Understanding Programmable Resistors for Sensor Simulation in Test

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If you think about it, sensors control much of our daily lives. Sensors ensure that the food in your refrigerator stays cold, count your steps on a smartphone when out for a run, and even protect you in an automobile accident. So many devices in our personal lives as well as in business, aerospace/ defense, medical, and other niches contain sensors.

All these sensors add a layer of complexity to your test strategy, as you need to simulate them when testing the circuit board that makes decisions based on a sensor's response. Since it is usually not practical to incorporate actual sensors into a test fixture, Pickering Interfaces has created external hardware that is designed to replace these sensors in an automated test program. In this paper, we will talk about sensor simulation, how to select these products, and show a couple of examples where sensor simulation made perfect sense. Given Pickering's history of more than 15 years designing programmable resistors, we have the expertise and product depth to play an important role in testing sensor-driven products.

What is a Programmable Resistor?

As the name suggests, it is a resistor that is changed in value by a test program. The programmable resistor could be a device that plugs into a modular test format such as PXI. It can also be a stand-alone device that is controlled via USB or Ethernet.

For most programmable resistors, the values are changed using relays to short out a series of resistors. The relays could be reed relays, electro-mechanical relays, or solid-state relays. Each of these relay types has different advantages and disadvantages that we will touch on later.

There are many choices of programmable resistors in terms of range, power, accuracy, and resolution. Our goal here is to help you understand the differences and give guidance in selecting the correct programmable resistor for a given test application.

So, where in testing would you use programmable resistors to simulate sensors? You can use this technology to simulate any sensor that varies its resistance when subject to changes in whatever it is designed to measure. This includes most sensors that measure temperature, altitude, light, and strain.

As a portion of a test strategy, replacing actual sensors with simulation can lower costs by creating smaller test systems; for example, if you used actual temperature sensors in test, you will need an oven or a different heat source to make the sensor react. A strain gauge will require a mechanical fixture that flexes a plate on which a strain gauge is mounted. Not only will the test system be much larger, chances are it will be slower when compared to using sensor simulation.

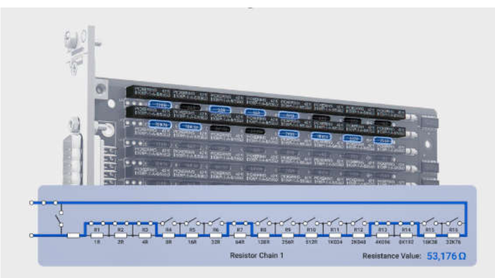
So, the bottom line is that a programmable resistor provides a simpler test system that takes up less space, is faster, and is more repeatable and accurate.

Markets and Technology Forces

The market for sensors is so large today you can be certain that if you are not testing products that incorporate sensors yet, you will be soon. It is estimated that the market for pressure sensors alone will be an almost $12 billion market by 2025 (Source: Grand View Research). The worldwide automotive sensor market, which incorporates most of the sensors mentioned earlier, will be a $36 billion market by 2023 (Source: Research and Markets). Such market estimates indicate that the technology will be around for quite some time and we need to test the controllers of these sensors.

With sensors in so many products, sensor simulation is likely to be part of your test strategy. As mentioned earlier, it is often not practical to use the end-product and the integrated sensors in this product as the test bed. The point here is an obvious one: if I am testing an EMU (engine management unit), it is not practical to have the actual automobile as part of the test station. In order to test the EMU, you need to simulate sensors for temperature, airflow, altitude, and other parameters to make sure the unit being tested is operating properly.

Programmable Resistor Types and Parameters

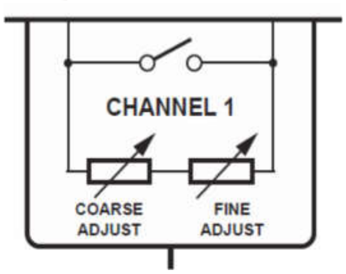


In figure 2, you see a PXI-based programmable resistor module (Pickering Interfaces' model 40-295, similar models are available from several vendors) based on relay chains. If we take a single channel, we see that it is composed of multiple resistors with individual relays connected across them. When all the relays are closed, the series resistance is effectively zero ohms. In actuality, it can be a few hundred milliohms, as each relay and the PCB itself will exhibit a very low resistance.

As each relay is open, the value of the resistor chain changes and will equal the series resistance value of the resistors where the relay across one or more resistors is open. Resistor chain modules are available in 8-bit, 12- bit, 16-bit, and 24-bit. The larger the resistor chain, the greater the resolution that can be achieved—the tradeoff is fewer channels on a module with higher bit resolution.

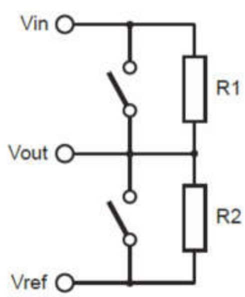
Need More Accuracy?

A precision programmable resistor module is designed to meet highly accurate test applications (figure 3 shows Pickering Interfaces' model 40-262). The design is similar to the resistor chain mentioned above, as it does have a resistor chain for the coarse adjustments (see figure 4 showing the channel example). With the addition of a digital potentiometer (Fine Adjust) and software that knows the value and accuracy of the resistor chain, the module can make fine adjustment settings to the channel being programmed. This configuration provides resistor settings an order of magnitude greater than standard resistor chains. The resolution on the precision resistor module is as low as 2 milliohms versus 25 milliohms on standard resistor chains and at an accuracy of 0.03% versus ±0.3% on standard resistor chains.



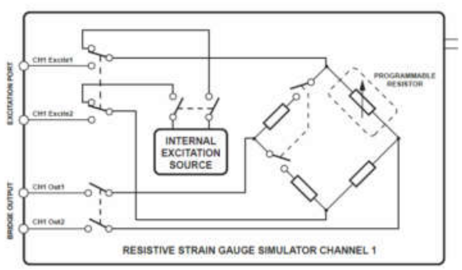
A precision resistor costs more than a standard resistor chain and may have fewer channels because of the added circuitry. But if the application demands this kind of accuracy, there are choices in the market.

For very simple sensor simulation requirements, there are modules available with no resistors specified. You can ask the vendor to populate the module with the select values required or just do it yourself. If you decide to do it yourself, keep in mind what the recommended wattage is and be sure that the amount of power is dissipated.



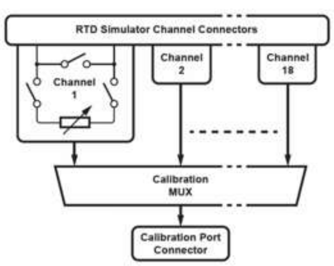
Some versions of programmable resistors include two relays per resistor to inject faults into the test program. These relays can simulate a sensor short or an open. Remember that a fixed-value resistor module may be dedicated to one application only. While a resistor module with a broad resistance range may cost more, it can be more easily reused for future applications.

Potentiometer simulation is created by connecting two resistor chains together, as shown in figure 5. Your test code should raise the value of one resistor chain and lower the other resistor chain's value, just as a potentiometer works. You can also hard-wire two channels together.



Finally, there are programmable resistor modules configured for a particular sensor type. The two most popular simulate an RTD (Resistive Temperature Detector) or the resistor bridge circuit in a strain gauge. These modules will have software drivers that allow you to set temperatures or program the value required to balance the bridge, and the setting of the simulator can be varied above and below this value to simulate extension and compression of a strain gauge (see figure 6).

Some additional features to look for are the ability to isolate a resistor channel or short the channel to present near-zero ohms to the device under test. This allows the program to inject faults into the test by simulating a bad connection to a sensor in the form of an open or short circuit.



If high-accuracy settings are required, look for resistor modules with a calibration port. In the schematic seen in figure 7, the calibration port is a multiplexer that switches the port to each channel, one at a time. Connecting a precision DMM to the port allows the user to verify the value of every setting required for their test program.

Depending on the manufacturer, there is another feature that could be of benefit to you. Some programmable resistor modules feature uncommitted relays that can be used for several different reconfigurations of the resistor module. These include:

- Linking two resistor chains together, either in series or parallel, allowing the user to either extend the range of a resistor channel or improve its resolution.
- Add a fixed resistor to be switched in to provide an offset resistance.
- Add additional fault conditions.

In a Modular Test platform, it is like having two modules in one chassis slot, which can free up a slot for additional instruments or switching.

Specifications Make the Simulation Just Right

Now that we have gone through all of the configuration options, you need to be aware of the properties of each resistor channel (see figure 8 for a specification of a typical resistor module). Here are the considerations you need to keep in mind for resistor selection:

Specification

Accuracy:	±0.2% ±Resolution @ ±10°C from calibration temperature (factory calibration @ 21°C)
Fault Simulation:	Open and short circuit (typically <0.3Ω)
Power:	0.5W maximum
Temperature Stability:	<50ppm
Number of Operations:	100 million (10mA)
Maximum Voltage:	100V or as limited by power
Settling time:	<3ms
Software Control:	By resistance calls to module for selected channel.

1) Resistor Properties

a) Programmable range – Initially, you need to know that maximum and minimum resistance meet the needs of your test requirements.

b) Resolution – You'll need to understand the minimum resolution of each channel. If your application requires higher resolution, your options with resistor chain designs are to either go to a higher bit configuration or parallel two or more channels together. The latter configuration can be tricky to program and will limit your channel count per module.

c) Voltage and power – These are often forgotten until it may be too late. It is important to understand that the clear majority of resistor modules is limited to about half a watt at a max voltage of 100 volts. There are a few exceptions, but in general, power dissipation in PXI is limited to about 15 watts per card because of cooling specification of the chassis. Therefore, if you need a load card, consider placing the load outside of the PXI chassis.

d) Accuracy – Remember that the accuracy is driven by the components used. As most accuracy specs are both plus and minus, you need to consider each setting or perhaps have a software driver that calculates the required value and sets the appropriate resistors and digital pots.

e) Stability – Over a period of time, stability may be critical to your testing requirements. The resistors used will vary over a temperature range. As seen in figure 8, the specifications note a stability of less than 50 parts per million—if you are testing products with very low-voltage signaling, the thermal offset of the relays used in the resistor module may be enough to skew your sensor simulation settings.

f) Number of channels – Selecting the number of channels required sounds like a simple decision; however, depending on your testing needs, there may be a balancing act here. As mentioned earlier, higher-accuracy channels come at a price—higher accuracy usually requires more hardware, meaning that the module has fewer channels than you may require. It is recommended that you look at the accuracy and resolution needed for each sensor and select the type of modules that give you what is needed for your test program as well as saving slot count for other instruments.

g) Special functions – Make sure to look at the specs of any special functions required. Do you need to purchase programmable resistor modules that exactly meet the sensor simulation requirements, or can you purchase simpler, lower-cost resistor chain modules and configure them for your requirements?

h) Relay types – The relays used in a programmable resistor channel have an influence on how the resistor channel performs; therefore, you many need to factor in relay types depending on your requirements. Below is an explanation of each type of relay that can be used in a programmable resistor:

   i) Electro-mechanical relays or EMRs – These are the lowest-cost relays. In some instances, EMRs can cost as much as 30% lower when compared to an equivalent reed relay, which can significantly lower the cost of your test system when using many channels. EMRs have a very low thermal EMF –

typically less than 3 µv – which can be important in very low-level signals. The downside of EMRs is that they are the slowest in terms of switching times, typically rated in milliseconds. They also have the shortest life span of relays, roughly >$2x10^7$ operations at low-power switching.

ii) Reed relays – These relays have the fastest switching time of any mechanical relay, typically 500 µ seconds or less. Also, reed relays will exhibit an average life of $1x10^9$ operations. This does come at a higher cost than EMRs and they have a moderately higher thermal EMF. Typically, this specification will be less than 5 µv.

iii) Solid-state relays – These relays have the fastest switching times, typically 200 ns and there is no switch bounce, providing a more stable simulation environment. In practice, if the test program stays within the specifications of the module, the module will not wear out. The downside is that there is relatively high leakage and a lower isolation resistance. These factors can make solid-state switching unusable in certain applications.

2) Control Method – Now that you have chosen the parameters required for the test, how are you going to control it? Depending on the module type, there are choices:
   a) Bit-level control – For a resistor chain, the simplest way is to program the resistor module at the bit level where you close individual relays to create the resistor value you require. If you are using a lot of resistor channels, this can be cumbersome.
   b) Resistance calls – Many manufacturers will provide software drivers that allow you to specify the resistance required in your test code and the driver will make the appropriate relay closures.
   c) Soft front panel – A soft front panel is ideal for debugging, as it allows you to vary the resistance without writing code.
   d) Special functions – There are special function calls for special functions like temperature or strain bridges; the calls should be intuitive in order make your job easier.

"Care and Feeding" of Resistor Channels

As programmable resistor channels use relay and resistors, it is possible to damage the module in use if certain guidelines are not followed in the test system design or in the test code. As pointed out earlier, the relay type used in the module can affect the life and usability of the resistor channels – care in use is important. Below are a couple of points to keep in mind:

1) Number of operations – In our experience, we have had customers that are using Pickering programmable resistor modules in a high-volume environment. Their test systems are running two and even three shifts daily. At that rate, the modules will wear out in several years or less. Make sure to review your test program to see how many times the resistor channels are exercised as well as daily tester throughput. Then you can see if you need to plan a replacement program sometime in the future.

2) Resistor damage – All resistor modules have specifications indicating maximum voltage and power dissipation. Exceeding either of these specifications can cause the resistor to overheat and change its value.

3) Hot switching – This is a test technique that switches relays while power is applied. Depending on how much power is switched, hot switching can greatly reduce the life of the relays in the resistor chain. If possible, try to cold switch – in other words, set the values with the power turned off and apply power after the relays are in the correct state.

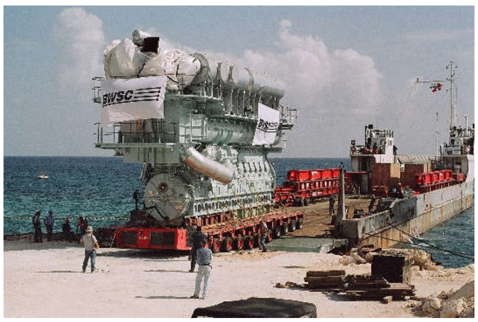
If your test code and applications do not follow these guidelines, what are the symptoms? They can include low or high resistor values, intermittent settings, and even offset voltages not planned for. Worst case: you may end up with burnt contacts or even a burnt module.

It is best to keep in mind the module's parameters and evaluate your test code.

The Use of Programmable Resistors

Now let's look at a couple of applications where sensor simulation was the best solution for the test strategy.

<u>Engine Management Systems</u>



Here is a photo of a very large diesel engine (55,000 horsepower) designed for oceangoing ships. The German manufacturer was planning to test the Engine Management Unit. This module controls the fuel injection based on throttle position and other factors. Of particular interest was the monitoring of the engine block temperature. As this is a very large engine -- as you can tell by the people standing at the base -- they had to monitor 144 temperature probes.

Clearly, they could not use the actual engine as the test bed because of its sheer size. Also, as they wanted to see how the Engine Management Unit reacted to faulty sensors as well as overtemperature situation, simulation was necessary.

Initially, their test bed had 288 precision potentiometers in a panel that were controlled manually. This was painfully slow and prone to errors; therefore, a way to automate the test process was developed.

The test engineers selected the PXI form/factor because of the number of vendors involved with PXI as well as scalability and interoperability of different vendors' PXI products. It was also important that whatever PXI vendors they worked with had to support Real Time Operating Systems, or RTOS.

Pickering's family of RTD simulators – specifically, the model 40-262 -- offered the simulation of temperature ranges needed along with RTOS compatibility, allowing for programmatic control of their RTD simulators. Additional relays in the modules allowed for fault simulation of shorts and opens in each RTD channel. Eight modules that took up 16 PXI slots allowed for a compact solution to their test requirements

<u>Space Vehicle Sensor Simulation</u>

Space vehicles operate in one of the harshest environments of any human-made device. The temperature can range from -170°C to + 123°C for satellites in low earth orbit.

A satellite's control system must keep tabs on the environment at all times, at one moment having to heat up the circuit boards and the next moment keeping the circuit boards within their operating range.

The customer was looking for a way to simulate these temperatures for control system testing. Putting the space vehicle in an environmental chamber and then testing the systems is not always practical and would be very time-consuming.

The customer chose Linux as the operating system in order to reduce CPU overhead and to better control or eliminate unwanted Windows and LabVIEW updates.

There were two test levels: at the circuit board level and finally the vehicle itself. As a cost-saving measure, lower-cost and lower-accuracy Pickering programmable resistor chain modules (model 40-295) were used at the circuit board level and Pickering's precision resistor modules (model 40-297) were used at the vehicle test level, as it was felt that accuracy was far more important at the vehicle level.

Conclusions

As you can see, there are many things to consider when selecting programmable resistor modules. It is undeniable that sensors are in virtually every application for electronics, making testing important, and sensor simulation can help you get there.

Fortunately, Pickering Interfaces has the broadest range of programmable resistors available in both PXI and PCI formats. From standard resistor chains to precision resistors to specialized modules, chances are that Pickering has sensor simulations for your test applications. If you don't find what you need, challenge us to design new products that better fit your requirements.

To help you in your selection, Pickering Interfaces has resources on our web site (www.pickeringtest.com), including articles and videos on programmable resistors, in addition to success stories from our customers on how programmable resistors made their test systems more comprehensive and accurate.

Finally, you can download our unique programmable resistor reference map. This is single-sheet reference to our entire range of programmable resistors with guides to help you choose the programmable resistor that is right for your applications.

We hope you have gained some valuable knowledge for your test strategies. I encourage you to go to pickeringtest.com or contact one of our sales offices where you can learn more about selecting and using programmable resistors as well as see the choices provided by Pickering Interfaces.