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Signal Waveform Generator Performance Test

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16. Abstract

A signal waveform generator (SWG) was tested to determine its suitability for use in testing crash test data acquisition systems. The outputs of the SWG were recorded by a precise, high speed data acquistions card plugged into the option card slot of an IBM PC compatible desk top computer. The recorded data was analyzed using a modified version of the software that was developed for analyzing recorded SWG outputs when testing crash test data acquisition systems. For measuring small time differences between waveform leading edges, a digital storage oscilloscope was used.

SWG time base accuracy meets the requirements of SAE J211.

When the SWG is operated at the high output voltage level, the measured amplitude accuracy is ±0.06% of full scale. But when the SWG is operated at the low output voltage level, the measured amplitude accuracy degrades to ±0.31% of full scale. A large part of this accuracy degradation is caused by a measured offset of the waveform zero level from the calibration zero level.

The frequency response of the SWG meets the requirements implied by SAE J211.

The measured performance of the SWG is suffciently precise that the use of the SWG for testing crash test data acquisition systems will be satisfactory.

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Data Acquisition System Testing
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PREFACE

A signal waveform generator (SWG) design has been developed for the National Highway Traffic Safety Administration (NHTSA) by MGA Research Corporation. Ten SWGs were fabricated and delivered to NHTSA. Each SWG provides standard precision waveform signals for testing the performance characteristics of data acquisition channels at the facilities of DOT vehicle crash and sled test contractors. Initial development of the SWG was carried out under the Test-Site Instrumentation Study (Contract No. DOT-HS-8-01936, Task Order No. 3). The present SWG configuration was designed and fabricated under Phase II (Contract No. DTNH22-82-C-07041) of this study. Design modifications to the SWG were made under Phase III (Contract No. DTRS-57-84-C-00003, Task Order Nos. 3, 3A, 8, 8A, and Purchase Order No. DTRS-57-86-P-81655) of the study.

One of the SWGs produced under these contracts was tested at the Research and Special Programs Administration/Volpe National Transportation Systems Center (RSPA/VNTSC) to determine if the SWG was sufficiently accurate to serve as a standard for testing crash test data acquisition systems. This report describes the testing that was performed and the results of that testing.

The work described in this report was funded by the NHTSA Research and Development Office of Crashworthiness Research. Ms. Randa Radwan, the Contract Technical Monitor for this work, provided many helpful suggestions for the organization of this report.

METRIC / ENGLISH CONVERSION FACTORS

ENGLISH TO METRIC

LENGTH (APPROXIMATE)

1 inch (in) = 2.5 centimeters (cm)
1 foot (ft) = 30 centimeters (cm)
1 yard (yd) = 0.9 meter (m)
1 mile (mi) = 1.6 kilometers (km)

AREA (APPROXIMATE)

1 square inch (sq in, in^2) = 6.5 square centimeters (cm^2)
1 square foot (sq ft, ft^2) = 0.09 square meter (m^2)
1 square yard (sq yd, yd^2) = 0.8 square meter (m^2)
1 square mile (sq mi, mi^2) = 2.6 square kilometers (km^2)
1 acre = 0.4 hectares (he) = 4,000 square meters (m^2)

MASS - WEIGHT (APPROXIMATE)

1 ounce (oz) = 28 grams (gr)
1 pound (lb) = .45 kilogram (kg)
1 short ton = 2,000 pounds (lb) = 0.9 tonne (t)

VOLUME (APPROXIMATE)

1 teaspoon (tsp) = 5 milliliters (ml)
1 tablespoon (tbsp) = 15 milliliters (ml)
1 fluid ounce (fl oz) = 30 milliliters (ml)
1 cup (c) = 0.24 liter (l)
1 pint (pt) = 0.47 liter (l)
1 quart (qt) = 0.96 liter (l)
1 gallon (gal) = 3.8 liters (l)
1 cubic foot (cu ft, ft^3) = 0.03 cubic meter (m^3)
1 cubic yard (cu yd, yd^3) = 0.76 cubic meter (m^3)

TEMPERATURE (EXACT)

[(x - 32)(5/9)] °F = y °C

METRIC TO ENGLISH

LENGTH (APPROXIMATE)

1 millimeter (mm) = 0.04 inch (in)
1 centimeter (cm) = 0.4 inch (in)
1 meter (m) = 3.3 feet (ft)
1 meter (m) = 1.1 yards (yd)
1 kilometer (km) = 0.6 mile (mi)

AREA (APPROXIMATE)

1 square centimeter (cm^2) = 0.16 square inch (sq in, in^2)
1 square meter (m^2) = 1.2 square yards (sq yd, yd^2)
1 square kilometer (km^2) = 0.4 square mile (sq mi, mi^2)
1 hectare (he) = 10,000 square meters (m^2) = 2.5 acres

MASS - WEIGHT (APPROXIMATE)

1 gram (gr) = 0.036 ounce (oz)
1 kilogram (kg) = 2.2 pounds (lb)
1 tonne (t) = 1,000 kilograms (kg) = 1.1 short tons

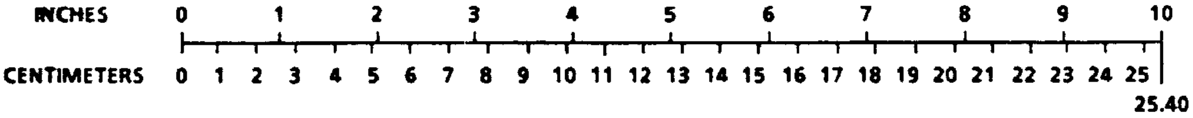
VOLUME (APPROXIMATE)

1 milliliter (ml) = 0.03 fluid ounce (fl oz)
1 liter (l) = 2.1 pints (pt)
1 liter (l) = 1.06 quarts (qt)
1 liter (l) = 0.26 gallon (gal)
1 cubic meter (m^3) = 36 cubic feet (cu ft, ft^3)
1 cubic meter (m^3) = 1.3 cubic yards (cu yd, yd^3)

TEMPERATURE (EXACT)

[(9/5) y + 32] °C = x °F

QUICK INCH-CENTIMETER LENGTH CONVERSION



QUICK FAHRENHEIT-CELCIUS TEMPERATURE CONVERSION

°F	-40°	-22°	-4°	14°	32°	50°	68°	86°	104°	122°	140°	158°	176°	194°	212°
°C	-40°	-30°	-20°	-10°	0°	10°	20°	30°	40°	50°	60°	70°	80°	90°	100°

For more exact and/or other conversion factors, see NBS Miscellaneous Publication 286, Units of Weights and Measures. Price $2.50. SD Catalog No. C13 10 286.

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1. INTRODUCTION

The signal waveform generator (SWG) developed by MGA Research Corporation is a calibration instrument used in testing to verify that the performance of a DOT vehicle and sled crash test contractor's data acquisition system (DAS) meets the requirements of the Society of Automotive Engineers (SAE) recommended instrumentation practices ~~[1]~~* as required by DOT contract specifications. The SWG provides a precise waveform input to the DAS for this testing. Ten SWGs were fabricated. To assure that the SWGs provide a sufficiently precise input, each SWG must be tested. This document describes the in-depth testing that was performed on SWG S/N 6 and the results of that testing. These results and the experience gained from this testing have formed the basis for the certification tests that will be performed on all SWGs.

1.1 BACKGROUND

The evaluation test of a crash test facility's data acquisition system (DAS) is conducted using a SWG combined with specialized signal processing software (SPSW). The testing is performed before a crash test series and provides an evaluation of the measured performance of the instrumentation and DAS from sensor interface to the data tape sent to NHTSA. The test facilities are required to setup their instrumentation and DAS in the same way as in a regular crash test. A NHTSA furnished SWG is placed at the sensor interface to provide the input signal source. The recorded waveform test data are processed using the specialized SPSW (described in [3]).

In DAS evaluation testing, typically each signal from the SWG is processed by the appropriate channel signal conditioner and multiplexer (if used), and sent through an umbilical cable to be recorded on tape by an analog instrumentation tape recorder. The analog data is played back, demultiplexed (if multiplexed to record), filtered (to prevent aliasing), sampled, converted to digital form, and recorded on magnetic tape. Usually, the digital data on this tape is reformatted to NHTSA specifications by a second digital computer and written on a tape that is sent to Washington, where it is processed on the NHTSA VAX computer cluster.

* Numbers in square brackets denote the References provided at the end of this report.

Crash test data acquisition systems now being installed are all digital in nature. In these systems there is no analog tape recorder. Each signal passes directly through the signal conditioner, the umbilical cable, and the analog antialiasing filter to the digital data acquisition system which samples and digitizes the test data "in real time" as the test takes place.

1.2 SWG DESCRIPTION

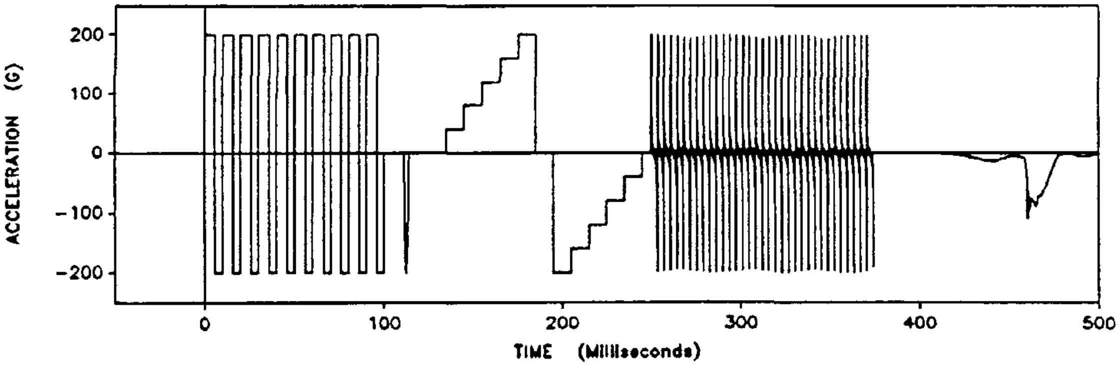
The SWG functions by storing the precision waveforms digitally in programmable read-only-memory (PROM). When a test is performed, the waveform data is read out of PROM under microprocessor control, converted to analog form by a digital-to-analog converter (DAC), and scaled by a resistive, operational amplifier network for transmission to the SWG output jacks. Every 30.5 microseconds (μs) a new data sample is processed by the DAC and made available at the SWG outputs. The SWG is described in greater detail in the SWG Operator's Manual [2].

Each of the precision waveform outputs provides five waveforms in a sequence. This sequence consists of the rectangle, half-sine, stair, sum-of-sines, and crash waveforms. The rectangle and stair waveforms are used to measure data acquisition channel time accuracy, amplitude accuracy, and amplitude overshoot. The half-sine waveform is used to measure channel-to-channel time differences. The sum-of-sines waveform is used to measure channel frequency response. The half-sine and crash waveforms are used to determine if any characteristic of the data acquisition channel is degrading the HIC values that would be calculated from the crash test data recorded by that channel.

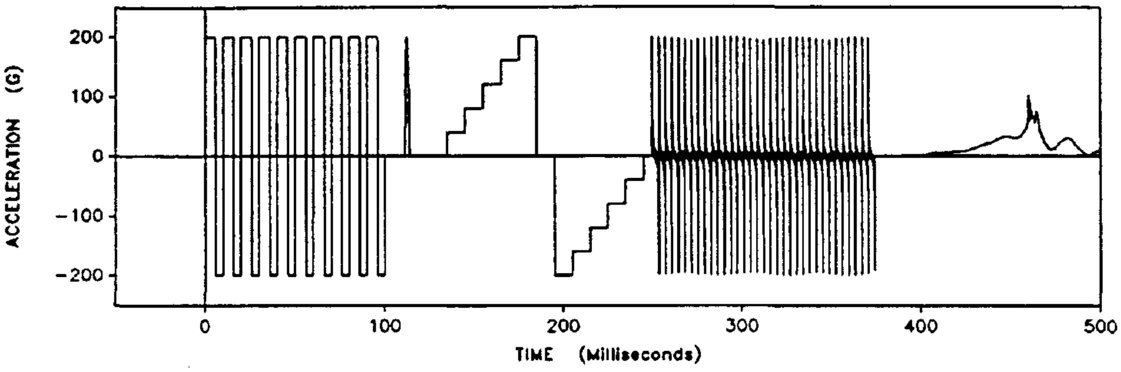
In addition to the waveform outputs, the SWG produces time reference outputs which are used to test facility sampling frequency and time shifts between "time-zero" (T0) and data channels. The time reference output is also used to separate each waveform from the input data stream. The T0 time reference signal consists of five positive pulses. The first is a pre-time-zero pulse approximately 10 milliseconds (ms) wide. This pulse can be used by digital data acquisition systems to start data recording. The leading edges of the first through the fourth T0 pulses after the pre-time-zero pulse correspond to the beginnings of the rectangle, stair, sum-of-sines, and crash waveforms, respectively.

A plot of the waveform output recorded from SWG S/N 6 is shown in Figure 1-1.

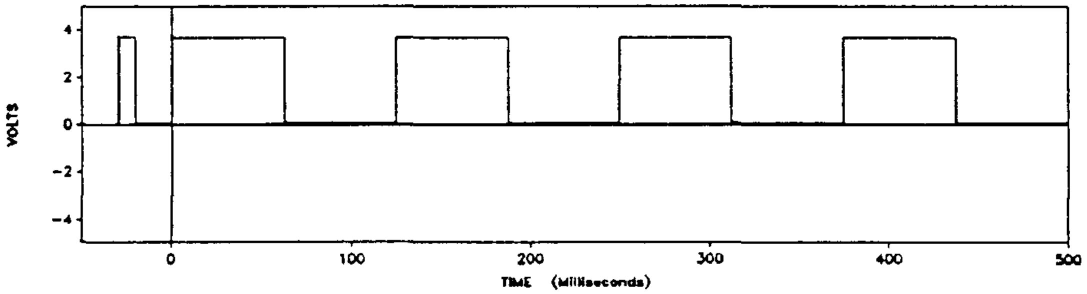
GROUP 1 WAVEFORM



GROUP 2 WAVEFORM



TO TIME REFERENCE SIGNAL



DTO TIME REFERENCE SIGNAL

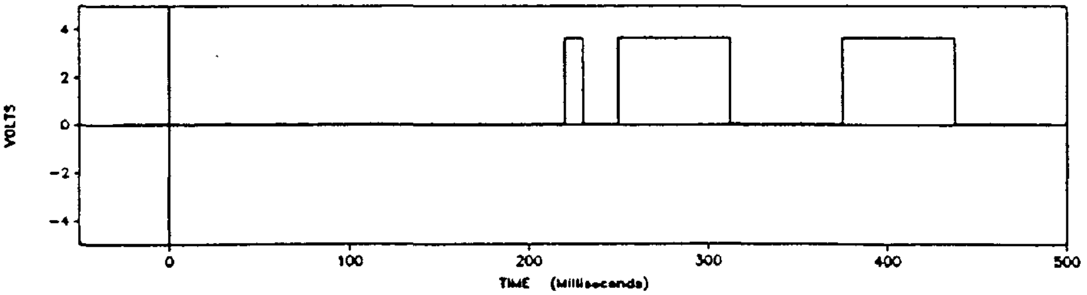


FIGURE 1-1 SWG WAVEFORM OUTPUTS

1.3 TEST DATA PROCESSING

The recorded waveform test data are processed on the NHTSA VAX cluster using the specialized SPSW described in the SPSW documentation [3]. Time, amplitude and frequency performance measures are computed and analyzed to assure conformance to the instrumentation practices of SAE J211 [1].

2. METHOD OF TEST

2.1 TIMING ACCURACY

Five factors contribute to SWG timing accuracy. The first is the actual frequency of the SWG crystal clock oscillator. The second is the timing accuracy of the time reference signals from the SWG. The third is the precision with which the SWG time reference pulses coincide with the SWG waveform data. The fourth is the precision with which the group 1 and group 2 waveforms are synchronized with each other. The fifth is the timing accuracy of the individual waveforms.

2.1.1 Clock Frequency

The frequency of the SWG crystal clock oscillator was measured using a precision frequency counter. It is this oscillator that determines the timing of all SWG outputs.

2.1.2 Time Reference Signals

The primary time reference signals from the SWG are the T0 and DT0 outputs. The accuracy of the time reference signals determines the accuracy with which the SWG can test the timing accuracy of a DAS. The time between the rising edges of the first and fourth T0 pulses after the pre-time-zero (T0) pulses is used to determine sample timing accuracy of the DAS under test. The leading edges of the first and second T0 pulses after the pre-T0 pulse are the time references that mark the start of the rectangle/half-sine and stair waveform segments.

The actual times of occurrence of the T0 and DT0 transitions within the 30.5 μs SWG DAC output sample interval was measured using the precision data acquisition system (PDAS), purchased for this test. The sampling of the PDAS was synchronized to the SWG DAC strobe pulse. Consequently, all time measurements over intervals greater than 30.5 μs are relative to the SWG crystal clock oscillator frequency. Sample timing within one 30.5 μs interval was controlled by the PDAS crystal clock oscillator.

2.1.3 Coincidence of Waveform Edges

The coincidence of the initial rising edges of the time reference pulse and the rectangle waveform was measured to determine the timing accuracy of the waveform data relative to the time reference. This was measured using a dual trace digital storage oscilloscope. The details of the rectangle waveform leading edge were determined using the PDAS. This is a critical measurement because the time reference pulses are used to determine the starting time of each waveform and thereby the timing accuracy of the DAS under test.

2.1.4 Waveform Group Synchronization

The half-sine pulses in each waveform group are used to measure any time differences between two data acquisition channels. If the half-sine pulses in each waveform group occur at different times, the facility under test could be faulted when no fault exists.

2.1.5 Waveform Timing

The software used to process SWG waveform data performs a test to determine the times at which recorded changes in level of the rectangle and stair waveforms occur. If the waveform recorded at a facility changes levels at times that are different from those that the software uses as a reference, a time difference error is calculated. These data provide a measure of time linearity.

2.2 AMPLITUDE ACCURACY

The accuracy of the waveform amplitudes was determined by two methods. The SWG SPSW, as modified to accept the longer data sets recorded for this test, was used to analyze the waveform data recorded by the PDAS. The SWG test SPSW is program [JOHNN.WGTEST.PROG]SWGTPROC.FOR on the NHTSA VAX cluster. Then, to verify the results of the software analysis, the recorded raw data printouts were examined at critical points. The amplitude accuracy measures determined are SWG full scale amplitude accuracy using the positive calibration signal from the SWG as a reference, amplitude linearity, and zero offset.

2.2.1 Calibration Level

The positive and negative calibration voltages at both "piezo resistive" and "strain gage" settings from all SWG output channels were measured with a digital multimeter to confirm that each channel output is providing the correct calibration voltage level (and thus, transmitting correct

DAC outputs). "Zero" output levels were also measured to establish "zero" offsets.

To establish the zero and calibration levels for scaling the PDAS, averages were computed of the SWG zero output level and the SWG +CAL output level, using the PDAS software. At first single 100,000 point averages of each level were computed. Later it was found that better estimates of the true averages could be determined by repetitively computing 16,000 point averages and plotting them. A 30.5 μs sampling interval was used for recording the zero and calibration level data. The positive calibration output represents a +200 g waveform data level.

The output of the analog-to-digital converter (ADC) of the PDAS is an integer between -32768 and +32752. This range of integers corresponds to a PDAS input voltage range of -5 volts to +4.998 volts. Similar correspondences exist for the ±10 volt and ±2.5 volt input settings. The SWG SPSW expects to see waveform data that varies between ±200 g. The ADC outputs are scaled by the PDAS using the following equation:

WVOUT = (ADCOUT - ZERO)*200/(CALOUT - ZERO)

where
WVOUT = the scaled waveform signal
ADCOUT = the ADC output
ZERO = the average SWG "zero" output
CALOUT = the average SWG positive calibration output

2.2.2 Waveform Amplitudes

The SWG SPSW compares the average values of the constant portions of the rectangle and stair waveforms with the theoretical values for these waveforms at those levels. The peak values for the half-sine waveforms were determined by examining the scaled raw data printouts.

2.3 FREQUENCY RESPONSE

The frequency response of a data acquisition system is determined by processing the sum-of-sines waveform from the SWG. For this test of the SWG, the frequency response measurement is measuring the unfiltered output of the SWG itself. The SWG amplitude frequency response should be 1.0 (flat) at all sum-of-sines signal frequencies.

2.3.1 Sum-of-Sines Waveform

The sum-of-sines waveform from the SWG consists of the sum of equal amplitude sine waves whose frequencies are consecutive integer harmonics of the fundamental (lowest) frequency of the composite signal. A discrete Fourier transform (DFT) is used to perform the frequency response analysis. The frequency increment between DFT output elements is 1/NT, where N is the size of the DFT and T is the sampling interval of the time series input to the DFT. When the sampling interval of the DAS under test is 75, 100, or 125 μs, the fourteen harmonics of the 273.4375 Hz fundamental frequency will coincide with 14 of the output frequencies of a 2048 point DFT.

2.3.2 Frequency Response Measurement Algorithm

The frequency response analysis is performed by subroutine FRSP3 of the SWG SPSW. FRSP3 starts the analysis by reading the recorded sum-of-sines data into an array. Then, an array of the theoretical sum-of-sines data is created, sampled at the same interval as the recorded data. Next, the recorded data and the computed data are each multiplied by a Gaussian data window. A 4096 point DFT of each of the windowed data sets is computed. The index of each DFT element whose frequency corresponds to a signal frequency is computed. The magnitude of each DFT element whose frequency corresponds to a signal frequency is determined. The ratio of the DFT of the theoretical data set to the DFT of the recorded data set, at the lowest signal frequency, is used as a scaling factor. The ratio of the DFT of the recorded data to the DFT of the theoretical data, at each signal frequency, multiplied by the scale factor, is the numeric amplitude ratio at that signal frequency. A description of this algorithm and its source program listing are provided in greater detail in the SPSW documentation [3].

2.4 DESCRIPTION SUMMARY

The measurement requirements for testing the performance of the SWG were derived from recommendations established by the Society of Automotive Engineers for impact tests [1]. The considerations and use of the appropriate recommendations of SAE J211 [1] to derive the measurement requirements for these tests are described in Appendix B. The instrumentation used to test SWG performance is described in Appendix C. The measurement procedures used in testing the SWG performance are described in Appendix D.

3. SUMMARY OF RESULTS

Although only one SWG, S/N 6, was tested, the results contained in this report are expected to be typical of all ten of the SWGs built by MGA for NHTSA because all of the SWG outputs are preprogrammed and stored on EPROM. If the crystal clocks timing the SWG microprocessor and SWG data output are within specifications and the analog circuits following the DAC are adjusted to specifications, all SWGs would be expected to produce outputs very much like those observed for SWG S/N 6 in this test. Until certification testing of all ten SWGs has been completed, the actual variation in SWG outputs between different units will not be known.

3.1 TIMING ACCURACY

3.1.1 Clock Frequency

The measured frequency of the SWG crystal clock oscillator was 4,000,003 Hz. This yields a negligible 0.38 μs timing error over the 0.5 second interval during which the waveforms are produced.

3.1.2 Time Reference Signals

The time intervals between the five leading edges of the pre-T0 and T0 time reference pulses are 30.009 ms, 124.913 ms, 124.974 ms, and 124.963 ms, respectively as shown in Figure 3-1. The length of the time segment that includes the rectangle and half-sine waveform is 0.087 ms shorter than the 125 ms expected by the SPSW. This caused the half-sine waveform data to be indexed to the wrong starting time, which caused a indicated error in calculated X and Z component time deviation for the half-sine waveform. The time interval between the second and the fifth leading edges is 374.850 ms. This is 0.150 ms less than the theoretical 375 ms duration that was expected by the SPSW. In past DAS test data processing, this 0.150 ms difference has caused an error in the value of DEL computed from the test data. The SPSW has now been edited to bring it into correspondence with the measured time intervals.

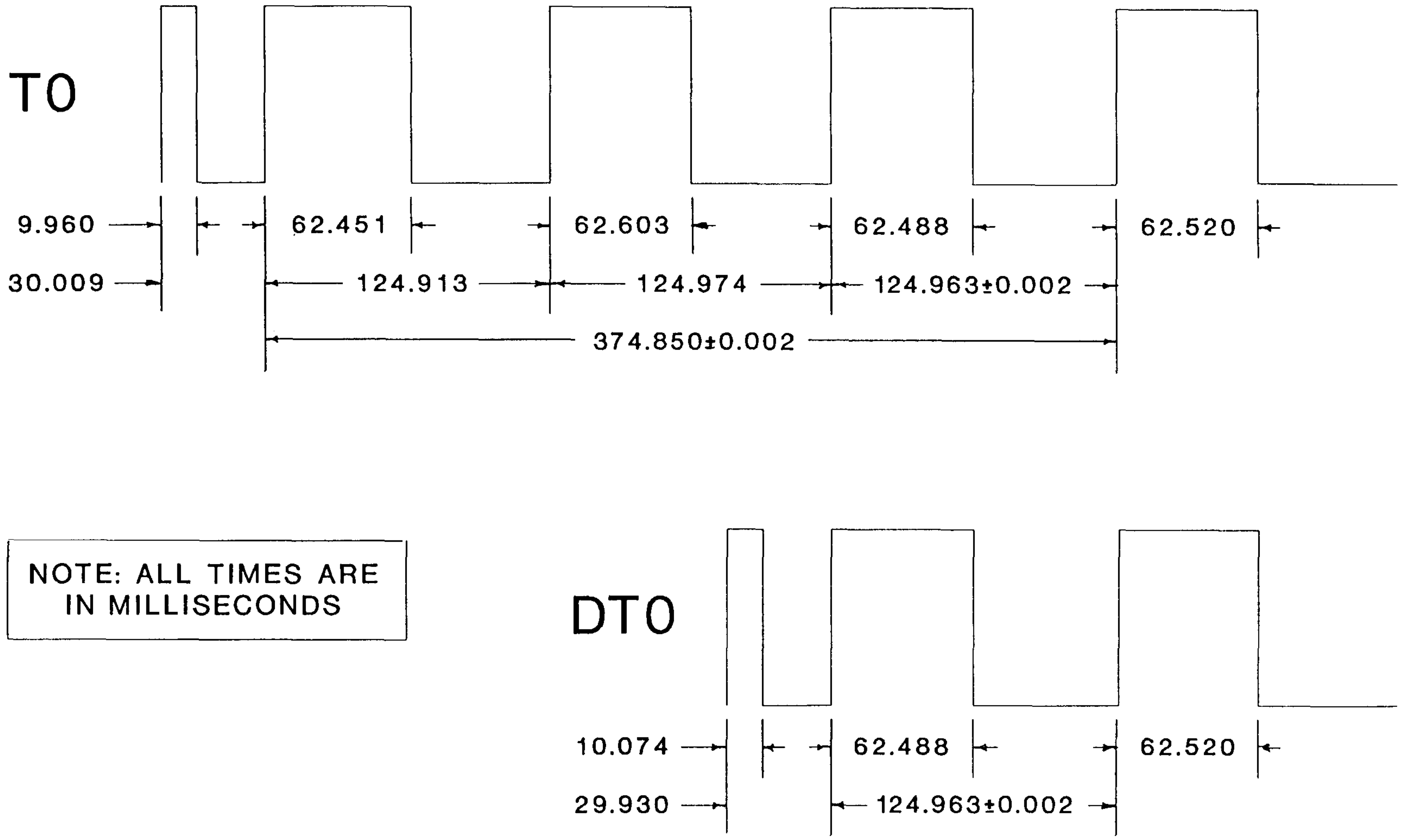


FIGURE 3-1 TIME REFERENCE SIGNAL TIMING SUMMARY

3.1.3 Waveform Edge Coincidence

The leading edge of the first T0 pulse after the pre-T0 pulse reaches its 50% amplitude 14 μs after the first leading edge of the rectangle waveform reaches its 50% amplitude. The 50% amplitude is 50% of the change in level encountered during a step change. Since the rectangle waveform will be high when the T0 pulse marks the beginning of the dataset, the SPSW will assume that both leading edges rose simultaneously.

The leading edge of the second T0 pulse after the pre-T0 pulse coincides with the start of the stair waveform.

The leading edge of the third T0 pulse after the pre-T0 pulse occurs 28 μs after the start of the sum-of-sines waveform. The Gaussian data window through which the sum-of-sines data are passed reduces the waveform magnitude to near zero at each end of the waveform time segment. Consequently, this starting time error should have a negligible effect on the computed frequency response.

3.1.4 Channel-To-Channel Time Difference

The group 1 and group 2 half-sine pulse waveforms rise and fall at exactly the same time so that the channel-to-channel time difference as exhibited by these two waveforms is precisely zero.

3.1.5 Waveform Timing

Each of the first nine cycles of the rectangle waveform has a duration of 10.004 ms, which is as close to the nominal 10.000 ms as can be achieved using a 0.0305 ms sample interval. The tenth cycle of the rectangle waveform is 0.061 ms shorter than the first nine.

The first six steps of the stair waveform and the eighth through the twelfth steps have a duration of 10.004 ms. The seventh step has a duration 0.061 ms (2 DAC samples) shorter than the other steps. Consequently, the maximum waveform timing error of the stair waveform was computed to be 0.033 ms. (See Appendix G)

Subsequent to processing the data from this test, the SPSW was edited to incorporate the measured time intervals for the rectangle and stair waveforms. The SPSW has been edited to remove the time deviation output that is calculated from the tenth cycle of the rectangle waveform. Appendix G has rectangle and stair summary reports for the waveform processing from before and after the SPSW was edited to take into account the measured waveform timing.

3.2 AMPLITUDE ACCURACY

At the "piezo resistive" output level, SWG amplitude error magnitudes are less than 0.06% of full scale, which is well within the ±0.25% design goal for accuracy. (See Appendix B.2.2.) However, at the "strain gage" output level, amplitude error magnitudes as large as 0.313% of full scale were observed. Examination of the processed data in Appendix G shows that at the center of the stair waveform, the zero level for data acquisition channel 2 is offset by -0.244% of full scale. Further examination of these data shows that this zero offset is a major contributor to the amplitude errors observed. It is obvious that as a consequence of this offset, SWG S/N 6 does not satisfy the ±0.25% of full scale design goal for accuracy at the "strain gage" output level. However, the SWG does satisfy the amplitude accuracy requirements of J211 at the strain gage level. Please note that any zero offset observable before the start of waveform output had been removed before these data were processed.

3.2.1 Amplitude Overshoot

At the "strain gage" output level, analysis of the stair waveform reported excessive overshoot. This was caused by noise superimposed on the signal.

3.3 FREQUENCY RESPONSE

The amplitude frequency response of the SWG meets its performance requirements.

3.4 TEST RESULTS DETAILS

The detailed results of the SWG performance testing are presented in Appendix E. A discussion of these results is provided in Appendix F.

4. CONCLUSIONS

All significant SWG "timing errors" have been eliminated by modifying the SPSW so that it conforms to the measured SWG timing.

The amplitude linearity of the stair waveform is excellent. The offset of the waveform zero output level from the calibration zero level at the low ("strain gage") signal level will degrade the accuracy of the SWG as an amplitude reference, slightly. The SWG still satisfies the requirements of J211 for amplitude accuracy of reference equipment at the strain gage output level.

Both groups of waveforms occur simultaneously so that the measurement of channel-to-channel time difference is precise and accurate.

The SWG amplitude frequency response satisfies the requirements implied by SAE J211 [1].

In general, the SWG can provide a precise waveform input for the valid testing of crash and sled test data acquisition systems.

APPENDIX A

ABBREVIATIONS AND ACRONYMS

ADC	analog-to-digital converter
CAC	channel amplitude class
CFC	channel frequency class
DAC	digital-to-analog converter
DAS	data acquisition system (In this report, DAS primarily refers to a crash test data acquisition system.)
DFT	discrete Fourier transform
DMM	digital multimeter
DT0	delayed time-zero
HIC	head injury criterion (a number computed to indicate the severity of head injury)
MHz	megahertz
ms	milliseconds
mV	millivolts
PDAS	precision data acquisition system (refers to the data acquisition system used for this testing)
PPM	parts per million
PROM	programmable read-only memory
RAM	random access memory
SAE	Society of Automotive Engineers
S/N	serial number
SPSW	signal processing software (refers to software developed to analyze SWG output waveforms)
SWG	signal waveform generator

TIM	test interface module
T0	time-zero
μs	microseconds

APPENDIX B

MEASUREMENT REQUIREMENTS

Since the SWG is used to test crash test data acquisition systems (DAS), the requirements for the SWG are derived from the recommendations established by the Society of Automotive Engineers for Instrumentation for Impact Tests [1]. As a general engineering rule-of-thumb, the SWG, which is reference instrumentation for testing a crash test DAS, should be approximately 10 times more accurate than the DAS. Similarly, the instrumentation for testing the SWG should be approximately ten times more accurate than the SWG, if that is possible.

B.1 CRASH TEST INSTRUMENTATION

The latest performance recommendations for crash test instrumentation to be made available are in SAE J211 [1]. Each of the performance recommendations refers to an entire data channel, which includes the transducer and all of the instrumentation equipment and processing which follows the transducer right up to the data written on magnetic tape for delivery to the customer. Therefore, any errors determined by measuring the performance characteristics of a data acquisition channel that does not include the transducer should be considerably less than the numbers specified below. The recommended performance requirements that relate to the measurements made in this test are stated in the following paragraphs.

B.1.1 Timing Accuracy

SAE J211 [1] states "A time base shall give at least 1/100 second resolution with an error of less than 1/10000 seconds." The relative time delay between the signals of any two data channels shall not exceed one millisecond, excluding phase delay caused by phase shift. The relative time delay between two channel frequency class (CFC) 1000 channels from which the signals will be combined shall be less than 100 μs.

B.1.2 Amplitude Linearity

Amplitude linearity error is defined as the maximum difference between a calibration value (read during calibration of a data channel) and the corresponding value read on the best least-squares fit straight line to the calibration values, expressed as a percent of full scale value. Amplitude linearity error shall be less than 2.5% of full scale. The stair waveform of the SWG provides 11 calibration levels from - to + full scale.

B.1.3 Frequency Response

Amplitude frequency response shall differ from 0 dB by less than ± 0.5 dB (± 6 %) at 0.1 Hz to +0.5, -1.0 dB (+6, -11 %) at 1000 Hz for a CFC 1000 channel. Frequency response measurements shall be made at frequencies from 0.1 Hz to at least 3000 Hz for CFC 1000.

B.2 REFERENCE EQUIPMENT FOR CALIBRATION

The SWG is considered reference equipment for crash test DAS instrumentation. SAE J211 [1] presents requirements for the accuracy of reference equipment used to calibrate crash test data acquisition channels.

B.2.1 Timing Accuracy

SAE J211 states "The error in the reference time shall be less than 0.00001 s." However, J211 does not make clear over what time interval this 10 μs error tolerance in reference time applies. For the sake of this test work, it is assumed that the 10 μs error tolerance is applied to the total time of the test signal, 0.5 seconds.

As applied to the SWG, the reference time accuracy requirement would apply to the SWG crystal clock frequency, the accuracy of the time reference signals, the relative timing accuracy between the time reference signals and the waveform outputs, synchronization between waveform group signals, and the time between level changes in the rectangle and stair waveforms. That is, the sum of the timing errors from the five timing factors just listed must be less than 10 μs to satisfy the requirements of J211.

B.2.2 Amplitude Accuracy

SAE J211 [1] specifies that errors in reference equipment shall be less than 1.5% of the channel amplitude class (CAC) for acceleration channels and less than 1% of the CAC for force and displacement channels. A design goal for the SWG was specified that was tighter than the requirements of J211. This design goal specified that the waveforms that measured amplitude accuracy should have errors no greater than ±0.25 % of the full scale calibration level. This calibration level defines a full scale value.

B.2.3 Frequency Response

For the SWG to test frequency response of a data channel to the requirements stated in B.1.3, the output frequency response of the SWG must be accurate to ±0.05 dB (±0.6 %). Since the range of the SWG sum-of-sines test frequencies is from 273.4375 Hz to 3828.125 Hz, the SWG frequency response should be accurate to ±0.6 % over this frequency range.

B.3 SWG TEST INSTRUMENTATION REQUIREMENTS

B.3.1 Timing Accuracy

To test the reference time measurement used to test data acquisition channels, an instrument having total timing error less than one microsecond is required.

B.3.2 Amplitude Accuracy

Since the design goal for SWG amplitude accuracy was that the waveforms that measure amplitude accuracy shall be accurate to ±0.25 % of full scale calibration level, the primary requirement for amplitude accuracy measurement is on the relationship of the amplitude measuring waveforms to the calibration level. The testing of this relationship was performed by the PDAS. Consequently, the amplitude accuracy of the PDAS should be ±0.025 % of full scale calibration level.

B.3.3 Frequency Response

Ideally, the test of frequency response should be accurate to ±0.06 % of full scale from 273 to 3828 Hz. However, the best accuracy obtainable from the frequency response measurement software, as determined by simulation of 12-bit data acquisition, is ±0.21 %. If the data acquisition system used for this test has accuracy close to what is required in B.3.2 from 273 to 3828 Hz, it will be sufficiently accurate for frequency response measurement.

APPENDIX C

TEST INSTRUMENTATION

C.1 TIMING ACCURACY

C.1.1 Frequency Measurement

The frequency counter used to measure SWG crystal clock oscillator frequency was the Hewlett-Packard 5386A-004, which is accurate to 0.5 Hz when measuring a frequency near 4.0 MHz. This yields a time measurement accuracy of ±0.1 μs over a 0.5 second time interval.

C.1.2 Time Reference Signals

The actual times of occurrence of the T0 and DT0 transitions within the 30.5 μs SWG DAC output sample interval was measured by programming the PDAS to sample T0 (or DT0) as many times as possible during each DAC output sample interval. The start of each PDAS sampling sequence was synchronized to the start of each DAC sample interval by the DAC strobe signal. Using the shortest PDAS sampling interval, 4.25 us, the T0 (and DT0) transition times were determined to within a 4.25 μs interval. By repeating these runs at many different PDAS sampling intervals, the transition time uncertainties of many of the T0 transition times were reduced further. However, when a T0 transition occurs near the beginning or end of a DAC sample interval, the uncertainty is limited by the shortest available sampling interval. That is, an uncertainty of 4.25 μs remains for transitions that occur at the beginning of the DAC sample interval and an uncertainty of somewhat more than 4.25 μs remains for transitions that occur near the end of the DAC sample interval. Because PDAS sample intervals are controllable to 0.25 μs increments, there is a temptation to assume that some of the time reference transition times can be determined to a resolution of 0.25 μs. However, the experience gained during this testing would indicate that the accuracy of determining pulse transition times is probably not much better than one μs. Hence, all results are rounded off to the nearest microsecond.

C.1.3 Coincidence Measurement

The relative timing of the time reference pulse and the rectangle waveform was determined using a Hewlett-Packard

54200D digital storage oscilloscope. The 54200D has a time base accuracy of ±2 ns or ±0.2 % of the time range, whichever is greater. The coincidence of waveform leading edges was also measured using the PDAS described below.

C.2 AMPLITUDE ACCURACY

C.2.1 Calibration Levels

A Fluke 8050A digital multimeter having an accuracy for DC voltage measurements of ±(0.03% of reading +2 digits) was used for this measurement. Thus, when reading 100 mV, its accuracy is ±0.05 mV. When reading 10 mV, its accuracy is ±0.02 mV. This instrument was calibrated on 5/9/89. The zero and ± calibration voltage level measurements were made on 10/27/89.

C.2.2 Precision Data Acquisition System (PDAS)

The PDAS used to measure waveform accuracy was a Model DAP 2400/5, manufactured by Microstar Laboratories of Redmond, WA. The DAP 2400/5 has the following capability:

1) After an external pulse is applied to the PDAS, the PDAS will sample each one of a sequence of up to 16 channels once and then wait for the application of the next external pulse before repeating the sampling sequence.

2) It has 512K bytes of on-board RAM for storage of data and use in real time processing.

3) It has the capability of acquiring data continuously after being started from a software command or an external trigger pulse.

4) Sampling interval in all modes is adjustable over the range of 4.25 μs per sample to 10.0 milliseconds (ms) per sample.

5) The PDAS 16 MHz crystal clock is accurate to ±30 PPM and stable to ±50 PPM from -20°C to +70°C. Drift with time is 5 PPM per year.

6) The internal input clock is synchronized to an external clock input within four CPU clock cycles (=0.25 μs).

7) It has the capability of acquiring data continuously after a change in level in one of the input channels is

sensed and recording data from up to 16 channels for at least 1000 samples before the change in level is sensed and including at least 1000 samples after the change in level is sensed.

8) 12-bit words are produced by the analog-to-digital conversion process.

9) Its accuracy is ± 0.025% of full range while meeting the above requirements.

10) It is a plug-in option board for an IBM PC compatible computer.

C.2.3 Test Interface Module

The analog outputs of the SWG are ±100 mV at the "PIEZO RESISTIVE" setting and ±10 mV at the "STRAIN GAGE" setting. The PDAS is adjustable to accept full scale input voltages of ±2.5 V, ±5.0 V, and ±10.0 V. To keep the errors introduced by the inherent quantization caused by digitizing the input data as small as possible, it is necessary to amplify the SWG outputs to a level close to one of the PDAS full scale input levels. The PDAS programmable amplifier provides input signal amplification by factors of 1, 10, 100, and 1000. However, each gain setting greater than 1 requires longer settling time for the amplifier response to settle to within 12 bit accuracy than for a gain of one. For example, using the amplifier on-board the PDAS to provide a gain of 100 would limit the sampling interval to 40 μs per sample. Since this test required sampling at least three samples in one 30.5 μs interval, use of the PDAS amplifier to provide the gain was not feasible. To be able to sample accurately two analog channels and a digital channel within the 30.5 μs output sampling interval of the SWG DAC, two instrumentation amplifiers were installed external to the PDAS. Each amplifier was connected to one analog output channel from the SWG. The output of each amplifier was connected to a PDAS input channel. The instrumentation amplifiers used for this purpose were Burr-Brown INA110/SG integrated circuit instrumentation amplifiers. When the Burr-Brown INA110/SG amplifier gain is set to 100, the time required for the amplifier response to a 20 V step to settle to within 0.01% of final value is specified to be 4 μs, typical, and 7.5 μs, max. At a gain of 100, amplifier nonlinearity errors are specified to be less than 0.01%, typical, and 0.1%, max. To be sure that the full ±100mV amplifier input signal plus noise would be within the ±5 V input range of the PDAS, the gains for each amplifier were set to 45.4 for channel 1 and 46.4 for channel 2 by using a resistor in series with one of the gain setting connections on each amplifier.

Since some amplifier zero shifting with time after power-up had been observed for gains near 46, increasing the external amplifier gain to 450 for testing the ±10 mV SWG outputs was expected to increase the amount of zero shifting and other deleterious effects of the external amplifier to an intolerable level. Therefore, it was decided to reconfigure the PDAS for a ±2.5 V full range input, minimizing the external amplifier gain required. For measuring the ±10 mV SWG outputs, external amplifier gains of 220.4 for channel 1 and 226.1 for channel 2 were used. At these gains, adjusting amplifier zero offset to less than one mV was extremely difficult. Since the calibration approach compensated for zero offset, setting the amplifier zero offset to "zero" was not critical. What was critical was how fast the zero output drifted. An additional computational procedure, which partially compensates for this zero shift, is described in Section D.2.1.2.

To test the timing of the SWG outputs to within the accuracy of one 30.5 μs SWG digital-to-analog converter (DAC) output sampling interval, it was necessary to synchronize the PDAS sampling to the DAC strobe signal. To access the DAC strobe signal required connecting a wire from the SWG backplane connector to an unused contact on SWG connector J1. Also required was a connection from another unused contact on this connector to the SWG ground. Then the DAC strobe signal could be transmitted from the SWG by coaxial cable. Once these connections were made, observation of the DAC strobe signal showed that it is a 50% duty cycle square wave that is active whenever the SWG is powered. Furthermore, when the waveforms are being produced, the sample time for the DAC is 30.5 μs. But at all other times, the sampling interval for the DAC is one-fourth of 30.5 μs or 7.625 μs. The mechanism available to synchronize the sampling of the PDAS to the SWG output is to feed the SWG DAC strobe pulse into the external clock input of the PDAS. Since the DAC strobe signal is always active, the DAC strobe signal seen by the PDAS has to be gated so as to start the PDAS sampling when the waveform outputs are produced. The time reference input was used to start the DAC strobe signal to the PDAS. The gating logic designed to do this task is shown in Figure C-1.

Observation of the SWG analog outputs directly with a digital storage oscilloscope indicated the presence of significant high frequency noise in the SWG outputs. To permit measurement of SWG outputs uncontaminated by noise, two Frequency Devices, Inc. Model 746LT-4 resistive tunable 6-pole Bessel low pass filters were purchased.

To provide an assembly for mounting and powering the digital logic, instrumentation amplifiers, and analog filters, a test interface module (TIM) was designed and fabricated at TSC. A block diagram of the TIM and the test set-up connections is shown in Figure C-2. A photograph of the complete test set-up is shown in Figure C-3. The aluminum box in front of the SWG is the TIM.

C.3 PREPARATION OF SWG FOR TESTING

To gain access to the DAC strobe signal, it is necessary to disassemble the SWG to such an extent that additional wires can be soldered to the backplane of the SWG. The backplane connector has the designation W1 in the MGA schematics. Connect a wire from W1-50 to J1-pin H and from W1-56 to J1-pin J. W1-50 carries the DAC strobe signal and W1-56 is a ground connection. J1 is the group 1 waveform output connector. The choice of J1 or J2 is arbitrary. Finally, the SWG should be reassembled before testing.

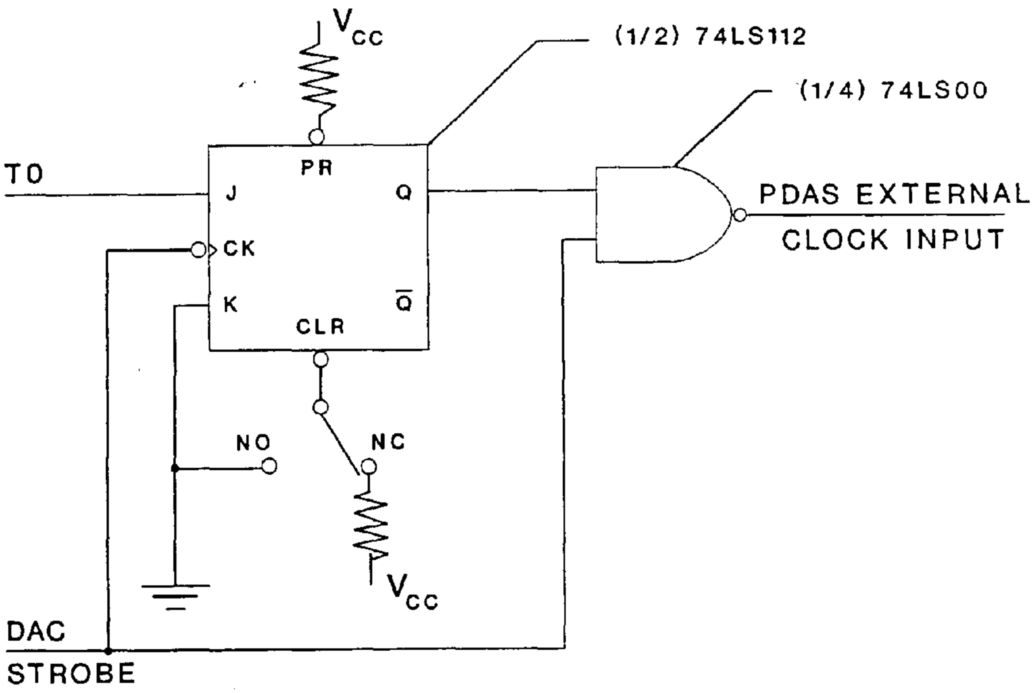


FIGURE C-1 GATING LOGIC

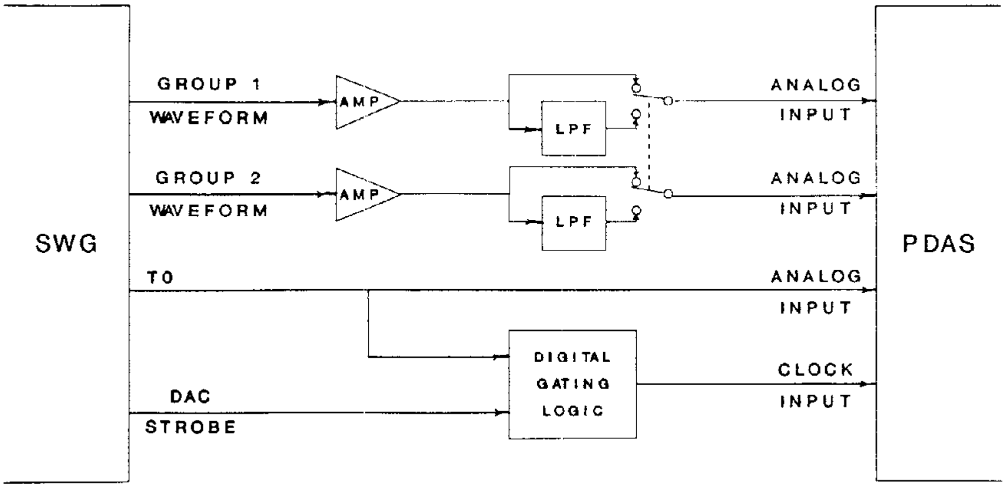


FIGURE C-2 TIM BLOCK DIAGRAM

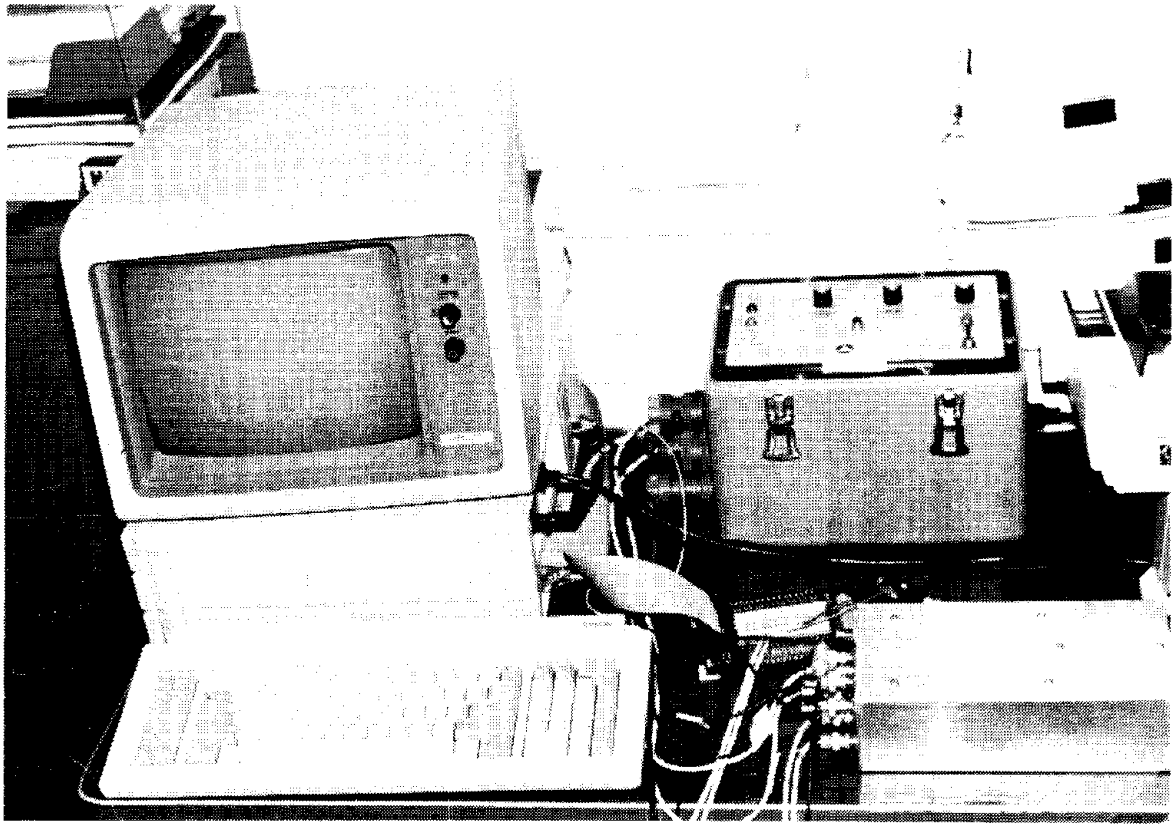


FIGURE C-3 TEST SET-UP

APPENDIX D

MEASUREMENT PROCEDURES

D.1 TIMING ACCURACY

D.1.1 Clock Frequency

1. Remove SWG cover.
2. Remove the eight screws that secure the SWG control panel to the SWG case.
3. Lift the control panel off of the SWG and set it to one side as much as the wiring will permit.
4. Apply power to the frequency counter and the SWG.
5. Refer to Figure A-2 of the SWG Operator's Manual [2]. This is the layout of the CPU board, the top board of the stack in the SWG. Locate test point TPG. This test point is connected to the output of the 4.0 MHz precision clock oscillator (T2) that controls all of the SWG timing. The other 4.0 MHz clock oscillator (T1) has been disconnected.
6. Connect a probe from the frequency counter input to TPG. Connect a return lead from the frequency counter to the SWG chassis.
8. Wait at least 20 minutes for readings to stabilize.
9. After the frequency reading becomes stable, record the T2 output frequency.
10. Remove probes, remove power, and reassemble SWG.

D.1.2 Time Reference Signals

The complete procedure for using the PDAS is presented below in Section D.2.2, Data Acquisition and Processing. To determine the transition time of a time reference signal, the procedure of Section D.2.2 is modified by assigning one input, either T0 or DT0, to as many PDAS input channels as can be sampled in one 30.5 μs DAC sample interval. (See Appendix H.) Each time reference signal is measured at sample times of 4.25, 4.5, 4.75, 5, 5.5, and 6 μs. This , in theory, would permit sampling the same signal at 0, 4.25, 8.5, 12.75, 17, 21.25, and 25.5 μs after the DAC strobe transition for a 4.25 μs PDAS sample interval. Similarly, samples of the time reference signal would be obtained at 0, 4.5, 9, 13.5, 18, and 22.5 μs after the DAC strobe transition for a 4.5 μs PDAS sample interval. Similar results would be obtained for the other PDAS sample intervals. By examining the output data file, the DAC sample number and the PDAS sample interval during which the T0 or DT0 transition occurred can be determined. By repeating the run at different PDAS sample intervals, the interval during which the T0 or DT0 transition occurred can be defined with ever decreasing intervals of uncertainty. In fact, by using enough different PDAS sampling intervals, it is possible to determine exactly when many of the T0 and DT0 transitions occur, if they occur between 4.25 and 25.5 μs after the DAC strobe pulse. When the T0 or DT0 transition occurs at the same time that the PDAS is sampling the input, the recorded value of the time reference signal is somewhere between the high and low values for that signal.

The paragraph above used the words "in theory" when referring to what samples would be available when the PDAS is operated in the externally clocked "channel list clocking" mode. The reason for this caveat is that after a considerable quantity of testing had been completed, anomalies in the recorded data indicated that the PDAS was not doing exactly what the PDAS reference manual said it would. Consultation with the manufacturer disclosed that there is a "bug" in the firmware provided with the PDAS such that the first sample after the initial clock pulse is applied is missed. After that, the sampling is correct. Because the first sample is missed, the sampled data output stream is shifted by one sample. That is, every sample value appears to occur one sample earlier than is correct. This discovery required repetition of some of the test runs and reprocessing of additional data to account for the correct interpretation of the PDAS operation. The results presented in this report are believed to be correct.

D.1.3 Coincidence of Waveform Edges

1. Connect either a Group 1 or a Group 2 SWG output to one of the input connectors of a digital storage oscilloscope.
2. Connect the time reference output (T0) from the SWG to the other input connector of the oscilloscope and to the oscilloscope trigger input connector.
3. Apply power to the SWG and the oscilloscope.
4 Set the 'scope sweep to the 200 μs range and the delay time to 30 ms after the trigger.
5. Clear the 'scope.
6. Press the "RECORDING" button on the SWG.
7 Use the 'scope timing markers to determine the exact time of occurrence of the rising edges of the waveforms and the time reference signal.

The complete procedure for using the PDAS is presented below in Section D.2.2, Data Acquisition. To use the PDAS to collect data for measuring the form and timing of the initial leading edge of the rectangle waveform, assign a waveform output to as many PDAS input channels as can be sampled in the 30.5 μs DAC output sample interval. (See Appendix H.) Set the PDAS sampling interval to 4.25, 4.5, 4.75, ..., 8.25 μs on successive data collection runs. Set the PDAS data count value so that the data display on the PC stops just after the first rise of the rectangle waveform. Print the PC screen after each run. By doing this, the value of the waveform output during the DAC sample interval that produces the initial rise of the rectangle waveform can be determined at 0.25 μs intervals from 4.25 μs to 8.5 μs after the DAC strobe pulse, and at 0.5 μs intervals from 8.5 μs to 17 μs after the DAC strobe pulse. After these runs, plot the recorded data to determine the exact time and shape of waveform edge rise.

D.2 AMPLITUDE ACCURACY

The amplitude accuracy of the SWG is determined by using the "zero" and "+ calibration" levels of the SWG outputs to scale the waveform outputs from the SWG. This is an identical procedure to that used to scale crash test DAS outputs from a SWG test. The scaled SWG waveform outputs were recorded by the PDAS, transmitted to the NHTSA VAX, and analyzed by the SWG signal processing software.

D.2.1 Calibration Level

D.2.1.1 All Output Channels - The following procedure was used to measure the zero and positive and negative calibration levels available from all SWG output channels.

1. Apply power to the digital multimeter (DMM) and to the SWG.
2. Refer to Figure 7-1 of the SWG Operator's Manual [2]. Connect test leads from the DMM to SWG output channel number 1.
3. With the "transducer type" switch in the "piezo resistive" position, record zero offset, and positive and negative calibration voltage levels.
4. With the "transducer type" switch in the "strain gage" position, record zero offset, and positive and negative calibration voltage levels.
5. Repeat steps 2 through 4 for SWG output channels 2 through 16.

6. Connect test leads from the DMM to the SWG "High Level Group 1" output and "SWG ground".
7. With the "transducer type" switch in the "piezo resistive" position, record zero offset, and positive and negative calibration voltage levels.
8. With the "transducer type" switch in the "strain gage" position, record zero offset, and positive and negative calibration voltage levels.
9. Repeat steps 7 and 8 for the SWG "High Level Group 2" output.
10. Remove probes and power from the DMM and the SWG.

D.2.1.2 PDAS Calibration - The "zero" and "positive calibration" levels of the group 1 and group 2 output channels tested (SWG channels 1 and 5 respectively) were recorded and averaged by the PDAS. At first, one hundred thousand points from each output at each level were averaged and used in the scaling algorithm described in Section 2.2.1. Later, it was found that better estimates of these averages were obtained by repetitively computing 16,000 point averages of these calibration levels and using the PDAS to plot them.

The calibration constants were verified by running the averaging programs with the scaling equations in them.

D.2.2 Data Acquisition and Processing

1. These procedures assume that a PDAS board (DAP 2400/5) has been installed and configured in the host PC/XT/AT compatible computer. This includes selecting the analog input voltage levels to the PDAS. As discussed in Section C.2.3, a PDAS input level of ±5 V was used for the SWG "piezo resistive" output level and a ±2.5 V input level was used for the SWG "strain gage" output level.
2. Connect the SWG Time Zero (T0) output to PDAS input connection 0 and to the TIM T0 input.
3. Connect the SWG DAC strobe signal to the TIM DAC strobe input.
4. Connect the TIM DAS trigger output to the PDAS external clock input.
5. Connect a SWG Group 1 output (SWG channels 1, 2, 3, 4, 9, 10, 11, or 12) to an instrumentation amplifier input and connect the instrumentation amplifier output to PDAS input connection 1.
6. Connect a SWG Group 2 output (SWG channels 5, 6, 7, 8, 13, 14, 15, or 16) to another instrumentation amplifier input and connect this instrumentation amplifier output to PDAS input connection 2.
7. PDAS input connection 3 is shorted to ground.

8. Connect the SWG Time Zero Delayed (DT0) to PDAS input connection 4.
9. Apply power to the PDAS, the TIM, and the SWG, in that order. Applying power to the equipment in any other order could destroy the input amplifiers of the unpowered equipment.
10. After the SWG completes its self test, set the SWG "transducer type" switch to "piezo resistive", set the SWG "time zero polarity" switch to positive, and set the "calibration mode" switch to "manual positive".
11. Set up the PDAS to sample each of seven input channels in sequence once when it receives an external clock pulse. Set the sampling interval to 4.25 μs. This procedure synchronizes the sampling of the SWG outputs to the SWG DAC strobe pulse. (See Appendix H.)
12. Assign PDAS input channels 0,1, and 2 to PDAS input connection S3 (shorted to ground). Assign PDAS input channel 3 to PDAS input connection S4 (DT0). Assign PDAS input channel 4 to PDAS input connection S1 (Group 1 waveform). Assign PDAS input channel 5 to PDAS input connection S2 (Group 2 waveform). Assign PDAS input channel 6 to PDAS input connection S0 (T0). By assigning the input channels in this order, a 17 μs time delay is built in between the SWG DAC strobe pulse and the first sampling of an analog data channel. Assigning T0 to the last sample to be sampled permits the recording of a T0 transition during the same DAC cycle in which it occurs, if the transition takes place before 29.75 μs after the DAC strobe pulse. This will be discussed in greater detail in Appendix E.
13. Following the PDAS instructions, set up the PDAS to convert the recorded data to ASCII and write them to hard disk.
14. Press and release the reset button on the TIM, start the PDAS data acquisition process, and press and release the "RECORDING" button on the SWG to initiate data transfer.
15. After PDAS processing and recording of the sampled data is complete, follow PDAS instructions to close the logged disk file.
16. Edit the logged data file to remove the program listing header and any other non-ASCII characters from the file.
17. Transfer the data from PC hard disk to the NHTSA VAX cluster.
18. Convert the ASCII data to one UDS file for each data channel recorded. A program to do this is [JOHNN.WGTEST.PROG]ASCII2UDS4.FOR.
19. Follow the instructions of the SPSW documentation [3] to use program [JOHNN.WGTEST.PROG]SWGTPROC.FOR to process the waveform data.

20. To record data for the "STRAIN GAGE" setting on the SWG, change the gains of the two instrumentation amplifiers in the TIM so that the ±10 mV signal plus noise will nearly fill the input voltage range of the PDAS.
21. Then repeat the steps of Section D.2.1.2 and this section.

Note of interest:

Since the PDAS has 512 K of RAM for data storage, and since each sample requires 2 bytes, approximately 200K samples can be stored in PDAS RAM. The remaining RAM is used for real time processing of the acquired data. The SWG output requires 530 ms from the rise of the pre-time zero pulse. 530 ms contains 17377 intervals of 30.5 μs duration. Since seven channels are being sampled during each 30.5 μs interval, 121639 samples are stored in PDAS RAM during each test.

APPENDIX E

RESULTS OF TEST

The results of processing the waveform data from channel 1 (group 1 waveform) and channel 5 (group 2 waveform) at the ±100 mV and ±10 mV levels from SWG S/N #6 are summarized in Table E-1. The more detailed Summary Reports for the processing of each waveform are in Appendix G. The following paragraphs present the detailed findings from this test. The significance of these results is discussed in Appendix F.

TABLE E-1, PROCESSED DATA SUMMARY FROM SWG S/N #6

SWG OUTPUT	TO_OFFSET MSEC	AMPDEVPOS %FS	AMPDEVNEG %FS	OVRST %	AMPLINREF %FS	AMPLINBFSL %FS	ARDEV MAXdB	HSHIC %	CTCTD MSEC	CRSHIC %
PR_G1	0.0	-0.024	-0.046	0.049	0.060	0.033	-0.02	-0.21	0.000	-0.15
PR_G2	0.0	-0.035	-0.043	0.043	0.054	0.027	0.01			
SG_G1	0.0	-0.220	0.150	0.165	0.220	0.024	-0.04	0.02	-0.001	-0.27
SG_G2	0.0	-0.234	0.245	0.148	0.276	0.037	-0.06			

The abbreviations and headings used in Table E-1 are defined as follows:

Under SWG OUTPUT -

PR = piezo resistive (±100 mV) output
SG = strain gage (±10 mV) output
G1 = group 1 waveform output
G2 = group 2 waveform output

The headings -

TO_OFFSET = the time difference between the initial rise of the TO waveform and the initial rise of the rectangle waveform as determined by the SWG SPSW
AMPDEVPOS = the average deviation from a theoretical 200g level of the 10 positive steady-state levels in the rectangle waveform
AMPDEVNEG = the average deviation from a theoretical -200g level of the 10 negative steady-state levels in the rectangle waveform
OVRST = the average indicated overshoot for the step changes of the rectangle waveform

AMPLINREF = the maximum deviation of any of the steady-state levels of the stair waveform from their theoretical levels

AMPLINBFSL = the maximum deviation of any of the steady-state levels of the stair waveform from a best least-squares fit straight line to the amplitude deviation data

ARDEV = the maximum deviation of the amplitude frequency response from 0 dB at any of the test frequencies

HSHIC = the difference between the HIC value computed for the SWG half-sine output and a reference HIC value computed by the SWG SPSW

CTCTD = channel-to-channel time difference

CRSHIC = the difference between the HIC computed for the SWG crash waveform output and the HIC computed for the original crash pulse used for this waveform

E.1 TIMING ACCURACY

E.1.1 Clock Frequency

The frequency of the T2 crystal clock oscillator was measured in an air conditioned laboratory. After power had been applied to both the frequency counter and the SWG for one hour, the measured frequency of the T2 crystal clock oscillator was 4,000,003 Hz.

E.1.2 Time Reference Signals

Since the T0 (and DT0) transitions are timed by the SWG microprocessor software, they are not constrained to occur in exact synchronism with the DAC strobe pulse. Figure E-1 shows that the T0 transitions are distributed over the entire DAC output sample interval. Figure E-1 plots time after the DAC strobe pulse vs DAC sample number. Time = 0 on the plot is within 0.25 μs of the DAC strobe transition. DAC sample number 0 occurs at the leading edge of the pre-time-zero pulse, which starts the PDAS test data acquisition process. As a time reference for this test, the leading edge of the pre-time-zero pulse is considered time = 0. The symbol _|‾ on Figure E-1 refers to a rising or leading edge of a time reference pulse. The symbol ‾|_ refers to a falling or trailing edge of a time reference pulse. The dashed line connecting _|‾ with ‾|_ schematically indicates that the pulse is in its "high" state.

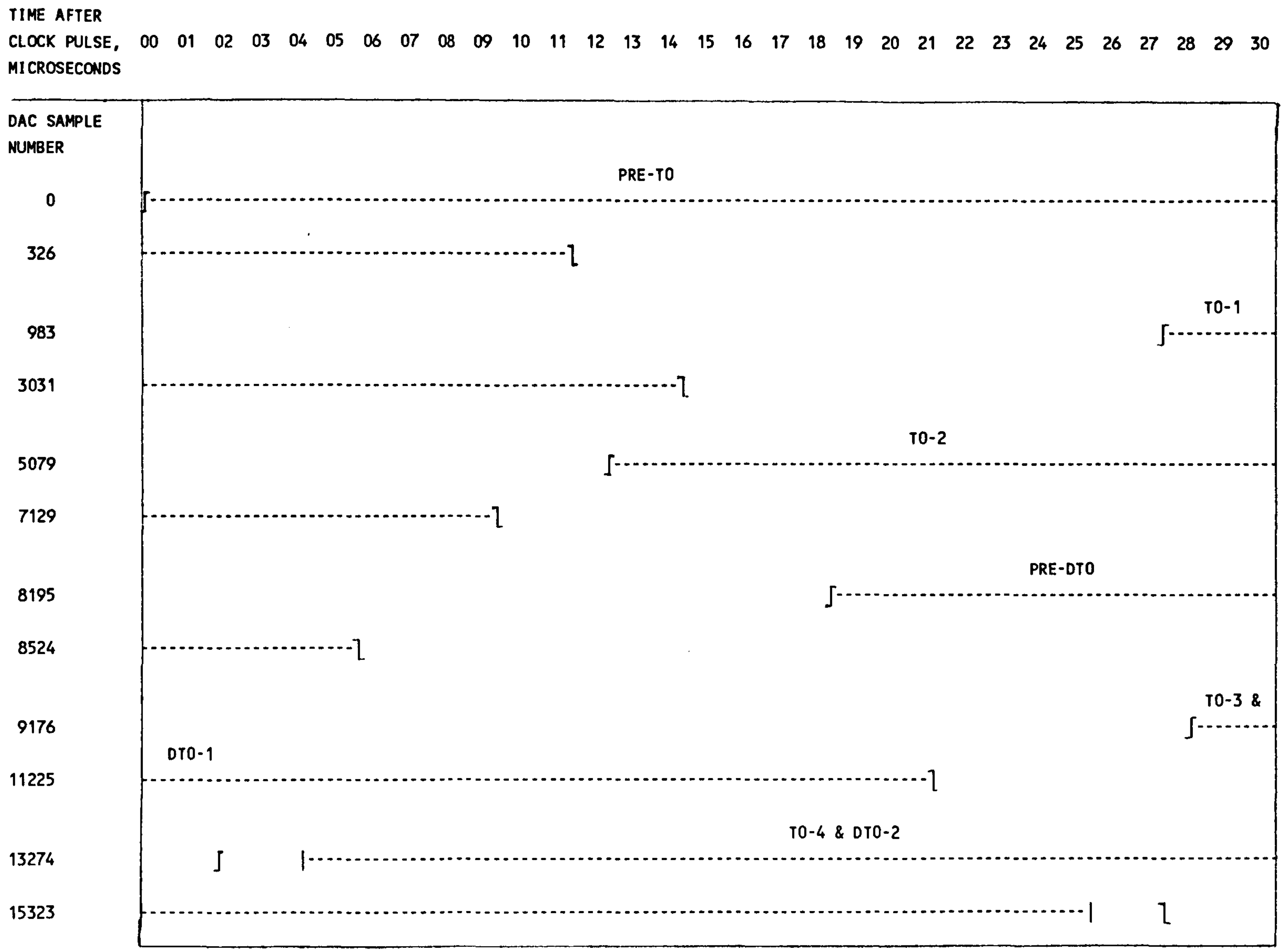


FIGURE E-1 TIME REFERENCE PULSE TIMING DIAGRAM

Notice in Figure E-1, that the leading edges of the first and third T0 pulses after the pre-T0 pulse and the trailing edge of the fourth T0 pulse occur after the last possible valid sample of the PDAS. The time of occurrence of these two leading edges was established by combining the results of the measurements made with the digital storage oscilloscope with the measurements made with the PDAS. It is assumed that the trailing edge of the fourth T0 pulse occurs at approximately the same relative time in the DAC sample interval.

Figure E-1 shows that the leading edge of the T0 pulse that is the time reference for the rectangle waveform occurs at time = 30.009 ms (983*0.0305+0.0275). The leading edge of the T0 pulse that is the time reference for the stair waveform occurs at time = 154.922 ms (5079*0.0305+0.0125). Subtracting 30.009 ms from 154.922 ms yields a rectangle/half-sine waveform segment interval of 124.913 ms, 0.087 ms shorter than the design length of 125.0 ms. The trailing edge of the rectangle waveform T0 pulse occurs at 92.460 ms or 62.451 ms after the leading edge of this pulse. This is 0.049 ms shorter than the design interval of 62.5 ms.

The leading edge of the T0 pulse that is the time reference for the sum-of-sines waveform occurs at 279.896 ms, which yields a stair segment length of 124.974 ms, or 0.026 ms short of the 125 ms design interval.

The leading edge of the T0 pulse that is the reference for the crash waveform occurs at 404.859±0.002 ms. The tolerance on this number indicates a 0.004 ms uncertainty because the pulse transition occurs sometime during the first PDAS sample interval that occurs during DAC sample interval number 13274. This yields a sum-of-sines waveform segment length of 124.963±0.002 ms, 0.037±0.002 ms short of the 125.0 ms design interval.

The time interval from the leading edge of the first T0 pulse to the leading edge of the fourth T0 pulse is 374.850±0.002 ms, 0.150±0.002 ms short of the 375 ms design interval.

When the DT0 time reference pulse is active, it is synchronous with the T0 pulse.

These results are summarized in Figure 3-1.

E.1.3 Waveform Edge Coincidence

The primary measurement for coincidence of time reference and rectangle waveform leading edges was performed using the HP 52400D digital storage oscilloscope. Because the first and third T0 pulses occur near the end of the DAC output sample interval, the PDAS could only bracket their times of occurrence. As described in section D.1.3, the PDAS was used to get the individual data points used to plot the leading edge of the rectangle waveform. Figure E-2 shows a plot of the rectangle waveform and the T0 pulse as they occur during DAC output interval number 983. As shown here, the rectangle waveform first drops to -200g and then rises to +200g. At a level of 50% rise to +200g, the time interval between the rectangle waveform and the T0 pulse is 14 μs.

The raw data show that the first rise of the stair waveform occurs 10.004 ms after the leading edge of the second T0 pulse. Thus, as closely as can be measured, the time reference for the stair waveform coincides precisely with the start of the stair waveform.

Oscilloscope measurement determined that the sum-of-sines waveform begins its rise within less than one μs of the DAC strobe pulse. The third T0 leading edge occurs 28 μs after that same DAC strobe pulse. Thus, the time reference lags the start of the sum-of-sines waveform by approximately 28 μs.

E.1.4 Channel-to-Channel Time Difference

The group 1 and group 2 half-sine pulse waveforms rise and fall at exactly the same time so that the channel-to-channel time difference as exhibited by these two waveforms is precisely zero. In the processing of the "strain-gage" level signals, the reports of Appendix G indicate a ±0.001 ms channel-to-channel time difference. This is most likely caused by noise on the signal.

E.1.5 Waveform Timing

The SWG SPSW algorithm for processing the rectangle waveform determines the time of waveform zero crossing by testing for when the value of the waveform equals zero or when it changes sign. The initial cycle of the rectangle waveform was recorded at a 4.25 μs sampling interval to provide data for plotting details of the waveform. Figure E-3 is the plot of these data. Portions of the plot have been plotted to an expanded time scale to show details of the waveform. Figure E-3 does not show the same level of detail at the beginning of the waveform as does Figure E-2 because it is sampled at a 4.25 μs interval instead of the effective 0.25 to 0.5 μs interval achieved in Figure E-2. As shown in the detailed portions of the rectangle waveform plotted in

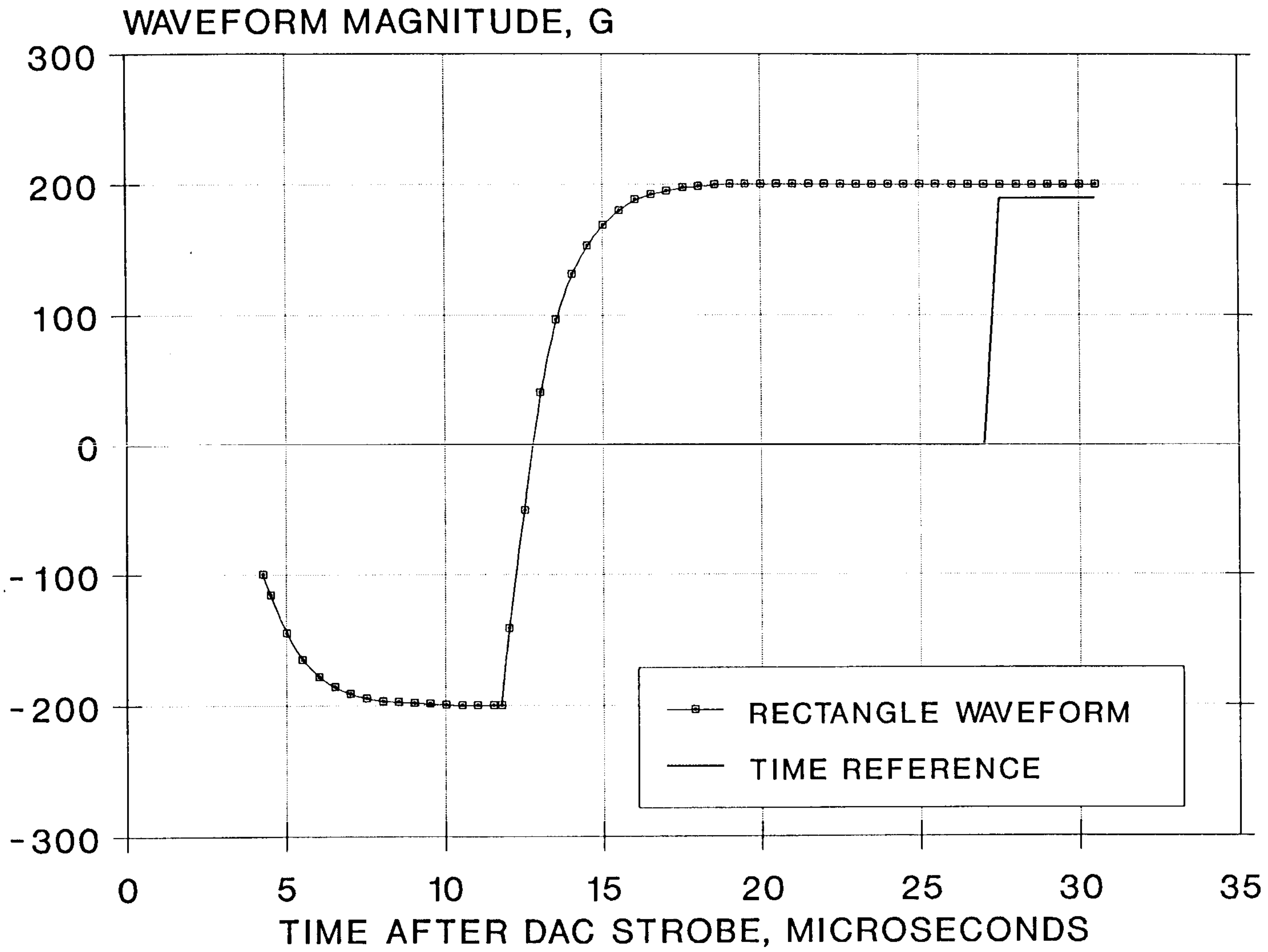


FIGURE E-2 WAVEFORM EDGE COINCIDENCE

Figure E-3, whenever the value of the waveform changes polarity, the DAC output pauses at zero for one 30.5 μs sample interval. For the purposes of this test, this results in an ambiguity of one 30.5 μs sample duration in the computed value of "time deviation from theoretical time" produced by the SPSW, depending on the polarity of the noise that is superimposed on the signal at the time of the zero level sample.

The printout of the rectangle waveform raw data was examined to determine the precise time at which each waveform level transition occurred. With the exception of the leading edge of the first cycle of the rectangle waveform, all transitions occur within 4.25 μs of the DAC strobe transition. Therefore, transition times and interval durations are calculated as if all waveform level changes occurred at precisely the same time as the DAC strobe transition. Referring to the sketch shown in Figure E-4, for the first nine cycles of the rectangle waveform the intervals labeled in Figure E-4 have the following values: A = 5.9475 ms, B = 5.978 ms, C = 3.9955 ms, and D = 10.004 ms. During the tenth cycle of the rectangular waveform, intervals A, B, and C are 30.5 μs shorter than for the corresponding intervals of the first nine cycles.

To relate these data to the information provided in the SWG SPSW output, Table E-2 provides the values for the intervals E and F shown in Figure E-4. These intervals are measured from the start of the DAC sampling interval in which the first rise of the rectangle waveform and the T0 leading edge occur. The columns in Table E-2 labelled E-error and F-error provide the difference between the values measured for intervals E and F and the theoretical values for those intervals used by the SWG SPSW. The SWG SPSW assumes the rectangle waveform to have a cycle length of 10 ms, and during each cycle, that the negative going edge occurs 6 ms after the positive going edge. Comparing the values given for E-error and F-error in Table E-2 with the values given in Appendix G for "time difference from theoretical time" in the rectangle waveform will show the effect of the one sample ambiguity caused by the waveform's one sample stop at zero.

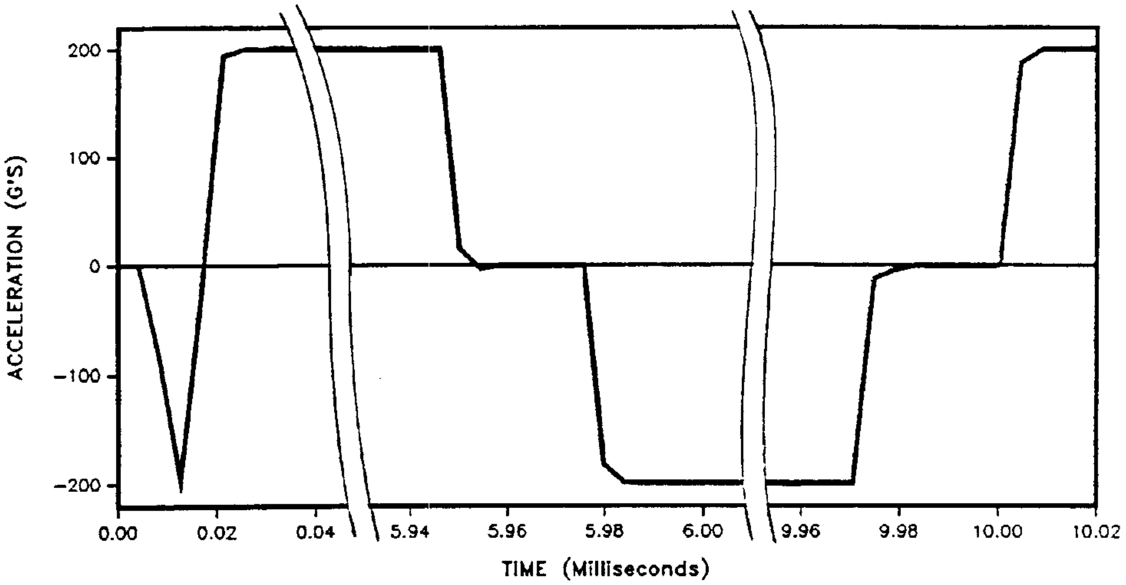


FIGURE E-3 RECTANGLE WAVEFORM DETAILS

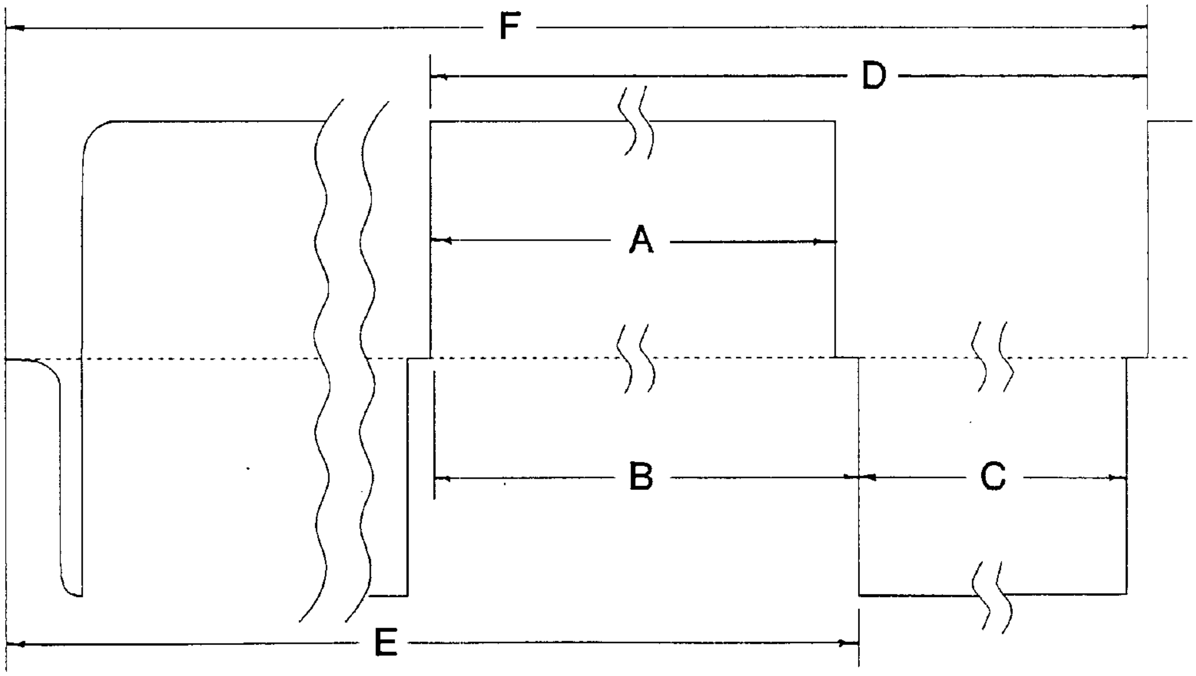


FIGURE E-4 RECTANGLE WAVEFORM TIMING

TABLE E-2 RECTANGLE WAVEFORM EDGE TIMING

Cycle #	Interval E ms	E-error ms	Interval F ms	F-error ms
1	5.978	-0.022	10.004	0.004
2	15.982	-0.018	20.008	0.008
3	25.986	-0.014	30.012	0.012
4	35.990	-0.010	40.016	0.016
5	45.994	-0.006	50.020	0.020
6	55.998	-0.002	60.024	0.024
7	66.002	0.002	70.028	0.028
8	76.006	0.006	80.032	0.032
9	86.010	0.010	90.036	0.036
10	95.9835	-0.0165		

Using the data in Table E-2 and the previous paragraphs, it can be shown that the rectangle waveform is 51.5 μs shorter than the 100 ms expected by the SWG SPSW. Section E.1.2 shows that the entire rectangle/half-sine waveform time segment is 87 μs shorter than the 125 ms expected by the SWG SPSW. Although small, these inaccuracies caused the algorithm that separates the half-sine waveform data from the rectangle waveform data to provide half-sine data that is displaced in time from its theoretical value. As a result, the SWG SPSW has been calculating half-sine "X" and "Z" component time deviation values larger than the correct values.

Prior to producing the results for the SWG performance testing shown in Appendix G, the SWG SPSW was edited to account for the correct time reference signal interval durations. Also included in the updated SWG SPSW, is the new value for the time of the half-sine peak, 12.523 ms after the beginning of the half-sine data set.

The analysis report for the stair waveform, shown in Appendix G, shows that even though the time reference waveform and the stair waveform are synchronized at the beginning of the waveform segment, the waveform edges drift to more than one 30.5 μs sample out of synchronization with the theoretical time as defined by the time reference waveform. The time differences shown in the report have been verified by examination of the raw data printout.

Subsequent to processing the data from this test, the SPSW was edited to incorporate the measured time intervals for the rectangle and stair waveforms. The SPSW has been edited to remove the time deviation output that is calculated from the tenth cycle of the rectangle waveform.

E.2 AMPLITUDE ACCURACY

The factors that affect the amplitude accuracy of the SWG are the waveform voltages provided at the SWG outputs, the zero and positive calibration voltages provided at the SWG outputs, and the method by which the zero and positive calibration voltages are used to calibrate the waveform voltage outputs.

The scaling algorithm used for this test was described in Section 2.2.1 and the PDAS calibration procedure was described in Section D.2.1.2. After the strain gage level outputs had been processed, it was apparent that the procedure described in Section D.2.1.2 was not sufficient to provide a sufficiently precise calibration for zero offset and full scale value. To augment the zero offset calibration, the strain gage level data was processed to remove the average zero offset that could be calculated from the first 30 milliseconds of waveform data. This somewhat parallels the procedure used by crash test facility operators. They use the data recorded immediately before the crash event to establish their zero value.

E.2.1 Calibration Levels

The zero offset and calibration voltage levels measured from all waveform outputs of the SWG are presented in Table E-3. These measurements were taken on 27 October 1989.

TABLE E-3 SWG CALIBRATION VOLTAGES

Output Channel #	Piezo Resistive 0 mV	Piezo Resistive +Cal mV	Piezo Resistive -Cal mV	Strain Gage 0 mV	Strain Gage +Cal mV	Strain Gage -Cal mV
1	0.06	100.14	-99.97	0.07	10.25	-10.11
2	0.04	100.22	-100.11	0.05	10.24	-10.14
3	0.04	100.16	-100.05	0.05	10.24	-10.14
4	0.04	100.18	-100.06	0.06	10.24	-10.14
5	-0.02	100.03	-100.04	0.00	10.05	-10.07
6	-0.02	100.01	-100.02	0.00	10.05	-10.07
7	-0.02	100.00	-100.01	-0.01	10.04	-10.07
8	-0.01	100.03	-100.02	0.00	10.05	-10.06
9	0.04	100.20	-100.09	0.06	10.25	-10.13
10	0.04	100.18	-100.05	0.06	10.25	-10.13
11	0.04	100.18	-100.05	0.06	10.24	-10.13
12	0.04	100.18	-100.08	0.06	10.22	-10.13
13	-0.02	100.07	-100.07	0.00	10.06	-10.06
14	-0.02	99.84	-99.85	0.00	10.03	-10.05
15	-0.02	100.04	-100.05	0.00	10.05	-10.07
16	-0.02	100.00	-100.00	-0.01	10.04	-10.06

TABLE E-3 CONTINUED

Output Channel #	Piezo Resistive 0 mV	 +Cal V	 -Cal V	Strain Gage 0 mV	 +Cal V	 -Cal V
H1	-17.70	4.982	-5.021	-16.79	0.4915	-0.5267
H2	22.43	5.020	-4.977	23.10	0.5265	-0.4825

E.2.2 Rectangle Waveform

The processed data summary reports of Appendix G provide the calculated amplitude errors for the rectangle and stair waveforms. The recorded data are compared with theoretical values (acceleration in g's) stored in the program.

E.2.2.1 Steady-State Amplitude - Table E-1 and Appendix G show that the amplitude accuracy of the SWG at the piezo resistive level is well within the ±0.25% design goal. At the strain gage level, the amplitude errors slightly exceed this tolerance during a number of the rectangle waveform intervals. The negative amplitude errors for AMPDEVPOS and the positive errors for AMPDEVNEG in Table E-1 indicate a significant zero offset. But these data are for two data sets that have had any zero offset measurable at the beginning of the run removed!

To explain the subsequent analysis of this apparent zero shift, let the average value of the data acquired during the first 29.9 ms after the pre-time-zero pulse leading edge be called "cal zero". Measurements show that the value of cal zero is very close to the zero measured in calibration mode (with the SWG in "stand-by"). This is the zero level output of the SWG before the first rise of the rectangle waveform. Let the average value of the data acquired in the 20.8 ms of zero output between the end of the half-sine pulse and the first rise of the stair waveform be called "waveform zero". At the SWG "strain gage" output level, for the group 1 waveform, the waveform zero was 0.36 g lower than the cal zero. For the group 2 waveform, the waveform zero was 0.46 g lower than the cal zero. The design goal for amplitude accuracy of the SWG was ±0.25% of full scale, which translates into ±0.5 g. Consequently, the zero offset of the waveform from the initial zero level has used up most of the allowable error tolerance. The zero offsets of the waveforms at the piezo electric signal level are an order of magnitude less than those at the strain gage level.

E.2.2.2 Amplitude Overshoot - A study of the detail plots of the raw data from this test indicates that the output of the SWG exhibits no overshoot in response to a step change in output level. Therefore, each overshoot indicated in the Processed Data Summary Reports of Appendix G is the largest noise spike detected by the processing software during the first half of each waveform's constant level portion, expressed as a percent of the magnitude of the level change.

E.2.3 Stair Waveform

The stair waveform provides a test of amplitude accuracy compared to a theoretical standard, amplitude linearity, and amplitude overshoot.

E.2.3.1 Steady-State Amplitude - The Processed Data Summary Reports provide the deviation of the steady-state value at each level from its theoretical level expressed as a percent of full scale. The largest of the deviations from theoretical value is listed in Table E-1 under the heading AMPDEVREF. This could be considered a measure of nonlinearity compared to a theoretical straight line reference. Table E-1 shows that for the group 2 waveform at the strain gage level, the largest deviation from theoretical level did exceed the ±0.25% design goal slightly.

E.2.3.2 Amplitude Linearity - The measure of amplitude linearity is the largest of the deviations of the amplitude errors from the best "least-squares" fit straight line to the amplitude error data. These maxima are given in Table E-1 under the heading AMPDEVBFSL. The small values given in this column of Table E-1 suggest that the larger numbers in the column headed by AMPDEVREF are caused by an offset.

E.2.3.3 Amplitude Overshoot - Appendix G.2 indicates that at the strain gage signal level the SWG exhibits excessive amplitude overshoot during the stair waveform. To understand this result, consider the following: Overshoot is measured by determining the peak value in the response to a step change in level during the first half of the level portion of the rectangle and stair waveforms following the step. A careful examination of the waveform output data from the SWG shows that the SWG output exhibits zero overshoot. Therefore, any overshoot recorded by the SPSW is peak noise that occurs in the interval following a step change in level of the rectangle and stair waveforms. The overshoot tolerance used in the SPSW for this test is one-tenth of the overshoot tolerance allowed in testing a crash test DAS.

Whenever the overshoot tolerance was exceeded in the stair waveform response, the noise amplitude exceeded 0.26% of full scale. The maximum noise peak sensed at the strain gage level was 0.442% of full scale in the rectangle waveform response of channel 1.

E.2.4 Half-Sine Pulse Waveform

The peak values of the half-sine pulses agree with the steady-state full-scale levels recorded for the rectangle and stair waveforms.

E.2.5 System Noise

A separate measurement of system noise was performed with the SWG, TIM, and the PDAS connected together the same way as for the SWG performance tests. The PDAS was configured for a ±5.0 V input range. The SWG was operated at the low (strain gage) output level. The TIM gain was at the appropriate setting for this SWG setting (high gain). The PDAS recorded 20000 points per channel at a sampling interval of 30.5 μs. These data were analyzed on the VAX to compute average and standard deviation over the 0.61 second interval. Data were recorded for TIM and SWG power off, TIM power on and SWG power off, TIM and SWG power on (SWG zero output level), and TIM and SWG power on (SWG positive calibration output level). From these measurements it is estimated that the SWG contributes from 3/4 to 7/8 of the noise measured at the system output. The balance of the output noise is largely from the high gain amplifiers in the TIM. There is no significant difference in the system noise level between zero output level and positive calibration output level. The standard deviation of the noise measured at system output was on the order of 0.1% of full scale calibration level.

E.3 FREQUENCY RESPONSE

The amplitude frequency response of the SWG is required to be "flat" to within ±0.05 dB over the full range of test signal frequencies. Table E-1 shows that the group 2 waveform at the strain gage level did exceed this error tolerance slightly.

APPENDIX F

DISCUSSION OF RESULTS

This discussion primarily relates to the significance of the results when considered against two criteria. The first of these is how do these results affect the application of the SWG to testing crash test data acquisition systems? The second criterion is did the SWG meet its design specifications, and when these were not specified, how well could a particular design detail have been accomplished?

F.1 TIMING ACCURACY

The timing errors accrued from each of the four remaining timing error sources will be discussed individually and then an overall assessment of SWG timing accuracy will be presented.

F.1.1 Clock Frequency

The designers of the SWG and the SWG SPSW started with the assumption that the 4 MHz SWG crystal clock oscillator was an accurate time reference. Thus the firmware and SPSW was designed assuming that 2,000,000 clock cycles would mark a 0.500000 second interval. 2,000,000 cycles of a 4000003 Hz clock mark a 0.49999962 second interval, giving rise to a 0.38 μs timing error. This error is negligible when compared to the 10 μs tolerance allowed by SAE J211 [1].

F.1.2 Time Reference Signals

In Section E.1.2, above, the time durations of the first three waveform segments as defined by the rising edges of the four time reference pulses were unequal and two were shorter than the theoretical times that were assigned to them. The shorter time of the rectangle/half-sine waveform segment caused the half-sine waveform data to be indexed to the wrong starting time. The shorter total time of the three waveform segments caused an error in the value of DEL computed by the SPSW. The time duration between the rising edge of the first and fourth time reference pulses after the pre-time-zero pulse is 374.850 ms. This is 0.150 ms less than the theoretical 375 ms duration that was expected by the SWG SPSW. This would be a critical problem except that the SWG

SPSW has been corrected to use the time values determined by this test in the SPSW algorithms. Consequently, the correct values for DAS DEL and half-sine time of occurrence are now computed.

F.1.3 Waveform Edge Coincidence

Since the rectangle waveform data set starts when the T0 waveform goes high and the rectangle waveform is high at this time, the 14 μs interval between the rise of the rectangle waveform and the T0 pulse is of no consequence.

The 28 μs interval between the start of the sum-of-sines waveform and the T0 pulse does not cause any problems for the processing of these data because the Gaussian window through which these data are processed reduces waveform amplitudes to near zero at both ends of the waveform.

F.1.4 Waveform Timing

Section E.1.5 showed that the first nine cycles of the rectangle waveform have a 10.004 ms cycle duration and that in these first nine cycles the time between the initial rising edge and the negative going edge from zero to -200 g is 5.978 ms. The rectangle waveform processing software was changed to conform with these time values after the test results were evaluated. The SPSW has been edited to remove the time deviation output that is calculated from the tenth cycle of the rectangle waveform. This has removed these error sources from rectangle waveform processed results as shown in Appendix G.3.

In the processed results of Appendix G, the timing errors of the stair waveform are shown to accumulate 0.004 ms with each 10 ms step of the waveform until it reaches 0.024 ms. At this point the designers of the waveform firmware removed two samples from the next step which resulted in the next time error being -0.033 ms. This indicates that the first six steps of the stair waveform are of 10.004 ms duration. The seventh step is of 9.943 ms duration. And the eighth through the twelfth steps are of 10.004 ms duration. After the data of this test were processed, the SPSW was modified to account for this measured waveform timing. As seen in Appendix G.3, the modified software has completely compensated for the stair waveform timing.

In the signal processing software for the SWG test, a tolerance of 0.028 ms was specified for most of the timing tests. This quantity was derived as follows: The design specifications for the Phase III SWG specified a ±0.0025%

SWG time base accuracy over the 0.5 second waveform sequence duration. The 0.028 ms tolerance is the sum of the specified ±0.0025% SWG time base accuracy over the 0.5 s output duration (12.5 μs) plus one-half of a 30.5 μs DAC output sample interval (15.25 μs).

Although the one 30.5 μs sample stop at zero each time the rectangle waveform makes a level transition caused an ambiguity in the SWG performance test results, it is not expected to have a significant effect on the results of testing a crash test facility DAS because all facilities filter their analog data with a Class 1000 filter before digitizing the data. Most facilities use a 1650 Hz 4-pole Butterworth low pass filter for this purpose. The rise time to 50% of final value for a 1650 Hz 4-pole Butterworth low pass filter is at least 240 μs. Consequently, the 30.5 μs stop at zero is expected to be well smoothed by the longer response time of the Class 1000 filter.

F.1.5 Timing Error Summary

Modifications to the SPSW have made the software conform to the measured SWG timing. Thus, there are no significant timing errors in the SWG output.

The crystal clock error is negligible compared to the 10 μs tolerance permitted by SAE J211 [1].

F.2 AMPLITUDE ACCURACY

The calibration voltage levels at the test output signal channels are uniformly close to the desired ±100 mV and ±10 mV levels. The measured zero signal voltage levels are acceptably small. The large zero signal level voltages from the high level output channels are not expected to cause a problem because the primary use of these two outputs is to display the SWG waveform outputs on an oscilloscope for verification that the waveform outputs look like the picture in the operator's manual.

The amplitude linearity of the steady-state levels of the stair waveform is excellent.

The measured offset between the zero level that precedes the rectangle waveform and the zero level between the half-sine pulse and the first rise of the stair waveform is reflected in the processed results for both the rectangle and stair waveforms. At the strain gage signal level, this offset is between 0.2% and 0.3% of full scale. If other signal waveform generators exhibit a similar or greater offset, it may compromise their ability to make accurate amplitude measurements at the stain gage signal level.

The half-sine HIC errors do not appear to be sensitive to a zero offset of this type and magnitude.

The effect of the system noise is to reduce the accuracy of measurement.

F.3 FREQUENCY RESPONSE

The maximum deviations of amplitude frequency response at the piezo resistive signal level are equal to or less than the known error tolerance of the frequency response measurement software (±0.02 dB). From this it is concluded that the frequency response of the SWG is as close to zero dB at all test signal frequencies as can be measured by this technique. The greater deviations in the frequency response at the strain gage signal level are estimated to be the result of the higher noise level at that signal level corrupting the measurement.

APPENDIX G

PROCESSED DATA SUMMARY REPORTS

G.1 SWG "PIEZO RESISTIVE" OUTPUT LEVEL

```
                                             ** RECTANGLE WAVEFORM PROCESSED DATA SUMMARY **

A VALUE OF +/- 10000 INDICATES THAT THE QUANTITY COULD NOT BE DETERMINED
THE * SYMBOL INDICATES THAT THE ALLOWABLE LIMIT HAS BEEN EXCEEDED.

TIME QUANTITIES EXPRESSED IN MILLISECONDS
AMPLITUDE QUANTITIES EXPRESSED AS PERCENT OF FULL SCALE


                                                   21-DEC-89           15:11:09


RESULTS FOR FILE : c0627aa00.001                       CHANNEL NO. 001

FACILITY : TSC                    MEASURED VALUE OF DEL =0.030500 MSEC.  (MAXIMUM MEASUREMENT ERROR = +/- 0.000001 MSEC.)

1. TIME DEVIATION FROM THEORETICAL TIME   (ALLOWABLE LIMIT = +/- 0.028 MSEC)

                                                        INTERVAL NUMBER

     1        2        3        4        5        6        7        8        9        10
     0.000   -0.053    0.004   -0.018    0.008   -0.045    0.012   -0.010    0.016   -0.006
              *                                   *

                                                        INTERVAL NUMBER

    11       12       13       14       15       16       17       18       19       20
     0.020   -0.002   -0.007   -0.029    0.028    0.006    0.032    0.010    0.005   -0.017
                                *                          *

2. TIME LINEARITY (ALLOWABLE LIMIT = +/- 0.1 %)                   3. TIME OFFSET (ALLOWABLE LIMIT = +/- 0.028 MSEC)

        SLOPE =    0.025                                               INTERCEPT =  -0.014

4. STEADY-STATE AMPLITUDE DEVIATION FROM THEORETICAL AMPLITUDE   (ALLOWABLE LIMIT = 0.25 %)

                                                        INTERVAL NUMBER

     1        2        3        4        5        6        7        8        9        10
    -0.013   -0.038   -0.037   -0.049   -0.027   -0.043   -0.016   -0.044   -0.030   -0.041


                                                        INTERVAL NUMBER

    11       12       13       14       15       16       17       18       19       20
    -0.024   -0.047   -0.026   -0.040   -0.020   -0.049   -0.020   -0.060   -0.024   -0.050


5. AMPLITUDE OVERSHOOT RELATIVE TO CALCULATED STEADY-STATE AMPLITUDE (ALLOWABLE LIMIT +/- 1.3 %)

                                                        INTERVAL NUMBER

     1        2        3        4        5        6        7        8        9        10
     0.073    0.044    0.048    0.050    0.043    0.046    0.038    0.047    0.045    0.018


                                                        INTERVAL NUMBER

    11       12       13       14       15       16       17       18       19       20
     0.017    0.049    0.043    0.017    0.040    0.022    0.040    0.028    0.042    0.023
```

```
RESULTS FOR FILE : c0627aa00.002                    CHANNEL NO. 002

FACILITY : TSC                       MEASURED VALUE OF DEL =0.030500 MSEC.  (MAXIMUM MEASUREMENT ERROR = +/- 0.000001 MSEC.)

1. TIME DEVIATION FROM THEORETICAL TIME   (ALLOWABLE LIMIT = +/- 0.028 MSEC)

                                                        INTERVAL NUMBER

      1         2         3         4         5         6         7         8         9         10
      0.000    -0.053     0.004    -0.049     0.008    -0.014     0.012    -0.041     0.016    -0.037
                *                   *                                       *                   *

                                                        INTERVAL NUMBER

     11         12        13        14        15        16        17        18        19        20
      0.020    -0.033     0.024    -0.029     0.028    -0.025     0.032    -0.021     0.036    -0.017
                *                   *                             *                   *

2. TIME LINEARITY (ALLOWABLE LIMIT = +/- 0.1 %)                3. TIME OFFSET (ALLOWABLE LIMIT = +/- 0.028 MSEC)

        SLOPE =   0.026                                              INTERCEPT =  -0.019

4. STEADY-STATE AMPLITUDE DEVIATION FROM THEORETICAL AMPLITUDE   (ALLOWABLE LIMIT = 0.25 %)

                                                        INTERVAL NUMBER

      1         2         3         4         5         6         7         8         9         10
     -0.039    -0.029    -0.034    -0.040    -0.037    -0.052    -0.040    -0.050    -0.032    -0.034

                                                        INTERVAL NUMBER

     11         12        13        14        15        16        17        18        19        20
     -0.033    -0.028    -0.035    -0.050    -0.041    -0.046    -0.026    -0.046    -0.030    -0.053

5. AMPLITUDE OVERSHOOT RELATIVE TO CALCULATED STEADY-STATE AMPLITUDE (ALLOWABLE LIMIT +/- 1.3 %)

                                                        INTERVAL NUMBER

      1         2         3         4         5         6         7         8         9         10
      0.104     0.027     0.049     0.032     0.024     0.063     0.025     0.037     0.048     0.029

                                                        INTERVAL NUMBER

     11         12        13        14        15        16        17        18        19        20
      0.049     0.026     0.050     0.037     0.053     0.035     0.045     0.035     0.048     0.039


    FILE NAME                    CHANNEL NO.                 STATUS
c0627aa00.001                       001                       FAIL
c0627aa00.002                       002                       FAIL


TOTAL NO. OF CHANNELS PROCESSED =  2
NUMBER OF ACCEPTABLE CHANNELS =  0
NUMBER OF UNACCEPTABLE CHANNELS =  2
```

```
                              ** STAIR WAVEFORM PROCESSED DATA SUMMARY **

A VALUE OF +/- 10000 INDICATES THAT THE QUANTITY COULD NOT BE DETERMINED
THE * SYMBOL INDICATES THAT THE ALLOWABLE LIMIT HAS BEEN EXCEEDED.

TIME QUANTITIES EXPRESSED IN MILLISECONDS
AMPLITUDE QUANTITIES EXPRESSED AS PERCENT OF FULL SCALE


                                        21-DEC-89         15:11:17


RESULTS FOR FILE : c0627aa00.001                   CHANNEL NO. 001

FACILITY : TSC                 MEASURED VALUE OF DEL =0.030500 MSEC. (MAXIMUM MEASUREMENT ERROR = +/- 0.000001 MSEC.)

1. TIME DEVIATION FROM THEORETICAL TIME  (ALLOWABLE LIMIT +/- 0.028 MSEC)

                                              INTERVAL NUMBER

    1       2       3       4       5       6       7       8       9       10      11      12
    0.004   0.008   0.012   0.016   0.020   0.024   -0.033  -0.029  -0.025  -0.021  -0.017  -0.013
                                                    *       *

2. TIME LINEARITY (ALLOWABLE LIMIT = +/- 0.1 %)            3. TIME OFFSET (ALLOWABLE LIMIT = +/- 0.028 MSEC)

       SLOPE =  -0.037                                          INTERCEPT =   0.019

4. STEADY-STATE AMPLITUDE DEVIATION FROM  THEORETICAL AMPLITUDE (ALLOWABLE LIMIT = +/- 0.25 %)

                                              INTERVAL NUMBER

    1       2       3       4       5       6       7       8       9       10      11      12
   -0.018  -0.048  -0.036  -0.046  -0.012  -0.028  -0.025  -0.055  -0.060  -0.006  -0.011   0.030

5. STEADY-STATE AMPLITUDE DEVIATIONS FROM BEST FIT STRAIGHT LINE (% FULL SCALE) (ALLOWABLE LIMIT = +/- 0.25 %)

                                              INTERVAL NUMBER

    1       2       3       4       5       6       7       8       9       10      11      12
   -0.009  -0.031  -0.009  -0.011   0.031   0.025  -0.016   0.019   0.033  -0.012   0.002  -0.031

6. AMPLITUDE LINEARITY (ALLOWABLE LIMIT = +/- 0.25 %)          7. AMPLITUDE OFFSET (ALLOWABLE LIMIT = +/- 0.25 %)

       SLOPE =  -0.044                                          INTERCEPT =  -0.008

8. AMPLITUDE OVERSHOOT RELATIVE TO CALCULATED STEADY-STATE AMPLITUDE (ALLOWABLE LIMIT +/- 1.3 %)

                                              INTERVAL NUMBER

    1       2       3       4       5       6       7       8       9       10      11      12
    0.365   0.428   0.581   0.536   0.441   0.075   0.050   0.375   0.218   0.295   0.352   0.091
```

```
RESULTS FOR FILE : c0627aa00.002                         CHANNEL NO. 002

FACILITY : TSC                       MEASURED VALUE OF DEL =0.030500 MSEC. (MAXIMUM MEASUREMENT ERROR = +/- 0.000001 MSEC.)

1. TIME DEVIATION FROM THEORETICAL TIME  (ALLOWABLE LIMIT +/- 0.028 MSEC)

                                                            INTERVAL NUMBER

     1         2         3         4         5         6         7         8         9         10        11        12
     0.004     0.008     0.012     0.016     0.020     0.024    -0.033    -0.029    -0.025    -0.021    -0.017    -0.013
                                                                  *         *

2. TIME LINEARITY (ALLOWABLE LIMIT = +/- 0.1 %)                 3. TIME OFFSET (ALLOWABLE LIMIT = +/- 0.028 MSEC)

        SLOPE =  -0.037                                                INTERCEPT =   0.019

4. STEADY-STATE AMPLITUDE DEVIATION FROM  THEORETICAL AMPLITUDE (ALLOWABLE LIMIT = +/- 0.25 %)

                                                            INTERVAL NUMBER

     1         2         3         4         5         6         7         8         9         10        11        12
    -0.023    -0.049    -0.023    -0.046    -0.031    -0.041    -0.026    -0.046    -0.054    -0.016    -0.021     0.027


5. STEADY-STATE AMPLITUDE DEVIATIONS FROM BEST FIT STRAIGHT LINE (% FULL SCALE) (ALLOWABLE LIMIT = +/- 0.25 %)

                                                            INTERVAL NUMBER

     1         2         3         4         5         6         7         8         9         10        11        12
    -0.014    -0.030     0.006    -0.008     0.018     0.018    -0.016     0.007     0.025    -0.004     0.012    -0.027


6. AMPLITUDE LINEARITY (ALLOWABLE LIMIT = +/- 0.25 %)            7. AMPLITUDE OFFSET (ALLOWABLE LIMIT = +/- 0.25 %)

        SLOPE =  -0.049                                                INTERCEPT =  -0.010

8. AMPLITUDE OVERSHOOT RELATIVE TO CALCULATED STEADY-STATE AMPLITUDE (ALLOWABLE LIMIT +/- 1.3 %)

                                                            INTERVAL NUMBER

     1         2         3         4         5         6         7         8         9         10        11        12
     0.473     0.513     0.258     0.580     0.529     0.059     0.071     0.278     0.371     0.492     0.362     0.404


   FILE NAME                  CHANNEL NO.                   STATUS
c0627aa00.001                      001                        FAIL
c0627aa00.002                      002                        FAIL


TOTAL NO. OF CHANNELS PROCESSED =  2
NUMBER OF ACCEPTABLE CHANNELS =  0
NUMBER OF UNACCEPTABLE CHANNELS =  2
```

```
                                   ** HALF-SINE WAVEFORM PROCESSED DATA SUMMARY **

THE * SYMBOL INDICATES THAT THE ALLOWABLE LIMIT HAS BEEN EXCEEDED.

TIME QUANTITIES ARE EXPRESSED IN MILLISECONDS


                                             13-FEB-90        15:02:09


RESULTS FOR "X" COMPONENT FILE : c0627aa00.001                   CHANNEL NO. 001
        AND "Z" COMPONENT FILE : c0627aa00.002                   CHANNEL NO. 002

FACILITY : TSC                    MEASURED VALUE OF DEL =0.030500 MSEC.  (MAXIMUM MEASUREMENT ERROR = +/- 0.000001 MSEC.)

1. CHANNEL-TO-CHANNEL TIME DIFFERENCE =   0.000   (ALLOWABLE LIMIT = +/- 0.01 MSEC)

2. "X" COMPONENT TIME DEVIATION =   0.000   (ALLOWABLE LIMIT = +/- 0.028 MSEC)   "X" COMPONENT PEAK VALUE = -199.92 G

3. "Z" COMPONENT TIME DEVIATION =   0.000   (ALLOWABLE LIMIT = +/- 0.028 MSEC)   "Z" COMPONENT PEAK VALUE =  199.92 G

4. HIC DEVIATION =  -0.21   (ALLOWABLE LIMIT = +/- 0.6%)

THE CALCULATED HIC NO. = 1661.3 FOR T1 = 111.529 AND T2 = 113.511 WITH T2-T1 =   1.982 MSEC.

THE THEORETICAL HIC NO. = 1664.8 AND THE THEORETICAL VALUE OF T2-T1 =   2.013 MSEC.


    FILE NAME                CHANNEL NO.                 STATUS
c0627aa00.001                    001                      PASS
c0627aa00.002                    002                      PASS


TOTAL NO. OF CHANNELS PROCESSED =  2
NUMBER OF ACCEPTABLE CHANNELS =  2
NUMBER OF UNACCEPTABLE CHANNELS =  0
```

```
                                    ** CRASH WAVEFORM PROCESSED DATA SUMMARY **

THE * SYMBOL INDICATES THAT THE ALLOWABLE LIMIT HAS BEEN EXCEEDED.

TIME QUANTITIES ARE EXPRESSED IN MILLISECONDS


                                             21-DEC-89        15:13:04


RESULTS FOR "X" COMPONENT FILE : c0627aa00.001                   CHANNEL NO. 001
        AND "Z" COMPONENT FILE : c0627aa00.002                   CHANNEL NO. 002

FACILITY : TSC                    MEASURED VALUE OF DEL =0.030500 MSEC.  (MAXIMUM MEASUREMENT ERROR = +/- 0.000001 MSEC.)

1. HIC DEVIATION =       -0.15   (ALLOWABLE LIMIT = +/- 0.6%)

THE CALCULATED HIC NO. =  928.1 FOR T1 = 459.150 AND T2 = 471.044 WITH T2-T1 =  11.895 MSEC.

THE THEORETICAL HIC NO. =  929.5


    FILE NAME                CHANNEL NO.                 STATUS
c0627aa00.001                    001                      PASS
c0627aa00.002                    002                      PASS


TOTAL NO. OF CHANNELS PROCESSED =  2
NUMBER OF ACCEPTABLE CHANNELS =  2
NUMBER OF UNACCEPTABLE CHANNELS =  0
```

```
** FREQUENCY RESPONSE PROCESSED DATA SUMMARY **

        21-DEC-89         15:13:06



RESULT FOR FILE       c0627aa00.001
FREQUENCY RESPONSE FILE       FR0627.001

MEASURED VALUE OF DEL =0.030500 MSEC.  (MAXIMUM MEASUREMENT ERROR = +/- 0.000001 MSEC.)


  SIGNAL     DFT      DFT         INPUT       OUTPUT     SCALED  AMPLITUDE
FREQUENCY   LINE    OUTPUT        DFT          DFT        DFT      RATIO
   (HZ)      NO.   FREQUENCY     VALUE        VALUE      RATIO     (DB)

  273.4375    34    272.1568    284.7555    5426.1670  1.00000      0.00
  546.8750    68    544.3135    283.4248    5399.3237  0.99972      0.00
  820.3125   102    816.4703    281.2253    5353.7266  0.99904     -0.01
 1093.7500   137   1096.6317    282.9554    5383.1069  0.99838     -0.01
 1367.1875   171   1368.7885    284.5062    5421.5444  1.00002      0.00
 1640.6250   205   1640.9453    285.1701    5431.9146  0.99960      0.00
 1914.0625   239   1913.1021    284.9480    5426.2114  0.99933     -0.01
 2187.5000   273   2185.2588    283.8400    5401.5879  0.99868     -0.01
 2460.9375   307   2457.4155    281.8554    5361.6060  0.99827     -0.02
 2734.3750   342   2737.5769    282.4296    5381.2827  0.99990      0.00
 3007.8125   376   3009.7336    284.1993    5414.1323  0.99973      0.00
 3281.2500   410   3281.8906    285.0862    5427.1880  0.99903     -0.01
 3554.6875   444   3554.0474    285.0859    5423.5811  0.99836     -0.01
 3828.1250   478   3826.2041    284.2007    5407.7275  0.99855     -0.01



RESULT FOR FILE       c0627aa00.002
FREQUENCY RESPONSE FILE       FR0627.002

MEASURED VALUE OF DEL =0.030500 MSEC.  (MAXIMUM MEASUREMENT ERROR = +/- 0.000001 MSEC.)


  SIGNAL     DFT      DFT         INPUT       OUTPUT     SCALED  AMPLITUDE
FREQUENCY   LINE    OUTPUT        DFT          DFT        DFT      RATIO
   (HZ)      NO.   FREQUENCY     VALUE        VALUE      RATIO     (DB)

  273.4375    34    272.1568    284.7555    5420.8340  1.00000      0.00
  546.8750    68    544.3135    283.4248    5396.6055  1.00020      0.00
  820.3125   102    816.4703    281.2253    5354.8740  1.00023      0.00
 1093.7500   137   1096.6317    282.9554    5390.1978  1.00067      0.01
 1367.1875   171   1368.7885    284.5062    5416.2393  1.00003      0.00
 1640.6250   205   1640.9453    285.1701    5431.0063  1.00042      0.00
 1914.0625   239   1913.1021    284.9480    5425.1118  1.00011      0.00
 2187.5000   273   2185.2588    283.8400    5401.2676  0.99960      0.00
 2460.9375   307   2457.4155    281.8554    5365.3794  0.99995      0.00
 2734.3750   342   2737.5769    282.4296    5378.8931  1.00043      0.00
 3007.8125   376   3009.7336    284.1993    5411.4043  1.00021      0.00
 3281.2500   410   3281.8906    285.0862    5427.8130  1.00013      0.00
 3554.6875   444   3554.0474    285.0859    5426.6143  0.99991      0.00
 3828.1250   478   3826.2041    284.2007    5405.8452  0.99918     -0.01
```

G.2 SWG "STRAIN GAGE" OUTPUT LEVEL

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                                           ** RECTANGLE WAVEFORM PROCESSED DATA SUMMARY **

A VALUE OF +/- 10000 INDICATES THAT THE QUANTITY COULD NOT BE DETERMINED
THE * SYMBOL INDICATES THAT THE ALLOWABLE LIMIT HAS BEEN EXCEEDED.

TIME QUANTITIES EXPRESSED IN MILLISECONDS
AMPLITUDE QUANTITIES EXPRESSED AS PERCENT OF FULL SCALE

                                                  11-DEC-89             14:31:42

RESULTS FOR FILE : C0624AZ00.001                      CHANNEL NO. 001

FACILITY : TSC                         MEASURED VALUE OF DEL =0.030500 MSEC.  (MAXIMUM MEASUREMENT ERROR = +/- 0.000001 MSEC.)

1. TIME DEVIATION FROM THEORETICAL TIME   (ALLOWABLE LIMIT = +/- 0.028 MSEC)

                                                            INTERVAL NUMBER

      1         2         3         4         5         6         7         8         9        10
      0.000    -0.022     0.004    -0.049     0.008    -0.045     0.012    -0.041     0.016    -0.037
                                    *                   *                   *                   *

                                                            INTERVAL NUMBER

     11        12        13        14        15        16        17        18        19        20
      0.020    -0.033     0.024    -0.029     0.028    -0.025     0.032    -0.021     0.036    -0.047
                *                   *                             *                   *         *

2. TIME LINEARITY (ALLOWABLE LIMIT = +/- 0.1 %)                      3. TIME OFFSET (ALLOWABLE LIMIT = +/- 0.028 MSEC)

         SLOPE =   0.014                                                    INTERCEPT =  -0.015

4. STEADY-STATE AMPLITUDE DEVIATION FROM THEORETICAL AMPLITUDE   (ALLOWABLE LIMIT = 0.25 %)

                                                            INTERVAL NUMBER

      1         2         3         4         5         6         7         8         9        10
     -0.200     0.152    -0.229     0.150    -0.258     0.158    -0.204     0.170    -0.200     0.142
                                              *

                                                            INTERVAL NUMBER

     11        12        13        14        15        16        17        18        19        20
     -0.236     0.124    -0.189     0.184    -0.230     0.130    -0.227     0.157    -0.228     0.131

5. AMPLITUDE OVERSHOOT RELATIVE TO CALCULATED STEADY-STATE AMPLITUDE (ALLOWABLE LIMIT +/- 1.3 %)

                                                            INTERVAL NUMBER

      1         2         3         4         5         6         7         8         9        10
      0.311     0.167     0.142     0.140     0.184     0.221     0.157     0.158     0.127     0.171

                                                            INTERVAL NUMBER

     11        12        13        14        15        16        17        18        19        20
      0.203     0.208     0.122     0.178     0.142     0.120     0.141     0.136     0.114     0.150
```

```
RESULTS FOR FILE : C0624AZ00.002                      CHANNEL NO. 002

FACILITY : TSC                        MEASURED VALUE OF DEL =0.030500 MSEC.  (MAXIMUM MEASUREMENT ERROR = +/- 0.000001 MSEC.)

1. TIME DEVIATION FROM THEORETICAL TIME   (ALLOWABLE LIMIT = +/- 0.028 MSEC)

                                                          INTERVAL NUMBER

      1         2         3         4         5         6         7         8         9         10
      0.000    -0.053     0.004    -0.049     0.008    -0.045     0.012    -0.041     0.016    -0.037
                *                   *                   *                   *                   *

                                                          INTERVAL NUMBER

     11        12        13        14        15        16        17        18        19        20
      0.020    -0.033     0.024    -0.029     0.028    -0.025     0.032    -0.021     0.036    -0.047
                *                   *                             *                   *         *

2. TIME LINEARITY (ALLOWABLE LIMIT = +/- 0.1 %)                    3. TIME OFFSET (ALLOWABLE LIMIT = +/- 0.028 MSEC)

         SLOPE =   0.021                                                  INTERCEPT =  -0.020

4. STEADY-STATE AMPLITUDE DEVIATION FROM THEORETICAL AMPLITUDE   (ALLOWABLE LIMIT = 0.25 %)

                                                          INTERVAL NUMBER

      1         2         3         4         5         6         7         8         9         10
     -0.258     0.240    -0.204     0.313    -0.248     0.226    -0.234     0.234    -0.212     0.235
      *                             *

                                                          INTERVAL NUMBER

     11        12        13        14        15        16        17        18        19        20
     -0.212     0.278    -0.226     0.250    -0.279     0.230    -0.241     0.207    -0.221     0.241
                *                             *

5. AMPLITUDE OVERSHOOT RELATIVE TO CALCULATED STEADY-STATE AMPLITUDE (ALLOWABLE LIMIT +/- 1.3 %)

                                                          INTERVAL NUMBER

      1         2         3         4         5         6         7         8         9         10
      0.292     0.111     0.146     0.105     0.113     0.118     0.161     0.114     0.122     0.113

                                                          INTERVAL NUMBER

     11        12        13        14        15        16        17        18        19        20
      0.122     0.149     0.129     0.079     0.156     0.089     0.109     0.158     0.127     0.110


    FILE NAME                   CHANNEL NO.                    STATUS
C0624AZ00.001                          001                      FAIL
C0624AZ00.002                          002                      FAIL


TOTAL NO. OF CHANNELS PROCESSED =  2
NUMBER OF ACCEPTABLE CHANNELS =  0
NUMBER OF UNACCEPTABLE CHANNELS =  2
```

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                        ** STAIR WAVEFORM PROCESSED DATA SUMMARY **

A VALUE OF +/- 10000 INDICATES THAT THE QUANTITY COULD NOT BE DETERMINED
THE * SYMBOL INDICATES THAT THE ALLOWABLE LIMIT HAS BEEN EXCEEDED.

TIME QUANTITIES EXPRESSED IN MILLISECONDS
AMPLITUDE QUANTITIES EXPRESSED AS PERCENT OF FULL SCALE


                                  11-DEC-89       14:31:52


RESULTS FOR FILE : C0624AZ00.001                    CHANNEL NO. 001

FACILITY : TSC                 MEASURED VALUE OF DEL =0.030500 MSEC. (MAXIMUM MEASUREMENT ERROR = +/- 0.000001 MSEC.)

1. TIME DEVIATION FROM THEORETICAL TIME  (ALLOWABLE LIMIT +/- 0.028 MSEC)

                                              INTERVAL NUMBER

   1        2        3        4        5        6        7        8        9        10       11       12
   0.004    0.008    0.012    0.016    0.020    0.024   -0.033   -0.029   -0.025   -0.021   -0.017   -0.013
                                                          *        *

2. TIME LINEARITY (ALLOWABLE LIMIT = +/- 0.1 %)         3. TIME OFFSET (ALLOWABLE LIMIT = +/- 0.028 MSEC)

        SLOPE =  -0.037                                       INTERCEPT =   0.019

4. STEADY-STATE AMPLITUDE DEVIATION FROM  THEORETICAL AMPLITUDE (ALLOWABLE LIMIT = +/- 0.25 %)

                                              INTERVAL NUMBER

   1        2        3        4        5        6        7        8        9        10       11       12
  -0.173   -0.196   -0.171   -0.220   -0.204   -0.199   -0.186    0.169    0.144    0.187    0.169    0.199

5. STEADY-STATE AMPLITUDE DEVIATIONS FROM BEST FIT STRAIGHT LINE (% FULL SCALE) (ALLOWABLE LIMIT = +/- 0.25 %)

                                              INTERVAL NUMBER

   1        2        3        4        5        6        7        8        9        10       11       12
   0.012   -0.005    0.023   -0.021   -0.001    0.009    0.000   -0.005    0.024   -0.015    0.008   -0.017

6. AMPLITUDE LINEARITY (ALLOWABLE LIMIT = +/- 0.25 %)     7. AMPLITUDE OFFSET (ALLOWABLE LIMIT = +/- 0.25 %)

        SLOPE =  -0.022                                       INTERCEPT =  -0.186

8. AMPLITUDE OVERSHOOT RELATIVE TO CALCULATED STEADY-STATE AMPLITUDE (ALLOWABLE LIMIT +/- 1.3 %)

                                              INTERVAL NUMBER

   1        2        3        4        5        6        7        8        9        10       11       12
   1.354    1.704    1.576    1.394    1.842    0.284    0.371    1.592    1.715    1.245    1.296    1.259
   *        *        *        *        *                          *        *
```

```
RESULTS FOR FILE : C0624AZ00.002                  CHANNEL NO. 002

FACILITY : TSC                        MEASURED VALUE OF DEL =0.030500 MSEC. (MAXIMUM MEASUREMENT ERROR = +/- 0.000001 MSEC.)

1. TIME DEVIATION FROM THEORETICAL TIME  (ALLOWABLE LIMIT +/- 0.028 MSEC)

                                                     INTERVAL NUMBER

     1         2         3         4         5         6         7         8         9         10        11        12
     0.004     0.008     0.012     0.016     0.020     0.024    -0.033    -0.029    -0.025    -0.021    -0.017    -0.013
                                                                 *         *

2. TIME LINEARITY (ALLOWABLE LIMIT = +/- 0.1 %)                  3. TIME OFFSET (ALLOWABLE LIMIT = +/- 0.028 MSEC)

        SLOPE =  -0.037                                                INTERCEPT =    0.019

4. STEADY-STATE AMPLITUDE DEVIATION FROM  THEORETICAL AMPLITUDE (ALLOWABLE LIMIT = +/- 0.25 %)

                                                     INTERVAL NUMBER

     1         2         3         4         5         6         7         8         9         10        11        12
    -0.211    -0.276    -0.228    -0.225    -0.201    -0.221    -0.244     0.225     0.225     0.276     0.217     0.232
               *                                                                               *

5. STEADY-STATE AMPLITUDE DEVIATIONS FROM BEST FIT STRAIGHT LINE (% FULL SCALE) (ALLOWABLE LIMIT = +/- 0.25 %)

                                                     INTERVAL NUMBER

     1         2         3         4         5         6         7         8         9         10        11        12
     0.023    -0.044     0.002     0.003     0.025     0.004    -0.010     0.018     0.016    -0.037     0.021     0.004

6. AMPLITUDE LINEARITY (ALLOWABLE LIMIT = +/- 0.25 %)            7. AMPLITUDE OFFSET (ALLOWABLE LIMIT = +/- 0.25 %)

        SLOPE =   0.009                                                INTERCEPT =  -0.234

8. AMPLITUDE OVERSHOOT RELATIVE TO CALCULATED STEADY-STATE AMPLITUDE (ALLOWABLE LIMIT +/- 1.3 %)

                                                     INTERVAL NUMBER

     1         2         3         4         5         6         7         8         9         10        11        12
     1.648     1.252     1.337     1.892     1.268     0.279     0.237     1.412     1.524     1.318     1.248     1.477
     *                   *         *                                       *         *         *                   *


   FILE NAME                CHANNEL NO.                   STATUS
C0624AZ00.001                   001                        FAIL
C0624AZ00.002                   002                        FAIL


TOTAL NO. OF CHANNELS PROCESSED =  2
NUMBER OF ACCEPTABLE CHANNELS =  0
NUMBER OF UNACCEPTABLE CHANNELS =  2
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                                   ** HALF-SINE WAVEFORM PROCESSED DATA SUMMARY **

THE * SYMBOL INDICATES THAT THE ALLOWABLE LIMIT HAS BEEN EXCEEDED.

TIME QUANTITIES ARE EXPRESSED IN MILLISECONDS


                                        6-APR-90        16:58:29


RESULTS FOR "X" COMPONENT FILE : C2624AZ00.001                CHANNEL NO. 001
        AND "Z" COMPONENT FILE : C2624AZ00.002                CHANNEL NO. 002

FACILITY : TSC                    MEASURED VALUE OF DEL =0.030500 MSEC.  (MAXIMUM MEASUREMENT ERROR = +/- 0.000001 MSEC.)

1. CHANNEL-TO-CHANNEL TIME DIFFERENCE =  -0.001   (ALLOWABLE LIMIT = +/- 0.01 MSEC)

2. "X" COMPONENT TIME DEVIATION =   0.001   (ALLOWABLE LIMIT = +/- 0.028 MSEC)   "X" COMPONENT PEAK VALUE = -200.33 G

3. "Z" COMPONENT TIME DEVIATION =   0.001   (ALLOWABLE LIMIT = +/- 0.028 MSEC)   "Z" COMPONENT PEAK VALUE =  199.37 G

4. HIC DEVIATION =  -0.27   (ALLOWABLE LIMIT = +/- 0.6%)

THE CALCULATED HIC NO. = 1660.3 FOR T1 = 111.529 AND T2 = 113.511 WITH T2-T1 =   1.982 MSEC.

THE THEORETICAL HIC NO. = 1664.8 AND THE THEORETICAL VALUE OF T2-T1 =   2.013 MSEC.


    FILE NAME                 CHANNEL NO.                STATUS
C2624AZ00.001                     001                     PASS
C2624AZ00.002                     002                     PASS


TOTAL NO. OF CHANNELS PROCESSED =  2
NUMBER OF ACCEPTABLE CHANNELS =  2
NUMBER OF UNACCEPTABLE CHANNELS =  0
```

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                                   ** CRASH WAVEFORM PROCESSED DATA SUMMARY **

THE * SYMBOL INDICATES THAT THE ALLOWABLE LIMIT HAS BEEN EXCEEDED.

TIME QUANTITIES ARE EXPRESSED IN MILLISECONDS


                                        11-DEC-89       14:33:52


RESULTS FOR "X" COMPONENT FILE : C0624AZ00.001                CHANNEL NO. 001
        AND "Z" COMPONENT FILE : C0624AZ00.002                CHANNEL NO. 002

FACILITY : TSC                    MEASURED VALUE OF DEL =0.030500 MSEC.  (MAXIMUM MEASUREMENT ERROR = +/- 0.000001 MSEC.)

1. HIC DEVIATION =        0.02   (ALLOWABLE LIMIT = +/- 0.6%)

THE CALCULATED HIC NO. =  929.7 FOR T1 = 459.150 AND T2 = 471.044 WITH T2-T1 =  11.895 MSEC.

THE THEORETICAL HIC NO. =  929.5


    FILE NAME                 CHANNEL NO.                STATUS
C0624AZ00.001                     001                     PASS
C0624AZ00.002                     002                     PASS


TOTAL NO. OF CHANNELS PROCESSED =  2
NUMBER OF ACCEPTABLE CHANNELS =  2
NUMBER OF UNACCEPTABLE CHANNELS =  0
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              ** FREQUENCY RESPONSE PROCESSED DATA SUMMARY **


                      11-DEC-89          14:33:54



              RESULT FOR FILE       C0624AZ00.001
              FREQUENCY RESPONSE FILE       FR0624.001

MEASURED VALUE OF DEL =0.030500 MSEC.  (MAXIMUM MEASUREMENT ERROR = +/- 0.000001 MSEC.)


  SIGNAL    DFT     DFT        INPUT       OUTPUT    SCALED  AMPLITUDE
 FREQUENCY  LINE   OUTPUT       DFT         DFT       DFT     RATIO
   (HZ)     NO.   FREQUENCY    VALUE       VALUE     RATIO    (DB)

  273.4375   34    272.1568   284.7555   5432.0503  1.00000     0.00
  546.8750   68    544.3135   283.4248   5380.5620  0.99517    -0.04
  820.3125  102    816.4703   281.2253   5366.5752  1.00035     0.00
 1093.7500  137   1096.6317   282.9554   5379.0391  0.99654    -0.03
 1367.1875  171   1368.7885   284.5062   5436.6250  1.00172     0.01
 1640.6250  205   1640.9453   285.1701   5427.9868  0.99780    -0.02
 1914.0625  239   1913.1021   284.9480   5425.5210  0.99812    -0.02
 2187.5000  273   2185.2588   283.8400   5401.6157  0.99760    -0.02
 2460.9375  307   2457.4155   281.8554   5372.4409  0.99920    -0.01
 2734.3750  342   2737.5769   282.4296   5371.0898  0.99692    -0.03
 3007.8125  376   3009.7336   284.1993   5423.2241  1.00033     0.00
 3281.2500  410   3281.8906   285.0862   5431.1709  0.99868    -0.01
 3554.6875  444   3554.0474   285.0859   5422.2886  0.99705    -0.03
 3828.1250  478   3826.2041   284.2007   5420.3145  0.99979     0.00



              RESULT FOR FILE       C0624AZ00.002
              FREQUENCY RESPONSE FILE       FR0624.002

MEASURED VALUE OF DEL =0.030500 MSEC.  (MAXIMUM MEASUREMENT ERROR = +/- 0.000001 MSEC.)


  SIGNAL    DFT     DFT        INPUT       OUTPUT    SCALED  AMPLITUDE
 FREQUENCY  LINE   OUTPUT       DFT         DFT       DFT     RATIO
   (HZ)     NO.   FREQUENCY    VALUE       VALUE     RATIO    (DB)

  273.4375   34    272.1568   284.7555   5423.6470  1.00000     0.00
  546.8750   68    544.3135   283.4248   5362.7910  0.99342    -0.06
  820.3125  102    816.4703   281.2253   5384.0171  1.00515     0.04
 1093.7500  137   1096.6317   282.9554   5388.2617  0.99980     0.00
 1367.1875  171   1368.7885   284.5062   5392.5200  0.99513    -0.04
 1640.6250  205   1640.9453   285.1701   5437.2168  1.00104     0.01
 1914.0625  239   1913.1021   284.9480   5419.8032  0.99862    -0.01
 2187.5000  273   2185.2588   283.8400   5425.2617  1.00352     0.03
 2460.9375  307   2457.4155   281.8554   5378.9385  1.00196     0.02
 2734.3750  342   2737.5769   282.4296   5365.7222  0.99747    -0.02
 3007.8125  376   3009.7336   284.1993   5425.6665  1.00233     0.02
 3281.2500  410   3281.8906   285.0862   5442.7388  1.00236     0.02
 3554.6875  444   3554.0474   285.0859   5437.7373  1.00144     0.01
 3828.1250  478   3826.2041   284.2007   5412.1260  0.99982     0.00
```

G.3 PROCESSED RECTANGLE AND STAIR WAVEFORM RESULTS AFTER CORRECTING PROCESSING ALGORITHM TO USE MEASURED WAVEFORM TIMING

G.3.1 "PIEZO RESISTIVE" OUTPUT LEVEL

```
                                        ** RECTANGLE WAVEFORM PROCESSED DATA SUMMARY **

A VALUE OF +/- 10000 INDICATES THAT THE QUANTITY COULD NOT BE DETERMINED
THE * SYMBOL INDICATES THAT THE ALLOWABLE LIMIT HAS BEEN EXCEEDED.

TIME QUANTITIES EXPRESSED IN MILLISECONDS
AMPLITUDE QUANTITIES EXPRESSED AS PERCENT OF FULL SCALE


                                            26-MAR-90           14:31:01


RESULTS FOR FILE : c0627aa00.001                  CHANNEL NO. 001

FACILITY : TSC                   MEASURED VALUE OF DEL =0.030500 MSEC.  (MAXIMUM MEASUREMENT ERROR = +/- 0.000001 MSEC.)

1. TIME DEVIATION FROM THEORETICAL TIME   (ALLOWABLE LIMIT = +/- 0.028 MSEC)

                                                 INTERVAL NUMBER

    1        2        3        4        5        6        7        8        9        10
    0.000   -0.031    0.000    0.000    0.000   -0.031    0.000    0.000    0.000    0.000
             *                                   *

                                                 INTERVAL NUMBER

    11       12       13       14       15       16       17       18       19       20
    0.000    0.000   -0.031   -0.031    0.000    0.000    0.000    0.000   -0.031   -0.031
                      *        *                                            *        *

2. TIME LINEARITY (ALLOWABLE LIMIT = +/- 0.1 %)              3. TIME OFFSET (ALLOWABLE LIMIT = +/- 0.028 MSEC)

       SLOPE =  -0.010                                            INTERCEPT =  -0.004

4. STEADY-STATE AMPLITUDE DEVIATION FROM THEORETICAL AMPLITUDE   (ALLOWABLE LIMIT = 0.25 %)

                                                 INTERVAL NUMBER

    1        2        3        4        5        6        7        8        9        10
   -0.013   -0.038   -0.037   -0.049   -0.027   -0.043   -0.016   -0.044   -0.030   -0.041


                                                 INTERVAL NUMBER

    11       12       13       14       15       16       17       18       19       20
   -0.024   -0.047   -0.026   -0.040   -0.020   -0.049   -0.020   -0.060   -0.024   -0.050


5. AMPLITUDE OVERSHOOT RELATIVE TO CALCULATED STEADY-STATE AMPLITUDE (ALLOWABLE LIMIT +/- 1.3 %)

                                                 INTERVAL NUMBER

    1        2        3        4        5        6        7        8        9        10
    0.073    0.044    0.048    0.050    0.043    0.046    0.038    0.047    0.045    0.018


                                                 INTERVAL NUMBER

    11       12       13       14       15       16       17       18       19       20
    0.017    0.049    0.043    0.017    0.040    0.022    0.040    0.028    0.042    0.023
```

```
RESULTS FOR FILE : c0627aa00.002                    CHANNEL NO. 002

FACILITY : TSC                      MEASURED VALUE OF DEL =0.030500 MSEC.  (MAXIMUM MEASUREMENT ERROR = +/- 0.000001 MSEC.)

1. TIME DEVIATION FROM THEORETICAL TIME   (ALLOWABLE LIMIT = +/- 0.028 MSEC)

                                                        INTERVAL NUMBER

      1          2          3          4          5          6          7          8          9          10
      0.000     -0.031      0.000     -0.031      0.000      0.000      0.000     -0.031      0.000     -0.031
                  *                    *                                           *                      *

                                                        INTERVAL NUMBER

      11         12         13         14         15         16         17         18         19         20
      0.000     -0.031      0.000     -0.031      0.000     -0.031      0.000     -0.031      0.000     -0.031
                  *                    *                     *                     *                      *

2. TIME LINEARITY (ALLOWABLE LIMIT = +/- 0.1 %)                 3. TIME OFFSET (ALLOWABLE LIMIT = +/- 0.028 MSEC)

         SLOPE =  -0.010                                              INTERCEPT =  -0.009

4. STEADY-STATE AMPLITUDE DEVIATION FROM THEORETICAL AMPLITUDE   (ALLOWABLE LIMIT = 0.25 %)

                                                        INTERVAL NUMBER

      1          2          3          4          5          6          7          8          9          10
     -0.039     -0.029     -0.034     -0.040     -0.037     -0.052     -0.040     -0.050     -0.032     -0.034


                                                        INTERVAL NUMBER

      11         12         13         14         15         16         17         18         19         20
     -0.033     -0.028     -0.035     -0.050     -0.041     -0.046     -0.026     -0.046     -0.030     -0.053


5. AMPLITUDE OVERSHOOT RELATIVE TO CALCULATED STEADY-STATE AMPLITUDE (ALLOWABLE LIMIT +/- 1.3 %)

                                                        INTERVAL NUMBER

      1          2          3          4          5          6          7          8          9          10
      0.104      0.027      0.049      0.032      0.024      0.063      0.025      0.037      0.048      0.029


                                                        INTERVAL NUMBER

      11         12         13         14         15         16         17         18         19         20
      0.049      0.026      0.050      0.037      0.053      0.035      0.045      0.035      0.048      0.039


    FILE NAME                  CHANNEL NO.                 STATUS
c0627aa00.001                      001                      FAIL
c0627aa00.002                      002                      FAIL


TOTAL NO. OF CHANNELS PROCESSED =  2
NUMBER OF ACCEPTABLE CHANNELS =  0
NUMBER OF UNACCEPTABLE CHANNELS =  2
```

```
                              ** STAIR WAVEFORM PROCESSED DATA SUMMARY **

A VALUE OF +/- 10000 INDICATES THAT THE QUANTITY COULD NOT BE DETERMINED
THE * SYMBOL INDICATES THAT THE ALLOWABLE LIMIT HAS BEEN EXCEEDED.

TIME QUANTITIES EXPRESSED IN MILLISECONDS
AMPLITUDE QUANTITIES EXPRESSED AS PERCENT OF FULL SCALE


                                      26-JUN-90          14:12:08


RESULTS FOR FILE : c2627az00.001                 CHANNEL NO. 001

FACILITY : TSC                MEASURED VALUE OF DEL =0.030500 MSEC. (MAXIMUM MEASUREMENT ERROR = +/- 0.000001 MSEC.)

1. TIME DEVIATION FROM THEORETICAL TIME  (ALLOWABLE LIMIT +/- 0.028 MSEC)

                                                 INTERVAL NUMBER

     1       2       3       4       5       6       7       8       9       10      11      12
   0.000   0.000   0.000   0.000   0.000   0.000   0.000   0.000   0.000   0.000   0.000   0.000


2. TIME LINEARITY (ALLOWABLE LIMIT = +/- 0.1 %)           3. TIME OFFSET (ALLOWABLE LIMIT = +/- 0.028 MSEC)

      SLOPE =   0.000                                          INTERCEPT =   0.000

4. STEADY-STATE AMPLITUDE DEVIATION FROM  THEORETICAL AMPLITUDE (ALLOWABLE LIMIT = +/- 0.25 %)

                                                 INTERVAL NUMBER

     1       2       3       4       5       6       7       8       9       10      11      12
  -0.012  -0.043  -0.030  -0.041  -0.007  -0.023  -0.020  -0.061  -0.065  -0.012  -0.016   0.025


5. STEADY-STATE AMPLITUDE DEVIATIONS FROM BEST FIT STRAIGHT LINE (% FULL SCALE) (ALLOWABLE LIMIT = +/- 0.25 %)

                                                 INTERVAL NUMBER

     1       2       3       4       5       6       7       8       9       10      11      12
  -0.009  -0.031  -0.009  -0.011   0.031   0.025  -0.016   0.020   0.033  -0.012   0.002  -0.031


6. AMPLITUDE LINEARITY (ALLOWABLE LIMIT = +/- 0.25 %)       7. AMPLITUDE OFFSET (ALLOWABLE LIMIT = +/- 0.25 %)

      SLOPE =  -0.044                                          INTERCEPT =  -0.003

8. AMPLITUDE OVERSHOOT RELATIVE TO CALCULATED STEADY-STATE AMPLITUDE (ALLOWABLE LIMIT +/- 1.3 %)

                                                 INTERVAL NUMBER

     1       2       3       4       5       6       7       8       9       10      11      12
   0.365   0.428   0.581   0.537   0.441   0.075   0.051   0.376   0.218   0.295   0.352   0.091
```

```
RESULTS FOR FILE : c2627az00.002                    CHANNEL NO. 002

FACILITY : TSC                  MEASURED VALUE OF DEL =0.030500 MSEC. (MAXIMUM MEASUREMENT ERROR = +/- 0.000001 MSEC.)

1. TIME DEVIATION FROM THEORETICAL TIME  (ALLOWABLE LIMIT +/- 0.028 MSEC)

                                                   INTERVAL NUMBER

      1        2        3        4        5        6        7        8        9        10       11       12
      0.000    0.000    0.000    0.000    0.000    0.000    0.000    0.000    0.000    0.000    0.000    0.000

2. TIME LINEARITY (ALLOWABLE LIMIT = +/- 0.1 %)                  3. TIME OFFSET (ALLOWABLE LIMIT = +/- 0.028 MSEC)

        SLOPE =   0.000                                                INTERCEPT =   0.000

4. STEADY-STATE AMPLITUDE DEVIATION FROM  THEORETICAL AMPLITUDE (ALLOWABLE LIMIT = +/- 0.25 %)

                                                   INTERVAL NUMBER

      1        2        3        4        5        6        7        8        9        10       11       12
     -0.025   -0.051   -0.025   -0.048   -0.033   -0.043   -0.028   -0.044   -0.052   -0.014   -0.020    0.029

5. STEADY-STATE AMPLITUDE DEVIATIONS FROM BEST FIT STRAIGHT LINE (% FULL SCALE) (ALLOWABLE LIMIT = +/- 0.25 %)

                                                   INTERVAL NUMBER

      1        2        3        4        5        6        7        8        9        10       11       12
     -0.014   -0.030    0.006   -0.008    0.018    0.018   -0.016    0.007    0.025   -0.004    0.012   -0.027

6. AMPLITUDE LINEARITY (ALLOWABLE LIMIT = +/- 0.25 %)             7. AMPLITUDE OFFSET (ALLOWABLE LIMIT = +/- 0.25 %)

        SLOPE =  -0.049                                                INTERCEPT =  -0.012

8. AMPLITUDE OVERSHOOT RELATIVE TO CALCULATED STEADY-STATE AMPLITUDE (ALLOWABLE LIMIT +/- 1.3 %)

                                                   INTERVAL NUMBER

      1        2        3        4        5        6        7        8        9        10       11       12
      0.472    0.513    0.258    0.580    0.529    0.059    0.071    0.278    0.371    0.492    0.362    0.404


    FILE NAME                 CHANNEL NO.                STATUS
c2627az00.001                     001                     PASS
c2627az00.002                     002                     PASS

TOTAL NO. OF CHANNELS PROCESSED =  2
NUMBER OF ACCEPTABLE CHANNELS =  2
NUMBER OF UNACCEPTABLE CHANNELS =  0
```

G.3.2 "STRAIN GAGE" OUTPUT LEVEL

```
                                        ** RECTANGLE WAVEFORM PROCESSED DATA SUMMARY **

A VALUE OF +/- 10000 INDICATES THAT THE QUANTITY COULD NOT BE DETERMINED
THE * SYMBOL INDICATES THAT THE ALLOWABLE LIMIT HAS BEEN EXCEEDED.

TIME QUANTITIES EXPRESSED IN MILLISECONDS
AMPLITUDE QUANTITIES EXPRESSED AS PERCENT OF FULL SCALE


                                              6-APR-90         16:57:50


RESULTS FOR FILE : C2624AZ00.001                     CHANNEL NO. 001

FACILITY : TSC                     MEASURED VALUE OF DEL =0.030500 MSEC.  (MAXIMUM MEASUREMENT ERROR = +/- 0.000001 MSEC.)

1. TIME DEVIATION FROM THEORETICAL TIME   (ALLOWABLE LIMIT = +/- 0.028 MSEC)

                                                 INTERVAL NUMBER

     1        2        3        4        5        6        7        8        9        10
     0.000    0.000    0.000   -0.031    0.000   -0.031    0.000   -0.031    0.000   -0.031
                                *                 *                 *                 *

                                                 INTERVAL NUMBER

    11       12       13       14       15       16       17       18       19       20
     0.000   -0.031    0.000   -0.031    0.000   -0.031    0.000   -0.031    0.000   -0.061
              *                 *                 *                 *                 *

2. TIME LINEARITY (ALLOWABLE LIMIT = +/- 0.1 %)               3. TIME OFFSET (ALLOWABLE LIMIT = +/- 0.028 MSEC)

        SLOPE =  -0.022                                             INTERCEPT =  -0.005

4. STEADY-STATE AMPLITUDE DEVIATION FROM THEORETICAL AMPLITUDE   (ALLOWABLE LIMIT = 0.25 %)

                                                 INTERVAL NUMBER

     1        2        3        4        5        6        7        8        9        10
    -0.200    0.152   -0.229    0.150   -0.258    0.158   -0.204    0.170   -0.200    0.142
                                          *

                                                 INTERVAL NUMBER

    11       12       13       14       15       16       17       18       19       20
    -0.236    0.124   -0.189    0.184   -0.230    0.130   -0.227    0.157   -0.228    0.133


5. AMPLITUDE OVERSHOOT RELATIVE TO CALCULATED STEADY-STATE AMPLITUDE (ALLOWABLE LIMIT +/- 1.3 %)

                                                 INTERVAL NUMBER

     1        2        3        4        5        6        7        8        9        10
     0.311    0.167    0.142    0.140    0.184    0.221    0.157    0.158    0.127    0.171

                                                 INTERVAL NUMBER

    11       12       13       14       15       16       17       18       19       20
     0.203    0.208    0.122    0.178    0.142    0.120    0.141    0.136    0.114    0.149
```

```
RESULTS FOR FILE : C2624AZ00.002                    CHANNEL NO. 002

FACILITY : TSC                  MEASURED VALUE OF DEL =0.030500 MSEC.  (MAXIMUM MEASUREMENT ERROR = +/- 0.000001 MSEC.)

1. TIME DEVIATION FROM THEORETICAL TIME   (ALLOWABLE LIMIT = +/- 0.028 MSEC)

                                                        INTERVAL NUMBER

      1        2        3        4        5        6        7        8        9        10
    0.000   -0.031    0.000   -0.031    0.000   -0.031    0.000   -0.031    0.000    -0.031
              *                 *                 *                 *                  *

                                                        INTERVAL NUMBER

     11       12       13       14       15       16       17       18       19       20
    0.000   -0.031    0.000   -0.031    0.000   -0.031    0.000   -0.031    0.000    -0.061
              *                 *                 *                 *                  *

2. TIME LINEARITY (ALLOWABLE LIMIT = +/- 0.1 %)                3. TIME OFFSET (ALLOWABLE LIMIT = +/- 0.028 MSEC)

        SLOPE =  -0.014                                              INTERCEPT =  -0.010

4. STEADY-STATE AMPLITUDE DEVIATION FROM THEORETICAL AMPLITUDE   (ALLOWABLE LIMIT = 0.25 %)

                                                        INTERVAL NUMBER

      1        2        3        4        5        6        7        8        9        10
   -0.258    0.240   -0.204    0.313   -0.248    0.226   -0.234    0.234   -0.212     0.235
    *                           *

                                                        INTERVAL NUMBER

     11       12       13       14       15       16       17       18       19       20
   -0.212    0.278   -0.226    0.250   -0.279    0.230   -0.241    0.207   -0.221     0.241
              *                          *

5. AMPLITUDE OVERSHOOT RELATIVE TO CALCULATED STEADY-STATE AMPLITUDE (ALLOWABLE LIMIT +/- 1.3 %)

                                                        INTERVAL NUMBER

      1        2        3        4        5        6        7        8        9        10
    0.292    0.111    0.146    0.105    0.113    0.118    0.161    0.114    0.122     0.113

                                                        INTERVAL NUMBER

     11       12       13       14       15       16       17       18       19       20
    0.122    0.149    0.129    0.079    0.156    0.089    0.109    0.158    0.127     0.110


   FILE NAME                  CHANNEL NO.                  STATUS
C2624AZ00.001                     001                       FAIL
C2624AZ00.002                     002                       FAIL


TOTAL NO. OF CHANNELS PROCESSED =  2
NUMBER OF ACCEPTABLE CHANNELS =  0
NUMBER OF UNACCEPTABLE CHANNELS =  2
```

Note: The "channel 2" output in the above summary reports is the group 2 output from SWG channel 5.

```
                                    ** STAIR WAVEFORM PROCESSED DATA SUMMARY **

A VALUE OF +/- 10000 INDICATES THAT THE QUANTITY COULD NOT BE DETERMINED
THE * SYMBOL INDICATES THAT THE ALLOWABLE LIMIT HAS BEEN EXCEEDED.

TIME QUANTITIES EXPRESSED IN MILLISECONDS
AMPLITUDE QUANTITIES EXPRESSED AS PERCENT OF FULL SCALE


                                          26-JUN-90          14:28:58


RESULTS FOR FILE : c2624az00.001                   CHANNEL NO. 001

FACILITY : TSC                  MEASURED VALUE OF DEL =0.030500 MSEC. (MAXIMUM MEASUREMENT ERROR = +/- 0.000001 MSEC.)

1. TIME DEVIATION FROM THEORETICAL TIME  (ALLOWABLE LIMIT +/- 0.028 MSEC)

                                                     INTERVAL NUMBER

     1        2        3        4        5        6        7        8        9        10       11       12
     0.000    0.000    0.000    0.000    0.000    0.000    0.000    0.000    0.000    0.000    0.000    0.000

2. TIME LINEARITY (ALLOWABLE LIMIT = +/- 0.1 %)                   3. TIME OFFSET (ALLOWABLE LIMIT = +/- 0.028 MSEC)

        SLOPE =   0.000                                                  INTERCEPT =   0.000

4. STEADY-STATE AMPLITUDE DEVIATION FROM  THEORETICAL AMPLITUDE (ALLOWABLE LIMIT = +/- 0.25 %)

                                                     INTERVAL NUMBER

     1        2        3        4        5        6        7        8        9        10       11       12
    -0.173   -0.196   -0.171   -0.220   -0.204   -0.199   -0.186    0.169    0.144    0.187    0.169    0.199

5. STEADY-STATE AMPLITUDE DEVIATIONS FROM BEST FIT STRAIGHT LINE (% FULL SCALE) (ALLOWABLE LIMIT = +/- 0.25 %)

                                                     INTERVAL NUMBER

     1        2        3        4        5        6        7        8        9        10       11       12
     0.012   -0.005    0.023   -0.021   -0.001    0.009    0.000   -0.005    0.024   -0.015    0.008   -0.017

6. AMPLITUDE LINEARITY (ALLOWABLE LIMIT = +/- 0.25 %)             7. AMPLITUDE OFFSET (ALLOWABLE LIMIT = +/- 0.25 %)

        SLOPE =  -0.022                                                  INTERCEPT =  -0.186

8. AMPLITUDE OVERSHOOT RELATIVE TO CALCULATED STEADY-STATE AMPLITUDE (ALLOWABLE LIMIT +/- 1.3 %)

                                                     INTERVAL NUMBER

     1        2        3        4        5        6        7        8        9        10       11       12
     1.354    1.704    1.576    1.394    1.842    0.284    0.371    1.592    1.715    1.245    1.296    1.259
     *        *        *        *        *                          *        *
```

```
RESULTS FOR FILE : c2624az00.002                        CHANNEL NO. 002

FACILITY : TSC                         MEASURED VALUE OF DEL =0.030500 MSEC. (MAXIMUM MEASUREMENT ERROR = +/- 0.000001 MSEC.)

1. TIME DEVIATION FROM THEORETICAL TIME  (ALLOWABLE LIMIT +/- 0.028 MSEC)

                                                           INTERVAL NUMBER

     1         2         3         4         5         6         7         8         9         10        11        12
     0.000     0.000     0.000     0.000     0.000     0.000     0.000     0.000     0.000     0.000     0.000     0.000


2. TIME LINEARITY (ALLOWABLE LIMIT = +/- 0.1 %)                   3. TIME OFFSET (ALLOWABLE LIMIT = +/- 0.028 MSEC)

         SLOPE =    0.000                                                INTERCEPT =    0.000

4. STEADY-STATE AMPLITUDE DEVIATION FROM  THEORETICAL AMPLITUDE (ALLOWABLE LIMIT = +/- 0.25 %)

                                                           INTERVAL NUMBER

     1         2         3         4         5         6         7         8         9         10        11        12
    -0.211    -0.276    -0.228    -0.225    -0.201    -0.221    -0.244     0.225     0.225     0.276     0.217     0.232
               *                                                                               *

5. STEADY-STATE AMPLITUDE DEVIATIONS FROM BEST FIT STRAIGHT LINE (% FULL SCALE) (ALLOWABLE LIMIT = +/- 0.25 %)

                                                           INTERVAL NUMBER

     1         2         3         4         5         6         7         8         9         10        11        12
     0.023    -0.044     0.002     0.003     0.025     0.004    -0.010     0.018     0.016    -0.037     0.021     0.004


6. AMPLITUDE LINEARITY (ALLOWABLE LIMIT = +/- 0.25 %)              7. AMPLITUDE OFFSET (ALLOWABLE LIMIT = +/- 0.25 %)

         SLOPE =    0.009                                                INTERCEPT =   -0.234

8. AMPLITUDE OVERSHOOT RELATIVE TO CALCULATED STEADY-STATE AMPLITUDE (ALLOWABLE LIMIT +/- 1.3 %)

                                                           INTERVAL NUMBER

     1         2         3         4         5         6         7         8         9         10        11        12
     1.648     1.252     1.337     1.892     1.268     0.279     0.237     1.412     1.524     1.318     1.248     1.477
     *                   *         *                                       *         *         *                   *


    FILE NAME                 CHANNEL NO.                  STATUS
c2624az00.001                      001                      FAIL
c2624az00.002                      002                      FAIL


TOTAL NO. OF CHANNELS PROCESSED =  2
NUMBER OF ACCEPTABLE CHANNELS =  0
NUMBER OF UNACCEPTABLE CHANNELS =  2
```

APPENDIX H

PDAS PROGRAM LISTINGS

The following annotated program listings are examples of the principle PDAS programs used in this testing. Instructions for use of and programming for the PDAS are provided in References 4, 5, and 6.

This program was used for acquiring data from the SWG for analysis by the SWG SPSW.

```
#RESET                             ;Clear memory
#PIPES P0,P1,P2,P3,P4,P5,P6,P7     ;Define FIFO buffers
                                   called pipes
#IDEF A 7                          ;Defines input procedure A
                                   with 7 inputs
  >CLOCK EXTERNAL                  ;Requires external clock
                                   pulse to start 7 sample
                                   sequence
  >SET 0 S3                        ;Connects input S3 to
                                   input channel 0.  S3 is a
                                   shorted input.
  >SET 1 S3                        ;Connects S3 to input
                                   channel 1
  >SET 2 S3                        ;Connects S3 to input
                                   channel 2
  >SET 3 S4                        ;Connects S4 (DT0) to
                                   input channel 3
  >SET 4 S1                        ;Connects S1 (group 1
                                   waveform) to input channel
                                   4
  >SET 5 S2                        ;Connects S2 (group 2
                                   waveform) to input channel
                                   5
  >SET 6 S0                        ;Connects S0 (T0) to input
                                   channel 6
  >TIME 4.25                       ;Sets the PDAS sampling
                                   interval to 4.25 us
  >COUNT 121639                    ;Total number of samples
                                   to be acquired = 121639
  >DIRECT(3,P3)                    ;Transfers data from
                                   channel 3 to pipe P3
  >DIRECT(4,P1)                    ;Transfers data from
                                   channel 4 to pipe P1
  >DIRECT(5,P2)                    ;Transfers data from
                                   channel 5 to pipe P2
  >DIRECT(6,P0)                    ;Transfers data from
                                   channel 6 to pipe P0
```

```
  >END                             ;End of input
                                   configuration and input
                                   task definition commands
#PDEF B                            ;Defines processing
                                   procedure B
  >P4=(P1+2)*20000/29807           ;Scales group 1 data
  >P5=(P2+22)*20000/30434          ;Scales group 2 data
  >P6=P0*4998/32752                ;Scales T0 data
  >P7=P3*4998/32752                ;Scales DT0 data
  >FORMAT(#,P4:2,P5:2,P6:3,P7:3)   ;Transfers data to output
                                   in the following sequence:
                                   sample number, group 1
                                   data to two decimal
                                   places, group 2 data to
                                   two decimal places, T0
                                   data to three decimal
                                   places, and DT0 data to
                                   three decimal places
  >END                             ;End of processing task
                                   definition commands
#START A,B                         ;Start procedures A and B
                                   (PDAS now waits for
                                   external clock pulse to
                                   start a sampling
                                   sequence.)
```

The # precedes system commands and the > precedes task definition commands.

The following program was used to determine SWG output zero and +CAL levels in terms of ADC numerical output. These numbers were then used in the scaling equations of the data acquisition program.

```
#RESET
#PIPES P0,P1
#IDEF A 2
  >SET 0 S1                ;S1 is group 1 waveform output
  >SET 1 S2                ;S2 is group 2 waveform output
  >TIME 15.25              ;Each channel is sampled every 30.5
                           us
  >AVERAGE(0,16000,P0)     ;Each set of 16000 samples from
                           channel 0 is averaged and the
                           average is transferred to pipe P0.
  >AVERAGE(1,16000,P1)     ;Each set of 16000 samples from
                           channel 1 is averaged and the
                           average is transferred to pipe P1.
  >END
#PDEF B
  >FORMAT(P0,P1)           ;The two averages are transferred to
                           output.
  >END
#START A,B                 ;PDAS sampling begins immediately.
```

The following program was used to confirm the scaling values derived from the data from the previous program.

```
#RESET
#PIPES P0,P1,P2,P3
#IDEF A 2
  >SET 0 S1
  >SET 1 S2
  >TIME 15.25
  >AVERAGE(0,16000,P0)
  >AVERAGE(1,16000,P1)
  >END
#PDEF B
  >P2=(P0+2)*20000/29807       ;Scales the averaged data from
                               the group 1 output.
  >P3=(P1+22)*20000/30434      ;Scales the averaged data from
                               the group 2 output.
  >FORMAT(P2:2,P3:2)           ;Transfers the scaled data
                               averages to output.
  >END
#START A,B
```

The following program was used to determine the timing of time reference pulses and waveforms with respect to the DAC strobe pulse.

```
#RESET
#PIPES P0,P1,P2,P3,P4,P5,P6
#IDEF A 7
  >CLOCK EXTERNAL
  >SET 0 S0
  >SET 1 S0
  >SET 2 S0
  >SET 3 S0
  >SET 4 S0
  >SET 5 S0
  >SET 6 S0
  >TIME 4.25
  >COUNT 107310
  >DIRECT(0,P0)
  >DIRECT(1,P1)
  >DIRECT(2,P2)
  >DIRECT(3,P3)
  >DIRECT(4,P4)
  >DIRECT(5,P5)
  >DIRECT(6,P6)
  >END
#PDEF B
  >FORMAT(#,P0,P1,P2,P3,P4,P5,P6)
  >END
#START A,B
```

Note: The same PDAS input is assigned to all seven PDAS input channels so that a sequence of seven samples of the same variable are collected during one DAC output sample interval.

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