AUTOMATIC MULTI-PIN TEST SYSTEMS (AMPTS) FOR DIRECT PIN-DRIVE TESTING

The procedure of direct multi-pin signal injection is rapidly becoming a required test procedure for many new electronic systems.

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INTRODUCTION

The direct-drive testing procedure has been a valuable tool in the electromagnetic pulse (EMP) and general electromagnetic compatibility (EMC) disciplines for many years. Traditionally, direct-drive testing has been used as a vulnerability assessment tool on a systems level to determine the tolerance of systems to upset or damage from specific signals injected directly into the system at various suspect points of entry.

The role of direct-drive testing is now broadening from a simple assessment tool into a type of quality assurance (QA) tool. There is a general trend in the EMP/EMC community toward the use of direct signal injection for verification of transient signal tolerance of subsystem elements, commonly referred to as line replaceable units (LRUs), to assure an element's "quality" by demonstrating that it survives application of certain drive signals without performance degradation.[1] This form of direct-drive testing is in its infant stages of development with the required procedures and equipment still being defined.

There are three major methods of direct-drive testing: surface-injection, bulk-injection, and pin-injection. Surface-injection testing involves the injection of relatively high currents through the skin or other external conductive surfaces of the unit under test. Bulk-injection is used to drive the interconnecting cables within a system with a "bulk" current of several tens of amperes to perhaps several hundred amperes.

The third application of direct drive is that of direct pin-injection. In this test procedure, each pin of an LRU is independently subjected to predetermined drive signals. The signal waveform, level, and frequency (and other parameters, if applicable) of the drive signal are determined by the pin type, LRU application, and other LRU-related parameters, as well as the host-system mission. The majority of this testing is most commonly performed with the LRU in a power-off condition and without the LRU in an actual application environment.

A serious consequence of the increasing requirement for direct pin-injection testing is the very large volume of test data that must be handled. It is not uncommon for an LRU to have five or six hundred pins that must be 100 percent tested. Further, each pin must be tested with several test parameters, such as frequency and polarity. The additional requirement that 100 percent of all LRUs fielded for a specific system must be pin-tested results in a very large test program and an unbelievable data acqusition problem.

One of the most significant improvements that could be implemented is that of total testing automation. Systems providing automation of the individual LRU tests are presently available from several instrumentation manufacturers. The test system, an automatic multi-pin test system (AMPTS), requires the manual attachment of the LRU to the test system and the manual loading of the test program. The system then executes the complete LRU pin-injection test automatically. The level of automation offered minimizes costly labor requirements and provides a test point test rate well in excess of that feasible with manual testing. Further, the level of automation presently offered is a good compromise between cost and convenience for the volume of testing typically involved in present test applications.

The basic AMPTS includes five major subsystem tasks:

1. Signal generation
2. Signal amplification
3. Signal delivery
4. Signal measurement
5. System control

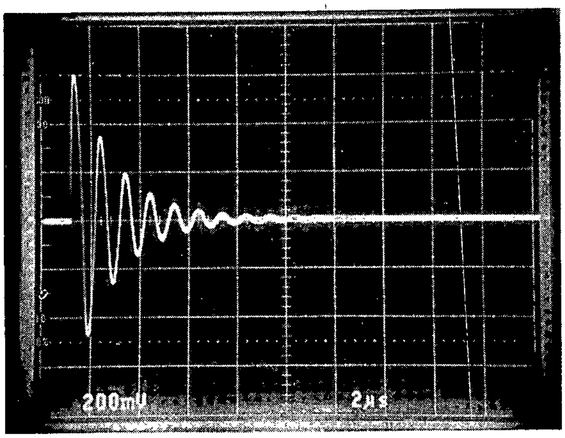
The complete review of any one of these would be a lengthy treatise in itself. This article addresses each very briefly, and highlights the parameters critical to direct pin-injection testing.

SIGNAL GENERATION

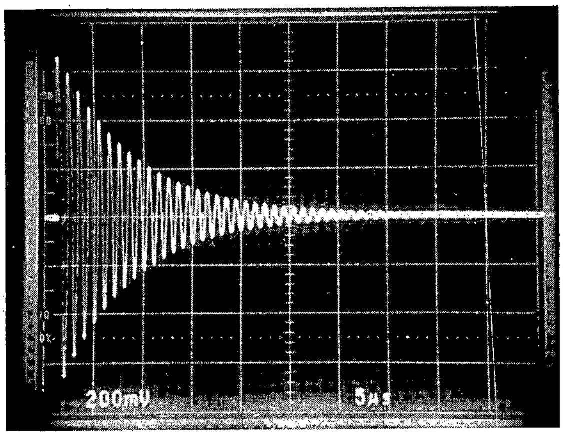
There are essentially two competing signal-generation technologies. The more common is the energy-storage source, sometimes referred to as a charge-and-dump or ballistic pulser, where the energy for a test pulse is stored in a capacitor or inductor and then dumped into the test object through a suitable pulse-forming network. The pulse-forming network is designed to provide the specific waveform required for a given test, and the charge level is selected for the specified drive. The advantage of this source configuration is that very high levels of potential and current can be provided. However, the dynamics of a specific source are determined by relatively large, nonvariable components (inductors, capacitors, resistors, etc.), making such a source relatively difficult to design for programming to random test parameters. Generally, the test parameters of tests incorporating this type of source are driven as much by the source capability as by the test requirements. Also, direct pin-injection is a comparatively low-level test procedure so that the high-level capability of the energy storage sources cannot be used to advantage.

Because of its versatility, the signal-generation technique most popular for direct pin-injection testing is that of generation of the test waveforms at a low level and then amplifying them to the required test levels by means of linear amplifiers. The most common test waveform is that of a true damped sinusoid. The Q-values and characteristic frequencies required are a function of the particular test specification, and the levels of the various pin parameters. A typical damped sine generator allows selection of the Q-value over a range of, perhaps, Q = 1 to Q = 20,000, with a resolution of 0.1 Q-unit over a frequency range of 10 kHz to 150 MHz in 10 Hz steps. This flexibility generally covers all present damped-sine test requirements. To provide such flexibility, the damped sine is generated by means of coherent modulation (modulation functions timed to the carrier zero crossing) of a CW carrier with an exponential decay function. The CW carrier is provided by a frequency synthesizer, and the exponential function by a combination of digital and analog circuitry. A high-speed, zero-crossing detector synchronizes the exponential modulation such that a true damped sinusoid is generated (as opposed to a damped cosine or something in between). Two major considerations with this type of damped-sine generation are providing precise starting of the signal at the zero crossing, and reducing carried feedthrough to acceptably low levels.

Two damped-sine waveforms with commonly specified Q-values are shown in Figure 1, one with a Q of six and the other, a Q of 24. These photographs show that the waveforms very closely start at the zero crossing, and the carrier feedthrough is good. (The peak-to-peak carrier feedthrough is about 40dB below the peak-to-peak level of the first cycle of the damped sine pulse.) However, these data are at a characteristic frequency of 1 MHz where the damped sine generation is quite simple. In the octave between 50 MHz and 100 MHz, high-quality damped-sine waveform generation is much more difficult. Figure 2 shows the same two waveforms at a characteristic frequency of 50 MHz; Figure 3 is at 100 MHz.



A. Q = 6



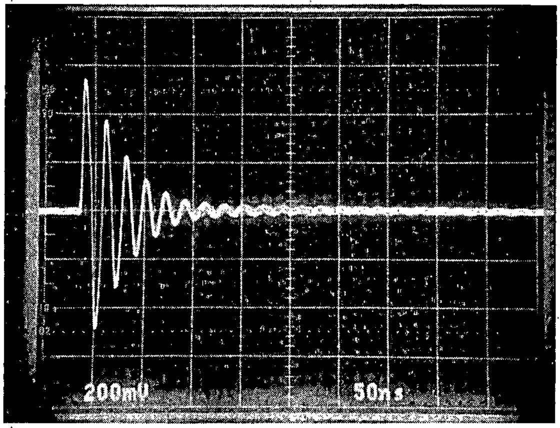
B. Q = 24

Figure 1. Common Damped-Sine Waveforms at a 1 MHz Characteristic Frequency.

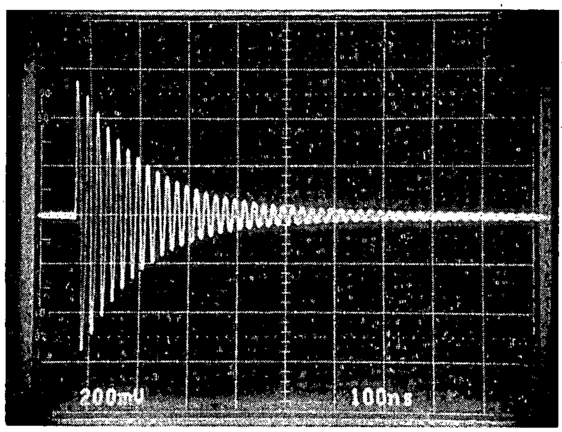
Figure 2 shows that at 50 MHz, the starting performance is still quite accurate and the carrier feedthrough is still acceptable. At 100 MHz, some trade-off of performance is generally required. From Figure 3, the starting performance is still accurate at 100 MHz, and the carrier feedthrough acceptable (the peak-to-peak carrier is about 35dB below the peak-to-peak value of the initial cycle of the pulse), but the initial peak is slightly low. This performance is less than ideal, but it is not generally considered a serious anomaly at the maximum operating frequencies, provided the highest peak occurs at one of the first three peaks, and the following peaks decay monotonically.

Various other features are often included in a typical damped sine generator, such as polarity reversal, pulse count, programmed number of pulses to be delivered, programmable repetition rate, single pulse, and burst sine (infinite Q). Another feature that is required occasionally is the capability to generate pulses in a pseudorandom sequence, but that is more common in upset testing than typical direct pin-injection testing. These added features provide additional versatility to improve the cost effectiveness of the total system, making it usable as an engineering design and laboratory tool. These units are typically fully programmable over a standard interface such as the IEEE-488 (or GPIB), allowing total computer control.

The configuration utilizing low-level generation also lends itself well to the use of an arbitrary waveform generator as the signal source. At the present state of development, the commercially available arbitrary waveform generators do not provide the needed frequency performance and resolution to cover the complete testing spectrum, but they are quite useful to well above 10 MHz, perhaps to 50 MHz. The use of this source in conjunction with a dedicated damped sine generator provides the ultimate in waveform versatility,



A. Q = 6



B. Q = 24

Figure 2. Typical 50-MHz Damped-Sine Waveforms.

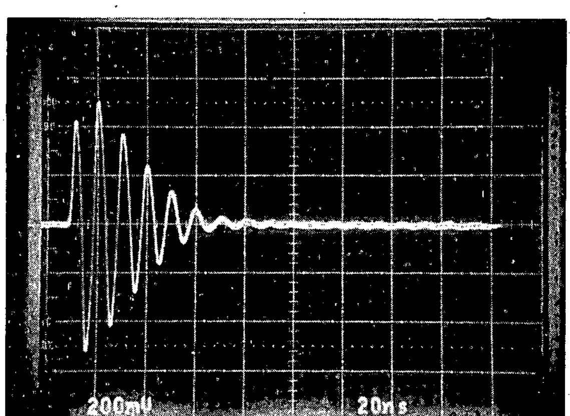
meeting the waveform requirements of almost all of the present direct pin-injection test specifications.

SIGNAL AMPLIFICATION

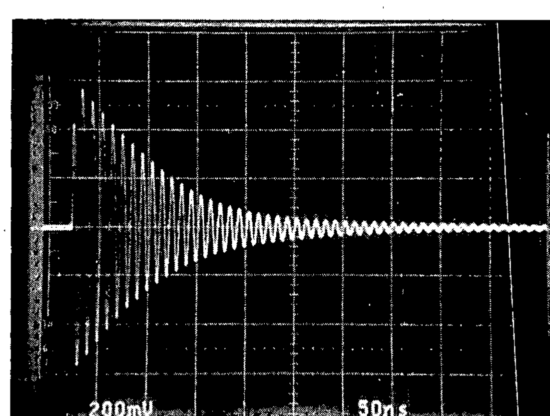
The second AMPTS task is that of bringing the test-waveform level up to the drive level required for specific tests. In the case of low-level generation, amplification is needed to raise the signal level. Since the waveforms are, for all practical purposes, arbitrary, a true linear amplifier system is required.

As indicated, the most common waveform for direct pin-injection testing is the damped sine, and it must be faithfully reproduced by the amplifier system. The spectra of the two typical damped sinusoids from above are shown in Figure 4.[2] The spectral content of the damped sinusoid extends from dc peaking at the characteristic frequency and then falls off asymptotic to 40dB/decade. In order to faithfully reproduce a damped sinusoid, the amplifier lower cutoff frequency must be at least one decade below the lowest characteristic frequency of interest, and the upper cutoff frequency must be about an octave above the highest. The −3dB frequency response of a typical linear amplifier for direct pin-injection must then be about 1 kHz to 200 MHz, a range of about 18 octaves. This is a rather stringent requirement for a typical linear RF amplifier, but there are several manufacturers of suitable amplifier systems.

The typical test levels for pin-injection range from a minimum of 100 V and 1 A peak to 1500 V and 15 A peak (some higher levels are seen for



A. Q = 6



B. Q = 24

Figure 3. Typical 100-MHz Damped-Sine Waveforms.

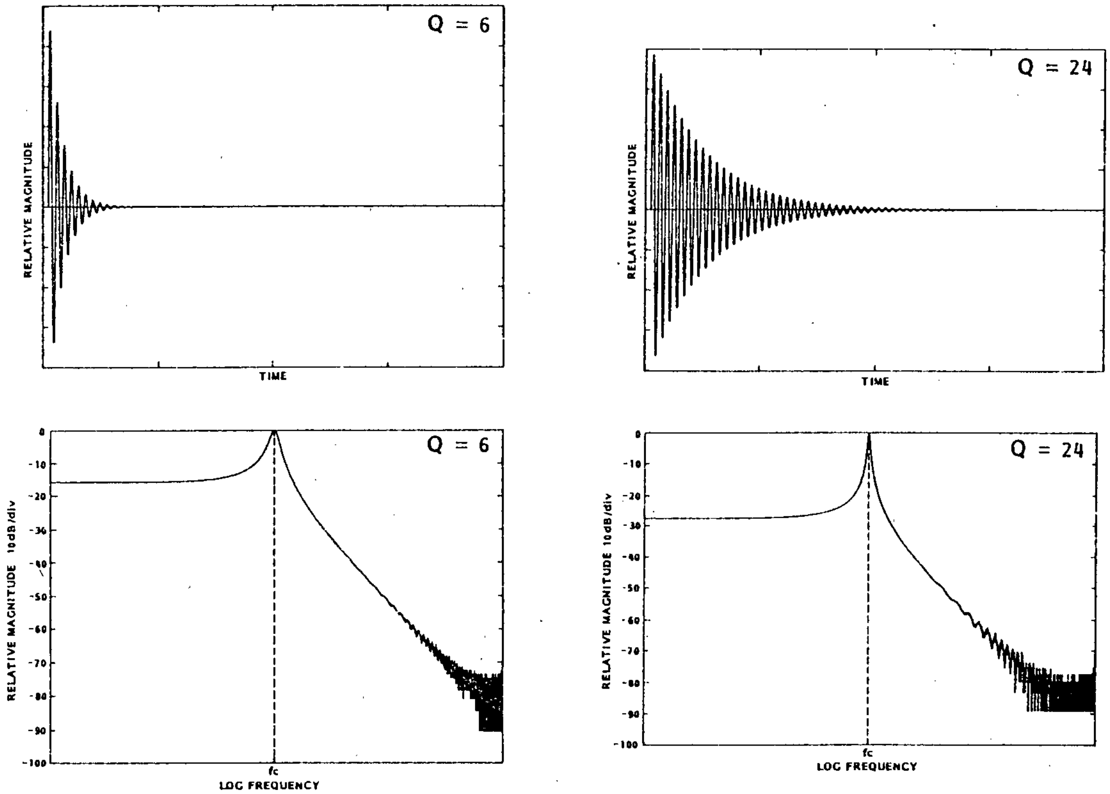


Figure 4. Damped-Sine Waveform Spectral Characteristics.

lightning tests). The linear amplifier must be capable of delivering a peak power of 22.5 kW. This corresponds to an average sine-wave power of 11.25 kW (linear power amplifiers are generally specified in terms of average CW sinewave power rather than peak pulsed power). Since various losses are associated with the signal delivery components, the actual amplifier must be capable of delivering perhaps 3dB excess power, or 45 kW peak for the maximum level above. That is a formidable RF power-amplifier system, but such systems are commercially available, and at prices that are actually competitive with energy-dump systems providing similar overall test-system capability.

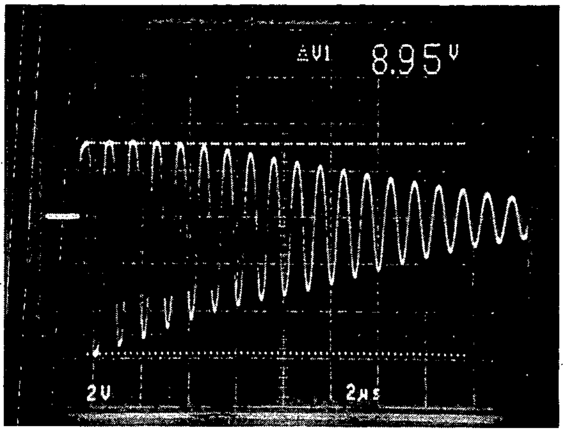
The gain of typical RF power-amplifier systems is relatively difficult to control accurately in an automated system. The level of the drive signal is therefore usually controlled by the use of a precision programmable attenuator in the low-level signal path with a fixed power-amplifier gain. An attenuator step resolution of 0.1dB is used to allow the fine control necessary to assure that the specified test levels are fully satisfied with the minimum of overdrive.

The source impedance of the amplifier system is another amplifier parameter that must be carefully considered. The source impedance for the driving source is often specified (occasionally quite stringently) for direct pin-injection tests. The amplifier system output impedance must be tailored to meet that requirement. However, the amplifier output impedance is determined by the required operating parameters of the amplifier (bandwidth, for example) and cannot be modified to any useful extent. Further, the available impedances are rarely those required for testing.

A typical direct pin-injection source impedance specification is 100 ohms. A typical wideband, RF amplifier may be specified for operation at 50 ohms, but its output impedance is not matched to that load. A more typical output impedance is 100 ohms. If a single amplifier may be used to meet the test needs, that impedance matches the test requirement well. The specified test levels often require the combining of two amplifier assemblies to meet the drive-level requirement (based on commercially available amplifier configurations). Parallel combining results in a 50-ohm source impedance and series combining in a 200-ohm source impedance. Neither of these meets the test requirements very well.

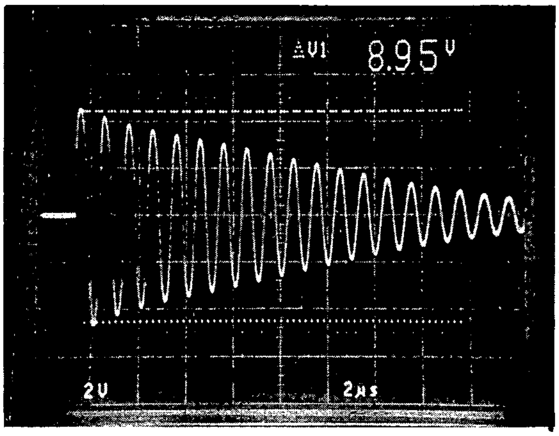
It is often assumed that since the amplifier is specified to drive 50 ohms, its output impedance is 50 ohms, and the 100-ohm test requirement may be satisifed by series combining two amplifiers. This, however, is generally an incorrect assumption. The output impedance must be tailored to the needed 100-ohm level (or other specified value). Transforming is difficult since a 2:1 transformation in impedance over about 18 octaves at a peak input power of perhaps 45 kW is required. Four 100-ohm amplifiers could be combined to provide a 100-ohm source impedance — two parallel pairs combined in series, for example — but could possibly result in a highly over-designed system. This in itself is not objectionable, but since the individual RF power amplifiers are the highest-cost sub-assemblies in an AMPTS, over-design simply to meet the source impedance requirement of a test specification could increase the test system cost significantly, perhaps by as much as a factor of two. Other means of satisfying the source impedance requirements, such as the use of minimum-loss pads, are very effective and inexpensive if significant drive margin over the test requirement is provided by the selected amplifier system. This issue of source impedance is often considered of little consequence, but if the letter of the test specification is to be satisfied, the requirement to provide specific source impedances can be a considerable challenge and can result in significant impact on the test system configuration and cost.

The RF amplifiers introduce various degrees of distortion into the test waveform.[2] Such waveform parameters that affect this distortion are the peak output power level demanded, characteristic frequency, and waveshape. The amplifier configuration also has a pronounced effect on distortion. Simple Class A systems will tend to have the highest distortion, but the lowest cost. A typical Class A output is shown in Figure 5, with the amplifier at full rated power. A pair of amplifiers may be operated in push-pull for reduced distortion, but at a considerable increase in cost (two amplifiers and power combining required). In Figure 6, the full-power, push-pull performance of the same amplifier system of Figure 5 is shown.



Vert : 200V/Div.
f_c: 1 MHz
R_L: 50 ohms
P(rated): 2 kW

Figure 5. Distortion at Full-Rated Power with a Class A Power-Amplifier Configuration.



Vert : 200V/Div.
f_c: 1 MHz
R_L: 50 ohms
P(rated): 2 kW

Figure 6. Distortion at Full-Rated Power with a Push-Pull Power-Amplifier Configuration.

Amplifier systems can also be operated in a gated mode in order to achieve higher pulsed output powers from an amplifier than available in CW. The gated mode is essentially a Class A mode that is gated on for only the period of the pulse. This introduces certain duty-cycle limitations that must be observed, but which are easily accommodated in direct pin-injection testing. However, the gating procedure generates a large transient at the amplifier output. This is minimized by operating a pair of amplifier stages in push-pull. Nevertheless, it is very difficult to eliminate the transient totally or even reduce it to tolerable levels for direct pin-injection testing by means of the push-pull configuration alone. Generally, other suppression procedures are necessary.

In addition to the amplifier parameters noted here, there are a number of other critical parameters to be considered in the selection of a power amplifier system for use in pin-drive testing. Unless one is experienced in both RF power amplifier design and direct-drive testing, it is best to seek the guidance of the various manufacturers of linear amplifiers and pin-drive test equipment when organizing a test program and specifying test-system parameters to assure that a workable system results.

SIGNAL DELIVERY

The third system task of a direct pin-injection system is that of actually delivering the test signal to the various pins to be tested.[3] This in itself is a formidable task due to the large number of pins that can be involved — as mentioned, perhaps 750 pins in a single connector. There are basically two common methods of pin access, with each having advantages and shortcomings. The more elegant approach utilizes a variation of an industrial robot to move a probe to the selected pin. The more conventional approach utilizes a switching matrix composed of miniature relays implemented in a transmission-line configuration.

The robotic approach allows the accessing of arbitrarily configured connector pins by simple programming, which generally requires little or no connector-specific hardware. This is a very valuable feature in tests where a large number of different connector types must be accessed. Also, since a single probe is moved from pin to pin, the applied potential and current may be measured almost directly at the pin, providing a very accurate measurement of the actual signals applied.

This approach does have several shortcomings, however. First, the mechanical configuration of all LRUs cannot be easily accommodated. In some situations, the LRU connectors are oriented in such a manner that it is necessary to use adapter cables to reach the connector. This can result in significant measurement errors if the adapter cable must be more than a few centimeters long. Since the pin impedance is totally unknown and is very unlikely to even approach a matched load to the test system source impedance, power is reflected from the pin back into the switching system, and subsequently to the source (the source does, however, properly terminate the reflected wave to prevent multiple reflections). This reflected signal combines with the incident signal constructively and destructively along the transmission path (the pulse equivalent of a CW standing wave). The larger the pin impedance mismatch with the source impedance and the further the point of measurement from the pin, the greater the measurement error. For example, with CW excitation, if the load is an open circuit and the measurement point is chosen at ¼ wavelength from the load, the potential measured in an ideal lossless system would be zero for any potential actually delivered to the load.

A similar, but not quite identical, phenomenon occurs with damped-sine signals. Based on this phenomenon and the typical impedances exhibited by LRU pins at the higher test frequencies, a maximum distance of ⅛ wavelength from the pin to the measurement point has been established as an acceptable limit. This can still result in significant errors above about 20 MHz with highly mismatched loads (with the pin-to-measurement-point distance ⅛ wavelength at 100 MHz). However, typical pins tend to exhibit complex impedances with magnitudes within an order of magnitude or so of the source impedance at the higher frequencies, resulting in errors that are acceptable.

A serious potential problem, if not carefully engineered, is the physical method used to introduce the test probe into the LRU connector pin. If some method is not included in the basic physical design to limit the insertion force to a specified safe value, a programming error resulting in an incorrect insertion position could physically damage an LRU. If the programming error is undetected in a test series, an entire group of LRUs could potentially be damaged by the test system itself.

Another difficulty with a robotic approach to pin selection is that many test procedures require various pins to be driven with respect to specific return pins, or for pairs of pins to be driven differentially, both floating with respect to ground, and balanced to ground. Such drive configurations are difficult to implement robotically. Two or more independent robots would be required for total flexibility in pin access. That would increase the system's complexity and cost, and would likely have a significant impact on system maintenance.

Finally, in spite of the seemingly daily exposure to advertisements showing robots in the background busily at their tasks, robotics is not an "off-the-shelf" technology. Depending on the complexity of the robotic system employed, some level of expert "care and feeding" may be required to maintain system performance.

The relay steering method is much less elegant than a robotic approach and could even be considered a "brute force" approach. However, its performance is quite adequate for the task. In this approach to signal steering, a tree arrangement of miniature relays is configured, with the relays included as elements of a suitable transmission line (stripline or microstrip). If simple drive with respect to a common chassis return is sufficient, a single tree structure is necessary. If differential drive of two pins is required, two trees are necessary. Drive of any pin with respect to any other pin as the common return can be provided, with one full tree for the drive signal, and a reduced tree for switching the selected return pin to the return path. All of these configurations are feasible using commercially available miniature commercial relays. The presently available test systems generally support drive of any pin with respect to chassis, and drive of any pin with respect to any other pin as the return. However, differential drive of any pair of pins has not as yet seen much application, and is not generally available from test system manufacturers.

The relay approach also has its negative points, one being measurement error. The signal applied to the pin under test is by necessity measured at the input to the switching network. The entire switching unit then separates the driven pin from the point of measurement. However, even for connectors of 750 pins, the switching unit pin-to-measurement-point electrical distance can be maintained below the ⅛ wavelength requirement. Further, the switching systems for smaller connectors, perhaps up to 250 pins, are electrically much shorter than ⅛ wavelength at 100 MHz, reducing the error to even more acceptable levels.

Another shortcoming associated with a relay switching system is that the switching unit must be fabricated for a specific LRU connector. The wiring complexity associated with the large volume of pins makes it impractical to change the interface connector. As a worse case, this then requires a different switching unit for each different LRU connector involved in a test. However, since the switching unit can be fabricated with an electrical length much shorter than the ⅛-wavelength guideline, adapters may be used to adapt a single switching system to many LRU connectors. Such an adapter is not an adapter cable, but rather a multi-pin equivalent of an N-to-BNC type of adapter where the electrical length is made as short as possible. The combined electrical length of such an adapter and the switching unit can still be maintained shorter than ⅛ wavelength at 100 MHz for connectors of approximately 250 pins or less. Larger connectors, up to 750 pins, can still be accommodated, but adapter cables cannot generally be tolerated if the entire connector is to be accessed in a single test session (many of the larger connectors have individual sections that may be tested separately). However, since few LRUs have more than one such large connector, the requirement for the switching unit to be dedicated to a specific LRU connector does not impose too serious a restriction on the test system.

SIGNAL MEASUREMENT

The signal measurement task of an AMPTS is complicated by two problems: the limited selection of instruments for capturing the data, and the very large volume of test data that can result from full-waveform acquisition, as shown previously. The data must be captured on a single-pulse basis, and the maximum characteristic frequency of interest in direct pin-injection testing is typically 100 MHz. For a fully automated test, the data must be captured using a programmable transient digitizer. Although various new instruments are expected imminently, there are presently only about two or three choices for programmable instruments that are capable of capturing a 100 MHz single-shot transient. These are relatively expensive and require some expert operator attention for their operation.

The direct pin-injection test is, in effect, a Go/No-Go type of test. All that is of interest is that the specified test waveform of the specified level is delivered to each pin. The waveform integrity must be specified into a "well-behaved" load, such as a matched-resistive load, since the actual waveform appearing at a pin will be a function of the pin load characteristics (non-linear pin characteristics, for example). The waveform integrity is then a calibrated feature of an AMPTS rather than one required to be recorded on a pulse-by-pulse basis. The pin-drive level is specified as a peak voltage and current for each specific pin, with the pin test satisfied when either level is delivered. Therefore, only peak information is required to be recorded. Actually, all that is really necessary to be recorded is that the specified peaks were delivered at each pin without any individual pin information. However, users generally require at least the peaks of both potential and current to be recorded for each pin and each pulse. This peak information can be reduced from the digitized full-waveform data, but this requires some degree of processing. Although this processing is minimal, the volume of data in typical direct pin-drive tests renders any data processing a significant task.

An alternate approach is the use of wideband peak detectors to capture only the peak potential and current applied to the pin. The data collected then essentially requires no processing for a Go/No-Go decision. Further, the cost of simple peak-detection circuitry is much less than that of full-waveform digitizers, and the actual circuitry may generally be integrated with the switching unit using relay-switching.

The use of peak detection is the most common form of data acquisition in the AMPTS presently being specified for direct pin-injection testing. It provides the needed information for the intended automated test tasks, but no qualitative signal information. Test limits are generally specified as a peak potential and peak current, with the test system drive level raised to the point at which either the specified level of potential or current is achieved, but not both. This method of test-limit specification easily accommodates real, imaginary, complex, and nonlinear pin impedances without the requirement for evaluation of the pin impedance prior to test.

To increase the versatility of an AMPTS, high-performance signal pick-off points are usually provided to allow the system to be used as an engineering design tool, with external full-waveform recording equipment, as well as a production test tool. This versatility helps amortize the system cost by allowing its use in various phases of development and test.

SYSTEM CONTROL

The final major AMPTS element to consider is that of the control system. For production testing, this system must provide totally automated control of the AMPTS, automatically accessing the pins and making test and retest decisions. The user implements a test by attaching the LRU to be tested and loading a test plan into the system control unit. The control system first verifies that the test plan matches the installed LRU. It must then select the first pin to be tested, configure the pulse system to the specified Q and characteristic frequency, or other parameters if an arbitrary waveform is specified, make a decision on the initial pulse level to be delivered, and configure the pulse system to deliver the computed level. The highest possible level that can be delivered in the initial pulse without the possibility of overtest is required so that the number of pulses at each pin is minimized. The control system must then deliver the initial pulse and capture the peak data, examine the captured peaks to compute a new drive level required to approach the specified test level for that pin (both potential and current levels must be examined), deliver additional pulses and make additional calculations to ultimately achieve the specified test levels, but without exceeding those levels. Finally, the system must log the final signals delivered to the pin for later verification of test-level compliance. However, most users require that the data for all pulses delivered to each pin be logged as an added QA measure to assure that no over-test of any pin occurred and to maintain a test history for each pin. The sequence is repeated for the next pin. At the conclusion of a test, report-generation features are generally offered in the control system to allow some minimal data to be relayed to a printer for test documentation. When the AMPTS is used as a design tool, the control system must allow convenient manual system control and such service tasks as logging of system configuration and test data.

The control tasks required of the control system are relatively simple and can be handled by a personal computer. However, the volume of test points involved in a typical LRU test demands speeds that cannot be easily provided by a personal computer. Therefore, a mini-computer is more commonly integrated into an AMPTS to provide the required speed. The computing power of even minimum mini-computer configurations provides additional test services such as word processing and editing for report generation and signal analysis for engineering applications at little, if any, additional hardware cost.

One problem associated with the use of mini-computer control units is the relatively complicated computer hardware and software associated with the mini-computer. In most applications of AMPTS, the operators are not experienced computer operators, or perhaps not even experienced in EMP testing. That requires very well developed "bullet-proof" software that carefully guides the operator through the test steps and is very forgiving of mistakes. It also must protect the unit from some common test errors (i.e., programming of a 10dB increase in drive level when 1dB is a more prudent choice). When the increased versatility of the system is needed for design engineering applications, the system manager may invoke different software operating parameters, allowing more user discretion in the control of test parameters. Such a system will generally require a knowledgeable system manager who understands the software and test procedures. Also, the AMPTS documentation must include the complete software source code in both machine and human readable format to allow for ease of software maintenance, and modification for different test procedures.

CONCLUSIONS

The procedure of direct multi-pin signal injection is rapidly becoming a required test procedure for many new electronic systems. The very large volume of data involved with this testing requires total automation and minimum data archiving to effect a useful and cost-effective test program. That mission is being provided by the relatively new concept of the Automatic Multi-Pin Test System — AMPTS.

The individual test parameters required by the different users of this type of equipment vary substantially. Also, the AMPTS are not truly "off-the-shelf" standard products and are generally configured to individual user needs. The cost of a typical AMPTS dictates that those contemplating such a system carefully consider all of the potential applications for the system, from unmanned high-volume pin testing to totally manual control in design and related engineering applications. In general, the more modular the system, the greater its versatility by allowing its modular elements to be excised from the integrated system and used individually in a variety of independent, simultaneous applications.

An AMPTS can be a very effective test tool, or a very expensive problem. Its success in meeting its intended uses depends on how carefully those charged with specifying the system consider the various applications. Any organization faced with direct pin-injection test requirements should seriously consider the use of an AMPTS. However, prior to the purchase or in-house development of such a system, careful attention should be paid to the development of a detailed set of system specifications unique to the specific test and engineering needs to assure that the maximum utility is achieved when the system is finally acquired and put into service. ■

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