How to decide between PNP and NPN

A CONTROL DESIGN *reader writes:* My question arises due to machines we received at our manufacturing plant in Arizona from an OEM in Asia. All of the PLC 24 Vdc digital input modules were NPN (sourcing 24 V dc) and our plant's standard is PNP inputs (sinking 24 Vdc inputs). These signal levels (sourcing input module with sinking sensor vs. sinking input with sourcing sensor) seem like they will double the number of input modules and sensor spare parts we stock. We need to make some decisions on NPN vs. PNP transistors.

I've been asked to clearly document the electrical standards related to NPN vs. PNP and other I/O signal levels, in a machine standard. The question is what signal level sensors and I/O modules should I standardize on—NPN or PNP—in our U.S. plant, and why do the signal levels seem to be different (negative vs. positive type) on the equipment from Asia? Also, do I have the terminology correct, such as a sourcing sensor connects to a sinking input is a PNP configuration?

In the standards, I also wanted to document when to use a pull-up resistor. Is that a way to convert an NPN to a PNP signal level, or am I confusing that with an open collector input? Or is a better solution to install an opto-isolator or just replace the I/O module and sensors? Finally, are there other signal voltage levels I should document such as 5 Vdc and 120 Vac that would have NPN vs. PNP or other signal issues?

ANSWERS

Wired to accommodate

To our knowledge there is no standard that dictates when NPN (sinking) or PNP (sourcing) type sensors or digital inputs are used in a control system. It is really dependent on each OEM's internal standard or type of control system used.

Our practice at JST is to use PNP (sourcing) type sensors and digital input cards. In our experience PNP type sensors are more available. When we encounter a sensor or component that is only available as an NPN type, we will provide an NPN type of input card instead of putting an intermediate type of optical amplifier to convert the signal. Most of the PLC cards we use can be wired to accommodate PNP or NPN and do not require hardware changes.

Ryan Zrno, engineering manager,
JST Manufacturing, www.jstmfg.com, Boise, Idaho

Pull-up, pull-down

If you cannot change the NPN to PNP—NPN sources current into a load to produce a logic 1 (inverts the logic), and PNP sinks the current to produce a logic 0 (doesn't invert the logic)—and I would assume the collectors of all output transistors are common to +24 V supply and you have open emitters, and if you cannot change via programming configuration the logic output of all controllers or the input logic of your device, the end result is that you need a logic 0 into your equipment instead of a logic 1.

A pull-up resistor only won't convert + to – logic. A pull-up is used for PNP and a pull-down used with NPN to develop a voltage across it for logic 1 (no current = logic 0, current flowing = logic 1). An opto-isolator for each output might be expensive since all PLCs that I know use 24 Vdc.

Otto Fest, president,
Otek, www.otekcorp.com

2 cheers for PNP

Weiler Labeling Systems has standardized on PNP inputs wherever possible. I do not know why some countries tend to prefer NPN. I am not aware of any NPN benefit and there are at least two good reasons to use PNP.

- In an NPN circuit, if a wire breaks and contacts ground, the PLC input is true. This can potentially result in undesirable machine behavior (for example, start push button input turning on). When a wire in a PNP circuit shorts to ground, the PLC input is false.
- Troubleshooting an electrical problem is less confusing with PNP wiring because when a meter reads 24 Vdc it is clear that an input is true.

"Sourcing sensor to sinking input" is typical industry terminology. NPN/PNP applies to all typical dc sensor voltages, with 24 Vdc most commonly used.

Pull-up and pull-down resistors are used to prevent a floating input from inadvertently changing an input state. I have never observed the need to install a resistor on a modern PLC. I am not aware of any technique to convert NPN/PNP with a resistor. Solid-state or mechanical relays are a clean and typical method to convert between the polarities.

Dana Breese, engineering manager,
Weiler Labeling Systems, www.weilerls.com,
Moorestown, New Jersey

Go PNP

As a full-line sensor manufacturer, we would suggest continuing to stock only PNP sensors. When interfacing PNP sensors to NPN controllers, we suggest stocking in-line PNP-to-NPN signal converters for use in these applications. This will eliminate the need to purchase NPN sensors, simplifying inventory management.

Shawn Day, marketing manager for object detection sensors, Balluff, www.balluff.com

Mitigate the impact

Like most competing standards, the technical, cultural and historical details behind the NPN vs. PNP debate are complicated, boring and arcane. Suffice it to say that, in the United States and Europe, PNP sensor and input modules are the standard, while the NPN varieties still enjoy some preference in Asia. Your concern about the cost of holding additional spares is valid, but there are two points that might help to mitigate the impact that it will have on your organization.

1. Many input modules (especially the IP20 versions that are most commonly installed in cabinets) can be wired either NPN or PNP. Unfortunately, all of the inputs on that module need to be either NPN or PNP. You can't mix and match them.
2. Just as you're concerned about carrying additional inventory, so are the sensor manufactures. New sensors are coming into the market that can be wired or configured as either NPN or PNP. Putting these sensors on your shelf will allow you to keep one spare for both types of control circuits.

The use of pull-up resistors in the industrial automation space is pretty rare. Most PLCs and other industrially hardened I/O equipment have this feature included onboard. Pull-up resistors are generally only required in the rare occasion where we see a company using a device like an Arduino or Raspberry PI for industrial control. The input pins on these devices can be configured for a variety of purposes, so, when used as an input, the pull-up resistor provides a positive reference so that the pin doesn't float.

Sean O'Grady, product manager—valve terminals & electronics, Festo, www.festo.com

Know the input circuitry

PNP sensors are current-sourcing devices, and NPN sensors are current-sinking devices. A current-sourcing sensor must be connected to a current-sinking input. Likewise, a current-sinking sensor must be connected to a current-sourcing input, so you must know the input circuitry of the device you are connecting with the sensor. Many PLC input modules allow NPN or PNP sensors to be connected. This is sometimes determined by what other types of devices are being connected to the PLC module.

Normally open sensors do not pass power to the PLC until an object is detected. Normally closed sensors always pass power to the PLC until an object is detected.

Two-wire sensors allow either NPN or PNP output. The user doesn't have to select. Three-wire sensors are the most common. When ordering, the user must choose an NPN or PNP output. Four-wire sensors allow either NO or NC output; the user doesn't have to select. But the user must choose between NPN or PNP output when ordering.

Chip McDaniel, educational specialist, AutomationDirect, www.automationdirect.com

PNP sensors for the U.S. plant

For the U.S. market, standardizing on PNP sensors would be the better option as they are more popular and easier to find than their NPN counterparts. PNP sensors are also easier to understand and troubleshoot by technicians, since the sensor will give a high-level voltage signal when the output is active. However, it almost always comes down to personal preference and which sensors are easier for you to source.

Historically, Asia standardized early on NPN sensors, while in Europe the popular choice is PNP.

Generally speaking, the sourcing sensor and sinking input terminology is correct. However, some manufacturers will label an input for the corresponding output device, rather than the actual function of the input itself. In the above example you would use a PNP sensor to connect to a PNP input, even though it is technically a sinking (NPN) input.

An external pull-up resistor could be used to convert an NPN sensor to work with a sinking input. However, care must be taken, as this will invert the logic of the sensor. When the output of the NPN sensor is off, the sinking input will be pulled high. Alternatively, a pull-down resistor can be used to convert from PNP to NPN.

For dc sensors, in addition to NPN or PNP, you might also come across two-wire sensors, which could be wired into a PNP or NPN input in either configuration. However, you should always consider the off-state operational current of the sensor in those cases, as it can sometimes cause problems depending on the voltage-level requirements of the input.

Thomas Kolleck, sensor technology engineer, Turck, www.turck.com

Sourcing and sinking and so much more

Let's start with discussing the two types of sensor output configuration: sourcing output and sinking output. A sourcing output sensor provides a voltage on the output pin and thus is able to source current to the input when the output is active. Sinking output sensors provide a connection to ground and thus are able to sink current to the input when the output is active.

Sourcing and sinking outputs lead to sinking and sourcing inputs. A sourcing output requires connection to a sinking input, and a sinking output requires a connection to a sourcing input. What makes an input sourcing or sinking is the common connection to all of the inputs on the card. If the common connection is to +24 Vdc, the input card will be supplying (sourcing) current to the sensor. If the common connection is to ground, the input card will be sinking current from the sensor.

In the event that one ends up with a sourcing input module and a souring output sensor or a sinking input module and a sinking output sensor, it is possible to connect them. There are modules and isolators available that have selectable inputs and outputs to convert the signal. Another option would be to use a resistor. The resistor would act as the current sink for the sourcing-sourcing application and as the current source for a sinking-sinking application. Although more cost-effective, the resistor method does impose one drawback. It inverts the signal into the PLC requiring program considerations during initial design or modification during installation or operation.

The electronics term "open-collector" refers to an output where the circuit contains an NPN transistor with its collector connected directly to the output pin. With no internal reference provided to the supply voltage, the output can only indicate the low state. It cannot indicate the high state without an external connection to the supply voltage. The connection can be made by either a resistor (commonly referred to as a pull-up resistor when used in this method) or LED or relay, providing the output can sink the current required to activate the device.

The advantage of using a sinking input card is a wire break or short to ground will not activate the input. When using a sourcing input card, there should be a fuse between the input terminal and the sensor as the voltage source will be present at the input terminal and a wire break that causes a short to ground may damage the input card or power supply.

Anthony Whitesell, senior project engineer, Superior Controls, www.superiorcontrols.com, Seabrook, New Hampshire

Document electrical standards

Generally there is no agreement on why equipment out of Asia is predominantly wired as NPN, but one well-accepted theory is that back in the 1960s and '70s NPN transistors were both higher power and cheaper to make, so that's what Asian manufacturers used in their machines. From then on, it was a case of ensuring backward compatibility. Machines made 20 years ago, 10 years ago or one year ago all had NPN transistors in them, so that's what machines made today have.

It is said that Europe and the United States tended to use PNP circuits because they are easier to fault-find. A short circuit in a PNP circuit can be found by tracing current or by lifting wires. Since NPN circuits conduct the same current to ground under fault conditions as normal operating conditions, they are naturally harder to troubleshoot.

Does a sourcing sensor connect to a sinking input? Yes. It really is a case of opposites attracting. If the field device is sourcing, then the I/O input must be sinking. If the field device is sinking, then the I/O input must be sourcing. If your PLC has a single common for all channels (either all positive or all ground), then all the field devices must be wired to match that input type. In other words, unless you have a special I/O module on the PLC—and you will know if you do—you cannot mix field sensor types.

When do I use a pull-up resistor? To convert a sinking field device with sinking I/O requires the use of a pull-up resistor. To convert a sourcing field device to a sourcing I/O requires the use of a pull-down resistor.

In both cases you will need to carefully calculate the value of the resistor to do the job it needs to. In the first case (sinking device and sinking I/O) you must find out if the load is connected to the same voltage source as the output module. If it is, the resistor must be low enough to pull the line up when the sinking output is turned off, but not so low of a resistance as to damage the output when it is switched on. Also note that this pull-up resistor will invert the logic. A zero on the output will be a one on the input. You must either correct it in software or mentally make the swap when working on the device.

In the second case (sourcing device and sourcing I/O), if the input and output are driven from the same voltage source, then the resistor must be sized so that the voltage is pulled down when the output is on, but not so low as to draw excessive current through the output.

If the machine has separate rails, then the resistor must be large enough to load the output and stop the line from floating when it is turned off.

NPN/PNP VS. SINKING/SOURCING

The terms NPN and PNP refer to how a transistor is constructed, according to Michael Sheldon, applications engineer at Maple Systems (www.maplesystems.com). A transistor is a three-layer sandwich of two different types of material; the two outside layers are the same, and the middle layer is different. The magic of the transistor is the layer in the middle can be used to control the flow of current between the outside layers. The two types of material that can be used to build a transistor are n-type and p-type. Thus, there are two possible types of transistor: NPN and PNP. The practical difference between these two transistor types is in how current flows through the circuit. In a bipolar junction transistor (BJT), the control leg—the middle of the sandwich—is called the base. The other two connection points are called the collector and the emitter. In a PNP transistor, a small current flowing from the emitter into the base causes a larger current to flow from the emitter to the collector.

In all cases care must be taken to calculate the value of the resistor to ensure that the power limits of both the output and the resistor itself are appropriately rated.

Is a sourcing sensor connecting to a sinking input a PNP configuration? Since a PNP transistor can be wired as either sinking or sourcing, there are no hard-and-fast rules as to what should be named what. A major cause of confusion stems from the tendency of electrical shops to view dc voltage in conventional terms, that is to say, voltage flows from the positive terminal to the negative terminal.

However, in electronics they tend to refer to actual electron flow, which is from the negative to positive terminals.

This difference may be based on culture, region or experience (age of the engineer), but it can also vary from shop to shop or from panel builder to draftsperson. You can try to set and enforce a standard way to describe the flow of electricity in your workplace. We wish you the best in that endeavor.

What is an open collector input? The collector is always on the output of a transistor and never the input. This term stems from the fact that the collector of the output stage is open for connections to the next device, usually the load.

Since the term “open collector” does not tell us the type of transistor (NPN or PNP), we need to refer to the wiring diagram to determine if the load should be wired between the open collector and the positive rail, or the open collector and ground.

Is it better to install an opto-isolator or just replace the I/O module and sensors?

- An opto-isolator is a natural choice for connecting like sensors to like inputs (source sensors to source inputs or sink sensors to sink inputs). If you have the space, this may well be the most elegant way to interface the two standards.
- Replacing the I/O is no doubt the cleanest, most logical way, but it goes back to your first concern, having to stock both types.
- Replacing the sensors I suspect will be a far more expensive and labor-intensive approach than using the opto-isolator, using the pull-up resistor or swapping the I/O module.

Are there other voltage levels that need the NPN vs. PNP decision to be made, such as 5 Vdc and 120 Vac? Sinking and sourcing apply only to direct-current (dc) circuits. The terms sinking and sourcing are in reference to current flow between a positive terminal and a negative (or ground) terminal. Since there is no reference like this in alternating-current (ac) circuits, we do not have to take sinking and sourcing into consideration when dealing with any ac control systems.

So, in short, yes, all dc circuits need sinking, sourcing and NPN vs. PNP consideration.

Ben Orchard, senior applications engineer,
Opto 22, www.opto22.com

Configuration communications

The question of sinking vs. sourcing and NPN vs. PNP causes confusion throughout the controls industry. Often two engineers working on different parts of a system will not communicate the chosen configuration. These errors will inevitably be discovered; the question is when and at what cost? To answer your questions, let’s start by defining the terms being used.

The terms NPN and PNP are commonly used as synonyms for sinking and sourcing, respectively. This is a reasonable assumption, but strictly speaking they refer to different concepts. For our purposes, we will follow convention and assume NPN = sinking and PNP = sourcing. In the question, you mentioned your vendor called the inputs, “NPN (sourcing 24 Vdc).” I take this to mean that the inputs source current and are intended to be connected to a sinking (NPN) output; however, I would double-check the wiring diagram supplied with the part to be sure.

The terms “sinking” and “sourcing” refer to current flow with respect to the terminal pin on the I/O card. A device is called sinking if current flows into the terminal and is called sourcing if current flows out of the terminal. The entire configuration will follow the convention set by the output because the output is the device that controls the flow of current through the circuit.

Let’s explore the different configurations possible and how the various components can be arranged. There are three components that need to be connected together, in the correct order, to make the circuit work. These are the power supply, the output and the input.

Since we are discussing dc circuits, the power supply will have positive and negative connections, typically 24 Vdc and a 0 Vdc.

The output could be several different types of devices: a switch, a relay contact or a sinking or sourcing transistor output. A transistor output will be a sinking (NPN) output that can only be used after the load (the load being the input in this case) or it will be a sourcing (PNP) output that can only be used before the load.

All of the outputs on the I/O card will have negative terminals tied together inside of the card and connected to a common pin. This can only be connected to 0 V in the case of a sinking (NPN) outputs or only to 24 V in the case of a sourcing (PNP) outputs. Relays and switches are more flexible; they can be wired to source or sink current.

The final piece of the puzzle is the input. For this discussion, model the input as an LED and current limiting resistor.

This is a simplification of an optically isolated input. To turn the input on, you allow current to flow through the diode so that it emits light. That light activates a photo transistor, which in turn sets the input bit to true. With this type of input circuit there really isn’t a good reason why it can’t be connected directly to 24 Vdc on the power supply when using a sinking (NPN) output or directly to 0 V on the power supply after the output when using a sourcing (PNP) output. As long as sufficient current is flowing through the diode, it will turn the input on.

The problem is there are several inputs on one I/O module and they all have one side tied to a common terminal pin. A sourcing input will have the 24 Vdc connection made internally. And a sinking input will have the 0 V connection made internally.

If you put the switch (output) on the common pin you would switch all of the inputs at once. If you try to reverse the polarity of the power supply, the diode will not let current flow backward through the input, regardless of the state of the output. One way to solve this problem is to use two diodes for each input. These are placed in parallel facing opposite directions.

With this configuration, if the power supply is reversed, one of the diodes will continue to function. Indeed, many manufacturers supply bidirectional inputs that can function in either direction. Note that the power supply will be connected to all of the inputs sharing a common terminal. As a consequence, the entire module can be used in sinking or sourcing configuration but cannot have a mix on the same common.

To answer the question of which configuration to standardize on, I would suggest that you preserve the maximum amount of flexibility possible. There are good design reasons to prefer a sourcing output with sinking input in one situation and a sinking output and sourcing input in another situation. For inputs specify bi-directional inputs.

Finally, what can be done if you need to connect a sinking output to a sinking only input or a sourcing output to sourcing only input? It is possible to use a resistor to convert a sinking output into a sourcing output, or a sourcing output into a sinking one. In the case of a sinking output, simply use the resistor as the load instead of the input.

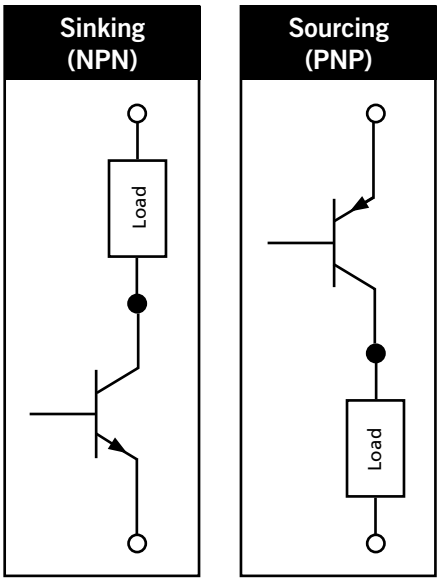
When the output is off, current only flows through the input, turning it on. When the output is on, current flows through the transistor, pulling the voltage of the low side of the external resistor down to nearly 0 V and turning the input off. The transistor turns off the input by stealing all the available current.

To turn a sourcing output into a sinking output, again the resistor replaces the input as the load. This time the resistor is placed between the output pin and zero volts on the power supply.

When the output is off, current can only flow through the input, turning it on. When the output is on, a larger amount of current flows through the transistor to the external resistor, bringing the high side of the resistor to nearly the power supply voltage and turning the input off.

In both cases, the resistor value must be selected so that, when the output is off, enough current flows through the external resistor to turn the input on, but, when the output is on, the output can sink or source enough current through the resistor to lower or raise the voltage enough to turn the input off. Inputs typically have very high impedance so this is not a problem.

A resistor connected between an input pin and the power supply is called a pull-up resistor. A resistor



SOURCE: MAPLE SYSTEMS

Figure 1: In a sinking NPN circuit, the transistor sinks the voltage, through the load, to a 0 Vdc common. In a sourcing PNP circuit, the transistor sources a voltage, typically +24 Vdc, to the load.

connected between the input pin and 0 V is called a pull-down resistor. The classic use of pull-up and pull-down resistors is to force the input in a known state when the input is not connected to anything.

On a circuit diagram this is indicated by a small arrow on the emitter pointing in to the base (Figure 1).

In an NPN transistor, a small current flowing from the base to the emitter causes a larger current to flow from the collector to the emitter.

On a circuit diagram this is indicated by a small arrow on the emitter pointing away from the base (not pointing in).

Note that, in a PNP transistor, current flows from the emitter to the collector, while, for an NPN transistor, current flows from the collector to the emitter.

Michael Sheldon, applications engineer, Maple Systems, www.maplesystems.com

Talk the same language

Let's first clarify the terminology.

- PNP output of a sensor provides sourcing output. It gets connected to a PLC input module which has sinking (NPN) input.
- NPN output of a sensor provides a sinking output. It gets connected to a PLC input module which has sourcing (PNP) input.

The vast majority of the usage in North America is 24 Vdc operation, PNP sourcing output sensors connected to NPN, sinking input modules. Asia is the opposite, with the bulk of applications being NPN, sinking output sensors interfaced with PNP, sourcing input modules. This does cause the kind of issue you have described when equipment is sourced and supplied globally. Use of PNP sourcing output sensors with sinking input modules would be best suited to your plant.

Several sensors now offer "Auto PNP/NPN" output. The output on these sensors gets configured automatically based on the input module to which they are connected. Another output style—the push-pull output—also detects the load connection and operates either as PNP or NPN. However, the output status LED indication doesn't follow the actual output status when operating as NPN output. In this mode, the output LED is off when output itself is on. Thus, to correctly interpret the output status LED indication, one needs to know whether the sensor output is operating as PNP or NPN.

NPN-to-PNP conversion, or vice versa, is not possible. A pull-up resistor is not relevant in this discussion, as such a resistor is internal to the input module.

To answer your final question, the use of 5 Vdc is uncommon, and the supply voltage for most sensors ranges from 10 to 30 Vdc. An NPN sinking output may be used to drive a TTL input module, powered at 5 Vdc. However, module specifications should be reviewed for on and off state voltage requirements. For example, the sensor-output on state voltage should not exceed 0.8 Vdc. And 120 Vac sensors may have solid-state nMOSFET or pMOSFET outputs, and both will work with an ac input module, provided wiring is correct per sensor and module instructions.

Jagjit Thiara, marketing manager for sensing and connectivity, Rockwell Automation, www.rockwellautomation.com CD

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630/467-1300
Fax: 630/467-1124

PUBLISHING TEAM

GROUP PUBLISHER & VP, CONTENT
KEITH LARSON klarson@putman.net

VP, SALES & PUBLISHING DIRECTOR
TONY D'AVINO tdavino@putman.net
630/467-1300 ext.408

DIRECTOR OF CIRCULATION
JACK JONES jjones@putman.net

SALES TEAM

NORTHEASTERN AND MID-ATLANTIC REGIONAL MANAGER
DAVE FISHER dfisher@putman.net
508/543-5172 Fax: 508/543-3061
24 Cannon Forge Dr.
Foxboro, Massachusetts 02035

MIDWESTERN AND SOUTHERN REGIONAL MANAGER
GREG ZAMIN gzamin@putman.net
704/256-5433 Fax: 704/256-5434
1501 E. Woodfield Rd., Suite 400N
Schaumburg, Illinois 60173

WESTERN REGIONAL MANAGER
LAURA MARTINEZ lmartinez@putman.net
310/607-0125 Fax: 310/607-0168
218 Virginia, Suite 4, El Segundo,
California 90245

DIGITAL SALES SPECIALIST
JEANNE FREEDLAND
jfreedland@putman.net
805/773-4299 Fax: 805/773-0451

INSIDE SALES SPECIALIST
POLLY DICKSON pdickson@putman.net
630/467-1300 Fax: 630/467-1124

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