Choosing Rack Type, Size, and Power Distribution Unit

Choosing your hardware and designing your test system can be a daunting task. It is absolutely essential that you get this step right to avoid spending additional money during the lifetime of the test system. For instance, not leaving enough empty space in the test rack can lead to a complete test system redesign, which can cost thousands of dollars and result in months of downtime. Some key factors that you should consider when designing rack-mounted test systems include rack type, rack size, power distribution within the enclosure. This section offers guidance on determining your rack type and size and examines important factors to keep in mind when choosing a power distribution unit for your rack.

Choosing the Rack
Rack-mount enclosures are typically used to store test equipment, including measurement instruments, switches, cables, fixtures, mass interconnect systems, power supplies, and cooling systems, in a limited amount of space. Some rack enclosures can protect your instruments under extreme conditions. Others can provide the necessary ventilation and cooling to prevent your test system components from overheating. You need to consider many factors when choosing a rack, including environment of use, portability, size, and cooling.

Environment of Use
The type of rack you choose for your test system depends a lot on the environment in which you plan to use the system. For example, a test system that is being deployed on the manufacturing floor of a global cell phone company can be considerably less rugged and portable than a system that is going to be deployed for military purposes. Consider the example of a system used for in-flight testing of Australian Army BlackHawk helicopters. A key requirement of the system was to acquire, process, and display up to 80 parameters in real time including engine data; flight control data; rotor, air, time, space, and position data; and both day and night cockpit video and audio. Only a few more weeks

Because the system was being built for use on the helicopter, it required a high degree of ruggedness. Thus, the Royal Australian Air Force chose the PXI platform, which was mechanically designed for industrial environments. To add more protection, the PXI system was placed in a rugged rack casing that withstands a high degree of shock and vibration during flight.
Figure 1. The Royal Australian Air Force placed its PXI system in a rugged rack that withstands a high degree of shock and vibration during flight.

**Portability**

Another factor when choosing your rack enclosure is portability. Some test systems are built to be stationary – chip testers usually fall in this category. Once a chip tester has been transported from the location where it was built to the manufacturing floor where it will operate, it is rarely ever moved again. In contrast, a test system built by the military to test radios on the battlefield is moving on an ongoing basis and must, therefore, be highly mobile.

Figure 2. Portable rack enclosures are suitable for test systems that need to be mobile.
Size

Rack size is an important consideration especially if you expect your system to expand in the future. Choosing a rack that is too small can cause you to run out of space and result in a complete redesign. It is also important to choose a rack size that is based on the Electronic Industries Alliance (EIA) standard because most test instrumentation is built according to this standard. EIA racks are typically 19 in. wide. Their height is measured in “rack units” or “rack U,” where 1U is equal to 1.75 in. A rack’s internal height is measured from the tallest point of any side rail to the bottom chassis, its depth is measured from the insides of both front and rear doors, and its internal width is measured from side to side.

![Figure 3. Typical Rack Enclosure Size](image)

Racks can vary in height: 8U, 12U, 15U, 20U, 24U, 32U, 42U, 44U, 45U, and 52U. Rack depth, which is measured in inches, also varies and typically falls between 24 and 42 in. To determine an appropriate size for your rack, pay close attention to the following factors.

**Instrument and Accessory Size:** You must ensure that the rack enclosure you choose has sufficient space for all of your instrumentation. Additionally, you must allocate space for accessories such as keyboards, LCD monitors, integrated test adapters, test fixtures, and accessory drawers, which you can use to house spares and manuals.

**Floor Space:** Be sure that you can accommodate the rack's external dimensions in the floor space allotted for it. Also, check that it can be transported through your facility’s doorways and elevators safely.

**Future Expansion:** If you plan to add more functionality to your test system to expand its capabilities, you need to leave some empty space in the rack to accommodate future test needs. A good rule of thumb for this is 20 percent of additional space.
**Ventilation:** Most test instrument vendors recommend that you maintain a certain amount of space above and below the instrument for hot air to escape. This prevents the overheating of test equipment. Typically, an NI PXI chassis with a rear air intake and top/side exhaust needs a minimum of 76.2 mm (3 in.) of clearance from the air intake on the rear of the chassis and 44.5mm (1.75 in.) of clearance above and on the sides of the chassis. Because different instruments and vendors have different requirements, you must ensure that you review the instrument specifications and plan for enough ventilation space when determining the size of your rack.

**Cooling**

You must also ensure that your rack enclosure is capable of dissipating the heat generated within the system. The type of rack you choose depends on the cooling methods used in your environment. Typically there are two main types of options for cooling.

**Option 1:** If your test system is set to operate in a relatively clean environment, you can select a perforated or vented rack that can provide a channel for the hot air to escape the system. A perforated rack is also the best solution if the primary method of cooling in your test environment is ambient air cooling (fans, air handlers, blowers, and/or room air conditioning). An example configuration is a push-pull system with filtered blowers located at the very bottom of the rack that pull ambient air in and an exhaust fan at the very top of the rack to push heated air out. The combination of the two rapidly removes heated equipment air.

**Option 2:** If your test system operates in an environment where it is exposed to dust, you may want to choose a fully sealed rack. However, when using such an enclosure, you must make sure that there is sufficient cooling inside the rack (typically with a liquid cooling unit or rack air conditioner) to prevent components from overheating. Because air conditioners and cooling units are typically rated for different British thermal units (BTUs), you must add the total wattage of each device and convert the sum into BTUs (1 kW = 3412 BTUs). Depending on this value, you can choose a suitable cooling system.

**Other Rack Design Considerations**

- Height and width – It must fit in doorways and elevators.
- Structure and wheel capacity – Power supply racks tend to get quite heavy.
- Style and color – You may want to blend well with existing equipment where the test system will be deployed.
- Adding attention indicators – Adding lights to alert the operator when to answer a test prompt or when there is a failure allows multiple test systems to be controlled by one operator.
- Work surfaces – Consider whether it will be deployed to a vehicle, a tarmac, or a factory floor.
- Operator ergonomics – Consider the average height of your operator.

**Real-World Example**

Now examine the four criteria of environment, cooling, portability, and size more closely by considering a real-world example. This example is based on the automated test system for testing various CompactRIO I/O modules.
Environment
The CompactRIO I/O module test system was designed for operation in NI manufacturing facilities. These facilities are similar to those at companies that manufacture electronics products; thus, they are air-conditioned and generally clean, with minimal pollution. As a result, the test system did not need to endure high vibration, pressure, or temperature, so a rugged rack enclosure was not required for the test system.

Cooling
Cooling on the test system was achieved through an exhaust fan located at the top of the rack enclosure along with perforated or vented panels that enable hot air to escape. As mentioned earlier, the operating conditions for the system are relatively clean and dust-free; thus, there was no need to use a fully sealed rack. NI test engineers did not need an internal air conditioning system because the factory air conditioning along with the exhaust fan within the system was enough to keep all instrumentation from overheating.

Portability
Because the system was designed to stay stationary on the manufacturing floor, it did not have to be extremely portable. Even so, the system did have to be transported from the location where it was built to the location where it is used. Test engineers therefore added wheels to the system. Additionally, they ensured that the system's size did not prevent it from fitting into the elevators and lobbies of the buildings between which it would have to be transported.

Size
Instrument and accessory size, floor space, future expansion, and ventilation are the four main criteria for determining rack size. This subsection discusses how each of these considerations shaped the decisions of NI test engineers when they chose a rack size for the test system.

Instrument and Accessory Size: In determining the rack size, the total height of all instrumentation in the test system was analyzed. In addition to simply calculating the size of instrumentation, the various types of
accessories as well as their sizes were measured. This was extremely important for pinpointing the size of the rack because some accessories took up a significant amount of rack space. For example, the touch panel monitor (see Figure 4) takes up 9U of rack space.

**Floor Space:** To optimize usage of floor space, NI test engineers were asked to fit the entire test system in a single 19 in. rack. To do so, they used the compact PXI platform. Modular instruments designed for the PXI platform provide the same quality of measurements as rack-and-stack instruments but in a more compact form factor.

**Future Expansion:** The CompactRIO product line is continually evolving and growing, so it is likely that the test system will grow over time. To accommodate future test needs, NI test engineers left sufficient space empty (this is shown as “blank” in the image on the left) in the rack.

**Ventilation:** The amount of ventilation or cooling space needed for each instrument in the rack was different. For example, both PXI chassis required at least 3 in. below and 1.75 in. above of empty space to dissipate heat. These requirements were factored into the rack size.

**Designing Rack Layout**
Placement of components in a rack depends mostly on personal preference. That said, there are some general guidelines you can follow to increase measurement accuracy, safety, and ease of use. Four of the most important considerations are weight distribution, operator ease of use, signal integrity, and debugging.

**Weight Distribution**
It is important to distribute the weight of your individual components evenly in the rack to ensure maximum stability. In general, it is always advisable to place your heaviest equipment, such as power supplies, at the bottom of the rack. This ensures a low center of gravity and thus increases stability. You must also make sure that the weight of all the equipment in the rack is evenly balanced from front to back and side to side. Another factor that can impact test system stability is the placement of external shelves, which are sometimes used for supporting fixtures that house the DUT. If you are using shelves, do not place extensive weight on them. Additionally, place the shelves near the center of the enclosure (height-wise). Also take into account the weight of the DUT when determining how to distribute weight evenly across the test system because your system must be stable with and without the DUT in place. Finally, as discussed in the previous section, you may need to leave some empty space in the rack to expand the system for your future test needs. It is best to leave some empty space at the top to allow for the addition of lighter instruments and some space at the bottom to allow for the addition of heavier instruments. By doing so, you can build a stable rack enclosure.
Operator Needs

When determining the layout of your rack enclosure, you need to know how the operator will interface with the system. For example, will the operator sit or stand when interacting with the system? The answer to this question can help determine how high your monitor and workstation should be and where you must place your DUT.

You must also determine how much access you plan to give the operator based on your specific application requirements. For security purposes, many test applications in the defense industry require operators to enter certain codes to access the system. For such applications, you want the operator to have a keyboard and mouse. If this is the case for your system, you must ensure that there is enough workspace for left- and right-handed operators to use the mouse on either side of the keyboard. For most applications, however, operators are required to enter a minimum amount of information to test a product. In this case, you need to provide the operator with just a scanner to scan the product serial number and a touch screen panel.

Signal Integrity

It is important to keep signal integrity in mind when laying out your test rack. Long cable lengths can often distort signals and cause measurement errors. If you need to measure low-level signals (currents, voltages, resistances, and so on), use minimal cable lengths. Consider an example where you are trying to measure the pin-to-pin leakage current of a specific integrated circuit. Typical values for leakage current on this device are less than 10 nA. If the total leakage current in the cables that connect the device to the measurement instrument is more than 5 nA, then your measurement has up to 50 percent of error. One way to eliminate errors due to cabling is to minimize cabling by placing your switching, measurement instrumentation, and DUT as close to each other as possible.
Cabling can also cause errors in radio frequency (RF) applications. RF signals incur voltage attenuation and power loss when traveling through components with different impedances. Although you can often purchase components that are impedance-matched, these components are never exactly the same. Thus, the longer the total cable length, the more loss the RF signal incurs. One way to reduce cable lengths is to place your RF switches as close to the RF analyzer or generator as possible.

Debugging
If you are using an instrument with a digital display on the front for debugging purposes, it is important to place these instruments in a location where the display is easily visible.

Real-World Example
Rack layout is integral to designing an efficient and user-friendly test system. NI test engineers put a lot of thought into the layout of the test system they built to test CompactRIO I/O modules. They paid special attention to weight distribution, operator needs, signal integrity, and debugging requirements. The following are examples of some decisions made when designing the layout of the rack enclosure.

**Weight distribution:** NI test engineers took great care to ensure that heavier instruments were placed at the bottom of the rack. For example, the Chroma power supply, which was the heaviest component in system, was placed at the bottom of the rack to ensure maximum stability. Test engineers also distributed empty spaces in the rack evenly across the rack so that the addition of new instruments for system expansion does not adversely affect the center of gravity of the rack. Additionally, all instruments were centered side to side and front to back to increase the stability of the rack. Finally, the shelf used to hold the DUT fixture was placed at the center of the rack. With these decisions, engineers ensured a stable test rack design with a low center of gravity.
Operator needs: The intent was to provide operators with enough access to scan the device and enter simple test parameters; thus, NI test engineers incorporated a scanner and a touch screen panel. Figure 5 shows that the monitor is at the top of the test rack on the left because the operators need to stand when operating it.

Signal Integrity: The test system is required to make several low-level (as low as a few millivolts when testing the NI 9219) and high-speed measurements. To maximize signal integrity, NI test engineers minimized cable by placing the switching modules as close to the measurement instrument as possible.

Debugging: Instruments for debugging purposes, such as the Keithley source measure unit, have been placed at the front of the rack. This provides test engineers with easy access to measurement readings.

Power Distribution
Typically in large test systems, instruments in the rack are plugged into terminal strips inside the rack. These individual strips connect to the main power distribution unit, or PDU, which is usually placed at the bottom of the rack to increase stability. Finally a single connection is made between the PDU in the rack and the power source on the wall. There are many best practices for choosing PDUs for your test rack. Prior to choosing a PDU, however, you should first determine the total power that your test system needs by adding the total watts of the equipment plugged into the main power supply and selecting a power supply with a watt rating that is higher than the equipment load. To allow for future system growth and power-on inrush current, a good rule of thumb is that the test system load should be about 70 percent of the power supply watt capacity.

Now that you know how much power you need, you can consider the other important features your PDU must have. NI test engineers incorporated the following key features when choosing the PDU for the CompactRIO I/O module test system.
Emergency Power-Off Button
It is always advisable to have a way to easily and quickly disconnect power to your system. With an emergency power-off (EPO) button on your test system, you can power down your entire test system from a single point by activating a push button.

In some test systems, the primary method for turning off power is through a power strip that sits at the back of the test rack. This requires the operator to reach behind the test rack to turn off power. This is a task that can result in dangerous situations. While there are many different scenarios where cutting power to the test station may be important, one common scenario is when a test station goes into an unknown state while sourcing a high-power signal to the DUT. In such a case, you may need to cut off the power supply immediately to prevent damaging components. Additionally, you may not want your operator reaching inside the test station, where there may be open wires carrying high-power signals that could cause injury. An EPO button provides a secure and fast way for the operator to cut power to the test station.

Circuit Breakers
Fitting your PDU with circuit breakers that protect specific load segments is another best practice. This technique ensures that an overloaded circuit does not affect other segments of the test system and thus increases system reliability.

*Figure 6. Emergency Power-Off Button on an NI Automated Test System*
Sequential versus Parallel Power-Up Options

Unless you absolutely need to power all of the components in your test system at once, you should power your instruments sequentially. Many measurement instruments draw more power during startup than they do during operation. By turning on all of the instruments at once, you may draw too much power and blow a fuse.

It is also fairly common in test systems to use multiple PXI chassis, one of which is the master chassis that houses the embedded controller and the rest of which are the slave chassis that interface with the main chassis using a MXI interface. In these scenarios, it is important to turn on the slave chassis first because if you turn on the master chassis first, it may fail to recognize slave chassis components that are connected to it and cause the test program to throw errors.

Designing for Multiple Continents

Different countries have different voltage standards. For example, in the United States, AC voltage from the wall outlet is supplied at 110 to 120 V and at 60 Hz. In Europe, electricity from the wall is supplied at 220 to 230 V and at 50 Hz. The specifications are different for Asia as well. Furthermore, the plug adapters also vary by country.

If you expect your system to be used on different continents, you must ensure that it supports the different plug configurations, voltage levels, and frequencies in the countries of use. Designing for use on different continents was an important consideration for NI test engineers because the CompactRIO module test system was built in North America for use on the
manufacturing floor in the NI Hungary manufacturing facility. Consequently, test engineers chose a PDU that enabled them to select between 120V~Single Phase 50/60 Hz (North American rating) and 240V~Single Phase 50/60 Hz (European rating) using a voltage switch.