Pin-It-Yourself Project

For the Pinhead Who Wants to Build a Custom Machine

Jim Winer

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Preface: Why This Site Exists

I want to build my own pinball machine.

I've spent days at DejaNews scanning hundreds articles with "build" or "building" or "MOSFET" and I'm beginning to get an idea of the scope of the problem. I have also looked at the threads about the future of pinball. I'm convinced that a large part of the future of pinball lies with the home game builder. Just as with video games, the future pinhead is the person who has learned to play the game at home.

There have been several threads on building your own machine. What all of these threads have lacked is:

- There has never been any mechanism for creating a reference work that others can use.
- There has never been any procedure for creating some standards so that many people can contribute to the development. This might include standard sizes for playfields, standard grids for identifying locations, standard light bulbs, standard connectors, and hundreds of other things all the way to the Application Programming Interface (API) or "Game Description Language" used to create the computer programming.
- There has never been any way to make this information freely available so that all of us (build it yourself addicts) and future pin-it-yourself types can build our own machines and build on the specifications.
- There has never been any way for us to share the games that we design and create with others who simply want an affordable hobby that includes the silver ball.

The Pin-it-Yourself web site has been created to provide the following services and resources to the community of pinball machine builders:

Set up a web site for the Pin-it-Yourself project so that all have access to the information.

- Organize the problem of creating your own pinball into its component parts, analyze each part, develop preliminary requirements, and suggest possible methods of meeting each of these requirements.
- Provide preliminary work on a "Game Description Language" that can be used by non-programmers to create a game based on events (contact closures, etc.), game state, history, etc.
- Organize the problem of creating playfields (design versus mechanical), analyze each part, develop etc.
- Create a handbook that describes step-by-step how to build each part of the Pin-it-Yourself project. (For example, one problem is how to build a cabinet if 1) you own a power drill, a power saw, and a screwdriver, and 2) you live in a dorm and expect Home Depot to cut the wood for you.)
- Create a handbook that describes step-by-step how to create a new game based on the Pin-it-Yourself project. (Game design and playfield design.)
- Create one or more handbooks that describe step-by-step how to build other individual game designed by members of rec.games.pinball to the Pin-it-Yourself specifications.
- Make these handbooks available to the public on a dedicated web site (download and print a few hundred pages) and as paper copies at a reasonable cost.

I hope the Pin-it-Yourself Project will solve some of these problems and gives us all the resources we need to have pinball at home at a reasonable price and with a reasonable labor of love.

Jim Winer
May, 1998, December, 1999

Overview: The Future of Pinball

The computer, graphic arts, and game journals are bursting with articles about the new 3-dimensional games and virtual reality. Computer Graphics World, E-Media, New Media, PC Graphics & Video — every place you look there are articles about new animation systems and computer generated graphics developed for the movies and moving to a game arcade or amusement park near you. In the meantime, the number of pinball machine manufacturers is declining. If you've been in an arcade lately, you've seen lots of video games, some simple simulators, and a few poorly maintained pinball machines.

An arcade operator wants to make money:

- A video game has a joystick and a few buttons — not much to maintain.
- A pinball game has dozens of switches and targets that are whacked and bent by a heavy steel ball every few seconds. It has electromechanical components driven by coils with pivoting levers and springs that wear and create dirt that jams those same pivots. A pinball game that isn't played costs money.
- A video game costs a quarter for a few minutes play. Even an inept player can keep occupied for an hour for a reasonable price.
- A pinball game costs 50 cents for three balls. If you're lucky, each ball will play for 20 seconds. If you're a beginner, you can't afford to learn to play. Pinball machines are almost as expensive as telephone sex, and considerably less compulsive. A pinball game that isn't played costs money.
- Babies learn to play Sony and Sega and Nintendo and other video games at home. Their parents pay the cost of a new game and it entertains them (and their friends) for weeks. They know what a video game is and go to the arcade for the latest and greatest.

- No one can afford a new pinball machine for their kids. $7,000 for a pinball machine is a much bigger investment that $40 for a new game that runs on the same old video machine. And that same old video machine is inexpensive enough to be a grand Christmas present. There is no new generation of pinball players.

So what is so special about pinball?

It's visceral — you can feel it in your gut. Ask any of the astronauts who walked on the moon if flying a simulator is as much fun as the real thing. If you've played Timeshock, you know that it's the best pinball simulator available (5/98). If you've also ever played a real pinball machine, even a really simple old electromechanical, you also know that the real machine beats the virtual machine every time. There's just something about the clacks and knocks and bongs and whizzers that doesn't come out of a speaker. You can feel it in your hands and in your gut. Would you want to ride a stationary exercise bike instead of the real thing for the rest of your life?

So, if pinball has long-term future, it may not be in the arcades (at least for the next few years). The short-term future of pinball may be as a computer peripheral. When we have raised a new generation of pinheads on our home-built machines, we will create the demand for the new generation of arcade pinball machines.

But what is a pinball machine?

- A playfield requires:
    - Flipper mechanisms
    - Slingshots
    - Targets
    - Drop targets
    - Light bulbs & flashers
    - Scoops, ramps, kickers, etc. — whatever the designer can dream up out of standard parts
    - Player controls

- A backbox requires:
    - An information display
    - Artwork
    - Flashing lights
    - Sound

- The rest of the pinball machine is hidden:
    - A computer that controls the play
    - Switch sensors for input
    - Lamp and coil drivers for output
    - Sound effects and music
    - Display animations
    - Power supply
    - Operator controls

Yet, a good pinball machine is more than the sum of its parts. It provides an experience that is sensual and exciting without requiring skill for a beginner, yet intellectually stimulating and skill building for the experienced player. It's whiz-bang enough for the occasional play, and it's challenging enough to engender addiction. It is a combination of hypnotic flashing lights, fascinating sounds, seductive voices, exciting music, manual dexterity, and the semblance of control. It's a way to escape to another world without becoming a couch potato.

To keep our love for pinball alive, we need new pinball machines. If these machines are to be of most benefit to us and our children, they must be inexpensive enough to have at home. One of the ways of making this dream a reality is to build our own machines. We have not only the fun of playing, but the fun of creating.

The first part of creating this new reality is to define a standard computer interface, a standard playfield interface, a standard backbox interface, and a standard programming interface - the APIs, if you will. It will also help to select some standard hardware like flipper mechanisms, targets, switches, lamps, sockets, connectors, etc. From there it becomes possible to bring the project into multiple actualities — you choose your own level of work and play.

The second part of creating this new reality is to teach what we can of the art of designing a pinball game — where to put all those switches and targets and lamps, and how to bring them together into an enjoyable experience.

These are the purposes of the Pin-it-Yourself Project. This web site provides ideas and information for a thousand variations that can work together to create a new pinball reality.

Enjoy! Even if you never build your own pinball machine, enjoy learning how people working together can make something that one person alone could never complete.

Copyright: Using This Information

Building Your Own Machine

So you want to build a pinball machine.

Well, there are approximately 37,673,312,370* ways to build a pinball machine. It's easy to understand why this number is so low — more than 50% of the people on Earth have never seen a pinball machine, so they don't know what they're missing.

One aspect of the problem is that if all of the people who actually build a pinball machine do it privately, and don't tell us how they did it, each of us must re-invent the wheel. I've found **exactly one** home-built pinball machine on the web at http://www.kobol.com. Even that is just a picture and not instructions or explanations.

Now, we haven't got enough hard disk space on the planet to provide instructions for 37,673,312,370 different pinball machines, so the first task is to cut that number down to a reasonable size — say a few hundred thousand at most.

Let's begin by taking an inventory of your skills. How good are you at:

- Carpentry and cabinetry?
- Electronic design?
- Electronic fabrication?
- Mechanical design?
- Mechanical fabrication?
- Computer programming?
- Game design?
- Original graphic arts?
- Plastic fabrication?
- Original animation?
- Original music composition?
- Collecting and organizing information?
- Writing?

If you're like me, you're good at one or two of these skills and have at least some experience in a few other areas. As far as some of these skills go, you haven't a snowball's chance in hell. What you'd really like to do is contribute something in the areas you're good at, and benefit from someone else's sophistication in providing easy and inexpensive solutions in the areas you're not good at. That's why this is an open site. Your contributions are welcome. If you can't write well, hey, that's one of the areas that I'm good at.

Let's look at some other factors before we continue. What tools do you own or have access to?

- Power drill?
- Screwdriver(s)?
- Hammer?
- Socket wrenches?
- Soldering iron?
- Wire cutter & stripper?

- Electric hand saw (circular)?
- Sabre saw?
- Router?

- Table or radial arm saw?
- Panel saw?
- Drill press?
- Bending brake?
- Injection molding machine?
- Vacuum molding frame?
- Silk screen?

Obviously, this list could go on and on. One of the things that we would like to do here is keep designs to the level where they can be built by people with the minimum investment in tools, yet not limit the work of those who have more or better tools. That means that basic designs should be simple with lots of room for adding your own personal bells & whistles.

The third major factor we need to look at is how much space do you have?

- Dorm room?
- Kitchen table?
- Space next to your computer?
- Basement?
- Game room?
- Garage?
- Arcade?
- Warehouse?

Ideally, you'd like a set of compatible designs that would fit not only the skills you have, but also the tools you have available, the space you have available, the funds you can afford to spend, and the time you can devote to the project. If you are a parent, you may also want to consider how you can involve your child(ren) in the project as builders as well as players.

So what this web site will do is provide *several* ways to do each thing required. You pick the way to do each thing according to your own needs. For example:

- build any of several different size cabinets with a power drill and a screwdriver by having Home Depot cut all the wood, or recondition an existing pinball cabinet
- build a lamp driver that will work with 6.3 volt (pinball) or 12 volt (automotive) bulbs, sense the bulb, and work automatically, or build a standard lamp driver for less money and spend time finding the right light bulbs
- connect one wire to each switch, light and coil and have a thousand wires going to the game computer (fly by seat-of-pants) or build a 40-wire bus and poll each switch and address each lamp (fly-by-wire)

- buy a circuit, build it with parts from Radio Shack, or etch your own circuit board from a suggested layout
- build an electromechanical with step relays and decade counters, use an old personal computer on a dedicated basis, use a 6509 or 6800 embedded processor, or use a PC-104 small form factor embedded industrial processor
- use a dedicated computer or use one that can be hooked up through the parallel port or a USB connector

All of those things aren't going to show up at once, and we'll only ever have as many of them as you and I provide.

In addition to collecting and organizing this information, this web site will provide two other major functions:

1. work toward development of standard interfaces between areas
2. distributing successful game designs

It's your web site. Take a look around. See what we have so far. See what you can contribute. Before you submit anything, please review the Copyright Information statement.

Finally, remember that there's a big difference between a pinball machine designed for home use and one designed for an arcade.

And now, let's begin. Click the *next* pinball on each page to proceed in sequence. Click the *up* pinball on each page to return to the table of contents.

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* Quite coincidentally, 37,673,312,370 is the same as the high score on 5/1/98 for Timeshock! held by Tarek Oberdieck.

Designing a Game:

Immediate Gratification & Building Skills

Designing a pinball game is far different from designing a game for home use by the designer and his or her spouse, friends, children, and children's friends.

A commercial pinball machine is designed in several steps that are totally inappropriate for designing a home-built machine. It is useful, however, to have some idea of how commercial machines are designed. The following steps are based upon information found on a major manufacturer's web site:

1. Define Game Concept

   Decide what the game is all about. What theme it has, and how things will be named and scored. Define any playfield or backbox "toys" that illustrate the theme.

2. Design Playfield

   Computer Aided Drafting (CAD) and a library of standard parts help layout a testable playfield. This is where the shots are designed.

3. Prototype the Playfield

   A computer controlled router cuts the playfield from a blank piece of plywood. The first version may have only flippers, bumpers, slingshots, and a few ball guides. The idea is to test the shots. Special software or hardware is used to allow the flippers, bumpers, slingshots, and other playfield devices to work in a minimal fashion.

4. Develop Software

   The basic functionality is available from a software library. Now the rules and special functions must be implemented.

5. Create Artwork

   Artwork is usually done before the playfield and rules have been finalized. It may be somewhat strange as a result, but waiting until the design of the game is finalized would result in missed schedules.

6. Cost Control and Parts Inventory

   After everything's working, go back and cut some corners to keep the costs under control. Also prepare a list of every part, and its specifications so that special parts can be put out for manufacturing quotes. If the quotes come back too expensive, cut some more corners. If the total cost of the nuts and bolts or the assembly comes out too expensive, cut some more corners.

7. Prototype

   Build a few machines. If you can't build them, there's something wrong with the design or the factory. Once you have a few, give a couple to the programmers, one to the shipping department for drop testing, one for FCC testing for radio frequency interference, one to the art department for photos and flyers, and a couple for public beta testing.

8. Production

   Build a short run for the distributors to put into their showrooms to see if the operators will buy them. If the response is favorable, put it into full production and hope you don't have to have a closeout.

Designing a home-made pinball machine is a little bit different. To start, there are some major considerations that don't apply to commercial machine development:

- How much fun is it to build?

  If it isn't fun to build, it will never get finished.

  Building a pinball machine must be a series of small, easily accomplished tasks that have some personal payoff at each stage.

- Can I do it myself?

  It's very nice to have a numerically controlled router, but it's not cost effective to have a $250,000 tool to make a one-of-a-kind pinball machine for home use. The techniques and tools have to be within reach of the person who wants to make the game.

  Creating a pinball machine must be reasonable in terms of time, work, and expense.

The steps for building your own pinball machine might look something like this:

1. Decide What Size and Type of Pinball Machine to Build

   This is mostly a matter of what space you have available and whether or not you have an old computer, monitor, and speakers that you can dedicate to the pinball machine, or must share your regular machine. The chapter on *Cabinet and Playfield* construction will help you with this decision.

2. Decide on a preliminary lower playfield design

   The section on *Lower Playfield Design Basics* will help you with this task.

3. Decide on a preliminary upper playfield design

   The section on *Upper Playfield Design Basics* will help you with this task and show you how to work a theme into your game at this point.

4. Decide on a preliminary middle playfield design

   The section on *Middle Playfield Design Basics* will help you with this task.

5. Review the total playfield design

   The section on *The Playfield as a Whole* will help you with this task and show you how to incorporate the underside of the playfield into the design.

6. Use a drawing program to layout the lower, middle, and upper playfield

   Show each playfield device and target on this drawing. Create a list of switches, lamps, coils, and toys for use in simulation.

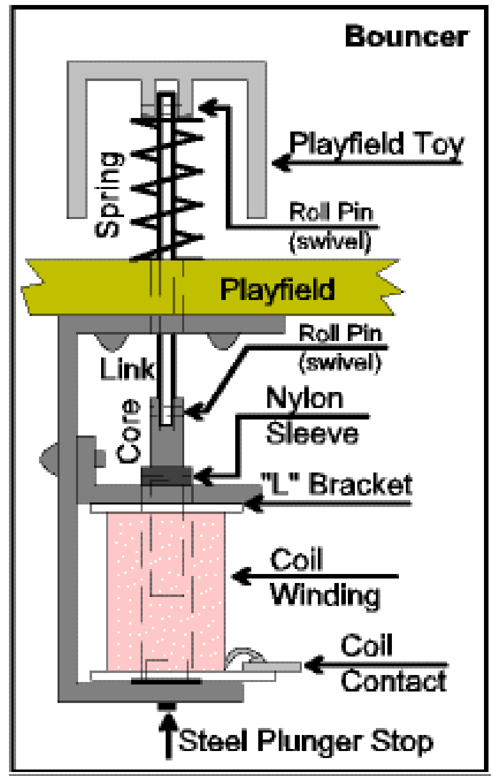
7. To be added.

Designing a Game:
Standard Parts Keep Prices Down

Standard playfield devices use only a limited number of parts. By using standard playfield devices, you can significantly cut down on the cost of building a pinball machine.

Bouncer

A bouncer is a solenoid coil connected to a playfield toy. When the coil is energized, the iron core is pulled into the center of the coil by the electromagnetic force. This causes the playfield toy to move downward. When the current to the coil stops, the spring returns the toy to the upmost position. By pulsing the coil several times at intervals, the playfield toy appears to bounce up and down. If the coil strength, current pulse duration, and interval between pulses are tuned to the spring constant and toy mass, the bouncing can be quite smooth.

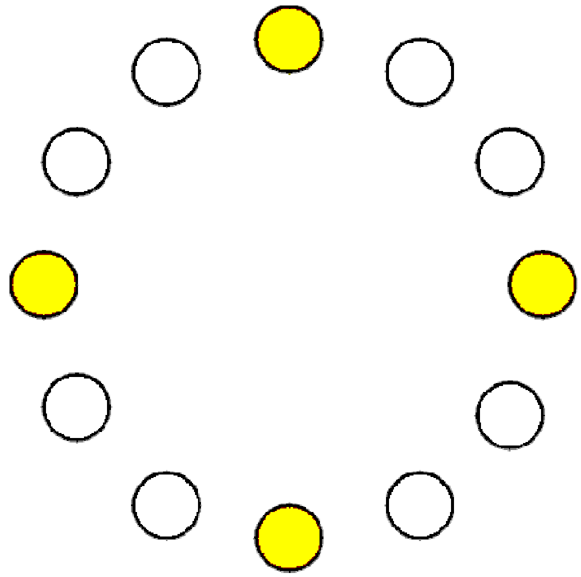


Bumper (Pop or Thumper)

To be added.

Chaser Lights (Toy)

Chaser lights give the impression of motion by lighting in sequence. Usually, there are three circuits that light in sequence to give the impression of moving lights. Both the rate of sequencing and the direction of sequencing can be changed for different effects. In rare cases, more than three circuits may be used.



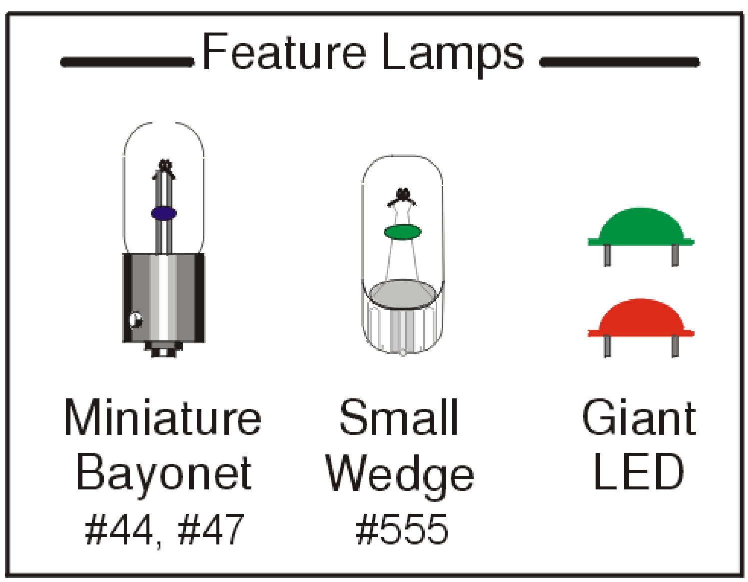
Deflector (Electrically Controlled Ball Gate)

To be added.

Drop Target

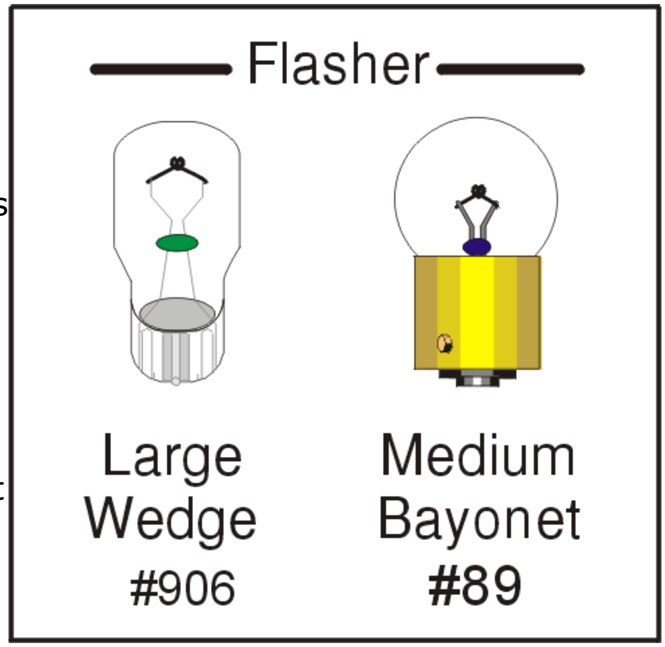
To be added.

Feature Lamps



In theory, feature lamps tell the player which features are enabled or help the player make decisions about how to play. On the best pinball machines, this is literally true — arrows light up to show the highest scoring shots or the next shot in combinations, individual target lamps light to show (by what's not lit) which targets remain to complete a bank, "feature" lamps light to show that a feature (such as a ball saver, a relaunch kicker, or a special mode) is enabled, and award lamps light to show what the player will win if a shot is made. Unfortunately on most machines, the feature lamps are more confusing than useful to the player.

Flasher Lamps



Flasher lamps are a form of "payoff" which rewards the player for making a shot, hitting a target, entering a mode, etc. They are part of the instant feedback of bells and whistles that make playing pinball fun.

As their name implies, flasher lamps flash. The bright flashes are usually accomplished by supplying a higher voltage than the lamp is designed to take for a very short time. The result is that the lamp turns on very fast, gets very bright, and shuts off before it can burn out from excess power. This out-of-specification use of filament-type lamps actually works better than using a photo or strobe flash and is considerably less expensive.

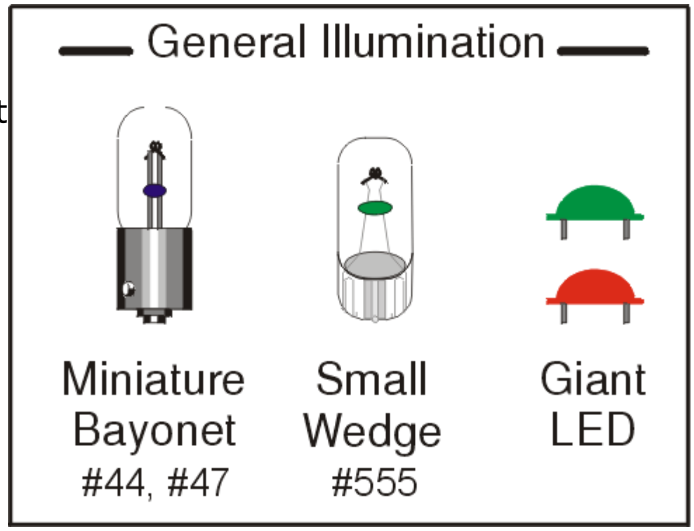
Flipper

To be added.

Gate (Mechanical Ball)

To be added.

General Illumination Lamps

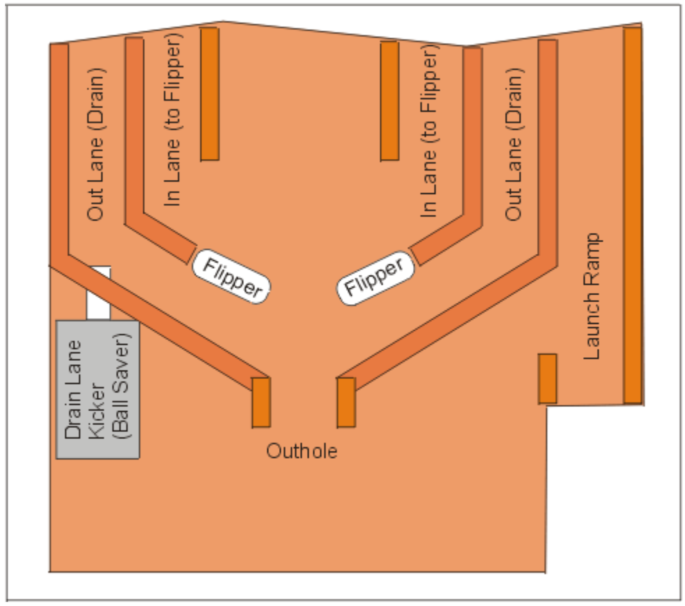


In theory, general illumination lamps provide light to play the machine. In practice, there doesn't seem to be any rhyme or reason for when general illumination lamps are on and when they are off, although there may be some relatively consistent (but not particularly useful) scheme within a single game. The only thing that can be accurately said for general illumination lamps is that they all go on and off at the same time.

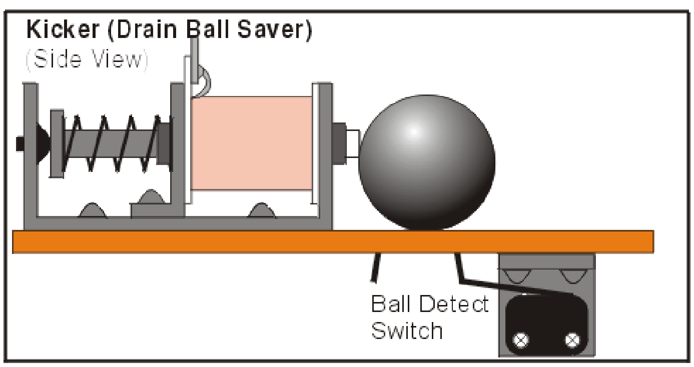
General illumination lamps are not individually controllable. The whole string of lamps is controlled by a single relay. (There may be more than one string of general illumination lamps.) Because they are not individually controllable, they do not require diodes and can run on AC power. An entire string of general illumination lamps only requires two wires for all of the lamps. General illumination lamps are cheap.

Probably the best use for general illumination lamps is to light up a specific portion of the playfield that is in use when multi-level playfields are part of a game. Unfortunately, the best thing that can be said about general illumination lamps is that they allow the player to see all the major features of the game during attract mode and they don't usually interfere too much with playability.

Kicker (Relauncher)



A **Kicker** is a solenoid coil mounted at the end of the out lane (drain lane) so that its armature (core) can strike the ball and launches it back onto the playfield instead of letting the ball drain. When the coil is energized, the iron core is pulled into the center of the coil by the electromagnetic force. This causes the core tip to hit the ball and launch it back into play. When the current to the coil stops, the spring returns the core to the rest position. A ball detect switch mounted under the playfield with a wire actuator that protrudes up through the playfield is used to determine when a ball is in position for kicking.

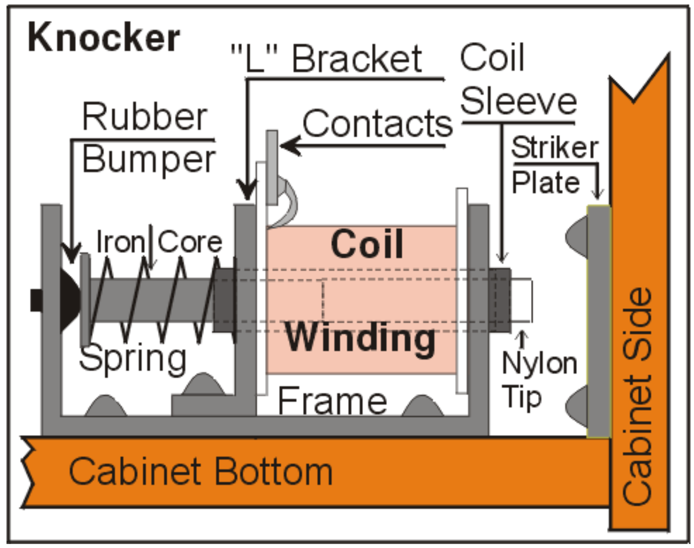


When the kicker is used as a ball saver, it is usually limited by game rules to operating only once (or some limited number of times), or for a specific number of seconds. A kicker can also be used in other locations.

Kicking Target

To be added.

Knocker

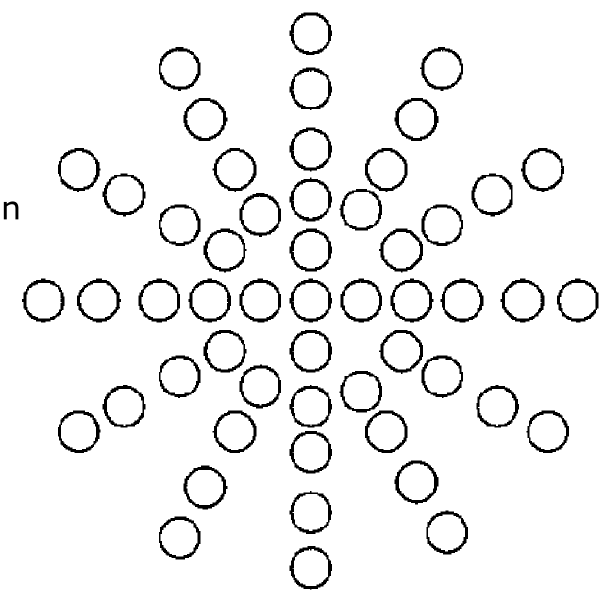


The **knocker** is a solenoid coil mounted so that its armature (core) strikes the cabinet side making a loud knock when the coil is energized. The **knocker** is used to signal a credit (free game) in response to a specific score, special shot, or other award. When the coil is energized, the iron core is pulled into the center of the coil by the electromagnetic force. This causes the core tip to hit the striker plate mounted on the cabinet side. When the current to the coil stops, the spring returns the core to the rest position.

Sometimes the knocker is mounted on the cabinet side and strikes the cabinet base, and sometimes the knocker is mounted in the backbox. The position and direction of the knocker controls how loud a "knock" it makes.

Lamp Sequencer (Explosion/Implosion Lights)

Sequenced lights can be used for many special effects. One of the more spectacular effects involves lights radiating from the center outward in an explosion or inward from the periphery in an implosion. Other possible effects include waves of color moving across or up and down the playfield.

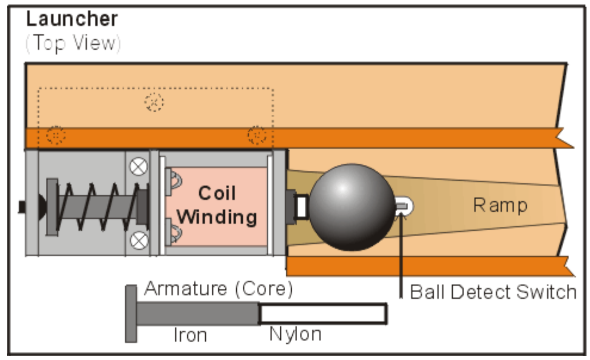


Lamps

To be added.

Launcher

A **Launcher** is a solenoid coil mounted so that its armature (core) strikes the ball and launches it onto the playfield. When the coil is energized, the iron core is pulled into the center of the coil by the electromagnetic force. This causes the core tip to hit the ball and launch it up the ramp and into play. When the current to the coil stops, the spring returns the core to the rest position.



Lift Ramp (Toy)

To be added.

Loader (Ball)

To be added.

Magnetic Flipper

To be added.

Magnetic Ball Grabber

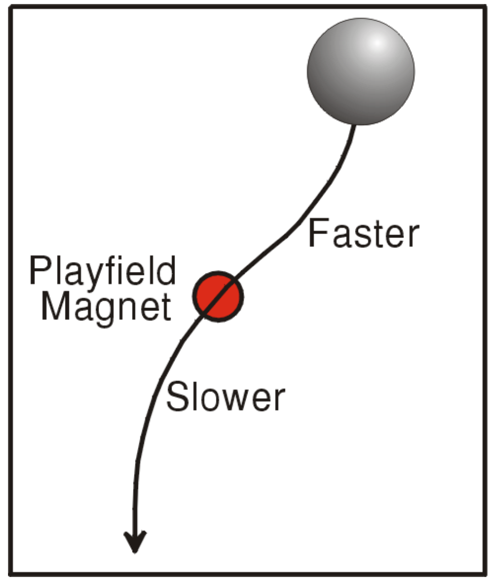
To be added.

Magnetic Stack

To be added.

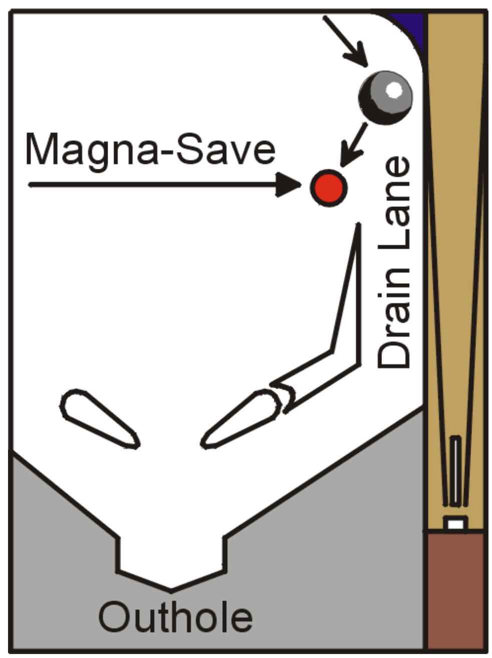
Magnet (Under-Playfield)

Playfield magnets are mounted below the surface of the playfield. They are not strong enough to stop the pinball, but affect its action by speeding it up as it approaches, slowing it down as it leaves, attracting it off course, and generally making it behave erratically. The playfield magnets are usually energized by some event in the game and are not directly under player control.



Magnasave

A magnasave is an electro-magnet that sticks through the playfield in the return lane (in lane) near the entrance to the drain lane (out lane). You can activate it to save a ball that is heading for the drain. It stops the ball by sticking it to the electro-magnet. When released, the ball goes to the return lane and the flipper instead of into the drain. You usually have to make some complex combination of shots to re-enable the magnasave after the first use.



Oscillator (Toy)

To be added.

Pinball Cannon

To be added.

Ramps

To be added.

Release (Locked Ball)

To be added.

Returns

To be added.

Rollover (Switch)

To be added.

Rotator (Toy)

To be added.

Saucer

To be added.

Scoop

To be added.

Slingshot (Kicking Rubber)

To be added.

Spinner

To be added.

Switches

To be added.

Targets

To be added.

Trap Door

To be added.

Up/Down Target

To be added.

Upkicker (Vertical Launcher)

To be added.

Designing a Game:

The Lower Playfield

For a traditional pinball machine, the lower playfield has fixed and customary requirements:

- Ball Storage Trough (required)

  The ball storage trough is where balls not in use are stored. Space for at least one ball is required. If the machine has multi-ball capabilities (more than one ball on the playfield at a time), the ball storage trough must have space for the maximum number of balls that can be on the playfield at any time.

- Outhole Mechanism (required)

  The outhole is the center drain between the flippers where the ball goes out of play. A mechanism is required to register the drained ball and to move the drained ball to the ball storage trough.

- Ball loader (required)

  The ball loader moves the first ball in the ball storage trough into the ball launcher.

- Ball launcher (required)

  The ball launcher launches the ball onto the playfield.

  Older pinball machines used a spring loaded plunger to launch the ball. By controlling how far back the plunger is pulled (force applied to the ball), you can cause the ball to take different actions on the playfield. This is called a "skill shot." It depends on fine motor skills, but not on reflex timing.

  Newer pinball machines use a kicker or relauncher to put the ball onto the playfield, often delivering it to one of the inlanes leading to a flipper. The skill shot changes from variable force to variable timing, i.e., when you activate the flipper controls the ball trajectory.

- Drains (outlanes, traditional)

  Drains located at the outside edges of the playfield. Some outlanes have a ball gate that leads to the inlanes if the machine is nudged sideways at the proper time.

- Kicker (Relauncher, optional)

A kicker is a solenoid actuated plunger that launches the ball onto the playfield. A kicker may be at any place on the playfield, but is usually used to initially launch the ball from the ball storage trough.

- Inlanes (required)

  The inlanes feed the ball to the flippers. The basic function is to slow the ball and deliver it to the flippers in a consistent way so that flipper timing can predictably control the trajectory of the ball.

- Flippers (required)

  The flippers are swiveling bars that are actuated by solenoid coils when “flipper” buttons on the sides of the cabinet are pressed. The timing of pressing the flipper buttons controls the direction and speed of the ball’s trajectory onto the playfield. The power of the flipper is determined by the type of coil installed in the flipper mechanism. The flipper always reacts the same way to being energized, so the only control the player has is the timing in relation to the ball position.

- Center Pin (optional)

  A center pin is sometimes placed in front of the outhole to bounce the ball back into the playfield or onto the flippers if the ball comes straight down the middle. With a center pin, the ball must be slightly off center to enter the outhole. Some machines have a center pin that retracts into the playfield and is elevated into place under game specific conditions.

- Slingshots (traditional)

  The slingshots are kicking rubbers (a kicker solenoid pushes against the inside of the rubber ring). A leaf switch just inside the rubber closes when the ball hits the rubber, triggering the kicker. The ball bounces off the slingshot with the additional force from the kicker instead of just the bounce of the rubber. The slingshots are traditionally located just above the flippers on each side, but there may be additional slingshots elsewhere on the playfield.

Designing a Game:
The Upper Playfield

The upper playfield usually has specific places where the ball can be targeted to cause different effects. This will include orbits (outside shots), ramps, targets, spinners, pop-bumpers, and game-specific toys.

- Gates
- Ramps
- Diverters
- Targets
- Switches
- Spinners
- Lamps
- Flashers
- Returns
- Poppers (UpKickers)
- Trap doors
- Scoops
- Saucers
- Bumpers
- Drop targets

Designing a Game:
The Middle Playfield

The middle playfield is usually bare of targets (except at the sides) so that the balls coming off the flippers can cross freely to the targets in the upper playfield. A large part of the middle playfield is used for feature lamps that indicate modes or preferred targets on the upper playfield. Magnasaves and playfield magnets that affect the trajectory of the ball are often found in the middle playfield, but are actually located below the playfield and are (sometimes) indicated by playfield markings.

- Feature lamps
- Magnasaves
- Playfield magnets
- Ramps
- Targets
- Switches
- Spinners
- Flashers
- Scoops
- Saucers
- Bumpers
- Drop targets

Designing a Game:
Multi-Level Playfields

- Trapdoors

  To be added.

- UpKickers

  To be added.

Designing a Game:
The Playfield as a Whole

To be added:

Designing a Game:
The Backbox Display

To be added:

Playfield Specifications & Application Programming Interface

- Game description languages

  To be added.

- Object and sequential orientations

  To be added.

- Events and actions

  To be added.

- Machine (game) states

  To be added.

- State tables and decision tables

  To be added.

- An Application Programming Interface (API)

  To be added.

- Other approaches

  To be added.

Cabinet and Playfield

Introduction

Building your own cabinet and playfield for a pinball machine allows you much greater freedom than refurbishing an existing cabinet. With a new cabinet, you control all aspects of the size and shape. With a new playfield, you control the materials which allows greater freedom. The first question that comes to mind is: "What size should I make the cabinet?" The answer is three more questions:

- What size door will the cabinet need to go through?
- What size cabinet will use standard-size materials efficiently and economically?
- What size do I want the playfield to be?

Getting Through the Door

Most interior doors in the USA are 30 inches wide while exterior doors are 36 inches wide. (Some interior doors are as small as 28 inches.) Allowing for clearance, the cabinet including backbox or head should be no wider than 28 inches at its widest part. Older pinball machines had detachable heads that were up to 30 inches wide, but less than 12 inches deep so that there was no problem getting the head through the door sideways. The pinball machine body was usually in the 22 to 26-inch wide by 16 to 24-inch high range which also fit through the door easily when the machine was loaded on a hand truck.

Newer machines with fold-down heads have a lot of problems with doors because the head is too wide to clear the doorway opening easily. (Even if the machine is moved "sideways," the height of the cabinet plus the depth of the head is too wide.) Because of this problem, machines with fold-down heads usually have the capability to detach the head. It is much more difficult to detach and reattach a fold-down head than to detach and reattach a head designed that way.

The recent development of backboxes containing a computer monitor rather than a DMD or scoring displays further complicates the problem because the head depth with a monitor included is greater than 12 inches. A fold-down head including a monitor would create a machine that was truly monstrous to move.

When creating your own cabinet, it is much more convenient to use a detachable head because it doesn't require hard-to-find or custom-built hardware for hinges and locking devices. The lack of hinge hardware is actually a blessing because it simplifies the doorway problem. If the cabinet width and height are limited to no more than 26 inches, the machine will go through almost any door.

Standard Materials

Most game cabinets are made from 3/4-inch nominal thickness plywood or pressboard. "Nominal" means *you could call it (or name it) that.* (Actual size is usually 11/32-inch.) The small difference in thickness will have no practical effect. Using thinner materials is generally not a good idea as they are harder to work with and not as strong. Standard sheet size is 4-foot by 8-foot. It is convenient (and efficient) if the cabinet parts can be cut from a standard sheet without too much waste, and with a minimum number of cuts.

Plywood is generally much stronger than pressboard, and resists damage better than pressboard. On the other hand, pressboard is available with a laminate finish that does not require sanding or painting. Pressboard requires drilling pilot holes for all screws while plywood does not, making plywood easier to use for construction. On the other hand, pressboard will accept screws in its edges while plywood will not. Generally, plywood works better than pressboard, even with the extra work necessary for painting.

In addition to plywood, the basic cabinet construction requires wood stringers and aluminum or steel angle irons. Several types of wood, metal, or plastic trim will also be required. These come in 8-foot lengths. The choice of exactly which to use depends on which is easy to find in your area.

Playfields are traditionally made from 1/2-inch thick hardwood plywood. Standard playfield parts (such as pop-bumpers and drop targets) are designed to work with 1/2-inch playfields, so there is really not much choice on thickness. However, there is some choice of materials. In particular, it is possible to use 3/8 inch plywood as a base with 3/32-inch plastic on top. This allows graphics to be printed with a computer and placed between the plywood and the plastic, and also allows simulated playfield inserts to be created as holes in the plywood but not in the plastic. This greatly simplifies the playfield graphics and insert problems. Standard sizes for both plywood and plastic is 4-foot by 8-foot sheets, but you can get both in 2-foot by 4-foot pre-cut pieces. 3/32-inch plastic is "glazing acrylic" or the modern substitute for window glass. You can get it in either acrylic/butyrate which breaks but is reasonably scratch resistant, or in Lexan (polycarbonate) which is almost unbreakable, but scratches easily. Perhaps the best combination is Lexan covered with Mylar (polyester) that is both scratch resistant and unbreakable.

Playfield Size

Normally, you would design a playfield based on the theme, what toys you want to put on the playfield (and how much room they require), and what size cabinet you want to use. In general, the maximum playfield size will be 24 inches by 48 inches which corresponds very nicely with the standard material sizes. However, the standard material sizes also make the available space for the playfield 24 inches by 48 inches, and you need some clearance. The optimum size for the playfield is 23-3/4 inches wide by 44 to 47 inches long. You need enough clearance at the sides to swing the playfield up and down, and you need enough clearance at the back for the playfield backing and any tall toys to swing without hitting the cabinet. (The exact length depends on the mechanism you use to hinge the playfield.)

Backbox Size

To be added.

Tools

Building a cabinet and playfield economically depends not only on efficient use of economical materials, but also on the tools required and their cost. Part of the design process for any product should include manufacturability - can it be built, how hard is it to build, and what tools are required? The design given here uses the minimum number of inexpensive tools. It assumes, however, that some special purpose tools such as a panel saw will be available on a "per cut" basis where you buy materials. The following tools are required:

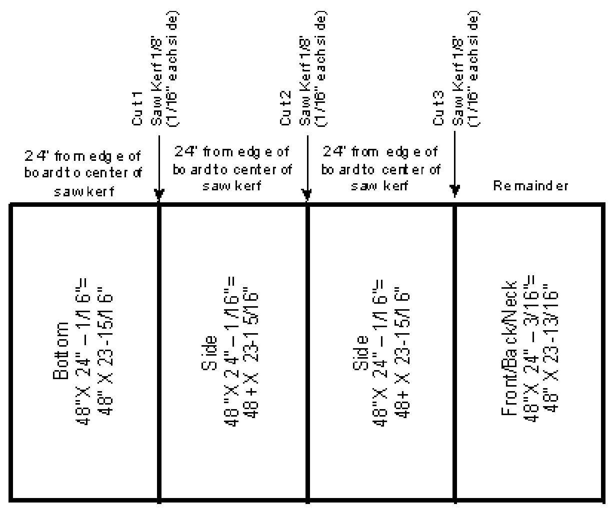
- **Panel Saw:** Have the plywood cut to basic size on the panel saw at the place you buy the plywood.
- **Power Drill and Bits:** Variable-speed reversible power drill with drill bits and screwdriver bits. (You can use a single-speed, non-reversible drill or even a hand drill if you have a separate power screwdriver, or are a masochist and have strong hands.) $40-$180
- **Whole Saw:** for pop-bumpers (about 3-inches) and round playfield inserts larger than the biggest wood bit you have (about 1-1/2"). Also used for the cable opening between cabinet and backbox if you don't have a power jigsaw. $6-$20
- **Power Jigsaw:** to make slots for drop targets and irregular shaped playfield insert holes. You could also use a router, a Dremel tool, or a spiral saw with appropriate attachments. $20-$180
- **Layout Tools:** Ruler or tape measure and pencils and markers. A square would be handy.
- **Hacksaw:** for cutting angle iron. $10
- **Mitre Box and Saw:** or any cutoff saw for cutting wood trim and molding. $20
- **Screwdrivers:** Phillips and flat. Also various hand tools.
- **Automatic Center Punch:** not absolutely necessary, but it makes life easier. Use it to mark screw holes and the drill won't wander. $3-$20
- **Hand Combination Saw or Power Saw and Saw Guide:** for cutting the angle on top of the sides. A saw guide will make cuts with a power saw much more accurate. You can rent both of these if you don't own them.

Instructions

The instructions for building a cabinet and playfield given here are designed to provide optimum use of materials (least waste, fewest cuts) and easiest assembly with minimum tools. Persons living in areas outside the United States where standard materials are different sizes will need to make adjustments.

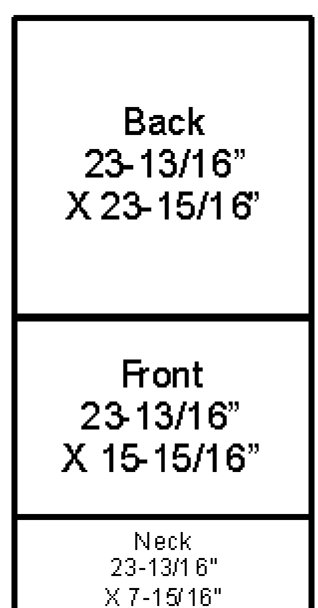
Sawing the Cabinet

1. Obtain a sheet of 3/4 nominal plywood with one side good. (See parts list for surface finish and glue variations). Have the lumberyard make the basic cuts on the panel saw unless you already own a panel saw. The basic cuts are shown in the diagram. If you have all cuts made from the same end, you should wind up with three pieces the same height and one piece slightly smaller. The smaller piece will be used for the front and back doors, and for the neck.

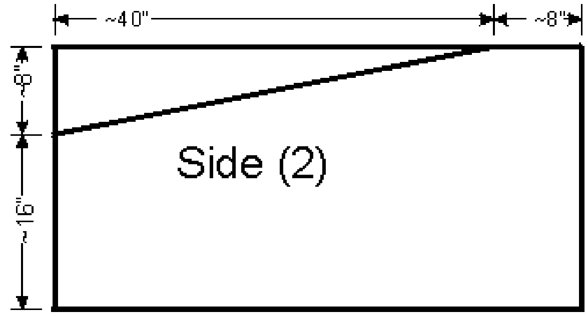


4' X 8' Plywood, 3/4" Nominal Thickness

2. Take the front/back/neck piece and make the second set of cuts shown in the diagram. This is done most easily on a panel saw. Usually, the lumberyard will make these cuts at a small cost per cut. The dimensions shown are based on making the cuts at 24" and 16" since each cut takes about 1/16" off of each side for the saw kerf.



3. If possible, do both side cuts at the same time with the sides clamped together. Make sure that both good sides are facing each other (both facing the inside) so that you will have one left side and one right side. Measure down 8 inches from the top and 8 inches from the back and draw a line. Cut along the line to create the slope. If you use a power saw, use a clamp-on saw guide to make sure the saw cuts straight.



Assembling the Cabinet

To be added.

Making and Attaching Legs

To be added.

Making and Adding the Playfield Bed

To be added.

Sawing the Backbox

To be added.

Assembling the Backbox

To be added.

Making and attaching the Back Glass Channel

To be added.

Cabinet and Playfield Graphics

Computer graphics programs

To be added.

Mylar printing substrates

To be added.

Inkjet printing on Mylar

To be added.

Laser printing on Mylar

To be added.

Laminating To be added.

To be added.

Adhering to Acrylic

To be added.

Cutting acrylic

To be added.

Sound: Adding Excitement

Computer sound editing programs

To be added.

Music libraries

To be added.

Music creation programs (automatic)

To be added.

Music composition programs

To be added.

Video/Display/Backbox Adding Bells & Whistles

Computer animation programs

To be added.

Score keeping and display

To be added.

Model and animation libraries

To be added.

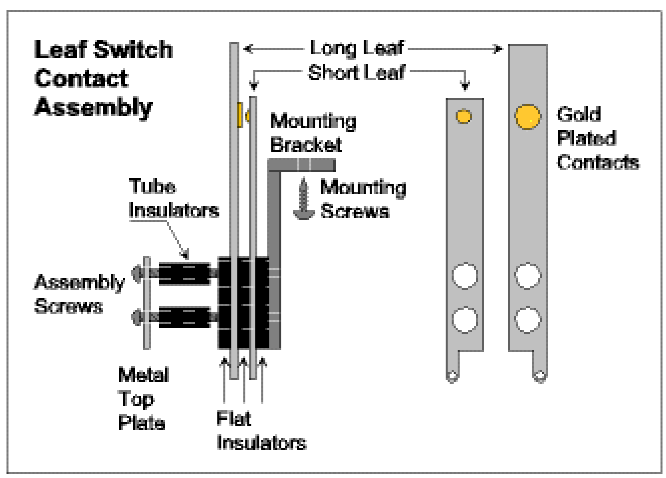
Hardware Interface: Switches

A switch is an electrical device that is either open (does not conduct) or closed (conducts). Switches tell the pinball machine where the ball is located. When the ball hits a target, a switch is closed by the mechanical action of the ball hitting the target. This may result in a score, in the activation of game options, or both. When the ball hits a *slingshot,* it moves the rubber which in turn moves a switch that tells the pinball machine to activate the *solenoid coil* that pushes the ball away. When you push a flipper button, it pushes a switch that tells the pinball machine to activate the solenoid coil that moves the flipper.

In its simplest state, a switch is two wires that either touch or do not touch. Moving the wires together or apart operates the switch. In pinball machines, momentary contact switches are used. That means that the ball (or your hand) pushing on something operates the switch, but as soon as the ball moves (or you let go), the switch returns automatically to its usual state. In most pinball machines, several types of switches are used:

Leaf Switches

A leaf switch consists of two metal blades held together in a contact assembly. One of the blades is usually longer than the other. In a normally-open leaf switch, the longer blade is pushed toward the shorter blade to close the circuit. On a modern pinball machine, only normally-open switches are used. The logic circuits of the pinball machine can translate this switch closure into any necessary action.

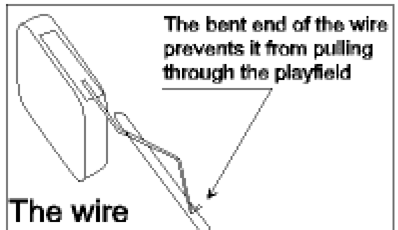


On older electro mechanical machines, two other types of leaf switches may be used. In a normally-closed leaf switch, the longer blade is pushed away from the shorter blade to open the circuit (and turn something off). A single-pole-double-throw (SPDT) leaf switch has a long blade in the center with shorter blades on each side. One side is normally-open and the other is normally-closed. Moving the longer center blade opens the normally closed switch and simultaneously closes the normally-open switch. This turns on one circuit and turns off another at the same time.

Modern leaf switches are "self-cleaning." This means that the movement of the blades causes a "wiping" motion that removes dirt. In a modern pinball machine (as opposed to an electro mechanical), the switches carry low voltages and very low currents so there is no arching across the contacts or pitting of the contacts. Modern leaf switches have gold plated contacts to prevent oxidation of the contacts. They are very reliable.

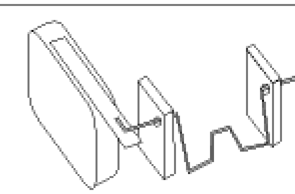
A leaf switch is adjusted by physically moving the contact assembly or by bending individual contacts. Most of the problems with leaf switches are caused by bending when you should be moving, or by improper bending.

Micro Switches



The wire of a rollover switch extends through the playfield

A microswitch is a tiny (hence "micro") enclosed switch that has a sheet metal blade or wire actuator to operate the switch. The actuator is not electrically connected to the switch contacts, so a microswitch can be used in situations where directly moving one of the switch leaves would be dangerous. The blade or wire actuator can be bent into a convenient shape for the game requirements. This allows a great deal of flexibility in operating switches that would not be possible with leaf switches.



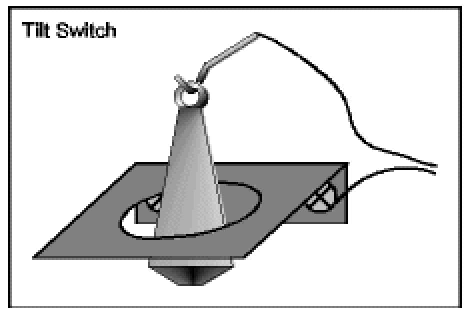
Wire gate pushes blade when ball passes through from back to front

Microswitches with wire actuators are used for playfield roll-overs. The wire is bent to stick up through a slot in the playfield. When the ball rolls over the wire, it pushes down on the wire which operates the switch. Microswitches with blade actuators are used for detecting a ball passing through a gate. As the ball moves the wire gate, one end of the wire swivels down to press the blade which operates the switch.

Microswitches are used on both electro mechanical and modern pinball machines. On modern machines, they carry low voltages and very small currents, so they are very reliable.

A microswitch is adjusted by moving the switch body or by bending the blade or wire actuator. Most of the problems with microswitches are caused by bending when you should be moving, or by improper bending.

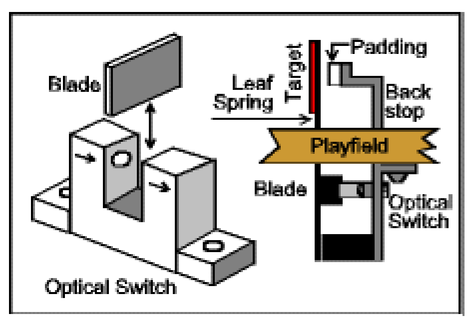
Tilt Switch



A tilt switch consists of a hanging pendulum and a ring. When you push on the machine, the ring moves with the case, but the pendulum swivels and doesn't move as much. If the pendulum touches the ring, electrical current flows through the pendulum and the ring and the machine registers tilt. This sort of switch is relatively insensitive. Adjustment is made by raising and lowering the pendulum (it's fatter at the bottom) or by counting the number of switch closures before registering tilt.

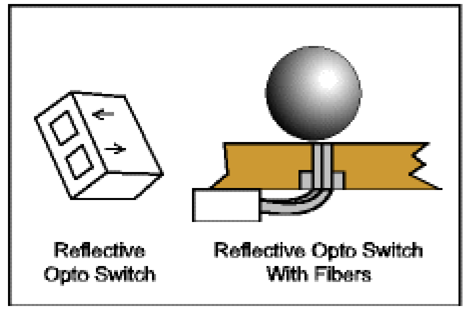
Optical Switches

Optical switches use an infra-red light emitting diode (LED) to activate a photo transistor. There are three variations that are useful in pinball machines:

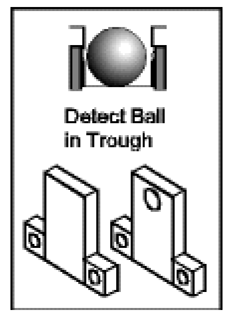


- A slot-type optical switch has the LED and the photo transistor mounted in the legs of a "U" shaped plastic. The light emitting diode is always on, and a "blade" that moves in and out of the slot interrupts the beam turning the photo transistor on and off. The circuit can be arranged so that the switch is "on" either when the blade is present or absent. This type of optical switch can be used with a target whose movement interrupts the beam. On some pinball machines, the flipper buttons move a blade into the path of a slot-type optical switch to activate the flippers.

- A reflective-type optical switch has the LED and the photo transistor mounted side-by-side and facing outward. When a reflective surface comes near the switch, the beam from the LED reflects back to the photo transistor. Typical range for this type of switch is 3-6 millimeters or 1/8 to 1/4-inch. Most reflective optical switches mount in a rectangular hole and cannot withstand the impact of a pinball. A variation connects plastic optical fibers to the LED and photo transistor. The two fibers can be mounted in a round hole and can withstand the impact of a pinball. Switches of this type can be used for rollover detection and are more reliable and easier to mount than the typical wire-operated microswitch.



- A separated-type optical switch has the LED and photo transistors in separate packages. The light emitting diode is always on, and an object moving between the LED and the photo transistor interrupts the beam turning the photo transistor on and off. The range for this type of switch can be up to 30 centimeters or 12 inches. These types of switches are useful for detecting the presence of pinballs in the loading trough or scoops.



Proximity Switches

A proximity switch may be inductive, ultrasonic, capacitive, or optical (including laser). As its name implies, a proximity switch detects the presence or absence of something within a certain "proximity" or range of the switch. Optical switches have been discussed in the previous section. Laser switches can be considered as optical switches on steroids. The other types of proximity switches are described below.

- An ultrasonic proximity switch emits ultrasonic pulses. When the pulses are reflected by objects or surfaces, the echoes are sensed. A sensitivity adjustment is used to make the switch ignore stationary objects. For the purposes of a pinball machine, the minimum working distance is too large to make this kind of switch useful. (Objects too close tend to overload the switch.)

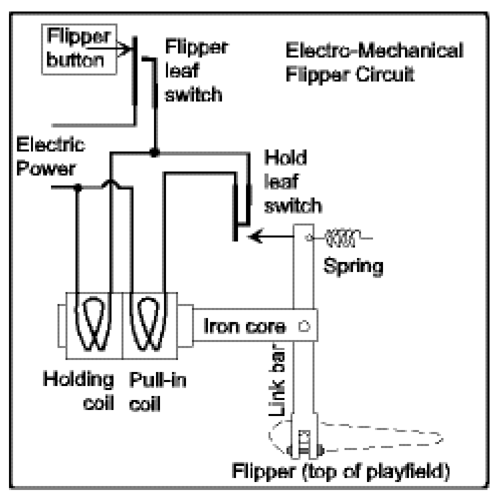
- Inductive proximity switches work in two different ways. In the active type, an oscillator generates an electromagnetic field. When an electrically or magnetically conductive object enters the field of the oscillator, its frequency is altered, and the output switches. This type of switch can only be used when oscillator field will not sense too large an area. The passive type uses a coil with an iron core or a semiconductor in a magnetic field (Hall Effect sensor). A moving magnetically conductive object disturbs the magnetic field and generates an electric current. This type of switch is not sensitive enough to detect a pinball reliably. It is used for detecting regular movement like gear wheel teeth rotating past, or with a magnet in a keyboard switch.
- Capacitive proximity switches work in two different ways. The passive type has a sensor that consists of two concentrically mounted electrodes (which are the electrodes of an opened capacitor). When an object approaches the sensor, the electrostatic field is changed. (It changes in opposite directions for conductive and non-conductive materials.) This change is detected by the switch. The active type capacitive switches operate by generating a radio frequency. As an object approaches, the impedance seen by the radio frequency changes. This influence is measured within the circuitry and compared with the reference point set by the sensitivity adjustment.

Switch Fly-by-seat-of-pants wiring

There is no memory or sequential logic involved in an electro-mechanical pinball machine. Switches generally operate directly to control the machine or to control relays that may control other relays or solenoid coils. For example, closing a switch may activate a solenoid coil that rotates a score wheel one notch. To create a temporary memory state, a switch may operate a solenoid coil that moves a wheel one notch and activates other switches depending on the position of the wheel.

Because switch contacts in an electro-mechanical often carry high voltages or currents, sparks often jump across the contacts causing burning or pitting so that switches fail often. In some games, a condenser is used across the contacts to absorb the spark and preserve the contacts.

Wiring in an electro-mechanical machine is called fly-by-seat-of-pants wiring because each individual action results in a direct reaction. Each switch actually controls something without going through an intermediary such as a computer. This is analogous to airplane controls where the steering yoke actually pulls cables that move the airplane's ailerons and elevator, and the rudder pedals push hydraulic actuators that actually move the rudder.



An electro mechanical flipper works as shown in the drawing:

1. Pushing in the flipper button closes a circuit on the flipper leaf switch. Current flows to both the holding coil (directly from the flipper leaf switch), and the pull-in coil (through the normally-closed contact of the hold leaf switch).
2. The electro-magnetic field created by the pull-in coil pulls the iron solenoid core into the coil. This moves the link bar which rotates the flipper from the down to the up position. The pull-in coil is very powerful. It uses a lot of electricity and generates a lot of heat.
3. The end of the link bar pushes the hold leaf switch, opening the circuit to the pull-in coil. Current still flows through the flipper leaf switch and the flipper holding coil.

4. The holding coil holds the iron core so that the flipper remains in the up position. The holding coil uses less electricity and generates less heat than the pull-in coil. It is strong enough to hold the iron core in, but is not strong enough to pull the iron core in by itself.
5. When the flipper button is released, the circuit opens and the spring returns the flipper to the down position.

Aside from the problem of burned and pitted contacts (which doesn't happen in modern pinball machines), the main reason that fly-by-seat-of-pants wiring is not used in a modern pinball machine is that it takes too many wires — 64 switches would require 64 to 128 wires and the appropriate sensors to determine the state of each switch. It's just too expensive.

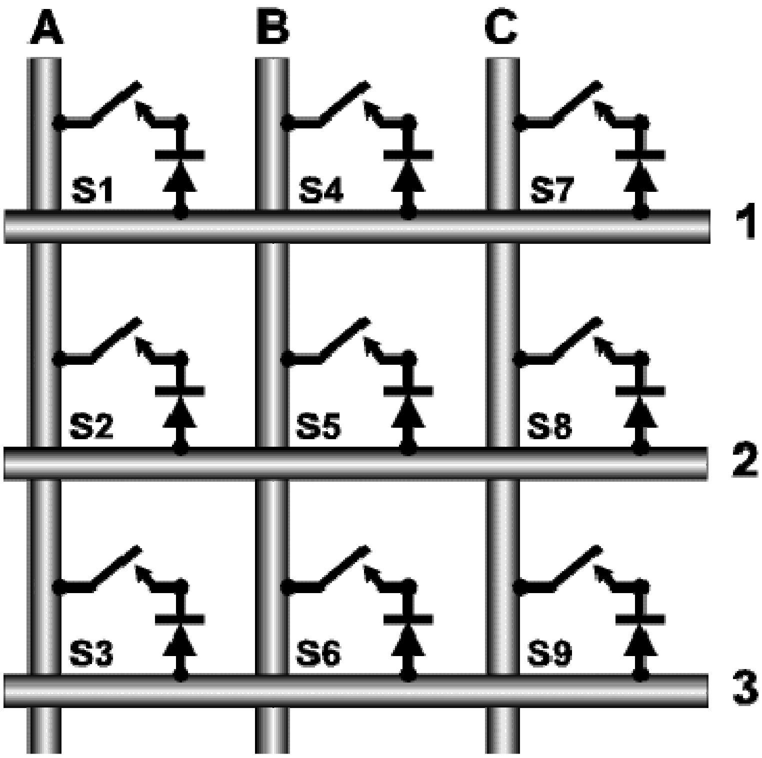
Switch Fly-by-Wire Introduction

A switch matrix (Fly-by-Wire-1) is used in most modern pinball machines because it cuts down on the number of sensors. The states of 64 switches can be sensed with only eight sensors and 16 wires. Eight of the wires are used to select one of eight columns of switches, and the other eight wires are used to transmit the status of each row of switches to the sensors. (An additional 16 wires are used to control up to 64 lamps, and 16 more wires are used individually to control coils.)

Intelligent objects (Fly-by-Wire-2 and Fly-by-Wire-3) are used in modern airplanes because they cut down on both the number of sensors and the number of wires. An unlimited number of switches, lamps, and coils can be controlled with just a few wires. For a pinball machine, a total of 254 devices (switches, lamps, coils) can be controlled with 16 to 24 signal wires and five power wires.

These approaches are called "Fly-by-Wire" because the switches (and steering yoke and rudder pedals) don't actually control anything — they just report status to the computer, and the computer flies the airplane by sending signals out over the same or other wires.

Switch Fly-by-Wire-1 — Matrix Translation



A switch matrix (Fly-by-Wire-1) is used in most modern pinball machines. The picture shows a simplified 3 by 3 matrix. A signal applied to column A gives output for switches S1, S2, and S3 on wires 1, 2, and 3 respectively. Removing the signal from column A and applying it to column B gives output for switches S4, S5, and S6 on the same wires. Similarly, the status of switches S7, S8, and S9 can be read by applying the signal to column C. The diodes at each switch prevent current from flowing backwards. Without the diodes, when more than one switch is on in a column or row, backwards current flow would create false indications that other switches were on.

The problem with a switch matrix is that you have to look at each switch about 60 times a second because the ball moves pretty fast. Looking at switches less often might mean a missed switch. Because the matrix allows you to look at eight switches at a time, you only have to look 8 X 60 (480) times a second instead of 64 X 60 (3840) times a second if you didn't have the matrix.

To use the matrix you need circuits to generate the eight column signals in sequence and circuits to sense the output of the eight rows. This requires only a few integrated circuit chips, and is inexpensive. Joe Watt has suggested an even simpler way to make a switch matrix workable by using a micro controller to sense the status of each switch and then send an interrupt to the main computer with new status for all switches each time it detects a change. This avoids having the main computer poll each switch. A circuit diagram, parts list, board layout, and instructions are available at: [Simple Switch Matrix Circuit.]

Switch Intelligent Objects Introduction

Intelligent objects (Fly-by-Wire-2 and Fly-by-Wire-3) are not currently used in pinball machines (1998), but are likely to be used in the future because of constantly lowering costs, easier manufacturing, easier programming, and better maintainability. An intelligent object has local circuitry that cuts down on the number of wires and sensors required.

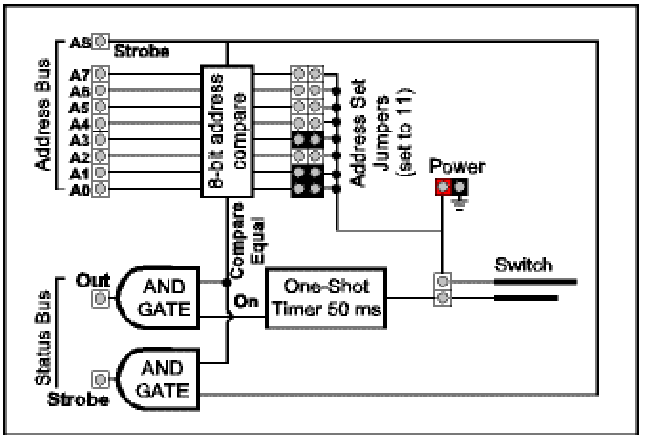
An *Intelligent switch* consists of a switch (either leaf or microswitch) connected to a near-by circuit board via a two-conductor connector. The circuit board has a power connector (+5 volts, ground) and a bus connector that has 16 to 24 wires. It also has a set of eight jumpers (or miniature switches) for setting the *address* of this particular switch. Each switch in the system must have a unique address. With eight bits, and not using 000000000 or 11111111, there are 254 addresses available. Since most pinball machines use less than 64 switches, less than 64 lamp circuits, and less than 16 coils, this address space should be sufficient for all switches, lamps, and coils. Individual switch circuit boards measure about one-inch by 2-inches. They mount to the bottom of the playfield with two screws. For construction purposes, it may be convenient to build circuit boards for four or eight multiple switches.

There are two types of intelligent switches:

- A polled switch looks for its address on the address lines. When a match is found, it reports its status on a status line. This means that the computer sends address signals to each switch 60 times a second. (64 X 60 = 3840 polls per second.)
- An interrupting switch sends a signal on an interrupt line whenever the status changes (from open to closed or from closed to open). The exact interrupt line used indicates the class of device (switch). The computer then polls all devices of the indicated class to update status. Since only a few switches change in any given second, the computer need poll only about 4 X 64 = 256 times a second.

Fly-by-Wire-2 — Intelligent Polled Switch

A polled switch operates as follows:



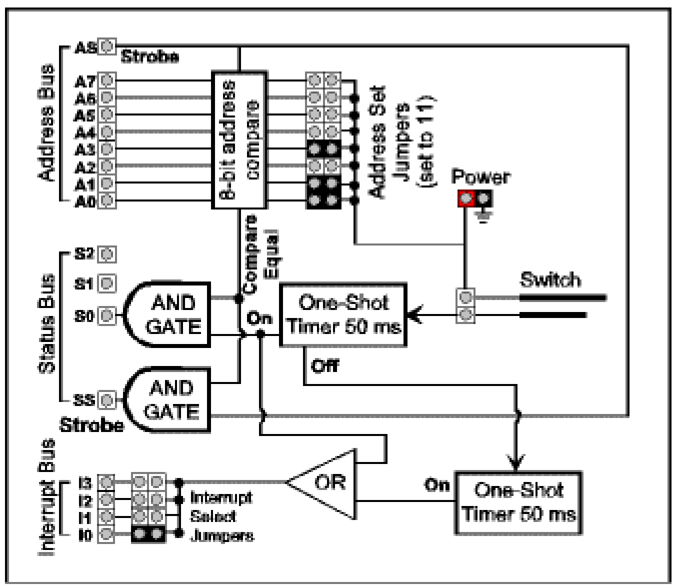
1. Closing the switch fires a one-shot timer. The timer output is ON from the initial switch closure, through any switch bounce time, and for a suitable time for polling, usually at least two times the expected polling frequency. (If the switch remains closed, for example a flipper switch, the one-shot timer will remain in the on state.) If the computer polls 60 times a second, each poll is 17 milliseconds long, so 50 milliseconds is a reasonable time for the one-shot timer to stay on.
2. When a poll is received on the eight address lines (A0- A7), a strobe is also received on the Address Strobe line (AS) to indicate that the address is stable and ready. The *Address Strobe* signal enables the eight-bit comparator. The address lines are compared to the signals from the eight jumpers. If both are the same, the *Compare Equal* is set ON.
3. The *Compare Equal* and *Timer On* signals go to an AND gate. If *both* signals are on, the output of the AND gate (*Status Out)* is also on. If either signal is off, the output of the AND gate (*Status Out)* is off.
4. The *Address Strobe* signal is sent to a second AND gate with the *Compare Equal* signal. If both signals are on, the output of the AND gate is also on and becomes the *Status Strobe* signal that tells the computer that the Status Output is ready. If the address doesn't match, the neither the *Status Output* nor the *Status Strobe* signals are sent, so other switches can share the same wires.

   More complicated versions of the intelligent polled switch have extra status lines (so that the same bus can be used for other device types). Circuit diagrams, parts lists, board layouts, and instructions for building several variations of the intelligent polled switch are available at: *Intelligent Polled Switch Circuit.*

Fly-by-Wire-3 — Intelligent Switch with Interrupt

An intelligent switch with interrupt operates slightly differently from an intelligent polled switch. With the polled switch, the computer sends an inquiry to each switch in turn asking for its status, and then starts over and polls each switch again. With an interrupt switch, the computer does no polling until one of the switches tells the computer, by means of an interrupt signal, that something has changed. Then the computer polls each device of the class that generated the interrupt (switches in this case) once until it finds out what has changed. The major advantage is that the computer does not have to poll continuously.

An intelligent switch with interrupt operates as follows:



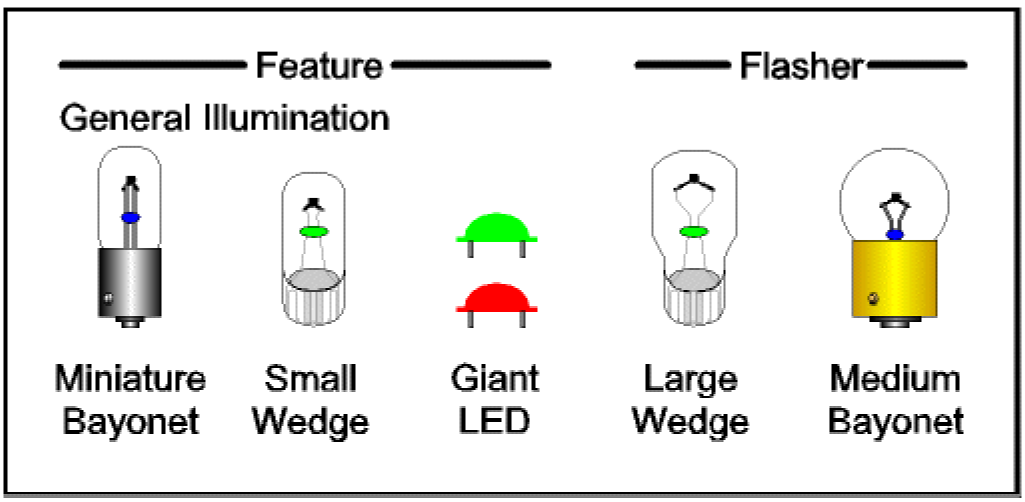
1. Closing the switch fires a one-shot timer. The timer output is ON from the initial switch closure, through any switch bounce time, and for a suitable time for polling, usually at least two times the expected polling time. If the switch remains closed, for example a flipper switch, the one-shot timer will remain in the on state. The output of this one-shot timer is called the *Closed ON* signal.
2. If the switch is open when the first one-shot timer expires, the OFF signal from the one-shot timer goes to another one-shot timer. The output of the second one-shot timer is called the *Opened ON* signal.

3. The *Closed On* signal and the *Opened On* signal are combined in an OR gate. The output of the OR gate is ON if *either* of the inputs is ON and is OFF only if *both* of the inputs are OFF. The output of the OR gate goes to whichever interrupt line (I0 through I3) has been chosen to represent the device class "switches."
4. The computer receives an interrupt on line I0 representing device class "switches." The computer responds by polling each device of class "switches."
5. When a poll is received on the eight address lines (A0- A7), a strobe is also received on the Address Strobe line (AS) to indicate that the address is stable and ready. The *Address Strobe* signal enables the eight-bit comparator. The address lines are compared to the signals from the eight jumpers. If both are the same, the *Compare Equal* is set ON.
6. The *Compare Equal* and *Timer On* signals go to an AND gate. If *both* signals are on, the output of the AND gate (*Status Out)* is also on. If either signal is off, the output of the AND gate (*Status Out)* is off.
7. The *Address Strobe* signal is sent to a second AND gate with the *Compare Equal* signal. If both signals are on, the output of the AND gate is also on and becomes the *Status Strobe* signal that tells the computer that the Status Output is ready. If the address doesn't match, the neither the *Status Output* nor the *Status Strobe* signals are sent, so other switches can share the same wires.

Circuit diagrams, parts lists, board layouts, and instructions for building several variations of the intelligent polled switch are available at: *Intelligent Switch with Interrupt Circuit.*

Hardware Interface: Lamps

Lamp is a general term for a device that either gives off light (is lit) or does not (is unlit or dark). A lamp does not have any information capability other than on or off – dim or bright doesn't count. Most lamps consist of a "filament" wire enclosed in a glass "bulb." Electricity flowing through the filament heats the filament until it becomes incandescent, or glows and gives off light. (Hence they are called incandescent bulbs.) The lamps in a pinball machine differ in brightness, the strength (voltage) of electricity required to light them, the amount (current or amperage) of electricity they use, the size and shape of the bulb, and the size and shape of the base. In addition to incandescent bulbs, there are now giant Light Emitting Diodes (LEDs) in some pinballs. (Before the giant LEDs were developed, LEDs were too small to be useful in pinball machines except for diagnostic lamps and decoration - for example, the LED chaser lamps around the flying saucer in Attack From Mars.)



Incandescent bulbs usually come only in a clear color. When they are placed below the playfield, in the backbox, or inside playfield toys, they show through plastic inserts which may be colored or have pictures or text that light up. When general illumination lamps are exposed, they are usually clear. When feature lamps are exposed, they are usually covered with soft plastic sleeves to make them red, yellow, green, or blue. When flasher lamps are exposed, they are usually covered with special plastic lenses of any color. Giant LEDs are only available in red and green at this time (1998).

Older incandescent bulbs have a metal base with one contact in the "sleeve" portion and the second contact in the tip of the base. In the newer pinballs, "wedge-base" lamps are used because they cost less than metal based lamps and are more reliable. A wedge-base lamp has the wires bent around and embedded in the glass so that a special socket can contact them directly.

Lamps are used for five purposes in pinball machines:

- General Illumination

  In theory, general illumination lamps provide light to play the machine. In practice, there doesn't seem to be any rhyme or reason for when general illumination lamps are on and when they are off, although there may be some relatively consistent (but not particularly useful) scheme within a single game. The only thing that can be accurately said for general illumination lamps is that they all go on and off at the same time.

  General illumination lamps are not individually controllable. The whole string of lamps is controlled by a single relay. (There may be more than one string of general illumination lamps.) Because they are not individually controllable, they do not require diodes and can run on AC power. An entire string of general illumination lamps only requires two wires for all of the lamps. General illumination lamps are cheap.

  Probably the best use for general illumination lamps is to light up a specific portion of the playfield that is in use when multi-level playfields are part of a game. Unfortunately, the best thing that can be said about general illumination lamps is that they allow the player to see all the major features of the game during attract mode and they don't usually interfere too much with playability.

- Feature Lamps

  In theory, feature lamps tell the player which features are enabled or help the player make decisions about how to play. On the best pinball machines, this is literally true — arrows light up to show the highest scoring shots or the next shot in combinations, individual target lamps light to show (by what's not lit) which targets remain to complete a bank, "feature" lamps light to show that a feature (such as a ball saver, a relaunch kicker, or a special mode) is enabled, and award lamps light to show what the player will win if a shot is made.

Unfortunately on most machines, the feature lamps are more confusing than useful to the player.

- Flashers

  Flasher lamps are a form of "payoff" which rewards the player for making a shot, hitting a target, entering a mode, etc. They are part of the instant feedback of bells and whistles that make playing pinball fun.

  As their name implies, flasher lamps flash. The bright flashes are usually accomplished by supplying a higher voltage than the lamp is designed to take for a very short time. The result is that the lamp turns on very fast, gets very bright, and shuts off before it can burn out from excess power. This out-of-specification use of filament-type lamps actually works better than using a photo or strobe flash and is considerably less expensive.

- Diagnostic Lamps

  Diagnostic lamps are used to help the technician determine if the game is operating properly. Specific lamps used for diagnostic purposes are usually Light Emitting Diodes (LEDs) mounted on the computer board to indicate that the board is operating properly (or not), or associated with specific circuits to indicate that the circuit is energized (or not).

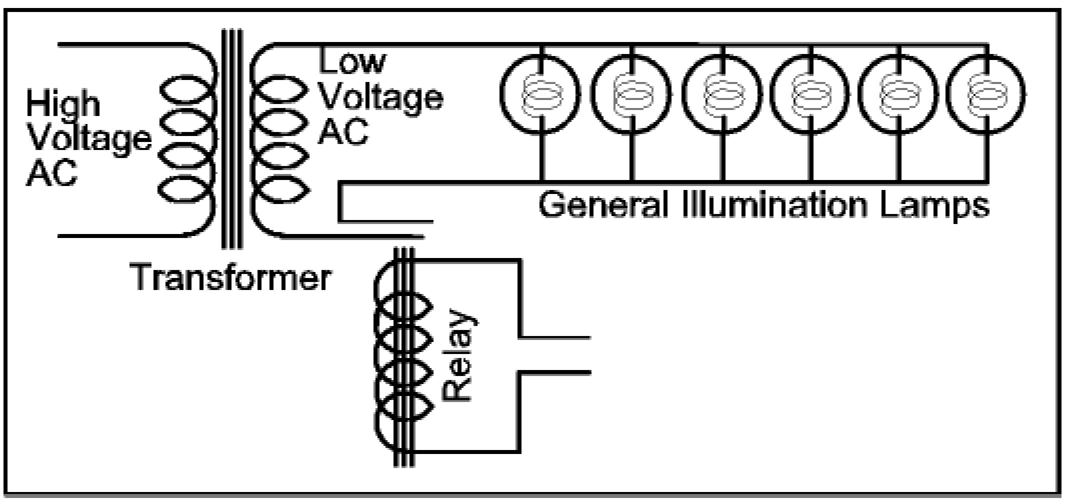
- Decorative Lamps

  Decorative lamps are used as either an attraction or a payoff. Some examples are "chaser" strings of either LEDs or incandescent lamps where a string of lights seems to be moving in a circle or regular pattern, and explosions where a series of light expands outwards in rings or collapses inward in rings. These types of displays generally use too many lamps to be included in the feature lamp count, and have a separate controller that creates the effect.

Fly-by-seat-of-pants Lamp Wiring (Electro Mechanicals)

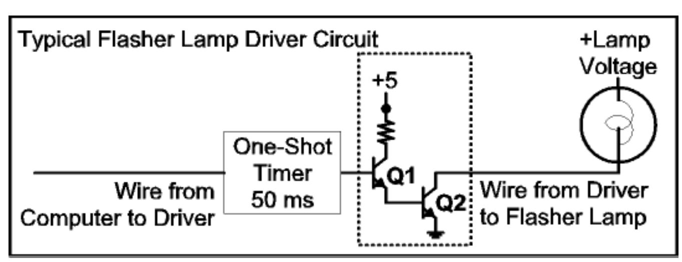
In an electro-mechanical machine, lamps are directly controlled by leaf switches, usually mounted on a relay. When the relay is on, the leaf switch closes and the lamp lights. When the relay is off, the leaf switch is open and the lamp is off.

The general illumination lamps of more modern pinball machines use this principle because it is an inexpensive way to control a group of lights at the same time. The only difference is that the general illumination relay is controlled by a computer rather than by another relay or switch. There may be more than one string of general illumination lamps.



Fly-by-Seat-of-Pants Wiring Lamp Drivers (Solid State)

A lamp driver is similar to a coil driver but has lower power requirements since lamps don't need as much power as coils. In practice, there is almost no difference between flasher lamp drivers and coil drivers since flasher lamps typically run at high voltages (for short periods of time) and often have several flasher lamps that flash simultaneously.



A signal from the computer triggers the one-shot timer. While the timer is running, it turns on low-power transistor Q1 which turns on high-power transistor Q2 causing current to flow in the flasher lamp. The lamp voltage is 2.5 to 4 times the rated voltage for the lamp, causing the lamp to light very quickly and brightly, but the short duration (controlled by the timer) prevents the lamp from burning out from too much power.

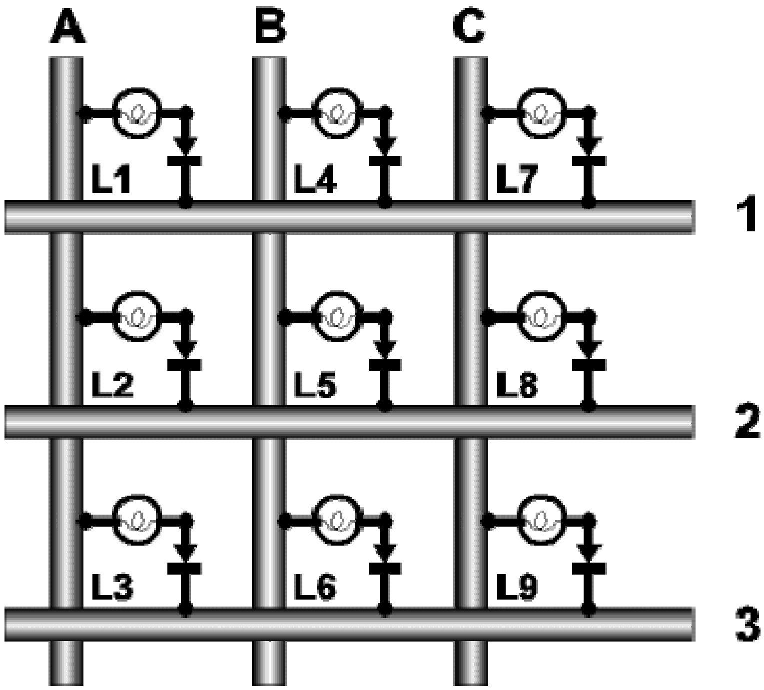
Fly-by-Wire Lamp Matrix Introduction

A lamp matrix (Fly-by-Wire-1) is used in most modern pinball machines because it cuts down on the number of wires and lamp drivers. The states of 64 lamps can be controlled with only 16 wires and 16 drivers. Each lamp is at the intersection of a row wire and a column wire. Eight of the wires are used to select one of eight columns of lamps, and the other eight wires are used to select one of eight rows.

Intelligent objects (Fly-by-Wire-2) are used in modern airplanes because they cut down on both the number of wires. An unlimited number of switches, lamps, and coils can be controlled with just a few wires. For a pinball machine, a total of 254 devices (switches, lamps, coils) can be controlled with 16 to 24 signal wires and five power wires.

These approaches are called "Fly-by-Wire" because the switches (and steering yoke and rudder pedals) don't actually control anything — they just report status to the computer, and the computer flies the airplane (and lights the lamps) by sending signals out over the same or other wires.

Fly-by-Wire-1 — Matrix Translation



A lamp matrix is used in most modern pinball machines. The picture shows a simplified 3 by 3 matrix. A voltage applied to column A can light lamps L1, L2, or L3 on wires 1, 2, or 3 respectively, depending on which row wire is also active. Removing the voltage from column A and applying it to column B can light lamps L4, L5, or L6, again depending on which row wire is also active. The diodes at each lamp prevent current from flowing backwards. Without the diodes, backwards current flow through other lamps in the same column or row would cause several lamps to go on dimly instead of one lamp to go on brightly.

The trick to using the matrix is that incandescent bulbs convert electrical energy to heat (incandescence) and don't cool back down very fast (about one-tenth of a second). This is called "persistence." The human eye also has persistence, and can't see changes that happen faster than nerve impulses can travel from the eye to the brain and be interpreted (about one-sixtieth of a second). If you energize each active lamp about 80 times a second for a very short time compared to its persistence, it will appear to be constantly lit to the player. Because the matrix allows you to energize only one lamp at a time, you have to cycle a maximum of 64 X 80 (5120) times a second.

To use the matrix you need circuits to generate the eight column signals in sequence and circuits to make the eight rows active in sequence. (Each row is active for all eight columns before moving to the next row.) This requires only a few integrated circuit chips, and is inexpensive. Joe Watt has suggested an even simpler way to make a lamp matrix workable by using a micro controller to read lamp status from the main computer and then control the lamp until the next status change from the main computer. This avoids having the main computer pulse the individual lamps. A circuit diagram, parts list, board layout, and instructions are available at: *Simple Lamp Matrix Circuit.*

Fly-by-Wire-2 — Intelligent Addressed Lamp

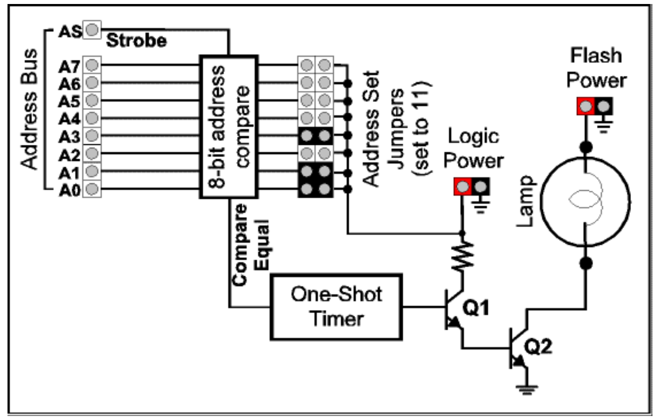
Intelligent objects (Fly-by-Wire-2) are not currently used in pinball machines (1998), but are likely to be used in the future because of constantly lowering costs, easier manufacturing, easier programming, and better maintainability. An intelligent object has local circuitry that cuts down on the number of wires required.

An *Intelligent lamp* consists of 1) a lamp connected to a near-by circuit board via a two-conductor connector or 2) a lamp installed in a near-by circuit board (wedge-base). The circuit board has a power connector (Lamp voltage, +5 volts, ground) and a bus connector that has 16 to 24 wires. It also has a set of eight jumpers (or miniature switches) for setting the *address* of this particular lamp. Each lamp in the system must have a unique address. With eight bits, and not using 000000000 or 11111111, there are 254 addresses available. Since most pinball machines use less than 64 switches, less than 64 lamp circuits, and less than 16 coils, this address space should be sufficient for all switches, lamps, and coils. Individual switch circuit boards measure about one-inch by 2-inches. They mount to the bottom of the playfield with two screws. For construction purposes, it may be convenient to build circuit boards for four or eight multiple lamps.

An addressed lamp looks for its address on the address lines. When a match is found, it sets its state based on a command on the command lines. This means that the computer sends address and command signals to each lamp only when it wants a state change. Generally, intelligent lamps have limited types of commands. A feature lamp may have On, Off, Blink Slow, and Blink Fast commands. A flash lamp usually has only a flash command.

An addressed flasher lamp operates as follows:

1. When an address is received on the eight address lines (A0- A7), a strobe is also received on the Address Strobe line (AS) to indicate that the address is stable and ready. The *Address Strobe* signal enables the eight-bit comparator. The address lines are compared to the signals from the eight jumpers. If both are the same, the *Compare Equal* is set ON.

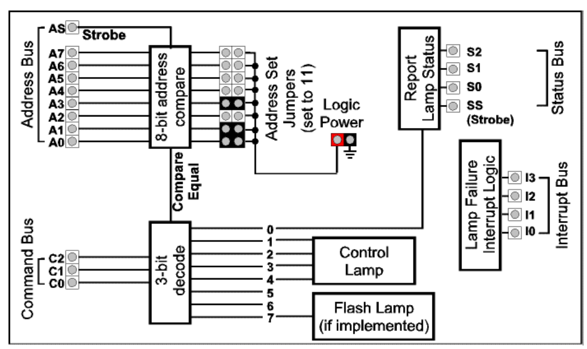


2. The *Compare Equal* signal activates a one-shot timer. The timer in turn activates the lamp driver. The timer is used to Images the lamp power on long enough to flash the lamp, and then shut the power off so that the lamp doesn't overheat and burn out.

This type of operation is suitable for lamps that have only a single possible function such as flashing once when addressed.

An addressed feature lamp operates as follows:

1. When an address is received on the eight address lines (A0- A7), a strobe is also received on the Address Strobe/Command Strobe line (AS/CS) to indicate that both the address and the command are stable and ready. The *Address Strobe* signal enables the eight-bit comparator. The address lines are compared to the signals from the eight jumpers. If both are the same, the *Compare Equal* is set ON.



2. When *Compare Equal* is ON, the command decode chip is enabled.
3. The three command lines (C0-C2) are decoded into eight individual signals:

   0 - Report Status
   1 - Lamp On
   2 - Lamp Off

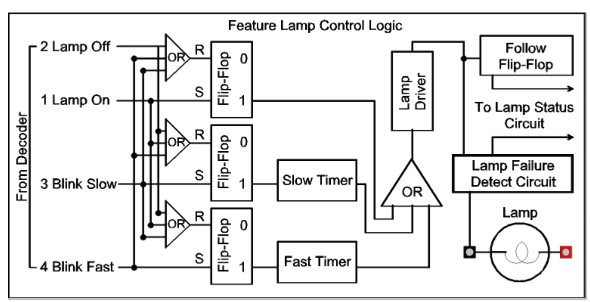
3 - Blink Slow
4 - Blink Fast
5 - Position 1 (not used)
6 - Position 2 (not used)
7 - Pulse/Flash

4. If the command is Report Status the status of the lamp is reported as On (1), Off (0), or burned out (3=1+2). For the burned out status to be reported, both of the following conditions must be true: the lamp must have been set to ON and the circuitry must include current or voltage monitoring to determine that the lamp is in fact not on. The circuitry for reporting lamp status is shown as a block in this diagram and is described following this general description.
5. If the command is Lamp On, Lamp Off, Blink Slow, or Blink Fast, the lamp is turned on, turned off, or blinked slowly or rapidly. The circuitry for controlling the lamp is shown as a block in this diagram and is described following this general description.
6. If the command is Pulse/Flash, the lamp is flashed as described earlier on this page for flasher lamps. (This command is not appropriate for most feature lamps and may not be implemented.)

Note that if current or voltage monitoring circuitry has been included to determine whether the lamp is in fact on when set to ON, this circuitry could also be used to generate an interrupt to the main computer to indicate that the lamp is not working.

The lamp control circuitry works as follows:

1. The decoded signals are fed to three flip-flops. (A flip-flop is a device that has two stable states, ON and OFF.) Each signal is sent to all three flip-flops in such a way that all three can be off, or at most one can be on.



   - The Lamp OFF signal goes to the R (Reset) lines of all three flip-flops. The Lamp OFF signal forces all three flip-flops to the 0 (off) state.
   - The Lamp ON signal goes to the S (Set) line of direct control flip-flop and to the R lines of the fast and slow timer control flip-

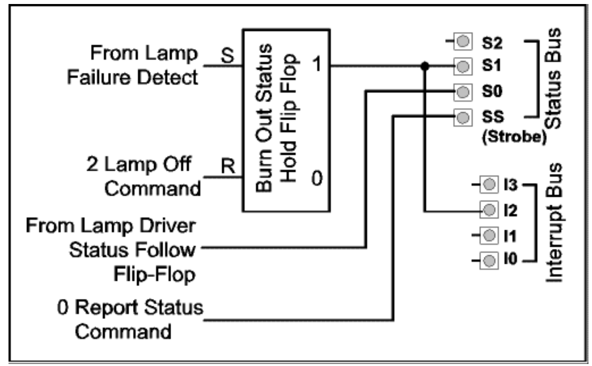
flops. This forces the direct control flip-flop to the 1 (on) state and the other two flip-flops to the 0 (off) state.

- The Blink Slow signal goes to the S (Set) line of slow timer control flip-flop and to the R lines of the direct control and fast timer control flip-flops. This forces the slow timer control flip-flop to the 1 (on) state and the other two flip-flops to the 0 (off) state.
- The Blink Fast signal goes to the S (Set) line of fast timer control flip-flop and to the R lines of the direct control and slow timer control flip-flops. This forces the fast timer control flip-flop to the 1 (on) state and the other two flip-flops to the 0 (off) state.

2. The slow timer is energized if the slow control flip-flop is in the 1 (on) state. The fast timer is energized if the fast control flip-flop is in the 1 (on) state. When energized, either of these timers cycles back and forth between the 0 and 1 states. The slow timer has a frequency of about 2 cycles per second. The fast timer has a frequency of about 6 cycles per second.
3. The outputs from the direct control flip-flop and the two timers are combined in an OR gate and fed to the lamp driver. Whenever any of these outputs are on, the lamp driver will be on. Whenever the lamp driver is on, the lamp will be on.
4. The Lamp Failure Detect Circuitry can either monitor voltage or monitor current flowing through the lamp. When the lamp driver is on, but the lamp is not lit, the circuit sends a signal to the Lamp Status circuit. The Lamp Status circuit may also generate an interrupt. Note that if the lamp state is blinking and the lamp is burned out, the lamp status will only indicate burned out during the half of each cycle when the lamp is supposed to be on. If this is not satisfactory, the lamp burned out status can be used to set a flip-flop and the flip-flop can be turned back off by the Lamp Off command.
5. The Follow flip-flop follows the state of the lamp driver. It is on when the lamp driver is on and off when the lamp driver is off.

The status report circuitry works as follows:

- The state of the Lamp Driver Follow Flip-Flop goes to line S0.
- The Lamp Failure Detect signal turns on a hold flip-flop. The output of the hold flip-flop goes to line S1. This circuit is required if an interrupt will be generated, but is optional if an interrupt will not be used. (If an interrupt is used, the status must be maintained to be interrogated.) If an interrupt is not used, the Lamp Failure Detect signal goes directly to line S1. In this case, the status may or may not be reported if the lamp is blinking depending on whether the lamp is in an on or off cycle.
- The Report Status command acts as a strobe on the status lines to tell the computer that the output is ready and stable.

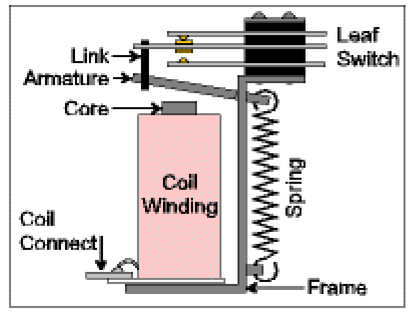


This type of operation is suitable for lamps that have multiple states such as on, off, blinking slowly, and blinking rapidly.

Hardware Interface: Coils

A coil operated device uses an electrical current flowing through a coil of wire to generate an electromagnetic field. The basic coil operated devices are relays, solenoids, and motors.

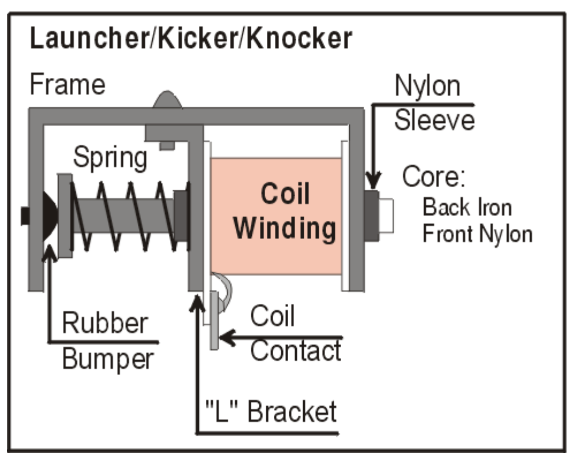
Relays



A relay consists of an iron core surrounded by a coil of wire. When the coil is energized, the iron core becomes an electromagnet and pulls the relay's "armature," a metal plate, down towards the core. The movement of the armature moves electrical contacts or switches, and hence "relays" a circuit. When the electricity is shut off, a spring moves the armature back to its original position. This moves the electrical contacts or switches back to their original position. The total movement of the relay armature is about one-sixteenth of an inch.

Typically, relays are used in pinball games to allow one circuit to control another circuit while maintaining isolation between the circuits. In more modern electronics, control between circuits with isolation is done using opto-isolators or solid state relays.

Solenoids

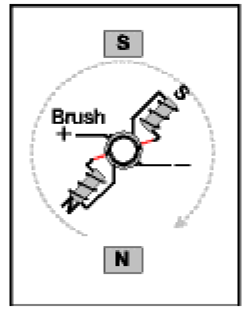


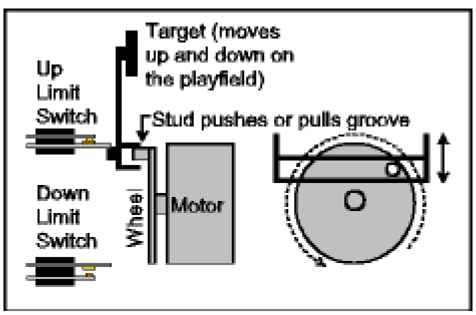
A solenoid is a coil with a moveable iron core. When the coil is energized, the iron core is pulled into the center of the coil by the electromagnetic force. The travel distance of the core can be from a fraction of an inch to several inches, depending on the size of the coil. The iron core is usually mechanically linked to some apparatus, so that the electrical energy used to activate the coil is converted into mechanical motion of a more-or-less "linear" form (as opposed to a motor where the motion is "rotary").

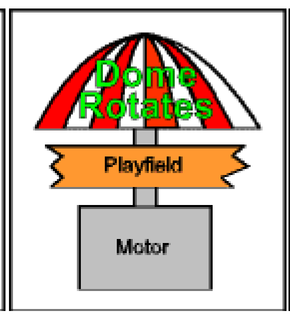
In a pinball game, solenoids are used to provide almost all electrically controlled mechanical motion. Solenoids are used for *flippers, ball launchers, kickers, scoops, drop target reset, bumpers, deflectors,* and various other hidden or public game features.

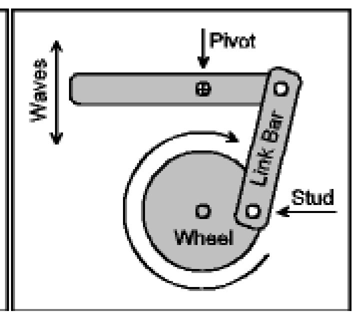
Motors

A motor uses several coils mounted on an armature (the rotating part) and a stator (the stationary part) to generate magnetic fields. In its simplest form, a rotating contact (commutator or split-ring and brushes) is used to change the polarity of the coils on the armature so that they are always the same as those of permanent magnets on the stator. The armature will rotate to attempt to separate the like polls, and when it does, the rotating contacts will change the polarity of the coils again so that the armature electromagnets are again the same polarity as the stator magnets. The rotational inertia of the armature will keep it rotating past the center point so that it does not just go back and forth.









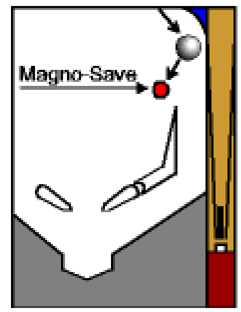
Motors are used in pinball machines with many variations of mechanical linkages. A motor can cause rotation of a dome, a back and forth or up and down motion, and many other variations. A motor with "limit" switches is used to control features that rise from below the playfield, stay in play for a while, and then disappear below the playfield again.

A motor used for automobile door locks has interesting applications for pinball. This is a motor that turns a nut at the end of a hollow shaft, pulling in or pushing out a screw. (Changing the polarity of the wiring to the motor changes the direction of rotation.) This can be used for raising or lowering targets, moving ball gates on ramps, locking and unlocking balls, and many other applications. A set of four add-on door lock motors made for automobiles is less expensive than a set of four coils specifically made for pinball use.

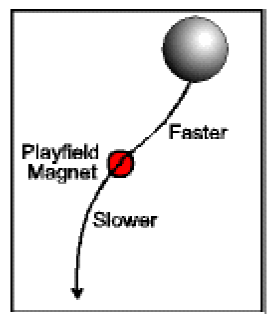
Electromagnets

Electromagnets are used in pinball machines to directly affect the course of the pinball. An electro-magnet is simply a coil of wire wrapped around an iron core that does not move. There are two variations of electro-magnets in common use:

- **A magnasave** is an electro-magnet that sticks through the playfield in the return lane near the entrance to the drain lane. You can activate it to save a ball that is heading for the drain. It stops the ball by sticking it to the electro-magnet. When released, the ball goes to the return lane instead of the drain. You usually have to make some complex combination of shots to re-enable the magnasave after the first use.



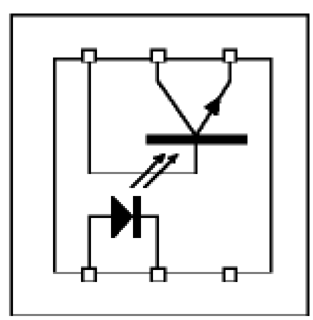
- **Playfield magnets** are mounted below the surface of the playfield. They are not strong enough to stop the pinball, but affect its action by speeding it up as it approaches, slowing it down as it leaves, attracting it off course, and generally making it behave erratically. The playfield magnets are usually energized by some event in the game and are not under player control.



Solid State Relays

In a modern pinball machine, some **semiconductor devices** can take the place of a relay:

- **An opto-isolator** is the equivalent of a signal relay that is used to isolate two circuits. One circuit energizes an infra-red light emitting diode (LED). This acts directly on a photo transistor in another circuit to cause the second circuit to become active. There is no electrical connection between the circuits, but physically, the LED and the photo transistor are in the same package, mounted right



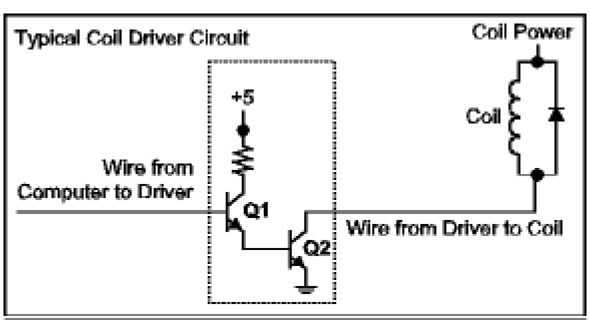
next to each other. Typically, an opto-isolator will be in a small package similar to other integrated circuits.

- **A solid state relay** is the equivalent of a power relay that is used to turn high-power circuits on and off. It is an opto-isolator that has a low-power LED on one side and a light-activated, high-power circuit on the other side. (SCR/TRIAC circuits are used for AC only loads; MOSFETs are used for AC/DC loads.) A solid state relay can be driven by a tiny computer signal and can control a large solenoid or motor. Typically, a solid state relay will be in a large package with high capacity screw or quick-connect terminals and a heat sink.

There are of course, many other variations of opto-isolators and solid state relays, and some combinations of mechanical with solid state components.

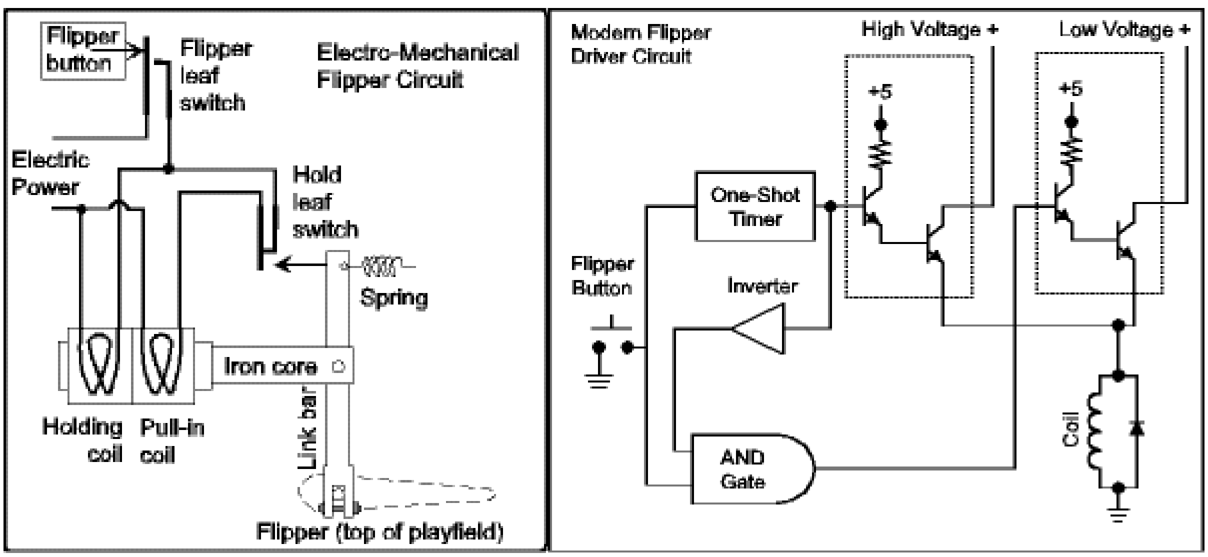
Fly-by-Seat-of-Pants Wiring and Coil Drivers

There is surprisingly little difference between the wiring of an electro-mechanical and a modern pinball machine with respect to coil wiring. In an EM, high-voltage, high-current electricity flows through a switch and down a wire to the coil. In a modern pinball machine, low-voltage, low-current electricity flows through a switch and informs a computer that the coil should be energized. Then the computer sends a signal to a coil driver circuit that sends high-voltage, high-current electricity through a wire to the coil. The only real difference is that the switches on a modern machine don't have arcing and pitting problems due to high currents. The number of wires is still the same, one or more per coil. A typical coil driver circuit looks something like the picture below. Note that there is one wire from the computer to each coil driver, and one wire from each coil driver to the associated coil.



A signal from the computer turns on low-power transistor Q1 which turns on high-power transistor Q2 causing current to flow in the coil. The diode across the coil routes the high-voltage spike, generated by the sudden collapse of the magnetic field when the coil is turned off, back into the coil instead of into the circuitry.

What's more interesting is how the EM machines handle flippers compared to modern machines. Both machines have to solve the problem of the power that it takes to move the flippers. That power creates heat that can damage the coil if it's turned on for too long. On the other hand, much less power is required to hold the flippers once they have been moved. The EM machines used two coils, one strong coil to pull in the flipper, and one weak coil to hold it once it has been pulled in. The EM machine used a switch to deactivate the pull-in coil and just leave the holding coil after the flipper had reached the up position. The modern machine uses a single coil and two different voltages. The high voltage is pulsed long enough to pull the flipper up, and then the low voltage is used to Images it up. In short, the EM used two coils and one voltage while the modern machine uses one coil and two voltages (effectively, two drivers).



In the modern flipper circuit, pressing the flipper button closes a circuit that energizes the one-shot timer. The output from the one-shot timer is reversed (inverted) and fed to an AND gate to prevent the low-voltage driver from operating. At the same time, the output from the one-shot timer activates the high-voltage driver for enough time for the flipper to pull in. When the one-shot timer finishes, the high-voltage driver goes off, and the AND gate is no longer blocked, so the low-voltage driver goes on to hold the flipper in. When the flipper button is released, the low-voltage driver goes off and the flipper returns to the off position. Pressing the flipper button and releasing it will cause the flipper to move up and then immediately back down when the one-shot timer finishes.

Coils: Intelligent Objects Introduction

Intelligent objects (Fly-by-Wire) are used in modern airplanes because they cut down on both the number of sensors and the number of wires. An unlimited number of switches, lamps, and coils can be controlled with just a few wires. For a pinball machine, a total of 254 devices (switches, lamps, coils) can be controlled with 16 to 24 signal wires and five power wires.

These approaches are called "Fly-by-Wire" because the switches (and steering yoke and rudder pedals) don't actually control anything — they just report status to the computer, and the computer flies the airplane by sending signals out over the same or other wires.

Intelligent objects (Fly-by-Wire-2 and Fly-by-Wire-3) are not currently used in pinball machines (1998), but are likely to be used in the future because of constantly lowering costs, easier manufacturing, easier programming, and better maintainability. An intelligent object has local circuitry that cuts down on the number of wires and sensors required.

An *Intelligent coil* consists of a coil (of various types) connected to a near-by circuit board that contains the coil driver and associated control circuitry. The circuit board has a power connector (+5 volts, coil voltage, ground) and a bus connector that has 16 to 24 wires. It also has a set of eight jumpers (or miniature switches) for setting the *address* of this particular coil. Each coil in the system must have a unique address. With eight bits, and not using 000000000 or 11111111, there are 254 addresses available. Since most pinball machines use less than 64 switches, less than 64 lamp circuits, and less than 16 coils, this address space should be sufficient for all switches, lamps, and coils. Individual coil circuit boards measure about one-inch by 2-inches. They mount to the bottom of the playfield with two screws. For construction purposes, it may be convenient to build circuit boards for two or four multiple coils.

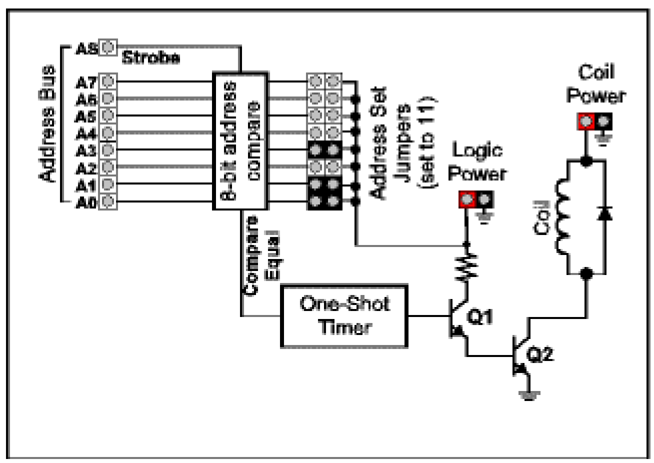
There are two types of intelligent coils:

- An addressed coil looks for its address on the address lines. When a match is found, it operates. This is suitable for coils that have only a single possible function such as *ball launchers*.

- An addressed coil with commands (and status) is generally capable of more than one operation. The most obvious application is the motorized rotator which can be either off or on. For this type of coil, an additional three wires are provided to send a command from the computer to the coil control circuit. Commands for a motor might be "on" and "off." Commands for up/down targets might be "up" and "down." In addition to accepting commands, this type of coil might report its status (report status command) such as whether and up/down target is up or down. Coils that accept commands, report status and/or generate interrupts might include bumpers. A bumper has commands to turn its lamp on or off, flash its lamp, operate the coil, report the status of the switch, and interrupt on switch status change.

Fly-by-Wire-1: Intelligent Addressed Coils

An addressed coil operates as follows:



1. When an address is received on the eight address lines (A0-A7), a strobe is also received on the Address Strobe line (AS) to indicate that the address is stable and ready. The *Address Strobe* signal enables the eight-bit comparator. The address lines are compared to the signals from the eight jumpers. If both are the same, the *Compare Equal* is set ON.

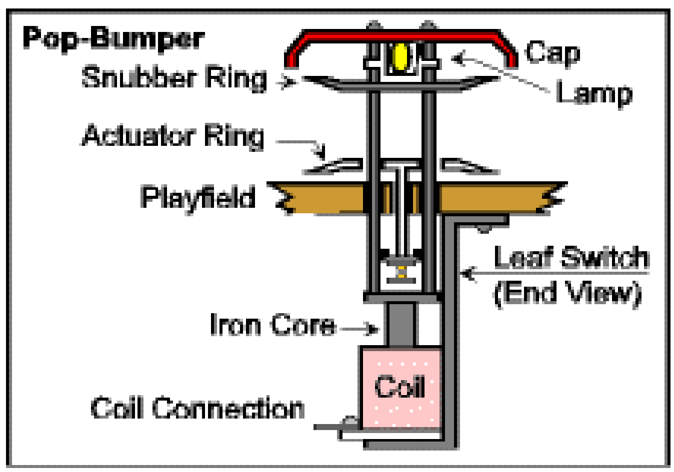
2. The *Compare Equal* signal activates a one-shot timer. The timer in turn activates the coil driver. The timer is used to Images the coil power on long enough to operate the coil, and then shut the power off so that the coil doesn't overheat.

   This type of operation is suitable for coils that have only a single possible function such as *ball loaders and launchers, slingshots, kickers, knockers, scoops, saucers, bouncers,* and *locked ball releases.*

Fly-by-Wire-2: Intelligent Addressed Coils with Command, Status, & Interrupt

A pop-bumper or thumper-bumper is the perfect device to use as an illustration of addressing, commands, status, and interrupts. A bumper works as follows:

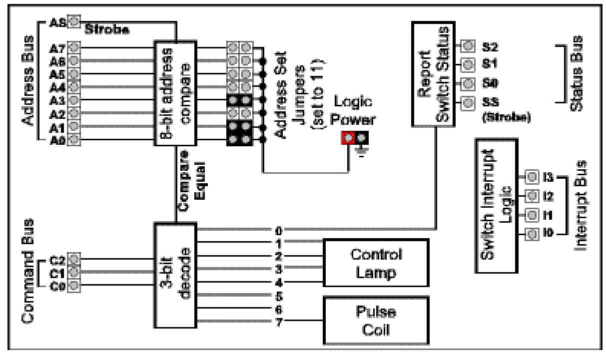
1. The lamp in the head of the bumper works independently of the bumper. It may be on all the time, on only at certain times, or flash when the bumper operates. Separate commands are used for "Lamp On," "Lamp Off," "Short Flash," and "Long Flash."



2. When a ball rolls onto the circular plastic actuator, it is pushed down and the central shaft operates the bumper switch. The switch generates an interrupt to inform the computer of its change in status.
3. The computer sends a "Pulse Coil" command to the bumper causing it to pull down the snubber ring and kick the ball out.
4. When the ball stops pressing down on the actuator, the switch opens. The switch generates an interrupt to inform the computer of its change in status.

The circuitry for the bumper operates as follows:

1. When an address is received on the eight address lines (A0- A7), a strobe is also received on the Address Strobe/Command Strobe line (AS/CS) to indicate that both the address and the command are stable and ready. The *Address Strobe* signal enables the eight-bit comparator. The address lines are compared to the signals from the eight jumpers. If both are the same, the *Compare Equal* is set ON.



2. When *Compare Equal* is ON, the command decode chip is enabled.
3. The three command lines (C0-C2) are decoded into eight individual signals:

    0 - Report Status
    1 - Lamp On
    2 - Lamp Off
    3 - Blink Slow
    4 - Blink Fast
    5 - Position 1 (not used)
    6 - Position 2 (not used)
    7 - Pulse/Flash

4. If the command is Report Status, the status of the switch is reported as described under *Hardware Interface: Switches: Fly-by-Wire-2 — Intelligent Polled Switch*
5. If the command is Lamp On, Lamp Off, Blink Slow, or Blink Fast, the lamp is turned on, turned off, or flashed short or long as described under *Hardware Interface: Lamps: Fly-by-Wire-2 — Intelligent Addressed Lamps* (Feature Lamps section).
6. If the command is Pulse/Flash, the coil is pulsed as described under *Hardware Interface: Coils: Fly-by-Wire-1: Intelligent Addressed Coils* earlier on this page.
7. When the switch changes state either to closed or open, an interrupt is sent to the computer using an interrupt line that represents either class switch or class bumper (depending on how you choose classes). This is described under

Hardware Interface: Switches: Fly-by-Wire-3 — Intelligent Switch with Interrupt

This type of operation is suitable for devices (usually involving a coil) that have multiple functions such as *bumpers, flippers, drop target banks, up/down targets, rotators, oscillators, and deflectors.*

Hardware Interface: Circuits

Intelligent Addressed Bi-stable Driver

This circuit controls a DC permanent magnet reversible motor used for bi-state mechanical devices. This type of motor is used for automatic door locks in the automotive industry.

To be added.

Intelligent Addressed Coil Driver

To be added.

Intelligent Addressed Flipper Driver

This circuit uses a high-power, timed pulse to operate the flipper followed by a low-power holding circuit to hold the flipper up while the flipper button remains pressed. An End of Stroke (EOS) switch is not required, but can be used.

To be added.

Intelligent Switch with Interrupt

To be added.

Intelligent Addressed Lamp Driver

To be added.

Intelligent Addressed Limit/Stop Driver

This circuit is used for moving mechanical devices where a continuously rotating, slow-speed motor can be used with limit switches.

To be added.

Switch Matrix

This circuit is used to read switches arranged in a matrix using row and column wires.

To be added.

Lamp Matrix

This circuit is used to light lamps using row and column wires.

To be added.

Intelligent Addressed Motor Driver

This circuit is used for driving a playfield device or toy that requires a constant speed on/off rotation.

To be added.

Intelligent Polled Switch

To be added.

Hardware Interface: Computer

Direct connections to embedded computers

To be added.

Switch matrices

To be added.

Lamp matrices

To be added.

Controller cards

To be added.

Fly-by-wire interface

To be added.

USB interface

To be added.

Pinball: Sources & Resources

Where to get parts

To be added.

On-Line Resources

To be added.

Books & magazines

To be added.

Technical help

To be added.