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WHITE PAPER

Making AST/Burn-in Testing More Productive with Ethernet-based Instruments

AST means different things to different people. If done right, it usually means greater product reliability and reduced costs.

Depending on whose job it is, Accelerated Stress Testing (AST) can be thought of as pre-production design verification, production screening, temperature cycling, or proactive product monitoring. It is all those things and more. In any context, it is product specific and should be continually refined with historical data. (See the Glossary sidebar for formal definitions of AST and related terms.)

Cost reduction and quality assurance programs drive AST. As part of a production automation program, AST improves product consistency and reliability by reducing the number of uncontrolled manufacturing variables, such as manual tasks performed by operators of burn-in/stress testing stations (often referred to as HALT/HASS test systems). In many plants that make multiple products, AST burn-in chambers and measurement equipment are required at the end of each production line. To hold down costs, all the devices under test (DUTs) in these widely distributed chambers can be monitored, and pass/fail decisions taken from a central location by using a remote Ethernet-based instrument. With reliable measurements and sound analysis, there are fewer false failure indications, higher yields, greater productivity, and lower costs. Furthermore, data can be re-distributed to other users in the plant as needed. (***Figure 1***).

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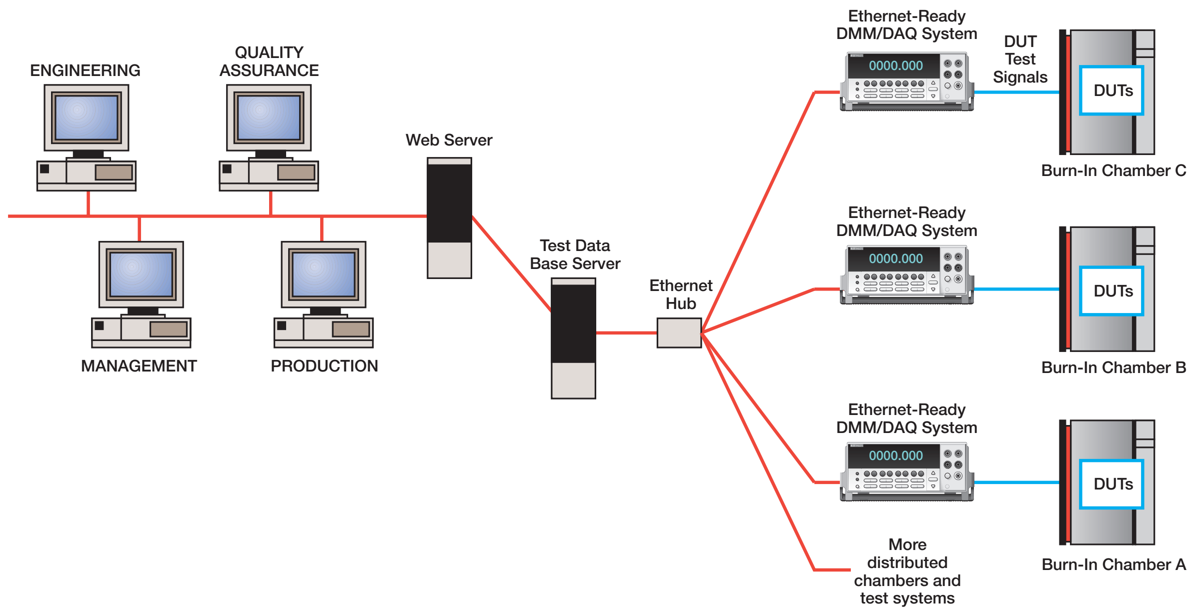

Figure 1. ***Test data can be delivered to desktops anywhere on an intranet within an enterprise using Ethernet connections***

AST Payoff

It seems intuitively logical to expect reduced warranty costs when fewer products must be replaced or repaired after shipment. Historical studies support this (see ***Table 1***).

Table 1. Historical Repair Cost Study Results

	Repair Cost Per Failure			
Level of Assembly	**Historical Nominal Cost Per Failure[1]**	**Major Contractor Study[2]**	**Typical Supplier**	**Auto Industry Study**
Piece Part	$1 – $5	–	–	$5
Module	$30 – $50	$382	$110	$30
Black Box Unit	$250 – $500	$495	$200	–
System	$500 – $1000	$1,125	$675	–
Field Unit	$5000 – $15,000	$15,345	–	$300

1. RADC (Rome Air Development Center) Report TR-82-87, May 1982.
2. W.J. Willoughby, Jr., Keynote address at IES National Conference and Workshop, ESSEH, 28 February – 2 March 1979.

When repair and replacement costs are high, it makes sense to perform rigorous AST on 100% of the products before shipment, especially mission-critical products that need to work reliably for long periods. For example, auto powertrain/chassis electronics must last for ten years in harsh conditions in cars. Power supplies and DC-DC converters must operate reliably in computers and other equipment that runs 24 hours/day, seven days/week. Hermetically sealed devices, such as heart pacemakers, must operate flawlessly in extreme humidity/temperature conditions to protect the life of the user. Aerospace and avionics equipment must function properly to avoid putting an aircraft and the lives of its crew and passengers in jeopardy. In less dramatic applications, AST reduces customer cost and improves goodwill.

Effective AST programs should have a favorable impact on OEM development costs. By quickly uncovering problems associated with product and process designs, AST shortens engineering and manufacturing start-up times. This is accomplished with techniques that shorten the time needed to identify and correct potential causes of product failure. From a marketing perspective, AST provides a competitive edge by helping companies get reliable products into the hands of consumers ahead of other OEMs.

Since AST requires capital investments, it forces an evaluation of how engineering and production equipment is being used. A well thought out AST program should identify ways to test more product with less equipment by using versatile instruments and switching systems on multiple DUTs. This also leads to maximum utilization of expensive manufacturing and test systems, whether they exist already or are purchased as part of the AST program. Although dozens test chambers may be distributed all over the factory floor, the net result is reduced costs and a better ROI, which more than repays the AST investment.

A Is For Accelerated

The theory behind AST is embodied in a concept called the product reliability curve (also known as the bathtub curve because of its shape). Typically, a population of products will exhibit reliability characterized by the curve in ***Figure 2***. The curve has three distinct failure rate regions. The early failure period, also called infant mortality, has a decreasing failure rate and is associated with built-in defects. These defects can often be identified by AST.

There are three major sources of early failure: design, components, and manufacturing. Whether infant mortality is caused by a flawed design, improper component selection, or faulty production processes, removing these flaws has the effect of deepening and widening the bathtub curve. Choosing the appropriate stress level allows AST to accelerate failures. Continuous monitoring (i.e., frequent measurements) during AST reveals these failures and helps pinpoint their cause. In general, the higher the stress applied to a product, the sooner it will fail due to built-in defects.

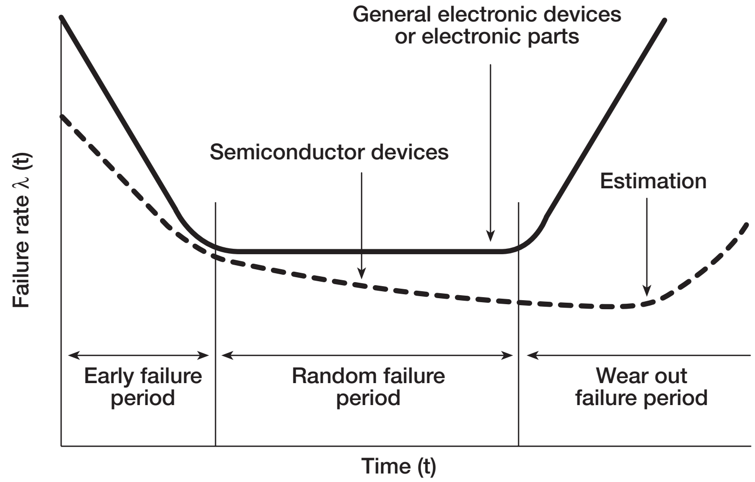

Figure 2. Reliability curves for typical product populations.

Standard end-of-line functional tests usually do not reveal subtle design and manufacturing flaws that cause early failures. Under actual use conditions, some of these flaws cause intermittent failures that are difficult to diagnose, resulting in costly warranty claims and bad customer relations. Using subtle voltage and current measurements during AST monitoring makes it possible to spot these "soft" failure modes.

The bottom of the bathtub curve (***Figure 2***) is characterized by scattered failures attributed to random component failures, isolated cases of flawed assembly, occasional material defects, and other random phenomena. Even so, AST can help identify patterns that locate the sources of these flaws. Eventually, good products fail due to wear and tear, represented by the increasing failure rate at the right-hand side of the bathtub curve. Depending on a product's wear-out mechanism, AST may or may not identify basic design and component characteristics that affect "normal" life.

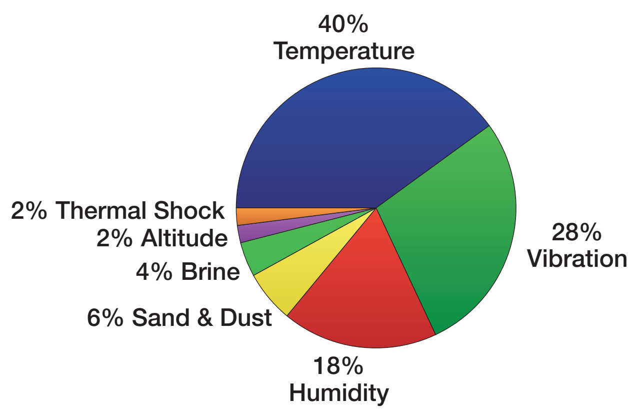

Figure 3. AST stress variables commonly used to accelerate failures.

Arrhenius Model

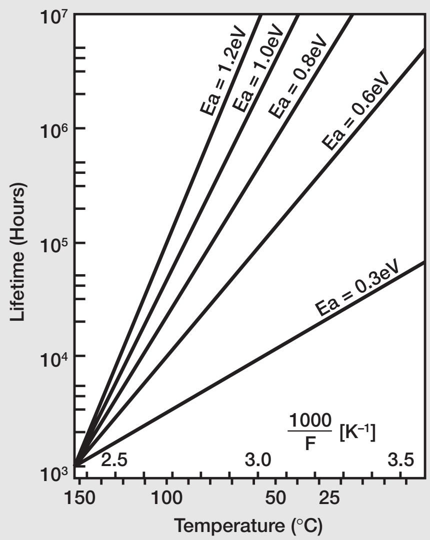

Figure 5 Relationship between temperature and life

From the “Semiconductor Device Reliability Handbook” (1988) of Matsushita Electronics Corporation

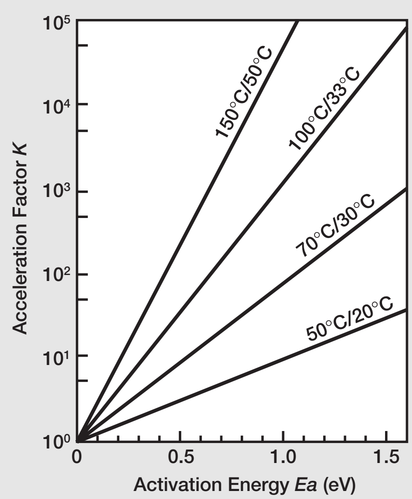

Figure 6 Relationship between activation energy and acceleration factor

From the “Semiconductor Device Reliability Handbook” (1988) of Matsushita Electronics Corporation

3.2 Temperature-related accelerated testing

When discussing the life of manufactured goods generally, the expression “θ°C rule” can be used. This expression can be used as in the “10°C rule” to mean that a 10°C rise in the ambient temperature cuts life in half, a 20°C rise in ambient temperature cuts life in one quarter, etc. This rule indicates how strongly temperature influences life (failure).

To put it another way, it is possible to cause failure that cuts life in half by raising the ambient temperature. This is known as accelerated life testing.

The Arrhenius model is widely used for acceleration of temperature-related stress. In the Arrhenius model, life and the inverse number of absolute temperature are always shown as straight lines on the semilog graph.

For acceleration factor K,

$$K = L1 / L2 = [\exp (Ea/RTo)] / [\exp (Ea/RTa)] = \exp \{(Ea/R) \times (1/To - 1/Ta)\}$$

A: Constant
Ea: Activation energy (eV)
R: Boltzmann’s constant 8.6159×10^{-5} (eV/°K)
T: Absolute temperature (°K) = 273.15 + Celsius temperature t°C
t: Celsius temperature (°C)
To: Criteria temperature (°K)
Ta: Test temperature (°K)
L1: Life (h) at test temperature Ta (°K)
L2: Life (h) at criteria temperature To (°K)
Given that Ta > To.

Ea is termed “activation energy” and varies according to the specimen provided. Ea also varies according to the failure mode even for the same specimen. The relationships between activation energy Ea, life L, and acceleration factor K are shown in ***Figures 5*** and ***6***. The greater the activation energy, the greater the acceleration in temperature testing.

To accelerate infant mortality, stress levels much higher than those found in normal product usage must be used. Also, the right kind of stress must be applied. Figure 3 shows the effectiveness of different operating and environmental stresses in screening for early failures. Although humidity and vibration are significant, the AST programs for many products gain little from combining these and other stress tests with temperature cycling.

Nevertheless, an effective AST program may require experimentation to determine if integrated temperature-humidity or temperature-vibration cycling will reveal defects earlier, or find different types of early failures that temperature alone would not reveal. The DUT must be thoroughly analyzed to make this determination. It's important to take advantage of the in-house expertise available by asking a lot of questions of design and production engineers concerning product characteristics, applications, and manufacturing methods. Then, consult with outside sources, such as the Institute of Environmental Sciences and Technology (www.iest.org), which publishes guidelines and standards that are very helpful in setting up effective AST programs.

Establish Test, Instrumentation, and Stress Chamber Parameters

A well thought out test strategy will encompass not only stress parameters, but also:

- Stress chamber requirement.
- Measurement physics (methods, parameter values, resolution, accuracy).
- Instrument features (control, triggering, firmware, data communication interfaces).
- Switching assemblies (for concurrent multipath testing).
- Other system elements - power supplies/sources, PC controller, OS, I/O support, racks, fixturing, cabling, plumbing, software, and documentation support required.

When practical, a major advantage of using only temperature cycling is reduced test development, less complicated test operations, and lower capital costs. To make temperature cycling the principal focus of AST, it's necessary to choose a temperature high enough to cause failures within a few hours or less. One guideline commonly applied is the θºC rule, which establishes the ambient temperature rise (θ) that causes product life to be cut in half. A temperature rise of 2θ cuts life by one-fourth, and so on. An Arrhenius model or similar statistical method is used to establish the test temperature and predict product life. (See the Arrhenius Model sidebar.) Whichever model is used, be sure to stick with it to allow making valid data comparisons over time. The goal is to create a model that accurately describes how elevated temperatures affect product life, and then use this to minimize test time while assuring reliable products.

The way temperature is applied is also important. This can involve cycling with a slow ramp, a rapid step increase (temperature shock), or merely aging at elevated temperature. In any case, a test chamber with appropriate features and temperature range must be purchased. It's important to consider future requirements when making this purchase.

Some guidelines for AST temperature parameters and chamber specifications are:

- Basic Chamber Range: 3°–60ºC/minute rate of change.
- Design Test: 10°–60ºC/minute rate (test should slightly exceed design margin).
- Component Test: 2°–20ºC/minute rate of change.
- Assembly Test: 2°–0ºC/minute rate of change.
- Total span of at least 100ºC (the wider the better).

Inside the test chamber, heated airflow elevates product temperatures. Therefore, make sure that products are mounted so they all reach the same temperature. To accomplish this, focus on airflow velocity, rather than volumetric rate. Generally, an air velocity in the range of 600–1000 FPM is desirable. This is high enough to "scrub off" the product's surface barrier effectively, which could otherwise impede temperature change. Air velocity that is too high or too low affects the chamber's ability to change temperatures—1000 FPM is about the upper limit.

Of course, chamber size and fixturing are important. They must be selected to conform to typical lot sizes and the physical size of DUTs. Other considerations are the mechanical design of the fixtures and racks, and connections that assure the integrity of electrical signals.

Large electronics manufacturers need many stress chambers operating simultaneously to meet production requirements, so networking is a major AST consideration. Historically, each chamber has required its own local PC to control instrumentation and gather data. Ethernet has become nearly universal as the data communication backbone in manufacturing and process plants, which means most industrial PCs come with an Ethernet card. With Ethernet evolving as a de facto communications standard, look for instrumentation with this type of network interface. This eliminates the need for separate PCs at each chamber, which offers a number of advantages:

- One central PC can be used with multiple Ethernet-based instrument at local test stations.
- Without the local PC, there is less operator and engineering involvement at each station, and reduced PC maintenance and troubleshooting.
- More efficient monitoring and control-the central PC controller simultaneously collects data from all DUTs at all test chambers for central processing and distribution.
- Long distance distribution and high data transfer speeds.
- Production managers can monitor data and make pass/fail decisions remotely, without going to HALT/HASS rooms.

Results are Only as Good as the Data

AST requires repeatable, traceable measurements of parameters such as voltage, resistance, and temperature over multiple channels for each test fixture in a chamber. Many burn-in test sequences require hours or days to complete, so long-term equipment reliability and data security are critical.

Figure 4 illustrates the key steps that assure good AST measurements. After requirements planning (discussed previously), the next step is to analyze the test environment. Then list all potential sources of measurement error. The aim is to limit the measurement uncertainty to an acceptable level.

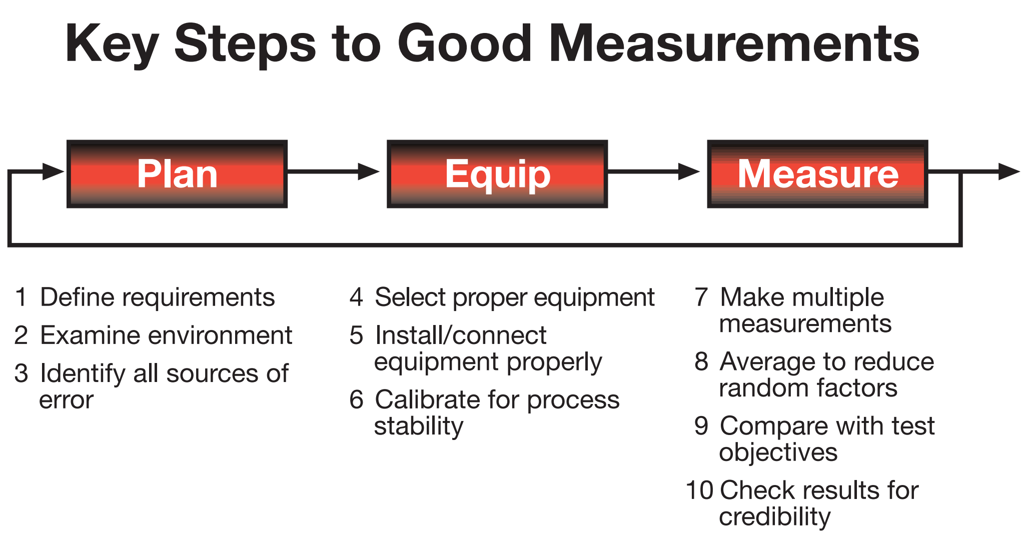

Figure 4. A plan for effective AST measurements.

Potential error sources include noise associated with the DUTs, external noise coupled into cabling, and the fundamental limitations of the instruments. More specifically, consider voltage offset caused by thermoelectric EMFs and offsets generated by rectification of RFI (radio frequency interference). Other external error sources include AC line cycle noise, Johnson noise, magnetic fields, and ground loops.

When making resistance measurements, test lead resistance and self-heating of the DUT that causes a resistance shift are common error sources. Generally, lead resistance error should be minimized by using the four-wire (Kelvin) measurement method. Pulse testing may be a solution for self-heating. (See Reference 1 for a more complete discussion of ways to minimize measurement errors.)

Successful AST requires instruments with adequate resolution/sensitivity to provide accurate, repeatable data. The instruments must be calibrated periodically to maintain accuracy. Multiple measurements can be taken and averaged to remove the effects of random noise that is superimposed on the DUT signal. Results should be checked periodically to make sure they are credible and meet test objectives.

In most cases, a voltage or current source is applied to the DUT, and then its response to that signal is measured. Switching systems are used for multiple DUT testing, so the signal path through switch hardware must not compromise the source or response signal accuracy. Therefore, measurement and switching instruments should be considered together and take into account:

- Channel count (associated with lot size and number of signals to be measured).
- Signal levels (both applied and measured).
- Speed, bandwidth, and throughput, including limitations imposed by data communications between different instruments.
- Cabling and connectors (selected for applied signal levels, low noise characteristics and quick connect/disconnect).
- Synchronization and triggering among different pieces of equipment (to optimize speed and accuracy).

Instrument Integration and Productivity

For AST system integrators, there are several other issues to tackle. For many AST voltage, current, and resistance measurements, a DMM might do the job, but it probably will not have all the switching and control functions needed for multiple DUT testing. Therefore, separate source, measurement, and switching systems would be required, posing integration problems associated with cabling, synchronization, triggering, and software.

Fortunately, integrated multimeter/switching systems are available with plug-in modules that provide the flexibility to vary channel counts from 20 to 400, apply a stimulus to DUTs, route signals, control system components, and make precision measurements over ranges wider than are possible with most standard DMMs. For example, the Keithley Model 2701 (***Figure 5***) provides 14 measurement functions with stable 6½-digit accuracy that helps reduce yield losses due to false failures.

Other features of multimeter/switching systems include per-channel programmable scan lists, large data buffers, battery-backed memory (for secure data storage in case of power interruption), built-in signal conditioning, scaling, and math functions that allow the user tooptimize system throughput in automated AST applications. Data communication options typically include Ethernet, GPIB, and RS-232. Per-channel costs for these systems are usually lower than those of “build-your-own” test systems with equivalent channel count and accuracy.

Figure 5. ***Multimeter/switching systems are tightly integrated instruments that combine DMM functions, high channel count switching, control, and 10/100BaseTX fast Ethernet communications in a single enclosure, making them well suited for AST systems.***

Data management is another productivity issue that AST system users and integrators must address. As mentioned previously, in many plants that make multiple products, AST chambers and measurement equipment should be located at the end of each production line. Raw test data from all these AST stations would then be routed over the plant communications network to a central repository. Without meaningful context, this mountain of raw data would overwhelm a user. Therefore, the plant’s data management system must provide data mining and analysis tools to create context, particularly for cycle test failures.

For remote and distributed data sharing over LAN/WAN systems, Ethernet-based instruments should have software (usually firmware) that makes integration easy. For example, firmware should provide an embedded IP (homepage) address for identifying the instrument's location on the network. It should also have web browser functions, such as "Send" and "Read" buttons. Besides standard data communications, these functions make it easier to debug measurement and communication problems.

Test application software has a big impact on AST system productivity. This software should help minimize instrument set-up time, provide on-line help utilities, and come with a library of instrument, I/O, and other device drivers to make programming transparent to the user. An intuitive GUI should make it easy to set up and operate the system, and let the operator know what is happening as tests progress. For integrators, software should support commonly used programming languages and facilitate development of the test executive. (Consider life cycle issues and in-house support of self-developed software vs. more standardized packages.) For maintenance personnel, the software must support calibration and diagnostics for debugging and troubleshooting. Assorted runtime, administrative, security and variance utilities should also be available. (See the System Development Checklist sidebar.)

With these capabilities, AST systems networked to a central computer supply a great deal of convenience and flexibility in viewing and reusing meaningful data. Ultimately, this results in much higher equipment utilization, reduces human resource requirements, and improves the plant's return on its AST investment.

AST Execution

Set-up and runtime issues influence the payback period on an AST investment. To shorten the payback time and improve ROI, AST hardware and software should facilitate DUT loading and calibration. The operator GUI ought to present loading instructions, and the software should verify that proper loading has been completed. The DUT loading subsystem should be able to recognize where a DUT needs to be loaded, minimize the chances of an operator or handler error, and initiate error messages when a loading fault occurs.

The first objective of runtime diagnostics is to let an operator know the system is running properly. There must be a high level of confidence that when the system indicates a DUT failure, there indeed is one, and not a system failure. Therefore, the diagnostic software should characterize all the major subassemblies in the system. At a minimum, this should include instrument self-tests, verification of mass interconnects, and fixture tests.

Clearly, setting up and operating an AST program involves a lot of details, not the least of which are networking and data management. Using instruments with Ethernet data communications capabilities helps simplify matters. In many cases, an expert system integrator or test chamber manufacturer specializing in AST can shorten development andinstallation times. In the final analysis, this may be the most cost-effective route and provide the best results. When measured against yield improvements, lower warranty costs, and higher customer satisfaction, AST usually is a bargain.

System Development Checklist

When serving as system integrator or project manager, ask a lot of questions and think things through; get advice from peers with AST expertise. Then make sure to cover the following milestones:

A. Program Development Steps

1. Outline the goals of the test program; anticipate and define future requirements.
2. Outline a test plan based on DUT specs and runtime issues; create and verify test specs with the groups that will use the data.
3. Decide how much of the test system development work will be done in-house, based on an inventory of technical expertise.
4. Let the expert in each type of equipment suggest/create specs for that equipment and its application.
5. Consider life-cycle issues:
    (a) How long will the system be in use, how will upgrades be accomplished; how will a system be replicated to expand product coverage and throughput?
    (b) How much time will it take to integrate the hardware, rack and stack the components, and integrate control software?
    (c) How easy will it be to modify the system when test requirements change?
    (d) Have commercial off-the-shelf hardware and software been thoroughly investigated, including the technical roadmaps of potential suppliers? (This often results in lower prices, better support, and reduced startup time compared to totally custom solutions.)
6. Assess equipment compatibility:

(a) Can/will equipment vendors work together on interfacing?

(b) Are system elements/interfacing compatible?

(c) Who is best qualified to provide interfacing for fixtures, electrical, system interconnects, component handler, automation interfaces, interactive control, production control, peer applications, networking/datacom, data management and plant services?

B. System Implementation

1. Verify that equipment quotations and subsequent P.O.s meet specs.
2. Get installation specs and drawings.
3. Verify compatibility with space available and plant facilities.
4. Arrange installation and training as required, in particular:

   (a) facility preparation and system deployment (footprint definition, power requirements, plumbing, and user personnel readiness).

   (b) on-site support and maintenance (preventative and otherwise).

5. Define the methodology for testing the test plan and test executive to verify they are bug-free and work properly with all known contingencies.

GLOSSARY

Accelerated life testing (ALT). A test activity during product development in which prototypes are subjected to stress (temperature, vibration, etc.) at levels much higher than those anticipated in actual use, with the aim of causing failures that identify weak design elements. These failure-prone elements are redesigned and tests are continued at higher levels. This procedure is sometimes called the Test, Analyze, And Fix (TAAF) cycle.

Accelerated stress testing (AST). A post-production test activity on a sampling (100% at first) of units. The intent is to precipitate hidden or latent failures caused by poor workmanship and to prevent flawed units from reaching the next higher level of assembly or the customer. Stress intensity typically is half that used in accelerated life testing.

Burn-in. Continuously powering a product, often at constant elevated temperature, in order to accelerate the aging process.

Environmental stress screening (ESS). Post-production testing in which 100% of produced units are subjected to stresses more severe than anticipated in actual service. The object is to precipitate failures associated with latent defects, so that the failed unit does not proceed further in production or reach the customer.

Environmental testing. Subjecting a sample of products to a simulation of anticipated storage, transport and service environments (such as vibration, shock, temperature, altitude, humidity, etc.)

HALT. Highly accelerated life testing. See accelerated life testing.

HASS. Highly accelerated stress screening. See environmental stress screening.

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