The Pitfalls of Instrument Compatibility

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***Abstract*— In military and aerospace applications test systems are expected to have a service life of more than 20 years. Over the life of the test system individual test instruments may become obsolete or may require upgrading due to changes in TPS requirements. Any changes to these legacy test instruments may cause problems with the deployed Test Program Set (TPS). Most test systems are designed with an instrument wrapper layer to isolate the TPS developer from the instrument driver Application Programming Interface (API). This wrapper layer will minimize the changes to the TPS due to changes in individual test instruments. This paper discusses some of the issues that may be encountered when either replacing obsolete instrumentation or upgrading instrumentation in a test system. Some of the issues are easy to discover and understand such as minor differences in the instrument specifications between the legacy test instrument and the replacement instrument. Other issues may not become apparent until attempting to use the replacement instrument within a test program or when upgrading system checkers. For example a test program may fail with a replacement instrument due to signal settling time. This problem can occur when the replacement instrument performs measurements faster than the legacy instrument. The problem can be fixed by either adding a wait in the test program or by adding a trigger delay in the test program or wrapper. The main focus of this paper will be on the problems related to the replacement of analog instruments. This paper will not discuss issues related to differences in the instrument driver API since this can usually be handled in the instrument wrapper layer. The problem discussions will look at classes of problems and site some specific examples in each class. Guidelines will be presented for solving or avoiding the problem. Some of this information may also be useful in the design of future test systems and TPSs to avoid similar issues.**

Keywords—obsolescence; migration; compatibility

I. Introduction

Military and aerospace applications test systems are expected to have a service life of more than 20 years. Over the life of the test system individual test instruments may become obsolete or may require upgrading due to changes in TPS requirements. Replacement of these legacy test instruments may cause problems with the deployed Test Program Set (TPS).

When moving to a replacement instrument there will nearly always be physical and behavioral differences in a modern replacement instrument and the obsolete instrument.

Some of the differences will be obvious from a comparison of instrument specifications but other differences may not be apparent until attempting to integrate the replacement instrument into the test system.

In many test systems there is a hardware abstraction layer sometimes called an instrument wrapper to isolate the TPS from the instrument driver's Application Programming Interface (API). Test systems that have a life of 20 plus years should always use some form of wrapper to minimize changes to the TPS as instruments need to be changed. This instrument wrapper may not be present in all systems or there may be cases where the TPS developer made direct calls to the instrument API. Modern instrument drivers may support an Interchangeable Virtual Instruments (IVI) standard for the instrument class. This helps to minimize issues when migrating to a newer instrument, but it is unlikely that an older TPS or instrument wrapper made use of IVI drivers.

This paper will discuss why instruments need to be replaced and the process of choosing a replacement instrument, concentrating on the problems that may be seen when integrating the replacement instrument in a test system. This paper will be limited to discussing the issues with replacing analog source and measurement instruments. The types of problems will be organized by instrument type and include suggestions for how to solve the problem in either an instrument wrapper or by modification of the TPS.

II. Why Do Instruments Need to be Replaced?

There are two main reasons that an instrument may need to be replaced; the manufacturer has discontinued the instrument or requirements have changed for the test system[1].

A. Discontinued Instruments

Instrument manufacturers update their product offerings based on the needs of the market place and the popularity of their current product line. In the past a particular instrument model may have been available for 10 to 20 years. This is changing. Modern instruments from some vendors may have a manufacturing availability of 5 to 10 years.

Even if there is high demand for a particular instrument model, the manufacturer may discontinue the instrument when a newer replacement is available. In some cases the manufacturer decides to design a new model of the instrument due to competition from other manufacturers, but in many cases this is driven by manufacturing cost or the availability of components.

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When an instrument manufacturer designs a new version of a popular instrument or an instrument with a large installed base, care is taken to make sure the instrument is functionally compatible with the older model. The manufacturer will usually discuss the new version of the instrument with their customers to make sure the existing customer needs are satisfied in the new instrument. This is an opportunity for the customer to work with the manufacturer to minimize issues when moving to the new instrument model. Manufacturers of instruments for use in military test systems will go to great lengths to ensure backward compatibility[2]. The driver for the newer instrument model may include special functions to put the instrument into a mode to emulate the older instrument model. This may allow a new instrument model to be used in the test system with minimal changes to the instrument wrapper.

B. Additional Test programs With New Requirements

Sometimes the test system will need to support additional TPSs. The new TPS may require source or measurement capabilities that are not currently provided by the instruments in the test system. If space is available these instruments can be added to the test system, but in most cases the instruments in the system that have similar functionality will need to be upgraded to support the additional requirements.

III. The Process of Selecting a Replacement Instrument

The process of selecting a replacement instrument starts with finding an instrument that matches the form, fit and function of the obsolete instrument.

- form - refers to the physical parameters of the instrument
- fit - refers to the instrument working within the test system
- function - refers to instrument specifications and requirements

A. Form

For rack mounted instruments (RS232/RS422, GPIB, USB, LXI) the form factor (length, width, height) must be the same or less than the obsolete instrument. For chassis based instruments (VXI/PXI) the replacement instrument must be designed to fit in the test system chassis model. The replacement instrument must occupy the same or fewer slots in the chassis than the obsolete instrument.

B. Fit

The replacement instrument must be electrically compatible with the test system. Any additional power/cooling requirements of the replacement instrument must be within the total budget of the test system. Will the existing system cabling work with the replacement instrument? If not does the vendor offer a Cable Interface Board (CIB) that works with the existing system cabling? If cabling changes are required what is the impact on signal integrity? Signal integrity issues can be difficult to solve in the TPS.

C. Function

Finding a functionally compatible instrument begins with a comparison of instrument specifications. The specifications of the obsolete instrument must fall within the specifications of the replacement instrument. The replacement instrument must also provide all the source and measurement functions of the obsolete instrument. The API for the replacement instrument must also be compared to verify that all required functionality is provided. IVI drivers must be checked to make sure that the instrument supports all required IVI subclasses for driver. If no instrument satisfies the specifications of the obsolete instrument, then an analysis will be needed to determine what is actually required by the current TPS and any planned TPS. It may be difficult and time consuming to look at the source of the TPS to determine the capabilities required in the test instrumentation. There are tools such as VXI Spy, GPIB Capture, or LXI logging to monitor communication between the TPS and the test instruments to help determine the actual requirements[3].

Another aspect of instrument functionality is how the instrument is programmed. Obsolete VXI instruments probably had a VXI plug&play driver. Modern VXI replacement instruments may still provide VXI plug&play drivers, but will most likely provide IVI drivers. Changes in the driver API between the obsolete and replacement instrument can usually be handled in an instrument wrapper, but in some cases may require changes to the TPS.

D. Multifunction Instruments

In some cases, replacement instruments are chosen to combine the capabilities of existing instruments. This will free system space to allow for the inclusion of additional test instruments. The replacement multifunction instrument must have multiple channels to allow the instrument to simultaneously provide the source and measurement capabilities of the obsolete instruments. In most cases the replacement instrument will provide multiple source or measure capabilities on all or some of its channels.

When an instrument channel is able to support multiple functions, for example waveform generation, timer/counter and digitizer, the programming of a single source or measurement operation on the channel may be more complex. This may cause problems with the replacement instrument during system integration.

IV. Issues Discovered During Integration

After selecting a candidate replacement instrument the process of system integration begins. Most of the issues concerning compatibility between the obsolete and replacement instruments will be discovered during system integration.

A. Physical Cabling, and CIBs

The process of system integration starts with placing the replacement instrument in the test system and connecting to the fixture cabling. In many cases the system cabling connects to the instrumentation hardware with a CIB. Unless the replacement instrument uses the same connectors as the obsolete instrument and has exactly the same front panel layout, the CIB or system cabling will need to be changed. If the replacement instrument is an upgrade or newer model from the same manufacturer as the obsolete instrument there may be a new CIB available from the manufacturer that is compatible with the external connections of the obsolete instrument. If this is not the case, or if the instrument is from a different instrument manufacturer a new CIB will need to be created. As was stated earlier changes to the test system cabling and/or CIBs may impact signal integrity. Signal integrity issues may only effect measurements on some TPSs and may require changes to system cabling or the TPS.

B. *System Checkers*

Most test systems are shipped with a procedure and/or program to make sure the test system is functioning properly. This is referred to as system checkers. The system checkers execute self-test on each of the instruments in the test system and also run tests to check the interconnect cabling in the test system using 2 or more instruments simultaneously. This system checker program may require modification to use the replacement instrument. This is usually due to changes in the instrument API or range differences between the obsolete and replacement instruments. Most military test systems use a switching matrix to route source and measurement functions to the UUT. This switching matrix is used by the system checkers to interconnect instruments. In some cases, the checkers may fail due to settling time or small DC offsets produced during signal routing. These problems can usually be resolved with changes to the system checkers.

C. *TPS*

Most of the obvious integration issues with the replacement instrument will be resolved when the system checkers are working properly. Any remaining issues will be discovered during execution of the existing TPS. The remainder of this paper deals with the issues discovered during TPS integration. The issues are organized by instrument type. For each instrument type, typical problems are discussed and suggestions are provided for what needs to be changed to fix the problem. In most cases there is not a universal solution for how to fix particular a problem, since this will vary based on the test program procedure.

V. General Issues

This section covers integration issues that are common to all replacement instruments. The sections that cover instrument classes may provide additional information for some of these general issues.

A. *Differences In Reset State*

There are at least two different classes of reset for an instrument. The first is a hardware reset that occurs when power is applied to the instrument. The second is a software reset that is user controlled. These two types of resets are not guaranteed to place the instrument in exactly the same state. The hardware power on reset will typically put the instrument in a non-connected state with ranges and/or levels set to protect the instrument from damage. In plug&play and IVI instrument drivers there are also two ways that the software reset can be performed. The first is an option when the instrument is initialized the second is a driver call to reset the instrument. These two forms of software reset may not place the hardware in exactly the same state. Instruments of the same type from different manufacturers, for example signal generators, may have different reset states. Sometimes the reset state will vary for different instrument models from the same manufacturer. The TPS should never rely on the reset state of the instrument.

B. *Measurement Ranges*

Most measurement instruments have discrete ranges for input signals. The user configures the measurement range based on the expected signal level from the unit under test (UUT). Instruments will vary in their behavior when the input signal exceeds the selected range. Digital multimeters (DMM) will usually display and return an over range indication if the input signal exceeds the selected range. Digitizing instruments may not indicate an over range condition, but will clip the input signal when it exceeds the selected range. This clipping may saturate the input circuitry and require some time for the digitizer to properly capture the input signal after the level falls within the input range. The handling of over range may differ between instrument manufacturers and instrument models. The time to recover from saturation will vary between instruments of the same model and even between channels on the same instrument.

Measurement ranges are directly related to the resolution of a measurement. For example a 6.5 digit DMM measurement on a 100k resistance range will have a maximum resolution of 1 ohm. On the 10k resistance range the measurement will have a maximum resolution of 0.1 ohms. In digitizing instruments the voltage resolution is related to the number of bits in the analog to digital converter (ADC). For a 12bit ADC using a 10V range the resolution is approximately 2.44mV. On the 100V range the resolution is approximately 24.4mV. DMMs typically have ranges based on powers of 10. For example a DMM may have ranges of 100, 1k, 10, 100k, 1M, 10M for resistance and 200mV, 2V, 20V, 200V. Digitizers may have ranges based on powers of 10 or a 1, 2, 5 increment. The 1, 2, 5, increment is typical of voltage ranges on DSOs. Differences in ranges between instruments may have an impact on the measurement of signals that fall near a range boundary due to changes in measurement resolution.

VI. DMM Issues

The majority of issues that can occur when replacing a DMM in a test system can be avoided by a careful comparison of instrument specifications between the obsolete and replacement instruments. Also the replacement instrument must support all the measurement functions provided in the obsolete instrument. Even if this criteria is satisfied there may be some subtle differences in behavior between the obsolete and replacement instrument. Some of these issues are covered in the following sections.

A. *Resistance Source Current*

A careful comparison of the resistance ranges for a DMM may indicate a difference between the obsolete and replacement instrument in the source currents used to perform the measurement. Differences in the source current for a range may impact a resistance measurement of a diode or semiconductor junction. This can usually be corrected by either choosing a different range or by, if supported by the instrument, selecting a different source current for the range.

B. *Range Overhead*

DMMs may have some headroom for a measurement range before an over range condition will be reported. This headroom may allow the DMM to properly measure a signal that exceeds the input range by 10% or more. The headroom will be indicated in the instrument specifications as a full-scale value for the range or as a percentage of the range. Measurement headroom may be important when measuring signals that fall near a range boundary. When moving between instruments with different range headroom the TPS may require changes to either select a different range or to change the tolerance on the measurement.

C. *Additional Ranges*

Sometimes an obsolete instrument will have a non-standard range that falls between the usual ranges for the instrument type, for example a DMM with a 3k resistance range in addition to the usual 1k and 10k ranges. In this example, the 3k range may have better specifications than the 10k range or it may be present on the obsolete instrument to duplicate the functionality of some older instrument from a prior generation of the test system. In most cases, if the replacement instrument has specifications for the 10k range that are as good as the 3k range of the obsolete instrument no changes would be required to support the replacement instrument. Some replacement DMMs may also be designed with additional ranges to duplicate the behavior of legacy instrumentation. These additional ranges may be a problem when the TPS is performing a measurement using the DMMs autorange capability.

D. *Autorange Algorithms*

DMMs support autorange to simplify the setup for a measurement operation. In most cases autorange is not used in a TPS because the range of the value to be tested is known and autorange will typically increase measurement time. For those tests where autorange is required, the autorange algorithm may be important in getting repeatable results for the test. When a DMM is using autorange for a measurement there are different techniques the instrument may use to reduce measurement time and improve measurement resolution. For example in resistance measurements, the DMM may first attempt a measurement using the last successful measurement range. If this does not produce an optimal measurement the DMM will choose a direction for the next range to try and continue the process until the best range is found for the measurement. In other cases the DMM may always start from either the lowest or highest range then increment or decrement the range until the best range is found for the measurement. Voltage and current measurements will usually autorange starting from the largest measurement range. This will protect the instrument from damage from the input signal.

The choice of autorange direction may be important to get repeatable results from a test that uses the resistance measurement function of the DMM. If the replacement instrument uses a different algorithm than the obsolete instrument this may cause the TPS to fail or produce unreliable results.

VII. Waveform Generator Issues

Some of behavior that must be provided in a replacement waveform generator can be satisfied by comparing the replacement instrument specifications with those of the obsolete instrument. The replacement waveform generator must also provide all of the waveform types and modulation supported in the obsolete instrument. If the obsolete instrument supports arbitrary waveform generation, there may be some issues with minimum and maximum number of points. There may also characteristics for waveform bursts, arbitrary sequences, and repeated generation in the obsolete instrument that may need to be matched in the replacement instrument. Care must be taken to make sure that the replacement instrument not only supports the input triggering of the obsolete instrument, but also the trigger generation of the obsolete instrument. The following section describes other problems that may be seen when integrating a replacement waveform generator.

A. *Latency and Settling Time*

When a waveform generator receives a command to start waveform generation it may take some time for the onset of waveform generation. This latency between the command and the start of waveform generation is usually very short but may vary between the obsolete and replacement instruments. This delay will only be present for non-triggered waveform generation. When the waveform generation is triggered from either an event within the instrument or from an external trigger signal, generation will start almost immediately after the trigger.

If the amplitude or offset of a waveform is changed during waveform generation there will be a delay before the new amplitude and offset are applied to the waveform. This delay and the shape of the waveform during the change in amplitude or offset will probably vary between the obsolete and replacement instruments. Some instruments support changes in the waveform frequency during waveform generation while others may require the generator to be paused to change the frequency. Even if the generator supports changing the frequency during waveform generation it may take some time for the waveform to settle at the new frequency.

If the TPS attempts to make a measurement immediately after either starting waveform generation or changing the waveform frequency, amplitude or offset the TPS may not work reliably when moving to a replacement instrument. Any issues can be corrected by allowing some settling time after waveform changes. The delay can be added in the wrapper layer or in the TPS.

VIII. Digitizer Issues

Most of the issues encountered when replacing or upgrading a digitizing instrument, this includes DSOs, in a test system can be eliminated by making sure the replacement instrument has comparable ranges, both voltage and time ranges, to the obsolete instrument. Other issues, especially with DSOs, can be avoided by making sure the replacement instrument supports all the trigger modes from the obsolete instrument. Even when these criteria are satisfied, there are still problems that may appear during system integration. Some of these problems are covered in the following sections.

A. Differences In AC Coupling

Most digitizers and DSOs support switching the input channel coupling between DC and AC. AC coupling is useful for observing the AC component on an input signal that also contains a DC offset. The default coupling for the channel will vary between instrument manufacturers and models. The instrument manufacturer may or may not specify a low frequency cutoff for the channel when AC coupling. If it is specified, the specification will be for a 3db point. The coupling capacitor will have an effect on signal amplitude measurements for frequencies greater than the cutoff frequency. When upgrading digitizers or DSO instruments, tests for low frequency signals may need modification due to attenuation of the input signal from the coupling capacitor. This will require a change to the TPS.

Another issue with coupling capacitors is the time required to block the DC component of the waveform. If the replacement instrument has a larger coupling capacitor than the obsolete instrument this may cause the TPS to fail due to the DC offset that is captured in the digitized waveform. The TPS may require additional settling time prior to performing the measurement.

B. Coercion of Programmed Values

Typically, digitizer and DSO hardware have restrictions on the voltage range (vertical scale) and capture time (horizontal scale) of a waveform. A digitizer that has a maximum input voltage of 20Vpp does not have an infinite number of ranges between its minimum range and the 20V max range. The instrument manufacturer will define a set of possible voltage ranges. The same will be true for the acquisition time or sample rate where there will be a set of possible values sometimes based on restrictions for acquired record lengths (number of points). Many digitizer and DSO instrument drivers are programmed using enumerated values for voltage and time ranges. IVI drivers define the programming of voltage and time ranges using double precision numbers. The IVI instrument driver will map these double precision numbers to legal values (from the enumerated set of values) based on the restrictions of the hardware.

A TPS may have been written with the knowledge of the finite set of voltage and time ranges in the digitizer or DSO instrument, but there is also a possibility that the TPS uses the coercion in the driver to program the instrument correctly. In either case there may be issues when attempting to execute the TPS with a replacement instrument. These issues are covered in the following sections.

1) Voltage Range Coercion and Conversion

Differences in the voltage ranges of the obsolete instrument and the replacement instrument can cause problems in measurements from the digitized waveform data. The problems occur from changes in acquisition resolution from differences in acquisition range. This problem may only affect a few ranges in a digitizer, but may impact all ranges in a DSO due to the architecture of the DSO instrument. In many DSOs the VXI/PXI instrument driver/hardware architecture will mimic a benchtop instrument with a graphical display. The instrument will program using ranges that are based on either 8 or 10 vertical divisions of the range. This way the instrument programming will follow the style of setup used with a benchtop instrument. When moving from an obsolete instrument that uses a different number of vertical divisions than the replacement instrument all voltage ranges will have a different resolution. For example, assuming both the obsolete and replacement instrument use 8 bit analog to digital converters, if the obsolete instrument uses 8 vertical divisions and is set to 1V per division, 8V range, captured waveforms will have a resolution of approximately 31mV. If the replacement instrument uses 10 vertical divisions and is set to 1V per division, 10V range, captured waveforms will have a resolution of approximately 39mV. This change in resolution may be sufficient to cause a TPS to fail a good UUT with the replacement instrument.

While it may be possible to manage changes in programmed voltage range in an instrument wrapper layer, changes in voltage ranges and the resulting changes in resolution may require modifications to the TPS.

As was mentioned earlier, changes in voltage ranges between the obsolete and replacement instrument may cause problems with the TPS due to either clipping of the captured waveform or not choosing the best range for the captured waveform. This problem may not be correctable in the instrument wrapper. Instrument wrappers can normally manage differences in configuring different versions of an instrument, but the wrappers do not have an understanding of the expected response from the UUT.

2) Sample Points and Sample Rate Coercion and Conversion

The resolution of the sample period of a digitizing instrument is based on the high-speed sample clock. In high-speed digitizers and DSOs the input signal is sampled at the maximum sample rate of the instrument. These samples are then placed into sample memory by decimating the samples based on the user requested sample rate. Decimation is the process of discarding samples that fall between the sample periods requested by the user. So samples are placed into memory at an effective sample rate that is probably not the actual hardware sample rate of the instrument. This process produces the most accurate sample timing since there is no variation of the clock to the analog to digital converter.

This process of determining the effective sample rate may differ between the obsolete and replacement instruments. In older instruments, the decimation process may be limited to a small set of powers of 2 or 10 of the high-speed sample clock. The driver of the obsolete instrument may have forced the entry of sample rates based on these values or may have coerced the user entered value to a legal value. Modern instruments may not be as restrictive in their handling of effective sample rates. In the replacement instrument, this may result in no coercion of the user specified sample rate or result in the coercion to values that are different than the obsolete instrument. Any changes in the effective sampling rate between the obsolete and replacement instruments will result in a difference in the number of acquired cycles of the sampled waveform and may also change the number of points acquired per cycle of the sampled waveform.

There may be similar restrictions in the number of captured points per sample record. Older instrumentation may restrict the number of captured points based on a small set of powers of 2. This restriction may be due to hardware limitations when using repeated triggering in the instrument. As with sample rate, the driver of the obsolete instrument may have either forced the entry of capture points per sample record to a legal value or may have coerced the user enter value to a legal value. Modern instruments may not be as restrictive in their handling of points per sample record. In the replacement instrument this may result in no coercion and the capture of exactly the number of points requested by the user. Any changes in the number of captured points of the input waveform over a given sample time (record time); will result in a difference in the number of acquired cycles of the sampled waveform.

Any changes in the number of acquired cycles or number of points in the captured waveform may have an impact on measurements based on the analysis of the waveform data[4]. If the number of points acquired per cycle is changed, there may be problems in voltage calculations. For example if a waveform is sparsely sampled, less than 10 points per cycle, measurements of RMS voltage, voltage peak-to-peak and amplitude may be different than those expected by the TPS. If the waveform record was attempting to capture a single cycle, any changes in record time may cause frequency and period measurements to fail. It is unlikely these problems can be corrected in an instrument wrapper layer. The TPS will need to be changed to account for these differences.

C. Bandwidth Differences

Instruments chosen to replace an obsolete instrument will usually have the same or greater bandwidth than the obsolete instrument. If the bandwidth of the replacement instrument is the same as the obsolete instrument there should be little or no impact on signals acquired using the replacement instrument. If the bandwidth of the replacement instrument is greater than the obsolete instrument this may cause issues with the existing TPS. Greater bandwidth will not only change the frequency where input signal attenuation begins it will also make the instrument more susceptible to noise on the input signal.

When an existing TPS is attempting to measure the amplitude of a signal that was near the upper frequency bandwidth of the obsolete instrument, the expected value and limits of the TPS may have been adjusted to account for the attenuation of the input signal. A replacement instrument with a greater bandwidth will pass the signal without attenuation and may cause a failure in the TPS. This will require changes to the TPS to adjust the expected value and possibly the test limits.

A replacement instrument with greater bandwidth will also be likely to trigger on noise on the input channel. This may cause false triggering in the TPS. This can usually be corrected in digitizers and DSOs by changing the trigger hysteresis. DSOs also have more advanced settings for the trigger circuit that may help with false triggering due to noise on the input signal. On DSOs setting the trigger to high frequency reject or changing the maximum channel frequency may help to correct false triggering problems. Changes to correct triggering issues due to signal noise will require changes to the TPS. It is unlikely that a wrapper layer could be changed to fix the problems without having side effects on the triggering of other measurements.

D. Differences In Trigger Hysteresis

Trigger hysteresis may be set as a percentage of the voltage range, a delta from the trigger level, or a fixed value. In most cases modern replacement instruments allow control of the hysteresis. Even if the obsolete and replacement instrument use the same technique to control the trigger hysteresis there may still be problems when moving to a replacement instrument due to differences in the control range and reset state.

Differences in the range of control for the hysteresis may either cause errors when attempting to program the hysteresis or problems in triggering the sampling of the input signal. These issues will require changes to the TPS.

In some cases the TPS may not attempt to program the trigger hysteresis and is relying on a default state of the instrument. This may cause problems in the TPS depending on the default settings of the replacement instrument and the noise level or slope of the trigger signal. These problems can be corrected in either the instrument wrapper or the TPS by programming the hysteresis of the replacement instrument to match the default condition of the obsolete instrument.

E. Different Analysis Algorithms

Some digitizers and DSOs include waveform analysis as part of the instrument driver. In IVI DSOs there are 20 defined measurements to provide time, frequency and voltage information for a captured waveform record[5]. If the obsolete and replacement instruments provide waveform analysis functions there may be differences in their results. These differences can arise from measurement thresholds and the handling of waveform data that only contains a single cycle of a waveform.

Rise time and fall time measurements are done using voltage thresholds that are typically a percentage of the amplitude of the signal. If the TPS developer did not specify a threshold for the measurement, the default of the instrument driver will be used. In Some instrument drivers the default thresholds for rise and fall time measurements are 10% to 90% or 20% to 80% of the amplitude. In IVI instrument drivers there are no defined threshold values for rise and fall time measurements. If the TPS is using the instrument defaults thresholds for rise and fall time measurements, this may cause the TPS to fail a good UUT when using the replacement instrument. This problem can be corrected in either the instrument wrapper or the TPS by programming the rise and fall time measurement thresholds to match those of the obsolete instrument.

In some cases the TPS may configure the digitizer or DSO to only capture a single cycle of the input signal. This can present problems when migrating to a replacement instrument. The measurement analysis algorithms of the replacement instrument may have different rules for determining the start and end of a waveform cycle. For example, if the first points in the waveform data indicate the signal is rising in excess of the trigger threshold can this be assumed to be a complete rising edge of the signal? Or if the last points in the waveform data indicate the signal is approaching the trigger threshold can this be assumed to be the complete transition of the signal? The replacement instrument may handle these cases differently than the obsolete instrument. Some analysis algorithms require the signal to pass through 3 thresholds to determine a complete transition of the signal. One of these thresholds will be based on either the average value of the signal or the trigger threshold. The other two thresholds may be an offset from the first threshold or possibly the same thresholds used for rise and fall time measurements. Any analysis differences between the obsolete and replacement instrument for determining signal edges may require changes to the TPS. The TPS may need to be modified to capture at least one and a half cycles of the waveform with the acquisition configured to capture the quarter cycle of the waveform prior to the trigger event.

Frequency and period measurements may also be different between the obsolete and replacement instruments. If the obsolete instrument uses edge detection to determine frequency and the replacement instrument uses an FFT, the change in measurement resolution may cause problems in the TPS. The frequency resolution of an FFT is related to the number of points in the waveform data. The TPS may need to be changed to capture more waveform data so the FFT will return a measurement with the required resolution.

F. Switching Between Real-Time and Equivalent-Time Sampling

When an instrument is sampling the input signal at a rate less than or equal to its maximum sampling rate this is known as real time sampling. Equivalent time sampling (ETS) is a method to overcome the real time sampling limits of the instrument hardware[6]. In ETS, multiple real time waveform captures are stitched together to create a combined waveform record that exceeds the real time sampling restrictions. Most DSOs can capture signals using ETS, digitizers usually do not provide this capability.

Some DSOs will automatically switch to ETS when programmed with a either a sample rate greater than the maximum real time rate or when programmed with a total capture time and number of points that will exceed the real time rate. It is not guaranteed that all DSOs will switch to ETS automatically or generate an error if the DSO is configured to sample greater than the maximum real time rate when not using ETS. In these cases the DSO may return waveform data that is incomplete. DSOs normally support some form of interpolation for missing points in the waveform data. Interpolation may not be on by default and the waveform data may contain entries that are not a number (NaN).

If the obsolete instrument automatically switches to ETS but the replacement instrument requires configuration for ETS, this may cause problems with the TPS. Automatic switching to ETS may not matter if the replacement instruments real time sampling rate is not exceeded within the TPS. If the real time sampling rate of the replacement instrument is exceeded, then the TPS may fail due to either NaNs in the waveform data or analysis differences because of the interpolated points in the waveform data. It may be possible to resolve these issues in the instrument wrapper, but it is likely that the TPS will need to be changed.

IX. Timer/Counter Issues

As with the preceding instruments, most of the problems that may be seen when upgrading or replacing a timer/counter instrument are related to differences in specifications and measurement functions. Timer/counter measurements may also have strict triggering requirements, so it is necessary to make sure that the replacement instruments supports all the triggering modes and functionality of the obsolete instrument. The following sections describe some of the more subtle issues that may be seen when replacing or upgrading a timer/counter instrument.

A. AC Coupling On Small Signals

Timer/Counter instruments usually support AC coupling of the input signal to remove any DC offset. If the trigger voltage for the measurement is near zero volts changes in the input coupling capacitor between the obsolete instrument and the replacement instrument will have little impact for large signal frequency measurements. This should be true for signals that are slightly less than the input cutoff frequency. Small signal frequency measurements may present a problem that will appear as either a measurement higher or lower than expected. In some cases these problems can be corrected using the trigger hysteresis control. On some instruments there is also a setting to control the input voltage range for the timer/counter. On these instruments the trigger hysteresis can be affected by the voltage range. If there is no control for trigger hysteresis, the TPS will need to be changed to use DC coupling and adjusting the trigger level to get a repeatable measurement.

B. AC Coupling with Rise and Fall Time Measurements

For rise and fall time measurements, differences in the input coupling capacitor between the obsolete and replacement instruments can have a significant impact on the measurement. For low frequency signals, it may not be possible to perform a rise/fall time measurement of 10% to 90% of the amplitude at frequencies slightly higher than the cutoff frequency for the channel. To make these measurements using the replacement instrument the TPS will need to be modified to use DC coupling and the levels will need to be modified to account for the DC offset. If this is not possible, or if changing the TPS does not result in a reliable measurement, AC coupling may need to be added to the test fixturing and the replacement instrument set to DC couple the signal.

X. TPS ISSUES

Some of the problems discovered during integration of a replacement instrument are due to programming decisions in the TPS. The following sections describe some of these problems and techniques that can be used to resolve them in existing TPSs and to reduce their likelihood in future TPSs.

A. Direct Use of the Instrument API

The API for the obsolete and replacement instruments will differ unless both instruments provide an IVI driver. Even with IVI drivers, there is usually an instrument specific API provided. This instrument specific API allows the driver to expose capabilities of the instrument that are not covered in the IVI specification. If the TPS makes any calls to the instrument API of the obsolete instrument the TPS will need to be changed for use with a replacement instrument. The changes to the TPS may be significant if the replacement instrument API does not directly support the required functionality.

B. Missing Measurement Functions

Sometimes the TPS developer requires a measurement capability that is not directly supported in the instrument. For example the test may require a diode measurement using the DMM but the DMM may not have a diode measurement function. The TPS developer may use the resistance measurement function with autorange to measure the diode drop. Any differences between the obsolete and replacement instruments for ranges, source currents or autorange algorithm may cause the TPS to produce unreliable results. For this example, the TPS will need to be changed to step through the ranges while possibly controlling source current, if supported by the replacement instrument, to make the measurement.

C. Exceeds Instrument Specifications

In some cases the TPS may use of the obsolete instrument in a way that is not covered in the instrument specifications. For example a waveform generator may be programmed to produce a 6Vpp signal into a 50ohm load. The specifications for the obsolete instrument may indicate that the maximum voltage into 50ohms is only 5Vpp. If this specification was missed during TPS development and the obsolete instrument did not generate an error, this mistake in the TPS may have been missed. The obsolete instrument may have been capable of generating the voltage for some waveform types and frequencies, so the TPS may have worked as expected. The replacement instrument may generate an error when attempting to program values beyond the specified limits. It may not be possible to correct this problem in the TPS. This issue may require either a different choice for the replacement instrument or changes to the test procedure to stay within the instrument specifications.

D. Uses Reset State of the Instrument

The TPS may depend on the reset state of the instrument to function correctly. This problem may occur even if the TPS developer programmed all the necessary parameters of the obsolete instrument. The replacement instrument may have additional functionality whose default state needs to be changed for the TPS to function correctly. Either the wrapper layer or the TPS will need to be modified to correctly program the default state.

E. Signal Settling Time

Usually a delay is required between changing the parameters of a source instrument and performing a measurement. The reason for this delay may be based on settling time of the source or measurement instrument or propagation of the signal through the UUT or test fixture. A TPS may have settling time problems when moving to a replacement instrument. In some cases these problems are on the source side as was discussed in the prior section on signal generator issues, but in most cases the problem is on the measurement side. The replacement measurement instrument may be able to perform the measurement faster than the obsolete instrument, so the signal may not be settled prior to the measurement. The TPS will need to be modified to add additional settling time prior to performing the measurement.

F. Missed Error From API Call

A TPS may fail because of a failure to check the return status from an API call. This mistake in the TPS may have been missed because the current state instrument, possibly a reset state, was correct for performing the measurement. In other cases the expect conditions for the measurement may have been adjusted to work with the incorrect instrument setup. Differences between the obsolete and replacement instrument may cause the TPS to fail due to this error in the TPS. In some cases, these errors can be difficult to track down because the API call with the failing status is not in the same section of the test program as the failing measurement. When the problem is located, the TPS will need to be changed to correct the API call with the bad status. After correcting the instrument setup the measurement expect conditions may also need to be adjusted.

XI. CONCLUSIONS

At some point in the service life of a military test system it will probably be necessary to replace one of more of the test instruments due to obsolesce or changing requirements. To minimize the impact on existing TPS when instruments need to be replaced, no calls should be made directly to the instrument API. Even with this restriction on the TPS issues may be discovered during system integration of the replacement instrument. Sometimes the differences are not seen by comparing instrument specifications, but arise from differences in the driver and hardware implementation. Many problems encountered during integration are due to the replacement instruments impact on source or measurement operations using other instruments. Sometimes these problems result from mistakes or omissions in the TPS for configuring the instrumentation. The issues presented in this paper should help in resolving replacement instrument integration issues in existing systems. Also knowledge of the possible integration problems can be used to change the creation of new TPS to reduce the number of problems in replacing obsolete instruments in the future.

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