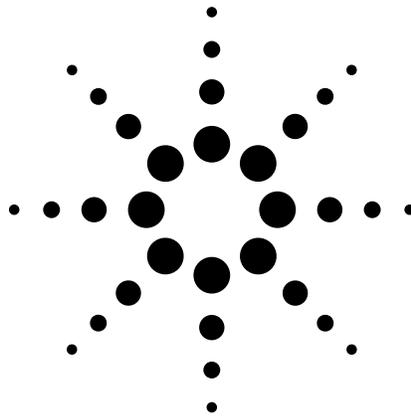


Test-System Development Guide

Understanding the Effects of Racking and System Interconnections

Application Note 1465-6



This application note is part of the Test-System Development Guide series, which is designed to help you quickly design a test system that produces reliable results, meets your throughput requirements, and does so within your budget.

This application note walks you through important considerations for arranging your test equipment in a rack, including weight distribution, heat dissipation, instrument accessibility and operator ease of use. It also explores ways to minimize magnetic interference and conducted and radiated noise to maximize measurement accuracy.

See the list of additional application notes in the series on page 11.

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Introduction

How you arrange test-system components can affect measurement accuracy, equipment longevity and operator ease of use and safety. In this application note, we focus on the important decisions you'll make if you are building a system from rack-and-stack test instruments, or a mixture of rack-and-stack instruments and cardcage components, and you are using a racking cabinet to hold your system components. However, many of the concepts we discuss are applicable to bench-top systems that are not racked.

Choosing racks and accessories

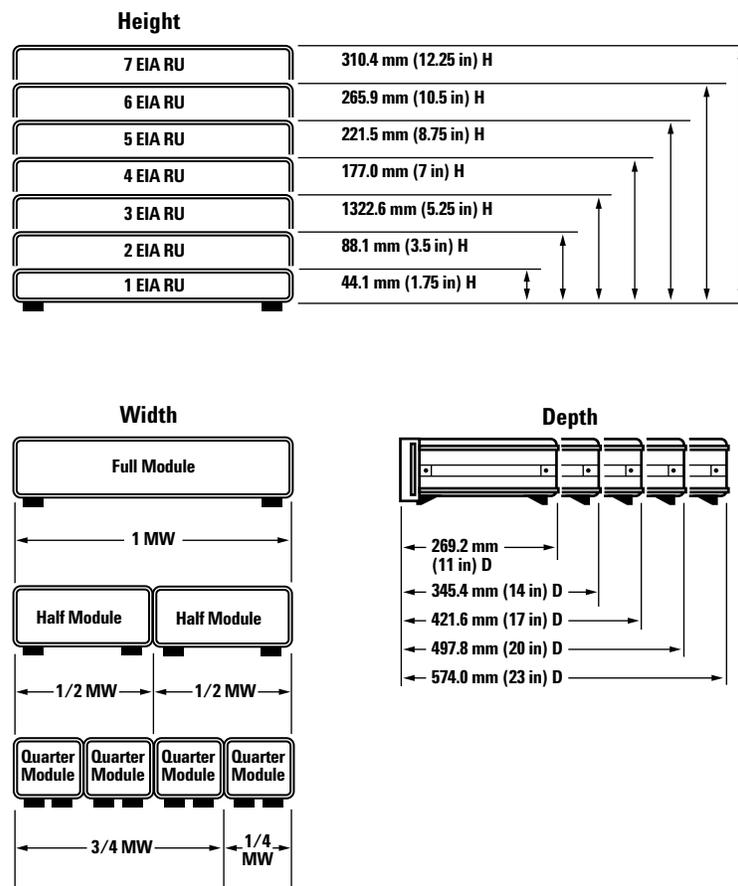
Before you choose your rack cabinet and accessories, you need to clearly define the quantity and size of the components your rack will house. It is also important to be aware of how users will interact with the equipment, how the equipment will be maintained and any special needs such as environmental or security considerations or the need to transport your system after it is built.

To facilitate racking, most test equipment manufacturers build test equipment according to size standards established by the Electronic Industries Alliance (EIA). The standard heights, widths and depths are illustrated in Figure 1. Instrument widths are usually specified as full module width (MW) or half or quarter MW.

When you calculate the size rack you need for your test equipment, you need to decide whether the system controller (typically a computer) and monitor also will be installed in the rack to display test procedures and results. If you are incorporating a computer and monitor, will you also

need a keyboard or mouse for operator inputs? If so, be sure to add space for these items into your calculations, along with space for a work surface. If there is a work surface, consider the fact that it may prevent the user from easily accessing any instrument in the space directly below the surface.

Figure 1. Most test instruments are a whole number of standard rack units (RUs) high and either a full, half or quarter module wide. A full module is typically 482.6 cm (19 inches) wide.



You may want to consider including space for accessory drawers, as well, to provide convenient storage for manuals, spare connectors and other small accessories (see Figure 2). Slide-out shelves are useful for attaching loads and other custom equipment, and they make access easy.

To maximize the re-usability of your test system, keep your future needs in mind when you choose your rack. In the future, you may want to add more instruments and more switches and accommodate bigger devices under test (DUTs) that require more power. To maximize your long-term flexibility, allow at least 20 percent extra room in your rack to accommodate instrument additions.

Figure 2. Adding an accessory drawer to your rack provides convenient storage for manuals, spare connectors and other small accessories.



Other questions to consider:

- What are the physical constraints of the location where your rack will be situated? Will the floor support your system's weight? Are doorways into the facility tall and wide enough for the rack you are considering? Is there adequate power, and does the room have adequate cooling to support the additional heat created by the system?
- Will your system need to be moved to its final destination? If so consider using multiple smaller racks and limiting total rack weight. If you need to ship the system to another location, also consider using ruggedized rack furniture with strain relief fittings and keep shipping concerns in mind (shipping company or airline size and weight requirements, etc.).
- Do you need to be able to prevent or limit access to your system? If so, consider a rack with lockable doors.
- Will you need rear access to your equipment? If the only way to gain rear access to your equipment is to move your rack, you may want to consider installing sliding shelves instead. A sliding shelf allows you to pull the instrument out of the front of the rack for easier access to the backside of equipment.

Instrument layout

When you plan the layout of equipment in your rack, you will attempt to achieve a number of objectives simultaneously. You will aim to:

- Ensure rack stability by carefully distributing the weight of system components in the cabinet
- Make it easy for operators to use the system and be productive
- Minimize magnetic interference
- Provide adequate power and heat dissipation
- Route power and measurement and stimulus signals to the right place as efficiently as possible
- Minimize conducted and radiated noise
- Ensure operator safety

Plan your instrument layout on paper before you start installing instruments in your rack, since you will probably change your layout multiple times before you determine the optimal layout.

Proper weight distribution

It is important to minimize the risk of your rack tipping over to prevent injury to operators and damage to expensive equipment. To achieve the greatest stability for your rack, keep the center of gravity low by placing the heaviest objects—typically power supplies and signal generators—near the bottom of the rack. You will have to balance this need with the need to make frequently adjusted equipment easily accessible to operators.

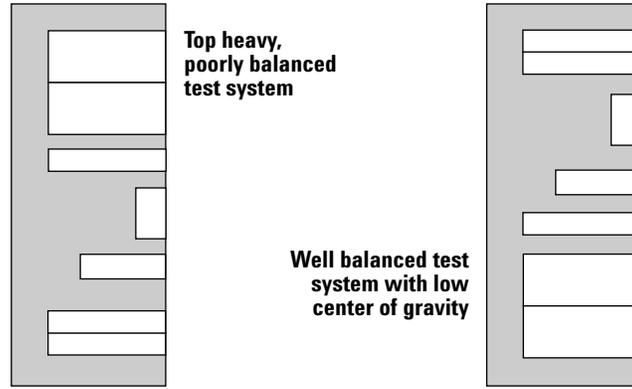
In addition to keeping the center of gravity low, make sure the weight of your system is centered (front-to-back and side-to-side) as much as possible. You may need to mount some system components in the back of the rack, rather than the front, to achieve this balance.

When you calculate your system's center of gravity, be sure to factor in the weight of the heaviest DUT you will be testing. Your system needs to be stable with and without the DUT in place. Also consider how weight distribution would change if you were to remove an instrument from the rack for maintenance, if the operator were to lean on the work surface or place heavy manuals on it, or if heavy instruments on slide-out rails were fully extended.

To download a spreadsheet that calculates center of gravity, go to <http://www.agilent.com/find/rackcenterofgravity>

If you have allowed room in the rack for future expansion, you will have empty spaces in your rack. To improve weight distribution, leave some empty spaces near the top of the rack for future addition of lightweight instruments and some at the bottom to allow for future addition of heavy instruments. Use a filler panel to cover the front of the rack to keep dust out of your system and help you manage airflow. Filler panels come in the same standard heights as test instruments (see Figure 1).

Figure 3. Well balanced and poorly balanced test systems



Keeping the center of gravity low is especially important if you will be moving your rack to another location after it is assembled, because the risk of tipping increases when you move it. Of course, the forces acting on your system's center of gravity will change if the system is tilted, so be sure to take this into consideration if you intend to move your system up a ramp as you move it to its final location. When you design your rack, keep in mind that ramps in industrial facilities can be angled at up to 15 degrees, so make sure the rack cannot tip over at that angle. When you push the rack up the ramp, turn the rack so the heaviest part (typically the front if your equipment is front-mounted) faces uphill, if possible.

Once your system is in its final location, you can improve its stability several ways. You can bolt it to the floor, to a wall or to another test rack. If you bolt it to another rack or to a wall, make sure you do not disturb the airflow and cooling and that you leave enough room at the back of the rack for servicing equipment. Some racks are equipped with retractable stabilization feet that you can pull out of the bottom front of the cabinet to prevent them from tipping forward.

Figure 4. This rack cabinet features a retractable anti-tip foot that improves the rack's stability when it is loaded.



You also can use ballast, or weights that fasten to the bottom of the rack, to improve rack stability. Most racking systems offer ballast as an option. Ballast mounted at the back of the rack cabinet helps keep the cabinet from tipping forward if you extend heavy, slide-mounted devices from the rack or if you place a heavy object on a work surface that extends from the rack.

Ballast, retractable stabilization feet and bolting rack cabinets to the wall or floor provide an extra margin of safety, but you should not rely on these measures to compensate for poor weight balance in your rack. Always make sure the center of gravity of your system is as low as possible and the weight of your system is centered as much as possible.

Instrument accessibility and operator ease of use

If your system is fully automated, you may be concerned about instrument accessibility only during system development or troubleshooting. If your system is operated manually or semi-automatically, an operator's ability to access instruments and use them easily during testing will be an important consideration as you decide how to rack your equipment.

Instrument access during development and/or troubleshooting

When they are low on rack space, system designers sometimes "bury" instruments inside the rack behind other instruments or mount them backwards or sideways in the rack. Before you choose this tactic, determine if you will need to access the instrument during system development to verify operation or for troubleshooting, repair or calibration. If you perform periodic system self

tests to verify operation, you may need access to the front panel of an instrument, making "buried" installation impractical.

In some situations, reverse-mounting (or rear-mounting) instruments in a rack makes sense. For example, if you place the DUT interface panel (mass interconnect or feedthrough panels) in front of a switching subsystem that has the plug-in cards facing the interface panel, you minimize rack space, because the switchbox and mass interconnect are in the same plane, and you reduce wire length from the switching to the DUT. If the switch box you choose has cards in the rear, you can simply reverse-mount the switchbox using the rails on the rear of the rack, as illustrated in Figure 5.

You may be able to rear mount shallow instruments behind front-mounted instruments to save rack space. This space-saving technique can be a practical way to reduce rack height if you have a problem with low doors or you need to meet airline size requirements. However, mounting instruments in both the front and back of a rack can make servicing the instruments in your rack more difficult.

Figure 5. Rear-mounting the switching subsystem reduces rack space and minimizes cable lengths.



Instrument access and ease of use during testing

If you are designing a manual or semi-automated system, you need to ensure that the operator can reach the necessary equipment controls and connectors/patch panels without straining. Decide whether operators will sit or stand during testing and position the work-surface height accordingly. If a test instrument has a display the operator needs to see, place it at eye level or above, and if appropriate, provide the ability to tilt the display to reduce glare and eye-strain. If the operator will interact with a computer, place the monitor where the operator can see it easily. If the operator needs to use a mouse or keyboard, avoid placing these items on the same work surface as the DUT. Provide for left-handed and right-handed operators by allowing a mouse to be placed on either side of the keyboard.

When you are planning the operator work surface, make sure operators sit or stand far enough away from the rack that they do not inadvertently hit controls with their feet.

If you plan to ship the rack to another country, consider operator height and local safety rules, and make sure adequate preparations are made for power, cooling, etc., before the rack is shipped. Obviously, local-language instructions may be necessary in some cases. Inadequate preparation can sometimes cause long delays in system deployment.

Minimizing magnetic interference

Magnetic fields generated by test-equipment transformers can interfere with a cathode ray tube (CRT) display. CRT displays are typically found in computer and oscilloscope displays. If you put a power supply directly below a scope, the magnetic field from the transformer in the power supply can cause the scope CRT to waver to the point where it may not be usable. To alleviate the problem, move the receiving instrument away from the transmitting instrument. The intensity of the magnetic field decreases as the distance from the source of the field increases; the amount by which it decreases depends upon the configuration of the source of the field and the proximity to the source, but clearly, the greater the separation between the source and the receiving instrument, the lesser the effect.

In some cases, magnetic fields also can affect performance and accuracy of instruments that don't have CRTs. For example, a voltmeter's circuitry could be susceptible to a large magnetic field produced by a transformer. If you are having measurement problems with an instrument, keep in mind that magnetic interference could be one of the causes. Try moving the affected instrument away from likely sources of magnetic fields. Power supplies, fans and high-power-consuming instruments have a higher potential for producing large magnetic fields.

If moving the instruments is not an option, try adding magnetic shielding between the different rack layers or between the instruments. High-permeability metal (μ metal) is sold for this purpose.

Vibration, especially in the presence of a magnetic field, is a difficult problem for system designers to solve. Cables moving in a magnetic field can generate current, and charge-related noise can be caused by internal stresses in vibrating cables connected to a charge amplifier or DMM. This issue is one of the big reasons for installing a mass interconnect in the system. It minimizes the relative motion between cables, and the chance of charge movement due to pinched cables.

Power dissipation and thermal management

All test instruments produce some heat when you operate them. If you have multiple instruments producing heat in an enclosed rack, the temperature can easily exceed environmental conditions specified for your test instruments. When this happens, your instruments can fail prematurely and your measurement results may be jeopardized. Temperature gradients are also an issue. If one end of the rack is ten degrees hotter than the other end, even if the overall

temperature is within instrument specifications, the resulting gradient can cause unwanted thermocouple effects or slow drift errors.

The best way to dissipate the heat inside a rack is to increase airflow. Installing extractor fans in the top of the rack, as shown in Figure 6, improves natural convection cooling by increasing the airflow in the rack. The fan moves warm air from the bottom of the rack up and out through the vented top cap, providing cooling to the entire length of the rack. It is a good idea to use a fan when internal rack temperatures are 15°C (27°F) above ambient temperature.

If you cannot create enough airflow to remove the heat with a fan, you may need to consider air conditioning your rack. There are standard NEMA enclosures that can be used for this purpose.

When you install equipment in your rack, do not block instrument fans or side air holes and be sure to follow instrument manufacturers' recommendations regarding air flow and

Figure 6. Extractor fan installed in rack



clearance around instruments. In general, place your deepest instruments at the bottom of your rack. If you place a full-depth, full-width instrument in the middle of the rack, you block airflow to the instruments below it.

Typical top-mounted extractor fans will move about 200 cfm (cubic feet per minute) of air, which is sufficient for dissipating up to 2500 W of power inside a rack. If your system uses more than 2500W, you could install additional top-mounted fans or use a 600 cfm fan in the rear rack door to increase air flow.

If your system includes high-power instruments like ac sources or electronic loads with their own fans, use ductwork to vent them directly out the back of the rack. You can make the ductwork out of sheet metal.

The amount of power an instrument dissipates typically is specified by the instrument manufacturer. If that specification is not available, you can estimate power dissipation requirements from the maximum current specification using the equation

$$\text{Worst case power (VA)} = \text{Voltage} \times \text{Amperage}$$

This calculation provides a conservative estimate of power dissipation requirements because power in watts, the true source of heat, is always less than or equal to power in VA. It is a good idea to use conservative figures, to safeguard against worst-case situations.

Many test instruments draw a fixed amount of current. However, a power supply draws variable current depending on how much power it is providing to the device it is powering. When you calculate heat dissipation requirements, plan around a power supply's maximum draw.

Routing power and signals

Once you have resolved the weight/balance issues, calculated your airflow and power needs and planned for operator accessibility, you are ready to turn your attention to how you will get power and signals to your instruments and your DUT. Your task is to route power and measurement and stimulus signals to the right place as efficiently as possible, while keeping noise to a minimum.

Multiplexing and matrix switching

Switches, or relays that route power and interconnect system instrumentation and loads to your DUT, are an integral part of most automated and semi-automated test systems and some manually operated systems. Multiplexers and matrix switches make it possible to minimize the number of test instruments in your system instead of using separate instruments for each test point. Switches deliver power and stimulus signals to the DUT when they are needed and route the measurement signals back to your test instruments.

Choosing the proper switch type and topology will impact the cost, speed, safety and overall functionality of your test system. For a thorough examination of switching in test systems, see Application Note 1441-1, *Test System Signal Switching*.

Wiring your system

Power wires radiate electronic noise and both stimulus and measurement signal-carrying wires are susceptible to this noise, so to minimize interference, separate power wires from signal-carrying cables. Proper shielding and grounding techniques can help alleviate noise problems (see "Grounding and shielding" on page 9). Selecting the proper type of cable is also important. A double-shielded or triaxial cable with insulation between the two shields provides the maximum protection against noise coupling.

In some cases, you may need to separate signal measurement cables (which can be sensitive to noise) from signal stimulus cables (which can generate noise). For example, if your stimulus signal is a high-frequency square wave with rapidly changing transitions (fast edges) produced by a function generator, it will radiate more noise than a square wave with slow edges or a high-frequency sine wave, and it would be more likely to interfere with the accuracy of a low-level measurement signal. If possible, keep wires carrying high-frequency square waves and other noise-generating signals away from your measurement paths to minimize interference.

For a detailed discussion of ways to reduce noise in switch systems, see the Application Note 1441-2, *Reducing Noise in Switching for Test Systems*.

Wiring dress and termination – Good-quality cabling is expensive, and you will get the best results if you buy the best cabling your budget will allow. Make sure the cable you select is designed for the task you have in mind and be careful not to exceed the manufacturer’s ampacity rating of the wires you choose.

It is a good idea to adopt a systematic approach to arranging and managing your system’s cables. For a large system, you may want to consider using cable harnesses or looms. For a smaller system, cable ties may be adequate for bundling cables. Be sure not to wrap power cables in the same bundle as signal cables. For all systems, decide on a consistent method for labeling cables, as it will simplify trouble-shooting, maintenance and future replacements. On the label, include either a reference to a look-up table or a full description of the cable’s signal type, connectors and purpose. It is also a good idea to document the type and supplier for each cable you use and retain copies of datasheets for all cables and connectors.

Keep your cabling as short as possible to minimize voltage drop and interference, leaving just enough slack to allow you to keep it out of the way. If your instruments are mounted on sliding shelves or rack slides, make sure you allow enough slack to allow the equipment to slide all the way out.

Wire termination devices may be already mounted on the wires you purchase, or you may build your own wire terminations. If you build your own, use gold-plated pins and match the current rating of the pins to your application. Gold-plated pins cost more, but they last longer because they do not oxidize. Ensure that the pin and the wire both can withstand

the maximum current you plan to use on that signal path or power path.

For RF applications, typically you will use coaxial cable – to match the characteristic impedance of the application and to minimize radiated noise – and terminate the cables with coaxial connectors to maintain the integrity of the connection between the inside of the rack and the outside of the rack. Of course, the coaxial signal path should also be terminated with the proper characteristic impedance to minimize signal reflections.

Strain relief – When you wire your system, be sure to protect your investment and minimize system downtime by minimizing sources of cable stress and damage, such as vibration, extreme bending and cutting and fraying caused by sharp edges. If your cable needs to pass through the rack cabinet wall, use a gasket in the hole and support the wire adequately along its path.

If you bend a wire back and forth repeatedly, it will eventually break. For wires in your system that need to be able to move, it is important to minimize the strain on the wires. For example, fixturing wires tend to move often as you connect and disconnect your DUT. If your system is designed for high-throughput manufacturing test, you will need to replace the fixturing wires regularly and pay careful attention to strain relief. Building strain relief into your system cabling helps protect both the cables and the connectors on the test equipment. Make sure that you support cables at regular intervals inside the rack cabinet, so the connectors do not bear the full weight of the cable.

Minimizing noise

We have already discussed some design considerations for reducing noise, but an understanding of where noise might originate is also helpful. In systems designed for testing electronic modules, the most significant causes of noise are conductive coupling, common-impedance coupling, and electric and magnetic fields. In addition, some systems are sensitive to noise from galvanic action, thermocouple noise, electrolytic action, triboelectric effect, and conductor motion.

Conducted and radiated noise

One of the easiest paths for noise to couple into a circuit is a conductor leading into it, resulting in conductively coupled noise. A wire running through a noisy environment has an excellent chance of picking up unwanted noise via radiation and then conducting it directly into another circuit. The power-supply leads connected to a circuit are often the cause of conductively coupled noise. Common-impedance coupling occurs when currents from two different circuits flow through a common impedance. The ground voltage of each is affected by the other. As far as each circuit is concerned, its ground potential is modulated by the ground current flowing from the other circuit in the common ground impedance, leading to noise coupling.

Radiated magnetic and electric fields occur whenever an electric charge is moved or a potential difference exists, and can also be a cause of noise coupling. In a circuit, high-frequency interference may be unintentionally rectified and appear as a DC error. Switch-system circuitry is also susceptible to electromagnetic radiation from radio, TV, and other wireless broadcasts, and it is important to shield sensitive circuitry from these fields. If you want to make accurate measurements of low-level signals in a test-system environment, you need to pay careful attention to the details of grounding and shielding.

It is always a good idea to have a line filter and surge protector in the main power distribution unit (PDU) of the rack. Also, each instrument usually has its own line filter, to reduce conducted interference from the instrument and reduce conducted susceptibility to the instrument. But remember, there is still some residual noise that each instrument can inject into the power grid. Sometimes it becomes necessary to put an additional power filter on an individual instrument to reduce its conducted noise.

Grounding and shielding

Grounding and shielding are the two primary methods for reducing unwanted noise in a test system. They often work together, such as when the shielding of a cable is connected to ground. In such cases it is important to understand where to ground the cable shield in order to maximize the shield's effectiveness. In some cases, the solution to one noise problem may reduce the effectiveness of the solution to a different noise problem, making it imperative that you thoroughly understand the noise source, method of coupling, and noise receiver so you can make the appropriate tradeoffs.

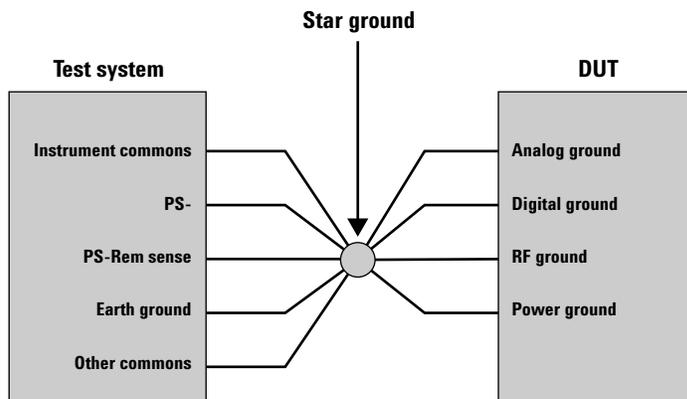
When you design a grounding system, your goal is to minimize the noise voltage generated by currents from two or more circuits flowing through a common ground impedance, and to avoid creating ground loops that are susceptible to magnetic fields and differences in ground potential.

To accomplish these goals, instrument, power and safety grounds should all be connected as close as possible to the DUT's power ground via a "star" mechanism as shown in Figure 7. This eliminates ground loops and contributes to quiet readings.

For a detailed discussion of grounding and shielding issues, see Application Note 1441-2, *Reducing Noise in Switching for Test Systems* and the white paper *Considerations for Instrument Grounding*.

In high-frequency systems, radio frequency interference (RFI) also can cause problems. To minimize RFI, make sure your cable diameter is suitable for the signal wavelengths you are transmitting, terminate all cables in their characteristic impedances, keep cable lengths as short as possible and use only high-quality cables and connectors. For more information, see the white paper, *Proper Cable Shielding Avoids RF Interference Problems in Precision Data Acquisition Systems*.

Figure 7. Star ground minimizes noise and eliminates ground loops.



Safety and interlocks

It is important to protect the safety of test-system operators, as well as safeguarding your DUT and the equipment in the rack itself. You need to plan for system safety as part of your overall system design, and you need to comply with company, local, national and international safety standards and regulations that may apply.

Install a system cutoff mechanism that is activated by any action that exposes the operator to potential harm. Make sure you document safety procedures and thoroughly train operators to use them.

Mechanical safety

Fans are a potential source of danger in a test system. Make sure that any fans you use are covered with fan guards that make them inaccessible to human fingers. Positioning fans on top of rack cabinets, instead of in the cabinet wall, reduces the chance that someone's long hair could get sucked in unintentionally.

If the rack is only waist high, be careful to consider what might happen if a liquid is spilled on top of the rack.

To safeguard against a rack tipping over, use the guidelines discussed in the "Proper weight distribution" section of this paper (see page 4).

Electrical safety

Install a system cutoff switch (often called an emergency off switch, or EMO) where operators can reach it easily. The switch should cut power to the entire system, not just the DUT. If the cutoff switch is used, make sure operating conditions are safe before you restart the system. Label all high-voltage, high-current and high-power devices in red, and make it clear they are hazardous. Devices carrying more than 42 volts AC or 60 volts DC are hazardous. After a power outage, latching relays may or may not return to a safe state. Consider what they will be controlling, and what equipment they will be connecting.

One key to electrical safety is making high voltages inaccessible to operators. If your DUT requires high voltages or high-bias current, use an interlock mechanism to cut power to the DUT when the operator is able to contact it. For example, you can use a special fixture with a see-through cover fitted with an interlock mechanism that cuts power to the device when the cover is opened. Look for a power supply with a "remote inhibit" feature that lets you remotely inhibit the output by simply making the connection between two points.

AC power distribution

In a big system with 10 to 14 instruments, you typically plug each of the instruments into terminal strips inside the rack itself. The terminal strips may get their power from a large power distribution unit (PDU), which is usually located in the bottom of the rack. The PDU typically has a single line that exits the rack and connects to a power source on the wall, floor or ceiling. When you plan your system, check the AC input current rating of individual instruments and make sure the total does not exceed the maximum current you can draw from the terminal strips or from your AC mains supply. Using maximum current figures for each instrument will help you plan for a worst-case situation and avoid tripping circuit breakers. The disadvantage of planning around maximum current draws is that you have the potential for overdesigning your system and wasting capacity.

If a single-phase power line cannot handle your needs, you will need to move to a 3-phase AC input scheme. If you do not know what power types are available at your site, get that information from your facility engineers.

If you use 3-phase equipment in your system, make sure the instruments in your rack share power evenly across all three phases. For line-to-neutral loads, you can accomplish that by designing the rack with three terminal strips, such that each strip runs off one of the three phases. Connect your test instruments so they draw current fairly equally from the three strips. To make this task easier, create a list of the instruments in the rack and the current they draw, keeping in mind which instruments consume fixed power and which draw variable current. For variable-draw instruments, use the maximum current for your calculation.

To calculate power draw for line-to-line loading in a perfectly balanced system, take the sum of the loads and divide by the square root of three to determine the current that is actually being drawn by the phase feeding the system.

If you have no 3-phase equipment in your system, you do not necessarily need to balance power evenly across all three phases. You can just size your cabling for the largest phase load. You also will want to know the actual current draw on each phase (even if they are not balanced) so you can balance correctly in your facility. You could find this number by measuring the current on each AC line with a true RMS meter.

It's a good idea to assess the quality of the mains power before installing any system. Use a power line monitor to check for voltage spikes (surge conditions) caused by motors, RF spikes, dropouts and brownout conditions (sag conditions). This simple test can save you headaches from non-repeatable results and also save damage to the test equipment itself.

Conclusion

It's one thing to connect a PC to one instrument, but when a rack might contain \$100,000 or more worth of equipment, it pays to do some planning. Arranging your test equipment in a rack to maximize measurement accuracy, equipment longevity and operator ease of use and safety also takes careful planning. Whether you are using your test system for R&D, design verification or manufacturing test, you need to consider a variety of issues, including weight distribution, heat dissipation, instrument accessibility and operator ease of use, and you need to pay close attention to minimizing magnetic interference and conducted and radiated noise.

Related Agilent literature

Agilent 3499 Switch/Control System, pub. no. 5988-6103EN

Agilent Enclosure Solutions Product Catalog, pub. no. 5980-0450E

Instrument Racks and Accessories: Calculated System Center of Gravity
<http://www.agilent.com/find/rackcenterofgravity>

Application notes

Test System Signal Switching (AN 1441-1), pub. no. 5988-8627EN
<http://cp.literature.agilent.com/litweb/pdf/5988-8627EN.pdf>

Reducing Noise in Switching for Test Systems (AN 1441-2), pub. no. 5988-8626EN
<http://cp.literature.agilent.com/litweb/pdf/5988-8626EN.pdf>

System Cabling Errors and DC Voltage Measurement Errors in Digital Multimeters
<http://cp.literature.agilent.com/litweb/pdf/5988-5511EN.pdf>

Use Remote Sensing to Compensate for Load-Lead Effects
<http://www.measurement.tm.agilent.com/hints/5965-8239E/hint01.shtml>

Proper Cable Shielding Avoids RF Interference Problems in Precision Data Acquisition Systems
http://we.home.agilent.com/upload/cmc_upload/tmo/downloads/EP5G084828.pdf

Considerations for Instrument Grounding
http://we.home.agilent.com/upload/cmc_upload/tmo/downloads/EP5G091090.pdf

Test-System Development Guide:

- *Introduction to Test-System Design* (AN 1465-1) pub. no. 5988-9747EN
<http://cp.literature.agilent.com/litweb/pdf/5988-9747EN.pdf>
- *Computer I/O Considerations* (AN 1465-2) pub. no. 5988-9818EN,
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- *Understanding Drivers and Direct I/O* (AN 1465-3) pub. no. 5989-0110EN
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- *Choosing Your Test-System Software Architecture* (AN 1465-4) pub. no. 5988-9819EN
<http://cp.literature.agilent.com/litweb/pdf/5988-9819EN.pdf>
- *Choosing Your Test-System Hardware Architecture and Instrumentation* (AN 1465-5) pub. no. 5988-9820EN
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