gamers because many video games have portions of the image that are fairly static for long periods. For example, console games often have score displays and on-screen controls that are always in the same place. Pinball is even worse in that most of the playfield just sits there motionless most of the time.

Fortunately, image retention is practically non-existent for LCD panels. If you're considering an LCD TV (whatever the backlight type - LED, QLED, fluorescent), you'll probably be immune from any concerns about pixel burn-in.

OLED sets are a different matter. Some OLED TVs are reportedly affected by image retention. If you're looking at an OLED model, look for reviews from console gamers to see if anyone has had problems with image retention on that model.

8. Selecting a Backbox TV

Most virtual cabs use a TV to simulate the backglass artwork of the real pinball machines. The backglass art is a distinctive and universal feature of pinball, and an important part of the aesthetic, so it's a must for most cab builders to replicate it in our virtual systems. It also serves a practical purpose, in that it's where many games display the score.

This chapter will try to help you design your backbox layout and pick a TV for it. We're just in the planning stages here; we'll get into the details of actually installing everything in Chapter 30, Backbox TV Mounting.

Choosing the right backbox TV

If you've just gone through the Chapter 7, Selecting a Playfield TV chapter, you're probably exhausted from thinking about all of the complex technical criteria that go into picking the right TV for your main cabinet. Fortunately, the backbox TV is a lot less demanding in terms of tech specs.

Really, the only important factor in choosing a backbox TV is size. You have to pick a TV that will fit in your backbox and fill the space it's supposed to cover. Most of the rest of this chapter is devoted to helping you decide what type of backbox layout you'd prefer, and to helping you determine the right TV size for your selected layout.

You can mostly ignore the rest of the technical factors that are so important to the playfield TV. The backglass area isn't part of the physical action in a real pinball machine, with the exception of a handful of tables with extremely novel designs, and even for those it's only a very small part of the action. For most games, it's mostly decorative, and shows mostly static images. So it's not all that important to find a TV with fast motion rendering or low input lag.

You don't even need a very high res monitor. Most people find that a 720p TV is perfectly fine for the backbox TV. The backglass artwork from real pinballs is mostly hand-painted graphics, and that kind of source material tends to look good even on lower resolution displays. The main picture quality features I'd look for are good black levels and color accuracy; those are more important than pixel resolution for cartoon graphics. Also consider viewing angle, so that the image doesn't fade too much when you're standing off to the side.

Virtual backglass options

There are two very different ways that you can set up your cab's backglass TV. Before you start picking out a TV, you should decide on one of these configurations, since it will determine the TV size you need.

The two options are commonly known as the **two-monitor** and **three-monitor** configurations.

The **three-monitor setup** mimics the physical layout of real pinballs made from about the mid 1980s. That's when the real machines started using a "speaker panel", a separate section at the bottom of the backbox containing the score display and speakers. Nearly all pinballs made after about 1984 used this arrangement.

For virtual pinball, this is called the "three-monitor" setup because it means you'll have a total of three video displays in your cabinet: the main one for the playfield, the TV in the backglass area, and a small monitor in the "DMD" (dot matrix display) area. The third monitor can be a small TV or laptop display, or it can be an actual pinball score display device just like the real 1990s machines used.

Most virtual cab builders creating full-sized cabinets use the three-monitor setup. It provides the most realistic rendition of modern games that had speaker panels in the real machine, and it also gives you a good place to put the audio speakers (which is one of the big reasons the real machines adopted this design in the first place).

The **two-monitor setup** dispenses with the speaker panel and uses a single large monitor to fill the whole backbox.

The advantage of the two-monitor design is flexibility. Classic tables from the 1960s and 1970s had larger backglasses that filled the entire backbox area, and the full-size monitor lets you display these older backglasses more realistically. A three-monitor setup has to squeeze the older, taller backglasses into a shorter area, which can distort the artwork. And you can still play modern games that had speaker panels originally, since the software can display a graphic rendition of the speaker panel on the screen.

Two-monitor setups are less common in full-sized virtual cabs, but you might be drawn to this design if you're especially fond of older tables from the "EM" (electro-mechanical) era. The artwork on those older tables can't be displayed as nicely on a three-monitor setup.

To help you decide, let's look at how various generations of real machines configured their backboxes.

Backglass styles through the years

Early pinballs displayed the score by lighting up individual point counter lights on the backglass. Pinballs in the 1960s and early 70s used mechanical score reels, which were positioned in little windows in the backglass art. These changed to 7-segment digital displays (similar to early pocket calculator displays) in the mid 70s, but they kept the same basic layout, with the digital displays positioned in the same little windows in the artwork that the mechanical reels had occupied.

Examples of pinball score display styles through the ages: point value lights (1940s-50s); mechanical reels (1960s); 7-segment digital displays (1970s-80s); dot matrix displays (1990s)

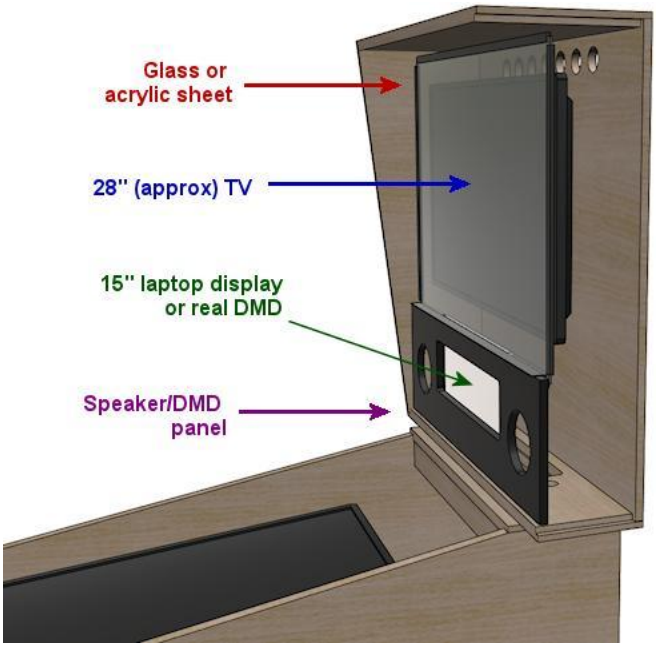
The biggest change came in the late 1980s, when Williams split the backbox between the glass artwork and a separate speaker/display panel. This arrangement had some major advantages, so it quickly became the standard. For one thing, it provided a good place for speakers. Pinball makers were doing everything they could to keep up with the competition from video games, and part of that was replacing the old bells and chimes from the electro-mechanical days with digital sound effects. Hiding the speakers inside the cabinet didn't make for very good acoustics, so Williams decided to dedicate some of the backbox area to speaker grilles. That meant sacrificing some of the artwork area.

Early examples of the split design with separate backglass and speaker/display panel (1987). The lower panel is a separate piece that contains the score displays and a pair of speakers. These early games used 14-segment alphanumeric displays; later games used a single large 128x32 dot matrix display.

The three-monitor configuration in detail

Most people building full-sized cabs opt for the three-monitor setup. Part of the reason is practical. It's easier to make everything fit, it gives you a good place for the speakers, and it's easier to find a suitably sized TV. The other part is the aesthetics: it looks more like a real machine from the modern era.

You'll probably gravitate towards this design if you're generally more interested in modern tables than classics from the 1970s or earlier. This is also the most straightforward design if you plan to use a dedicated dot matrix display (DMD) device, since it replicates the setup of the real pinball machines that used those devices. It would be possible to fit a DMD somewhere else if you really wanted to, but the main motivation most people have for using a real DMD in the first place is to make the cab look more authentic, so unconventional placement would somewhat defeat the purpose.



Standard three-monitor setup, with TV for backglass and separate display for DMD area. The third display can be a small TV or laptop display panel, or it can be a real pinball DMD device. The clear glass or acrylic cover in the shape of a standard translite is optional; it's there to better replicate the appearance of a real machine, and to help hide the edges of the TV, which won't quite perfectly fill the space.

A 16:9 TV is a close (but not perfect) match to the standard proportions for modern translites. It leaves just a little extra space above and below.

The three-monitor setup is great for reproducing the backglass art for modern machines that had the speaker panel setup in real life. It's not as good for older machines without speaker panels, since their backglass art was almost square. Displaying square artwork on a 16:9 TV requires a vertical squeeze to make it fit. This distorts the geometry a bit, as illustrated below.

Original proportions of classic backbox artwork (left); squeezing it onto a 16:9 monitor (right)

As you can see, full-height artwork is a little distorted by the vertical squeeze. I'm personally not too bothered by it on my own three-monitor setup, but then again I mostly play newer tables. If you play a lot of older games and you think the distortion would really bother you, you might consider the two-monitor option described later in the chapter.

Sizing the TV

The standard size of a modern backbox is about 27" by 27" on the inside. This leaves room side-to-side for about a 30" widescreen TV. Unfortunately, it's not possible (currently) to buy a 30" TV. The closest options I've seen are 28" and 29". If you can find a 30", it should be a perfect fit, but failing that you should look for a 29" or 28".

The next size up is 32", but this is too wide for a standard backbox. (You can't even fit a 32" with kludges like thinner side walls or routed slots in the side walls, since most 32" TVs are a hair wider than the *outside* dimensions of a standard backbox.) The only way to make a 32" fit is to build a custom backbox that's about two inches wider than standard. For some cab builders, it's worth doing this to get a perfect fit

to a common TV size. If you go this route, keep in mind that you'll also need to a custom speaker panel and translite to match the special width.

The proportions of the standard translite space are approximately 16:10 (width to height). That's very close to standard 16:9 TVs - just a hair taller. Some computer monitors come in 16:10 ratios, so you might check to see if you can find something like that in the 29" or 30" range, but it's unlikely. Fortunately, 16:9 is so close to the real aspect ratio that you don't have to worry about distorted geometry in the artwork. The only reason to prefer a 16:10 monitor is that it would more completely fill the available space.

Score panel options

The three-screen configuration obviously requires that third screen, in the score panel window in the speaker panel.

This third screen can be another video display, or it can be a dedicated DMD (dot matrix display) device like the ones used in the real machines from the 1990s. Furthermore, it can be *exactly* like the ones used in the 1990s - specifically, a certain type of monochrome plasma display, which is still being made - or it can be a similar device with the same pixel layout that uses LEDs instead of plasma.

We'll look at in detail in the next chapter, Chapter 9, Selecting a DMD Device.

The two-monitor configuration in detail

So far, we've only looked at the "three-monitor" setup. Way back at the top of the chapter, we said that there was another option, *without* the speaker panel, where you use one large TV to fill the entire backbox space. This is known as the "two-monitor" configuration, because you end up with two TVs in your system (one for the main playfield, one for the backglass). Let's finally take a look at this alternative.

This is arguably the more flexible option, although it's also the more difficult of the two to set up. It's more flexible because it does a better job at reproducing older machines with full-height backglasses at the correct proportions, but it doesn't leave out the newer machines either, since it can show a newer machine's speaker panel "virtually" with on-screen graphics. The virtual rendition of a speaker panel obviously can't look quite as realistic as an actual speaker panel, but it does the job. If you're a big fan of classic tables from the electromechanical era, where the backglass art filled the whole backbox space, you might be willing to live with the fake speaker panels on modern machines in exchange for proper artwork proportions on classic tables.

But there are some major drawbacks. One is that it doesn't leave room for speakers. The real pinball makers adopted the separate panel design in part because it allowed the speakers to be exposed, which makes them sound better. You'll have to find another place for your speakers if you go the two-monitor route. You might be stuck (as the older real machines were) with placing the speakers somewhere inside the cabinet, which might somewhat reduce the audio quality.

The other big challenge is that it's impossible to buy a TV with exactly the right proportions to fit a backbox. The modern standard backbox is roughly square, about 27" wide by 27" tall (on the inside). Virtually all TVs and computer monitors sold today have 16:9 aspect, and the ones that don't are mostly even wider.

The solution that most two-screen cab builders use is to turn the TV sideways, so that the long dimension is vertical. This will make the TV too tall for the backbox, but you can cut an opening in the floor of the backbox and tuck part of the TV through the opening and into the main cabinet. This is illustrated below.

Typical two-monitor setup. The TV has to extend into the cabinet through the "neck" in order to fit vertically.

Proportions of the display in a two-monitor setup. The monitor can't fill the whole width of the backbox because it has to fit through the neck into the main cabinet.

You should be aware of a big drawback of this arrangement: you won't be able to fold the backbox down without removing the TV. On real pinball machines, the backbox is designed to fold down so that it lies flat on top of the cabinet, to allow for easier transportation. With the TV arranged like this, you'll have to take out the TV if you want to fold down the backbox. And you really should fold it down before transporting it, because there's a big risk of breaking something during transport with the backbox up, due to its weight and the leverage it has in that position.

TV size

Considering only the backbox inside width of 27", the ideal set would be about 53". But that won't work because of the need to tuck the end of the TV into the main cabinet. So your actual size constraint is the main cabinet width. This means that **your maximum backbox TV size is exactly the same as your main playfield TV size.** For a standard width cabinet (20.5" inside width), you can use a 39" or possibly a 40" TV; for a widebody cabinet (23.25" inside width), you can use a 45" TV.

This will leave some leftover space on either side of the TV if you use the standard modern backbox dimensions. You could simply fill this area with a black border or decorative graphics.

There's another alternative, though. If you're enough of a fan of older EM machines to want a two-monitor setup in the first place, I'd suggest adjusting your cabinet plans to use a narrower backbox to fit the monitor. This will actually make your whole cabinet better fit the classic theme, since narrower backboxes were common until about the early 1980s. For example, the classic Gottlieb "wedgehead" style of the 1960s had backboxes about the same width as the cabinets. A 39" TV will fit these backboxes perfectly.

9. Selecting a DMD Device

Most real pinball machines from the mid 1980s to present use a split backbox setup, with a backglass at the top showing the game's theme artwork, and a separate panel at the bottom containing a scoring display and the audio speakers.

Typical WPC backbox layout. The bottom 1/3 is the speaker panel, containing the audio speakers and a dot matrix display (DMD). Games made up until about 1995 used the style shown here, with silkscreened graphics on the front of the speaker panel. Later Williams games used a more generic black plastic panel without any graphics apart from a Williams or Bally logo. The upper 2/3 is the backglass, displaying backlit still artwork for the game.

The scoring window through the 1980s used segmented alphanumeric displays, but starting in the early 90s, they switched to a 128x32 pixel plasma dot matrix display, or DMD, that can display full graphics, albeit they were rather low-resolution, and in living monochrome.

Many virtual cab builders follow this design, replacing the backglass with a video monitor, and more or less replicating the speaker/DMD panel. This means that you need a separate display device in the DMD area, which is why this design is usually called the "three-screen" cabinet: you have one screen for the playfield, a second for the backglass, and a third for the DMD.

This section looks at the options for the third screen, to help you decide which type to use, and offers some pointers for buying the equipment you decide on.

Overview of DMD technologies

The DMDs in the original 1990s pinball machines were monochrome plasma displays, 128 pixels wide by 32 pixels high. That made for very large pixels that you could see individually. This visible "dot" structure, and the particular amber color of the plasma, gave the displays a distinctive appearance that many people now see as a defining feature of this generation of pinballs. To a lot of people, it doesn't feel like real pinball if it doesn't have the amber dots.

You can still buy the original plasma panels, and it's even possible to use them in a virtual cab (although, as of this writing, there are no commercial interface kits available to facilitate this). There are also newer display technologies that can be substituted into the score panel to achieve similar looks, with some modern improvements.

The first newer alternative is LED-based displays. LED displays are available with the same pixel pitch and layout as the original plasmas, so they can serve as close substitutes. LEDs don't perfectly replicate the nuances of plasma's visual effect, which has a sort of soft, analog, neon feel to it that some people find charming; LEDs are crisp and bright but can seem a little harsh in comparison. But LEDs definitely share some of the more important positive properties of plasma, particularly high

brightness and wide viewing angle. LEDs are also cheaper than plasma and longer lasting, so collectors of the real machines often replace defunct plasmas with LED panels when repairs are needed. LEDs are also being used on many new titles being shipped today, so plasma is no longer the sole "original equipment" on real pinballs. Stern no longer ships new games with plasma displays at all; they switched to LED DMDs in 2013.

The original LED DMD panels were monochrome (available in a variety of colors, including something approximating the distinctive plasma amber), but panels are now widely available with RGB pixels, which can display full-color graphics.

The other newer alternative to plasma is to use an actual video display, typically an LCD panel. For a virtual cab, an LCD panel is easier to set up in terms of software, since it just looks like another video monitor as far as Windows is concerned. Pinball simulators will happily simulate the look of a plasma DMD on a video display by drawing large amber dots to simulate the 128x32 pixel structure. Of course, an LCD panel can't perfectly reproduce the brightness or viewing angle of a plasma, but it can at least do a passable impression of the appearance.

A 15" diagonal 16:9 LCD screen happens to fit the width of the standard DMD opening in the pinball speaker panels. It's a trifle taller than the standard panels overall, but since it sits behind the panel, that's not typically a problem, as it's hidden behind the translite, which sits directly on top of the speaker panel.

Recommendations

For a virtual cab, you can in principle use any of these technologies - an original plasma DMD, a monochrome LED DMD, a full-color RGB LED DMD, or a video display. (Although what you can actually buy right now is somewhat more limited.) The tradeoffs are complex, but it mostly comes down to your priorities:

- If you have fond memories of the 1990s machines, and you want to match that look, a plasma display is the way to go. Plasmas are the authentic equipment, so they'll look exactly right. A plasma is also quite bright, so some people like the way it becomes part of the "light show". The downsides are that plasma displays are expensive and fairly complex to set up. They require a special high-voltage transformer as the power supply; VirtuaPin sells an appropriate transformer, so it's at least easy to source, but it adds to the complexity for installation. Another downside to plasma devices is that they fade as they age and eventually wear out, although I believe their longevity is a function of powered-on time, so you can probably expect a plasma to last a very long time in home use. I have several real pinball machines with original plasma displays that have been in home use for over 25 years, and I haven't had one exhibit any signs of fading or failing yet.
- If you want to replicate the 1990s look but want to reduce the complexity a bit, a monochrome LED is a good choice. These look very close to the plasmas - they're even brighter, and you can even get them in a fairly close color match to that special plasma amber if you want, as well as in a range of other colors. They're a bit simpler to set up than plasmas because they don't require the special power supply. They also have a longer reliable service life than plasma. They're more complex to set up than a video display, though, and more expensive.
- If you like the "dots" look of the 1990s machines but want to add full color support, consider an RGB LED. These are slightly more expensive than the monochrome LEDs, and they're about the same in terms of setup complexity.

  I was really excited when the RGB LEDs first came out, because I thought they were going to be the perfect combination of the original plasma look and modern full-color flexibility. But I'm sorry to report that the reality isn't that simple. I know some people are going to hate me for saying this (particularly people selling RGB DMDs!), but I actually think a video display does a more convincing job of replicating the "dots" look than an RGB LED. The problem is that the sub-pixel structure on the RGB LEDs is way too obvious; it makes the individual dots look too small. It's very noticeably different from the plasma and monochrome LEDs. That's a first-hand opinion, too: I have machines with both kinds of displays at home, and to my eye the video display looks more like the real thing.
- If you're not attached to the idea of using 1990s-era equipment for its own sake, a video display is the best overall option. It's cheaper than any of the

128x32 DMD options, it's easier to set up, it's more flexible, and to my eye it actually does a better job of re-creating the "dots" look than the RGB LED displays do.

The only drawback of a video display (other than that it's not authentic 1990s pinball equipment, which you might or might not consider a drawback) is brightness. The plasma displays are quite bright, and a monochrome LED is even brighter. (RGB LEDs are a mixed bag on this score because of the sub-pixel structure; brightness depends quite a bit on the color being displayed at any given pixel.) From comparing my own machines with different display technologies, though, I think this is often overblown when people talk about it on the forums. Side by side, they're really not that different. And I think when you compare the overall visual quality, an LCD video panel has the edge.

In terms of flexibility, a video display can do both "dots" and full-resolution graphics. The "dots" look can be easily simulated on a full-res display, and all of the pinball software is set up to do just that, because it's all written primarily for desktop machines where video displays are the only thing going. What a video panel can do that a 128x32 DMD can't is display high-res graphics when it's not displaying "dots". For example, when playing an EM game that doesn't use the score window at all, you can use it to display added game graphics or manufacturer logos at full resolution. Video panels also look much nicer when playing 1980s "alphanumeric display" games, because they can accurately simulate the 14-segment display look.

Video is also the most compatible option. Every pinball program for Windows naturally works with a video display, since that's just how Windows works; support for a DMD device has to be intentionally added on by each program's creator (or hacked in by reverse-engineering, which the pin cab community has successfully accomplished with several commercial titles).

When I first started on my virtual pin cab project, it almost went without saying that plasmas were the Cadillac of scoring displays, worth almost any amount of extra cost and extra trouble to set up. But I think this has completely changed in the short time since then, because the real pinball world has largely moved on to more modern technologies. These days, pinball machines you might see in public places use such a mix of dot matrix and video displays that both seem perfectly "real" now. Some of the newer Stern titles are shipping with DMD-sized video displays as original equipment, and Jersey Jack Pinball's entire line uses large video monitors in place of the DMD panel. You even see lots of classic 1990s machines retrofitted with full-color video displays, thanks to ColorDMD, a company that makes drop-in replacement displays for the old machines. So I expect that many cab builders starting new projects now and in the days to come will be less fixated than earlier cab builders were on the idea that the plasma DMDs were the only "real" pinball displays. There's definitely a nostalgic value to the old plasmas, but overall I've come to think that video is the best option.

Purchase options

At one point, it was possible to buy any of the display technologies mentioned above - plasma, monochrome LED, RGB LED, or video. But the buying options have become a lot narrower lately. The PinDMD v2 doesn't appear to be available any longer, and that was the only readily available way to hook up an original plasma display or a monochrome LED panel.

So at the moment, there are two options: video, or RGB LED.

LCD video panel

If you plan to use a video panel for the score display, the best fit is a 16:9 panel, approximately 15.5" diagonal. This is just about a perfect fit for the 13.6" width of the standard DMD opening in a speaker panel. A panel of that size is just barely taller (by about a centimeter) than the standard speaker panel's outside dimensions, but that's typically not a problem, because the excess height is easily behind the translite panel, assuming you're using one.

A few TVs are available in this size range, but I'd recommend against those. They tend to use low-quality LCD panels. The much better solution is to use a laptop display panel.

You can buy replacement laptop LCD panels in this size range on eBay or Amazon. These panels come bare, with no interface electronics, because they're sold for repair work where you only need to replace the panel and nothing else. This means that you have to buy a separate piece of electronics, called a video controller, that serves as the interface between the panel and the PC video card.

To find these parts, start by searching eBay for "15 wuxga". You should find a number of matches, usually listed as replacement parts for Dell, HP, Acer, and other laptop brands. You should narrow the list to panels that specify 1080p or, equivalently, WUXGA (1920x1080) resolution, and a screen size of 15.5 or 15.6 inches. The price range for these panels as of this writing is about $50 to $100. The matches you're looking for are just bare laptop display panels - an LCD screen in a thin metal shell. They'll look something like this:

Don't try to choose a specific panel yet; just keep the search results ready. The next step is to find a video controller that works with one of these panels. eBay doesn't provide any tools to help with this, so you'll have to do some manual searching. Open a new eBay search window. Go down your list of panels. For each one, find its model number in the listing and type it into the search window, adding "controller". For example, if you find a panel with model number LP156WH4T, type "LP156WH4T controller" into the search box. If you're lucky, that will turn up a few hits with the model number in the title. Be sure the model number is actually in the title or is explicitly mentioned in the listing as a compatible model. The controllers will usually look something like this:

If you don't have any luck, or you're not sure you found the right match, I'd recommend picking a panel that looks good and contacting the seller to ask which controller to use. The seller should be able to point you to the right device. Most of these panels use similar control interfaces, so you don't actually need a controller designed especially for your panel. Sellers list them for specific panels simply because they know people like us are searching for them that way! Technically, you just need a controller that matches the interface type on your panel, but the ads don't usually list enough information to find them that way, so a model number search is the only way to be sure.

Pay attention to connectors. Most of the interface boards will have a VGA input and either a DVI-D or HDMI input. If you've already picked out a graphics card for your cabinet PC, be careful to pick an interface board that has a connector matching an available output on your graphics card, taking into account the outputs you'll be using for your main playfield TV and backbox TV.

How do you know if a panel is good in terms of video quality, reliability, etc.? You're not going to find reviews (professional or user-written) for any of these OEM parts, so it's a bit of a crapshoot. Fortunately, laptop panels in this class have gotten to be good enough that you should be okay with anything that meets the specs. Do pay attention to the resolution, though: the WUXGA laptop displays seem to be uniformly good, but the lower res displays are uniformly bad.

One note on setting up your new panel: be aware that the control board might support more resolution modes and refresh rates than the panel itself does. Many of the modes that the controller allows you to select with the Windows control panel might simply not work with the panel or might produce poor-quality video. When you first set up the panel in Windows, make sure you select the screen size (resolution) and refresh rate that exactly match the panel's physical design. That might take some trial and error, since eBay OEM parts don't usually come with any documentation. If the display looks fuzzy or distorted, or doesn't show anything at all, try other refresh rates to see if you can find one that looks better.

RGB LED

If you decide on to use an RGB LED dot matrix display device, there are two ways to accomplish it: you can buy one commercially, or you can build one yourself using DIY plans that some pin cab enthusiasts developed and published.

RGB LED - commercial

VirtuaPin sells the PinDMD v3, a full-color (RGB), LED-based, 128x32 dot matrix display. The display panel has the same physical dimensions and dot pitch as the original plasma displays in the 1990s machines. It's about $270.

This is a turn-key commercial kit, so it's relatively plug-and-play. It uses a USB device to interface to the PC. It requires some software setup; instructions are included, and VirtuaPin offers warranty support.

RGB LED - semi-DIY

Pin2DMD is a DIY project for building an RGB DMD panel from parts. The site provides a parts list and assembly instructions, as well as software for a microcontroller to interface to the PC and run the display. The prices for the parts vary, but at a guess they'll total about $100.

Note the confusingly similar name: Pin2DMD is the DIY project, and PinDMD v3 is the commercial product above.

The Pin2DMD site includes software to install on a microcontroller board (one of the parts that goes into building the project) that interfaces with the PC and runs the display. However, note that the software is *not* open-source, and requires payment of a license fee.

The closed-source software makes me hesitate to recommend the project. It's supposedly "DIY", but given that you don't have any control over the software or any ability to change it to suit your needs, I think "DIY" is actually a negative in this case. You have to do the assembly yourself, you don't get any warranty support, and you don't even get any control over the final product. Open-source projects have the first two drawbacks, but they make up for it by giving you full control to customize and expand. You don't get that here; you just get the bad aspects of DIY and the lack of control of commercial products. But I guess you can at least save some money vs the retail version.

Plasma panels

Plasma doesn't appear to be an option at the moment. VirtuaPin formerly offered the "v2" PinDMD, which was a monochrome of the PinDMD v3 device mentioned above that worked with your choice of monochrome 128x32 LED panels or the original plasma panels used in the 1990s machines. But that product doesn't appear to be available anywhere as of this writing.

You can still buy the bare Vishay plasma panels from VirtuaPin, along with the special 80V/100V transformers needed to power their high-voltage sections, but VirtuaPin doesn't sell anything that would let you hook it up to a PC. I don't know of any other commercial or DIY options for connecting these.

If you're an experienced software developer with some hardware knowledge, you could design your own controller using one of the inexpensive ARM-based microcontroller boards, such as a Raspberry, BeagleBone, or one of the STM32F series boards. The software involved is actually very simple: you just need to consume USB packets from the PC and send out a clocked serial bit stream to the plasma device, 1 bit per pixel. The electronic interface is documented in the Vishay data sheets, and it will be immediately recognizable and straightforward to anyone who's done any device interface work with a microcontroller before. If you do create

such a project, please publish it as open source, and let me know about it so I can include here.

Monochrome RGB panels

As with the plasma panels, you can buy monochrome RGB panels as components, but there's no software interface to the PC available. The panels are available from a few after-market pinball suppliers who sell them as drop-in replacements for dead plasma displays in real pinballs. Since they're specifically designed as drop-in replacements for the Vishay panels, their device interface is identical, so any solution you can find that will work with the Vishay panels will work equally well with these. As requested above, please let me know about any solution you develop or find for this and I'll add it here.

10. Cabinet Parts List

When I built my cabinet, one of the unexpectedly big jobs was just figuring out what I needed to buy. This chapter is an attempt to save you some of that legwork by presenting a master list of everything that goes into a virtual pinball machine. The list is organized into categories to make it easier to digest and easier to find things.

The list starts below after a few preliminary notes.

Pinball part references

Many of the items on the list are replacement parts for real pinball machines. When possible, these are listed with the original manufacturer part numbers. This makes it easy to find the exact part you're looking for, since most arcade suppliers include these numbers in their catalogs and databases. You can enter one of these numbers into the search box on most pinball vendor Web sites to find that exact part, without having to wade through a ton of hits for similar items, as is often the case if you search by name or description. Most of the part numbers are even unique enough to yield good results from a Google search.

The part numbers listed are mostly for Williams/Bally 1990s era machines, also known as WPC machines (for "Williams Pinball Controller", the core electronics platform used throughout that generation). Those machines had a very uniform cabinet design, and most of the core cabinet parts used a single design shared across many games. Williams is no longer in the pinball business (much to the regret of pinball enthusiasts), but the modern machines being made by Stern and a few smaller boutique pinball companies still hew very closely to the WPC cabinet design, and use most of the same parts, or equivalents that can be used interchangeably. As a result, it's easy to find new replacement parts for most of the WPC cabinet components, which makes the WPC hardware an excellent basis for building a new cabinet from scratch.

Bolt and nut sizes and types

Pinball machines use a lot of machine screws, in the form of hex bolts, carriage bolts, hex nuts, flange nuts, and T-nuts. All of these have several size specs, written in this order:

diameter-*thread* x *length*

For example:

#8-32 x 1" bolt = diameter #8, thread pitch 32, length 1"

The *diameter* is either in regular ruler units like inches or millimeters (and for WPC parts, it's almost always inches), or it's a "#N" designation, which refers to a standard US size scale for these parts. The most common sizes in a pinball context are #6, #8, ¼", and ⅜".

Every hardware manufacturer and hardware store uses these standard units to label their parts. #6 always means the same thing in a machine bolt or nut no matter where you buy it. However, if you see an "M" number, like M4 or M6, that's *not* the same thing. The "M" sizes are metric, and they're not compatible with the US "#" numbers. M6 and #6 are different sizes that can't be used interchangeably. (Confusingly, they *look* very close to the same size if you eyeball it, so don't go by looks alone when trying to find a match.)

For machine screws, the *thread* number is an important extra spec giving the thread pitch (the number of threads per inch). Nuts and bolts will only fit together if they have the same size *and* thread pitch; for example, a ⅜"-20 bolt won't fit into a ⅜"-32 nut, because the threads are spaced differently.

A few common types you'll see in the parts lists:

- Regular bolts, also called machine screws, with slotted heads for tightening with a screwdriver
- Hex-head bolts, for tightening with a socket wrench

- Carriage bolts. These are bolts with smooth rounded heads, for places where an external bolt should be inconspicuous and not easily removable from the outside. They have square necks that fit into square holes on the receiving end, which is what serves in place of a wrench to hold them still when you're tightening a nut on the other end. Most of the carriage bolts used in a pinball machines are available with a black finish that makes them blend better with the artwork.

- Flange nuts are hex nuts with integral washers. Whiz flange nuts or flange lock nuts have serrated surfaces on the bottom of the integrated washer to help lock them in place when tightened.

- T-nuts are threaded sockets that are installed permanently in a piece of wood. These are used when you need to be able to screw a bolt into an internal location that you can't access to insert a regular nut by hand. Some T-nuts have prongs that let you pound them into like a nail to secure them, while others can be screwed in to their install location with wood screws.

Cabinet variations

The WPC cabinets were basically all the same - Williams came up with a good design and stuck to it for many years. But there was one significant variation to be aware of: a number of titles, marketed as the "Superpin" games, had extra-wide bodies for the main cabinet, allowing a wider-than-normal playfield. All of extra-wide titles came in the same extra-wide size, so even taking these into account, there are still only two widths we need to concern ourselves with: the standard machines and the widebody machines. What's more, the only thing that's different about the widebody machines is the width of the main cabinet; the other dimensions (including the backbox dimensions) and all design elements are identical between the regular and widebody machines. As a result, the widebodies share all of the same hardware with the standard machines except for the main front-top metal trim piece, known as the lockdown bar, and of course the glass cover.

If you go back further in time, before the 1990s, the cabinets become increasingly different from WPC machines. You should be aware of this when you go shopping, particularly if you shop on eBay for used parts. If you're building from scratch to the WPC plans, you'll want to make sure that any used parts you buy are compatible with WPC cabinets.

By the same token, if you're refurbishing a used cabinet from the 1980s or before, check carefully when buying new replacement parts from arcade suppliers, because arcade suppliers mostly stock parts for 1990s machines. New parts probably won't fit a 1970s cabinet unless they're specifically listed as such. If you are trying to refurbish an old cabinet, one particularly good arcade vendor to try is Marco Specialties. They have an unusually deep catalog with parts for lots of older machines. Find the original operator's manual for the machine you're restoring, if possible, since that will usually include a detailed list of the machine's parts, with manufacturer part numbers that you can look up on pinball vendor Web sites to find the exact version. If you shop on eBay, it's harder to be sure of compatibility. Ideally, look for parts for the exact title you're refurbishing, but failing that, go by manufacturer and year; the pinball makers mostly re-used parts across their product lines for a few years at a time, so a part of the same vintage from the same manufacturer will usually fit.

Where to buy

Most of the parts in the master list are fairly standardized, interchangeable parts used in most WPC-era machines, and in most cases, used in 2000s machines from Stern, Jersey Jack, and others. Most of these parts are readily available on the Web from pinball parts vendors and arcade machine dealers. If you live in a major metro area, you might even be able to find a local arcade dealer who stocks some parts, although you'll probably still need to look to Web for the more obscure stuff.

Some of the vendors I've used:

- Pinball Life
- Marco Specialties

- Planetary Pinball Supply
- VirtuaPin

Most of the generic hardware (nuts, bolts, screws) can also be found at hardware stores, Amazon, and eBay. Note that some of these are available in special finishes from the pinball vendors that you might not find at regular hardware stores (e.g., carriage bolts in black, chrome bolts for attaching the legs).

Custom-cut pieces of glass can be found locally almost anywhere from window glass stores. Check for local businesses that install and repair residential windows. Custom sizes of acrylic and other plastics can be found locally at plastics stores and some hardware stores. (If you're on the west coast, check for a local TAP Plastics.) You can also buy an uncut acrylic sheet from a hardware store and cut it to size yourself with a special plastic cutter knife, but that doesn't produce as clean a cut as you can get from a pro at a plastics store.

VirtuaPin part bundles

If you're building a cab from scratch, you can save some time on shopping (and possibly save money as well) by buying a pre-packaged parts bundle from VirtuaPin. You can find these on their Web site under "Bundle Deals". They offer two packages of particular interest to new cab builders:

VirtuaPin Cab Builder's Kit: This includes most of the standard cabinet hardware items used on typical 1990s era machines (the "Williams WPC" style). The kit comes in standard-body and wide-body versions, so choose the one matching your cabinet plans. Parts included in these kits are marked in the lists below with VP Cab Kit.

I recommend this kit. It's cheaper than buying the same parts individually, and it gets you about 80% of the way to a complete cab in terms of the accessories.

The only downside is that the kit is only available in the standard chrome/stainless steel finishes for the trim parts. That's exactly what most people want, since it's the standard look on most real machines. But some of the newer Stern machines come with a powder-coat finish on most of the metal trim, color-coordinated to complement the artwork. That's a nice upgraded look that you might want for your own build. Other metallic finishes are possible as well, such as brass. Another custom upgrade that some people want is a lock bar with a "Fire" button in the middle. That requires a special lock bar and matching "receiver", which you can't currently get with the VirtuaPin kit. If you want to choose your own finishes (see "Custom finishes" below) or include a "Fire" button on the lock bar, you're better off skipping the kit and buying everything *à la carte*, since you'd throw away most of the kit.

VirtuaPin Button Kit: This includes most of the buttons in a typical virtual cab. In the list below, we've marked the items in this kit with VP Button Kit.

I'm ambivalent on this kit. It'll save you some time, but it's less of a bargain than the cab builder's kit because it includes some buttons you probably won't use. It also lacks some that you might want to add. If you don't mind doing the extra planning and shopping, I'd skip this kit and buy buttons individually, so that you can get exactly what you want.

Custom finishes

Most of the exterior metal trim - legs, side rails, lockdown bar - is available in multiple finishes. The "standard" finishes are chrome for the legs, brushed stainless steel for the lock bar and side rails, and black powder-coat for the coin door. With some extra work, you can get all of these parts in other finishes, such as brass, gold, or just about any powder-coat color.

The big vendors mostly just offer the standard finishes, but Marco Specialties often has a few alternatives available to match recent Stern titles. Stern typically releases a Limited Edition version of each new title, with upgraded trim, usually in a powder-coat color that complements the cabinet art. Marco usually stocks a selection of such trim, but it's hit or miss. If you're lucky, you might be able to find a full set of trim in a color featured on a past Stern LE game.

You might also be able to find trim in alternative finishes from pinball "mod" sellers. A number of small vendors sell upgrade parts, including custom-finished trim, to the

pinball collector market. These guys all sell online and on eBay; try a Web search for "pinball side rail" (for example) plus the type of finish you're seeking.

If you have a specific idea for the look you want, your best option might be to buy "raw" or "unfinished" trim and find someone to apply the desired custom finish. Pinball Life sells unfinished legs, side rails, and backbox hinges, specifically as a base for custom finishes. This is a much better starting point than the standard parts, because a refinisher would have to strip the existing finish off first, which is expensive and time-consuming.

You can find services online that offer custom powder coat and metallic finishes - you ship them the parts, and they do the work and ship them back. You might also be able to find a local business that does this, if you live in a major metro area. Try looking for local shops that refinish antiques and/or auto and motorcycle parts.

Master parts list for a virtual pinball machine

Miscellaneous supplies

Item	Qty
Wire: 22-24 AWG stranded You'll use a surprising amount of wire to connect various parts of the machine together: buttons, lights, feedback devices. It's convenient to have a few spools of wire on hand throughout the build. You can use 22 or 24 gauge wire for practically everything, and it's cheaper (by the foot) to buy wire in large spools, so I'd pick one size and buy lots of it. If you're only installing buttons, 100ft should be adequate; if you're installing feedback devices, you'll probably want at least 200ft on hand. Buy several assorted insulation colors to make the wiring easier to trace.	100ft+
Wire: 18 AWG stranged You'll also need some thicker wire for some of the power wires and speaker wires. I recommend 18 AWG as a good general-purpose choice for these higher power wires. 50 to 100 feet should be adequate for most pin cabs. I'd start with two 25' spools, one with white insulation and one with black.	50ft
Solder A good quality solder makes a surprising difference in the ease of work and the quality of your results. I really like Kester 44 rosin core solder. You can get it in 1oz tubes, but the 1lb rolls are a much better deal if you think you might do any significant amount of soldering in the future.	1oz-1lb
#6 wood screws, various lengths I found that I used an amazing number of wood screws for all sorts of random tasks. The vast majority were #6 wood screws - these are the right size for all sorts of miscellaneous jobs. Keep an ample supply on hand so that you don't have to keep running to Home Depot. Recommendation: buy 100 #6 x ½", 100 in ¾", 100 in 1", 100 in ¾", and perhaps 25 1¼".	Lots
Nails As with #6 screws, it's convenient to have a supply of various nails on hand. You'll mostly need finishing nails rather than anything heavy-duty. I mostly used 1" and ¾" brads, so I'd recommend buying a bunch of each.	Lots

Wood glue If you're doing your own woodworking or building from a flat pack, you'll need a good wood glue for the joints. It's a good thing to have on hand for miscellaneous jobs even if you have a pre-assembled cab.	1 tube
Epoxy Some things are easiest to assemble or attach with a strong glue. Get a two-component epoxy (the type with two tubes of goo that you mix together just before use). I don't recommend "superglues" (cyanoacrylate glues) for most cab uses.	1 tube

Cabinet wood shell

Hardwood plywood, ¾" If you're doing your own woodworking from scratch, I recommend using a furniture-quality hardwood plywood for all of the cabinet pieces. This is what they used on the real machines. The ¾" thickness is important for making the accessories fit properly. Some people use particle board or melamine, which are cheaper, but I don't recommend them because they're not as durable and they're much heavier than plywood.	4'x8'
Flat pack kit As an alternative to raw lumber, you can buy a pre-cut flat pack kit. VirtuaPin and others sell these. A flat pack has all of the cabinet pieces cut to size and ready to assemble.	1

Cabinet artwork

Most cab builders opt for decals printed with custom artwork. You can create your own artwork with a computer graphics program. Decals are popular because they can make your cab look just like a real machine - done properly, they make for a very professional finish. Some people prefer a simple black paint job or natural wood finish, and some go with stenciled paint decoration for a more vintage look (like machines from the 1960s or 1970s). See Chapter 22, Cabinet Art for ideas and resources.

Custom cabinet decal set A set of decals covering the visible surfaces of the cabinet and backbox.	1
Translite decal The backbox TV's display area will necessarily be smaller than the translite, so there will be some gaps around the edges. You can use decals to fill the gaps decoratively.	1

DMD panel decal The real machines during the late 1980s and early 1990s had printed artwork filling the DMD panel, with a custom design for each title to complement the backglass artwork. The later WPC-era machines (from about 1995 to 2000) switched to generic, matte black panels, decorated only with the manufacturer logo. I personally prefer the more ornate look of the early 1990s machines, which you can reproduce using a printed decal with your own custom artwork based on the graphics theme for your main cab. If you prefer the more neutral style of the later generic panels, you can approximate that with a simple black paint job.	1

Main cabinet hardware

Side rails WPC style: Williams/Bally A-12359-3, 01-8993-2 VP Cab Kit	2
Mounting tape for side rails Double-sided foam tape, ¾" wide, .032" (approx) thick. This goes between the rails and the side of the cabinet. About 80" length required.	80 inches
#8-32 x 1¼" carriage bolts For attaching the side rails	4
#8-32 hex lock nut These go with the carriage bolts for attaching the side rails	4
Lockdown bar • WPC Standard: Williams/Bally D-12615, A-18240 • WPC Widebody: Williams/Bally A-16055, A-17996 • WPC Custom width: available from VirtuaPin and others • Stern standard width with center "FIRE" button: search for "premium lockbar" VP Cab Kit	1
Lockdown bar receiver • WPC (standard, widebody, or custom): Williams/Bally part A-16673-1, A-9174-4 • Stern lockbar with center "FIRE" button: Stern 500-7237-00 ***Important:*** *This part mates with the lockdown bar, so make sure you choose a receiver that matches the type of lockdown bar you have. The Williams WPC receiver is the same for standard, widebody, and custom widths of WPC lockbars. For other brands, check the vendor site for the compatible receiver after you select a lockbar.* VP Cab Kit	1
Leg brackets Williams/Bally 01-11400-1 VP Cab Kit	4
#8 x 5/8" wood screws, hex-head, slotted For attaching the leg brackets to the cabinet. Williams/Bally 4108-01219-11, 4608-01081-1	32
Steel legs Williams/Bally A-19514 VP Cab Kit	4

Leg levelers with nuts Williams/Bally 08-7377	4 VP Cab Kit
Cabinet leg protectors Optional; these can help protect the cabinet decals or paint from wear around the leg joints. These weren't original equipment on WPC-era machines; Marco Specialties and Pinball Life carry several options, including felt and metal versions. The metal ones are said to be better for decals, but this is moot if you trim the decals around the leg contact area.	4
Leg bolts, ⅜"-16 x 2¾" or 2½" The longer 2-¾" length is easier to work with, especially if you're using leg protectors. The type sold by pinball vendors has a chrome finish and rounded dome ("acorn") head for a nicer appearance than generic hex bolts from hardware stores. Williams/Bally 4322-01125-40	8 VP Cab Kit
Leg bolt nuts, ⅜"-16 thread Hex nuts, ⅝" outside diameter. Williams/Bally 4422-01117-00	8
⅜"-16 T-nuts Install in the "shelf" at the back of the cabinet, to mate with the wing bolts installed in the backbox floor to secure the backbox in the upright position.	2
Coin door The WPC style is available fully assembled with the mounting frame, coin slots, slam tilt switch, operator buttons, and wiring harness, but generally without the coin acceptor mechanisms. Williams/Bally part 09-37000-1; alternate part numbers: 09-46000, 09-96017, 09-17002-26, 09-23002-1, and 09-61000-X, 09-61000-1. *Available as an add-on in the VP cab kit*	1
Coin mechanisms for coin door Optional. You need these if you want use actual coins. One "mech" is required per coin slot (the WPC doors above have two slots).	1-2
¼"-20 x 1¼" carriage bolts, black For attaching coin door and lockdown bar. Williams/Bally 4320-01123-20B *Note: another 6 are needed for backbox*	6 VP Cab Kit
¼"-20 flange locknuts Williams/Bally 4420-01141-00 *Note: another 6 are needed for backbox*	6 VP Cab Kit
Cashbox Optional. Sits under the coin slots to collect inserted coins. You need *something* for this purpose if you plan to use coins; the standard box is well designed for the job, but it's rather large. You might prefer to improvise something more compact. The standard cashbox consists of two parts: the plastic tray (Williams part 03-7626, Stern part 545-5090-00), and a metal cover (Williams part 01-10020, Stern 535-5013-03, 535-5013-02, 535-5013-01).	1

Cashbox nest bracket Optional; recommended for use with a standard cashbox. Attaches to the inside front wall of the cabinet just under the coin door to keep the cashbox from sliding around. Williams part #01-6389-01.	1
Cashbox lock bracket Optional; recommended for use with a standard cashbox. Attaches to the short dividing wall on the cabinet floor that delineates the cashbox area at the front, to anchor the cashbox when installed. Williams/Bally part 01-10030 or 1A-3493-1.	1

Playfield glass

Tempered glass sheet for playfield cover • Standard body: 43" x 21" x 3/16", Williams A-08-7028-T • Widebody: 43" x 23¾" x 3/16", Williams A-08-7028-1 • Custom cabinet: 3/16" thick tempered glass, cut to a custom size per your plans. You should be able to order this at a local window glass shop. Tip: ask the shop to omit any marking or etching certifying that it's tempered glass. Glass makers might assume that you want a certification mark, since some building codes require the marking for certain uses in home construction, such as a glass shower enclosure. You don't need any certification for use in a pinball machine, though, so you'd probably prefer to omit any such markings, to avoid visual clutter.	1
Playfield glass rear plastic channel Standard width: Williams/Bally 03-8091 Widebody: Williams/Bally 03-8091-2 VP Cab Kit	1
Playfield glass side rail plastic channels Williams/Bally 03-7135-1 VP Cab Kit	2

Plunger

Fully assembled: Williams/Bally B-12445-1, B-12445-6, B-12445-7. You can also buy the individual parts separately if you wish to customize. Pinball Life lets you choose colors for the knob and rubber tip, but you'll have to buy *à la carte* if you want a custom knob. Note that you can buy a knobless shooter rod and epoxy on your own custom knob for a unique look. Note also that springs are available in different tensions. I'd recommend a lower tension spring for virtual pinball use since you're never going to hit an actual ball: lower tension means lower speed and less cabinet rattling. The part numbers below are Williams/Bally references as usual: • Shooter rod: 20-9253 • Shooter housing: 21-6645-1 • Shooter housing sleeve: 03-7357 • Barrel spring (¾" long x ⅝" diam): 10-149 • Inner spring (5½" long x ½" diam): 10-148-1 • E-clip (⅜" shaft, 5/16" groove): 20-8712-37 • Washers (25/64" x ⅝", 16 gauage, qty 2): 4700-00051-00 • Rubber Tip: 545-5276-00 *If you buy a commercial plunger kit, the plunger assembly is usually included.*	1
Ball shooter mounting plate Williams/Bally 01-3535 *Note! This **isn't** typically included in the commercial plunger kits or the "complete assemblies" sold by arcade vendors.*	1
#10-32 x ⅝" machine screws *Not typically included with commercial plunger kits or complete assemblies.*	3

Tilt-up playfield TV mounting

Hardware for the tilt-up mechanism described in Chapter 29, Playfield TV Mounting. Only needed for that design (or a a similar design).

Playfield holder bracket (left side) Williams/Bally 01-8726-L-1	1
Playfield holder bracket (right side) Williams/Bally 01-8726-R-1	1
Pivot nut, 7/16" Williams/Bally 02-4244. The 1/2" version (Williams 02-4329) will also work.	2
Carriage bolt, 3/8"-16 x 1-3/4", black	2
Washer, 3/8" x 1" outside diameter (quantity 2)	1
Hex nut, 3/8"-16	2

Backbox hardware

Backbox hinges Williams/Bally 01-9011.2-R, 01-9011.2-L VP Cab Kit	2
Hex pivot bushings for backbox hinges ½" shaft, ¾" diameter head, ¼" hex center, ⅜-16 thread. Williams/Bally 02-4352 VP Cab Kit	2
Pivot bushing carriage bolts ⅜"-16 thread, ¾" long. Williams/Bally 4322-01139-12B VP Cab Kit	2
¼"-20 x 1¼" carriage bolts, for attaching backbox hinges Williams/Bally 4320-01123-20B *This is in addition to the 6 needed for the coin door and lockdown bar. The VP cab kit provides 10, so you need two extra for the full set.* VP Cab Kit	6
Backbox hinge backing plates These go inside the backbox to strengthen the connection points for the carriage bolts above. Williams/Bally 01-9012	2
¼"-20 whiz flange locknuts Williams/Bally 4420-01141-00 *This is in addition to the 6 needed for the coin door and lockdown bar. The VP cab kit provides 10, so you need two extra for the full set.* VP Cab Kit	6
Backbox latch Williams/Bally 20-9347 VP Cab Kit	1
Backbox latch bracket Williams/Bally 01-8397 VP Cab Kit	1
Wing bolts, ⅜"-16 x 2" Install in the floor of the backbox to lock the backbox in the upright position. Williams/Bally 20-9718	2
Backbox translite lock plate assembly Keyed lock to secure the translite. Not truly necessary in home use, but a nice touch to complete the look of the real machines. Williams/Bally A-13379	1
Lower speaker panel bracket A black metal "U" channel that screws into the bottom of the backbox, to hold the DMD panel in place. The only place I've seen the original part for sale is PlanetaryPinball.com, but you can sometimes find upgraded versions in custom finishes (brass, chrome) from "mods" vendors. You can substitute a generic aluminum ⅝" x ⅝" U channel from a hardware store, cut to the required length (27⅛" for the standard backbox width) and painted black. Williams/Bally 01-8569-1	1

Translite

Tempered glass or acrylic (Plexiglass) sheet, 18⅞" x 27" x ⅛" thick	1

Backglass side trim, Black trim pieces that attach to the side edges of the translite. Williams/Bally 03-8228-3 VP Cab Kit	2
Backglass top trim Black trim piece that attaches to the top edge of the translite. Williams/Bally 03-8228-2 VP Cab Kit	1
Backglass lift channel Black trim piece that attaches to the bottom edge of the translite, and serves as a handle for removing it from the backbox. This fits into the speaker panel H channel. Williams/Bally 03-8229-1 VP Cab Kit	1

Speaker/DMD panel (pre-WPC-95 style)

This is the separate panel at the bottom of the backbox, below the backglass, that you see on real 1990s pinballs. Many virtual cab builders reproduce this look by using the same type of panel, since it gives the machine a modern appearance and also provides an excellent place to put the audio speakers. This whole panel is optional, though; if you prefer the vintage look where the entire backbox is devoted to a single large backglass, you can skip the panel and use a larger backbox TV.

These parts are for the pre-WPC-95 style, used on Williams machines from about 1990 through 1995. A different style was used on later machines, with a single-piece molded plastic panel; those parts are listed below. See Chapter 31, Speaker/DMD Panel for a comparison of the two types.

Speaker panel H channel Black trim piece that attaches to the top edge of the DMD panel. The "H" shape makes a channel in the top that the translite fits into, to hold the translite in place. Williams/Bally 03-8265-1 VP Cab Kit	1
Speaker panel latch brackets These hold the speaker panel in place in the backbox. Williams/Bally 01-8535	2
#8-32 x 3/8" flat-head countersunk machine screws These attach the latch brackets to the speaker panel. Williams/Bally 4008-01041-06	4
#8-32 x 3/8" pan-head machine screws For attaching the speakers and "H" channel trim to the speaker panel. Williams/Bally 4008-01005-06, or SEMS version (with attached locking washer) 4006-01003-06	12
#8 external tooth locking washer For attaching the speakers and "H" channel trim to the speaker panel (required only if you're not using a SEMS screw with attached washer). Williams/Bally 4703-00008-00	12
4" Speaker screen for backbox speakers Use for DMD panels with 4" speaker openings. The standard type is black plastic; they're also available in metallic finishes (brass, chrome). Stern 535-8081-00, 535-8081-01	2

WPC-95 speaker screen for backbox speakers This is specifically designed for the molded plastic WPC-95 speaker panel, but it should also be adaptable to a 5.25" speaker opening in the older style of panel. You might have to cut holes for the speaker mounting screws to make it fit properly. Williams/Bally 04-10382-7-4	2
7" Speaker screen for backbox speakers Can be used for DMD panels with 5.25" speaker openings, but you have to cut it to size. Williams/Bally 03-8603-1, 03-8603-3, 01-6733.	2
Dot Matrix Display device This is the display device that goes in the opening in the middle of the panel to display the score and other graphics. Options: • 15-16" LCD TV, monitor, or laptop display • PinDMD 2 or 3 (commercial "real DMD" device) • Pin2dmd (DIY open-source LED DMD device)	1

Speaker/DMD panel (WPC-95 style)

These parts are for the WPC-95 style of speaker panel used on Williams machines from 1995 and after. This type of panel is made from molded plastic. Machines from 1990 through 1995 used a different style with an MDF panel and plastic facing printed with graphics; the parts for the older style are listed above. See Chapter 31, Speaker/DMD Panel for a comparison of the two types.

WPC-95 speaker panel Available with embossed Williams or Bally logos in silver or gold. Williams/Bally 04-10382-7A, 04-10382-7B, 04-10374-7A, 04-10374-7G.	1
Bushing buttons Installed in the backbox to support the speaker panel. Williams/Bally 02-5223	4
Speaker grill Usually included with the speaker panel assembly; available separately if not. Williams/Bally 04-10382-7-4	2
Speaker retainer rings for 5.25" speakers The speaker panel assembly might include retainer rings for 5.25" and 3" speakers. For a virtual cab you'll usually want two of the 5.25" retainers, so you might need to order one separately. Williams/Bally 04-10382-7-2	2
Dot matrix display shield Clear plastic cover for the DMD window. Might be included with the speaker panel assembly. Williams/Bally 01-13636	1

PC

For the sake of making this list fairly comprehensive, here's a list of the typical PC components you'll need. This is only an outline, though; we must leave it to

you to decide on specific products. See Chapter 11, Designing the PC for guidance.

Operating System Windows 7, 8, or 10 recommended. Home edition is fine.	1
CPU A CPU with 4 or more cores is recommended, such as a current generation Intel Core i5 series.	1
Motherboard Choose a motherboard based on the CPU you wish to use. Motherboards are designed to work with specific CPU types, so your choices will depend on the CPU type you plan to use.	1
CPU fan Most modern CPUs require a powered fan to be directly mounted on the CPU itself. Your CPU purchase might include this if you buy a boxed retail package; if not, many suitable third-party options are available.	1
Graphics adapter Virtual Pinball isn't as demanding as other 3D games but does require at least a mid-range graphics adapter. If cost is no object, buy a high-end gaming card. But those are usually two to three times as expensive the mid-range cards, which are fine for pinball. Get a card with at least 2GB, preferably 3G or more. You generally should use only **one** graphics adapter even for a 2- or 3-monitor system, as performance is usually higher with one card driving multiple monitors than with multiple cards.	1
ATX power supply Choose the wattage capacity according to the needs of your motherboard and graphics card.	1
RAM (system memory) Choose RAM chips that match the specs for your motherboard. RAM contributes to performance; more is better.	1
Hard disk or SSD I'd recommend using an SSD (solid-state disk) over a conventional hard disk, both for the dramatically faster boot times and for the immunity to shock and vibration.	1
Case or tray Optional. Some people like to use a conventional PC case, but this takes up a lot of room inside the cabinet. It's more common to mount the motherboard and other components directly to the cab wall or floor. You might also consider a conventional metal case to enclose the PC parts, or a "motherboard tray" (an open frame that holds the motherboard and helps secure the expansion cards, but doesn't enclose anything).	1
Fans Most cab builders include at least two standard PC case fans to move air through the cabinet. These can be mounted on the floor and/or the rear wall.	2+

Disk cables 1

Your motherboard will probably come with suitable cables for connecting your hard disk, but if not, you can buy these separately.

Power line input

Power strip 1+

Most cab builders like to be able to control power to the whole system through the PC's soft power button. You can do this with a "smart" power strip inside the cab, or you buy an ordinary power strip and make it "smart" with a contactor. A separate power strip in the backbox is useful (perhaps a small one with only 3 or 4 outlets), for plugging in the backbox TV(s) and any other devices situated there.

12VDC contactor 1

Not needed if you buy a "smart" power strip. If you buy an ordinary power strip, though, you use a contactor to make it act like a smart one. Route the line power to all devices other than the PC (including the TVs and the feedback device power supplies) through the contactor, and control the contactor via the main PC power supply's 12V output. When the PC is on, the contactor turns on and supplies power to everything else. More on this in Chapter 12, Power Switching.

Buttons

This is a list of the most common buttons needed for a virtual cab. Many cabs have extra buttons beyond these. See Chapter 34, Cabinet Buttons for specific products to buy and a more comprehensive list of optional buttons.

Some buttons have light bulbs inside. You can hard-wire these to be always lighted, but most people want the software to be able to control them so that they turn on and off at appropriate times during game play. To do this, you have to treat the lights as *output* devices, meaning the lights have to be connected to a separate output controller. The button controller only handles the switch part of the button. See Chapter 44, Feedback Devices Overview for more on this.

Flipper buttons 2-4

VP Button Kit

You need two for regular flipper buttons, and another two for Magna Save buttons if desired. If you want to light the buttons, buy a transparent type; if you want to light them with variable color (RGB) lights, buy clear transparent buttons.

Flipper buttons come in two lengths: 1⅛" and 1⅜". The VirtuaPin button kit uses the longer type to mate with their switch holders. Most real machines use the shorter length, so most of the options available from pinball vendors are only available in the shorter length. If you're looking for transparent buttons for illumination but you want the longer length so that you can use the VirtuaPin switch holders, look for part 515-7791-00.

Flipper button leaf switches The flipper buttons mentioned above are just the *buttons*, without the electronic switch part. The buttons have to be paired with switches. The gold standard is **leaf switches**. Some newbie cab builders really want to use microswitches instead, since they're so much easier to find and install, but it's almost universally agreed that leaf switches are the only thing that feels right. The problem with microswitches is that they have some intentional mechanical hysteresis at the point of contact, whereas leaf switches are perfectly smooth. That's critical for flippers because it gives you greater control and better tactile feedback. For a virtual pin cab, it's best to use low-voltage leaf switches with **gold-plated contact points**. That's the only type VirtuaPin sells, so you'll be safe if you go with theirs. If you buy from a pinball vendors like Pinball Life or Marco Specialties, make sure you get the low-voltage, gold-plated type, because the pinball parts vendors also sell a high-voltage type designed for older pinball machines. The high-voltage switches use tungsten contact points, which have higher electrical resistance than gold contacts, so they don't work as well in low-voltage logic circuits.	2-4 VP Button Kit
Flipper button leaf switch holders Optional. VirtuaPin sells their leaf switches with plastic holders that fit over the buttons and are held in place with Palnuts (below). This makes the switch positioning and installation dead simple, but be aware that these only work with the long (1⅜") buttons. If you're using the more common 1⅛" buttons, these won't fit. The holders might also conflict with lighting devices for the buttons, such as the LiteMite boards (below). If you can't use the holders, it's still fairly easy to install the leaf switches, by attaching them directly to the wall of the cabinet. So you definitely don't *need* the holders. But they're convenient if you're using compatible buttons.	2-4 VP Button Kit
Palnuts This screw onto the flipper button shaft on the inside of the cab to hold the button in place. You need one for each button. I prefer the nylon type, because they won't run the risk of shorting any nearby wire connections. Williams/Bally 02-3000, 20-9222, 3A-7532.	2-4 VP Button Kit
LiteMite PCBs for flipper button lighting (optional) These make it easy to install LEDs to illuminate transparent flipper buttons. Buy the full-color RGB type to let DOF set custom colors per game. Use one per flipper and Magna Save button.	2-4
Start button	1 VP Button Kit
Exit button	1 VP Button Kit
Extra Ball button (optional)	1
Launch Ball button (optional)	1 VP Button Kit
Coin button (optional)	1

Main PC power button VP Button Kit	1
Tilt bob (optional)	1

Audio system

The list below shows the basic elements needed in your audio system. There are too many options to list specific products here, so most of these are generic descriptions. There are also several common audio system configurations, so some of this equipment only applies to certain configurations.

Quick overview: The "primary" audio system is usually a pair of speakers in the backbox plus a subwoofer in the main cabinet. Some cabinets also have a "secondary" system that places a separate set of speakers inside the main cabinet to play back mechanical playfield sound effects (ball rolling sounds, flippers, bumpers, etc). This can use two speakers, two speakers plus a subwoofer, or four speakers for "surround sound". The secondary system can even replace other tactile feedback devices, especially if you're using an "exciter" (also known as a tactile speaker or tactile subwoofer) in place of the regular speakers.

See Chapter 41, Audio Systems for more details on o the various audio system configurations, and more specific product recommendations.

Amplifier for primary (backbox) audio system The standard setup needs a "2.1" channel amplifier (two stereo channels, one subwoofer channel). Most people use 12VDC car amplifiers. You can skip the amplifier if you're using powered PC speakers with their own built-in amplifier.	1
Midrange speakers for backbox speaker panel (primary audio system)	2
Subwoofer for main cabinet (primary audio system)	1
Amplifier for secondary audio system Optional. Only needed if you have a second audio system for mechanical playfield sounds.	1
Midrange speakers for secondary "in-cabinet" audio system Optional. Use one or two speakers for a basic system, four for a "surround" system (for placing sound effects at their proper location in the playfield area).	1-4
Subwoofer for secondary audio system Optional. Used for a 2.1 or 4.1 in-cabinet speaker system.	1
Tactile subwoofer for secondary audio system Optional; replaces the regular "subwoofer for secondary audio system" above. This can be used as a substitute for other tactile feedback devices, or together with them.	1
7" Speaker screen for subwoofer (or larger, if you're using a larger subwoofer) Williams/Bally 03-8603-1, 03-8603-3, 01-6733.	1

Feedback devices

Everything in this section is optional, applying only if you want to include feedback systems on your cab. If you're not sure you want feedback at all, you can build your cabinet without it initially, and add feedback systems later as a retrofit if you change your mind. It's a fairly isolated system that can be worked into a finished cabinet, although like anything else, it's always easier and neater if you plan for it from the outset. For recommendations for specific products and parts, see Chapter 44, Feedback Devices Overview.

Output controller USB device that receives commands from the pinball software on the PC and switches lights, solenoids, and motors on and off. Options: • LedWiz • PacLed • Pinscape Controller • SainSmart	1
Power boosters Most output controllers can only handle devices with low power, such as LEDs. Power boosters let you connect higher power devices, such as solenoids and motors. • Zeb's booster board • Pinscape expansion boards • DIY MOSFET circuit (described in Chapter 111, Pinscape Feedback Outputs) • Relays	1
Secondary PC power supply Most cab builders install a second ATX power supply for feedback devices, so that the main PC supply isn't affected by the extra load. PC power supplies are great for 5V and 12V devices because they have very large capacity; a cheap and low-end supply is fine for this job.	1
24V power supply Some devices require higher voltages. You can add an inexpensive closed-frame 24V supply if you have any devices that need it.	1
Step-down converter for 6.3V If you're using front-panel buttons with #555 incandescent bulbs, you can supply them using a step-down converter board to convert 12V from the PC PSU to the required 6.3V. Inexpensive converters are available on eBay to convert to selectable voltage levels. You can also find fixed-voltage 6V converters at pololu.com.	1
Step-down converter for shaker motor A second step-down converter can be used to supply your shaker motor. You can use this to reduce the voltage level if the shaking effect is too strong at full speed.	1
Step-up converter for replay knocker Pinball replay knockers are built for 50V supplies; they'll run on less but will make a weaker sound. A step-up converter can be used to supply them with higher voltages if desired.	1

High-output RGB LEDs for flashers A set of five bright RGB lights to reproduce the bright flashing lights on pinball playfields, for a more faithful reproduction of the real thing's brightness than the video rendition can achieve. Most people use 3W RGB "star" LEDs available on eBay.	5
Pinball dome lights for flashers	5
Strobe light This supplements the RGB flashers with an extra-bright white light for strobe effects. Most people use 22-LED white car strobe lights available on eBay.	1-2
Flipper feedback simulators A device inside the cabinet to simulate the tactile "thunk" of a flipper firing. You can use a real flipper assembly for the most authentic effect, but most people use a lower-cost option such as a contactor (a large relay) or a solenoid.	2
Slingshot feedback simulators Another tactile "thunk" effect generator. This is the same sort of effect as the flippers or bumpers, so most people use the same types of devices for all of these, but some like to vary the devices to get different effects.	2
Bumper feedback simulators Another "thunk" device, usually done with the same types of devices as for flippers and slingshots.	6
Shaker motor A DC motor with an off-balance weight attached, to make the machine vibrate when activated for a rumble or earthquake effect.	1
Gear motor A DC motor with an integrated step-down gear, used for the noise the gears make. This is to simulate the sound of the motors that many real pinballs use to animate playfield elements.	1
Replay knocker	1
Fan Usually placed on the top of the backbox, *à la* Whirlwind.	1
Beacons Rotating or flashing lights like on a police car, usually placed on top of the backbox. This is another light-show element, but it's also popular because so many real pinballs have these.	1
Under-cab or rear-facing RGB light strips RGB light strips attached to the underside of the cabinet and/or the back of the backbox, for ambient lighting while playing.	1
In-cab addressable RGB light strips A different type of light strip that allows each LED to be controlled individually. These can create animated lighting effects like on a theater marquis. A controller is required (below).	1
Controller for addressable RGB light strips	1