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Signal Waveform Generator Performance Specifications and Certification Requirements

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13. ABSTRACT (Maximum 200 words)

This report provides important information for users of the NHTSA signal waveform generator (SWG) and for those organizations that would perform testing to certify the accuracy of SWG signals.

The performance specifications for the SWG are based on the results of testing of all of the ten signal waveform generators fabricated for NHTSA.

The SWG certification requirements specify the measurements, measurement equipment, measurement procedures, and the measured SWG performance required to certify that a SWG is acceptable for use in testing a crash or sled test data acquisition system.

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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 NHTSA crash 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.

This report presents the performance specifications for the ten SWGs, based on SWG certification test results of all ten SWGs, and the requirements for certifying that a SWG is acceptable to use as a reference for testing a crash test data acquisition system.

The SWG was custom designed and built in the early 80's because the required technology was not commercially available. The past ten years of experience gained with the SWG, has shown that the basic concept and electronic design are good, but its mechanical construction has left the SWG vulnerable to shipment from one site to another and reliability on site is poor. Since the required technology is now available, the National Highway Traffic Safety Administration has developed an SWG hardware upgrade that uses commercially available hardware to the extent possible and can be used by any crash or sled test site in the world to evaluate its own system. Information about and documentation for the SWG hardware upgrade can be obtained from Ms. Randa Radwan Samaha, NRD-11, National Highway Traffic Safety Administration, Office of Crashworthiness Research, 400 7th Street, S. W., Washington, DC, 20590.

The work covered by this report was funded by the NHTSA Research and Development Office of Crashworthiness Research. Ms. Randa Radwan Samaha was the Contract Technical Monitor for this work.

METRIC/ENGLISH CONVERSION FACTORS

ENGLISH TO METRIC	METRIC TO ENGLISH
LENGTH (APPROXIMATE)	**LENGTH** (APPROXIMATE)
1 inch (in) = 2.5 centimeters (cm)	1 millimeter (mm) = 0.04 inch (in)
1 foot (ft) = 30 centimeters (cm)	1 centimeter (cm) = 0.4 inch (in)
1 yard (yd) = 0.9 meter (m)	1 meter (m) = 3.3 feet (ft)
1 mile (mi) = 1.6 kilometers (km)	1 meter (m) = 1.1 yards (yd)
	1 kilometer (km) = 0.6 mile (mi)
AREA (APPROXIMATE)	**AREA** (APPROXIMATE)
1 square inch (sq in, in^2) = 6.5 square centimeters (cm^2)	1 square centimeter (cm^2) = 0.16 square inch (sq in, in^2)
1 square foot (sq ft, ft^2) = 0.09 square meter (m^2)	1 square meter (m^2) = 1.2 square yards (sq yd, yd^2)
1 square yard (sq yd, yd^2) = 0.8 square meter (m^2)	1 square kilometer (km^2) = 0.4 square mile (sq mi, mi^2)
1 square mile (sq mi, mi^2) = 2.6 square kilometers (km^2)	10,000 square meters (m^2) = 1 hectare (ha) = 2.5 acres
1 acre = 0.4 hectare (ha) = 4,000 square meters (m^2)	
MASS - WEIGHT (APPROXIMATE)	**MASS - WEIGHT** (APPROXIMATE)
1 ounce (oz) = 28 grams (gm)	1 gram (gm) = 0.036 ounce (oz)
1 pound (lb) = .45 kilogram (kg)	1 kilogram (kg) = 2.2 pounds (lb)
1 short ton = 2,000 pounds (lb) = 0.9 tonne (t)	1 tonne (t) = 1,000 kilograms (kg) = 1.1 short tons
VOLUME (APPROXIMATE)	**VOLUME** (APPROXIMATE)
1 teaspoon (tsp) = 5 milliliters (ml)	1 milliliter (ml) = 0.03 fluid ounce (fl oz)
1 tablespoon (tbsp) = 15 milliliters (ml)	1 liter (l) = 2.1 pints (pt)
1 fluid ounce (fl oz) = 30 milliliters (ml)	1 liter (l) = 1.06 quarts (qt)
1 cup (c) = 0.24 liter (l)	1 liter (l) = 0.26 gallon (gal)
1 pint (pt) = 0.47 liter (l)	1 cubic meter (m^3) = 36 cubic feet (cu ft, ft^3)
1 quart (qt) = 0.96 liter (l)	1 cubic meter (m^3) = 1.3 cubic yards (cu yd, yd^3)
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)	**TEMPERATURE** (EXACT)
°C=5/9(°F - 32)	°F=9/5(°C) + 32

QUICK INCH-CENTIMETER LENGTH CONVERSION

INCHES	0			1			2			3			4			5
CENTIMETERS	0	1	2		3	4	5	6	7		8	9	10	11	12	13

QUICK FAHRENHEIT-CELSIUS 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 NIST Miscellaneous Publication 286, Units of Weights and Measures. Price $2.50. SD Catalog No. C13 10286.

Updated 8/1/96

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ABBREVIATIONS AND ACRONYMS

ADC	analog-to-digital converter
DAC	digital-to-analog converter
DAS	data acquisition system (In this report, DAS primarily refers to a crash or sled test data acquisition system.)
dB	decibel
DMM	digital multimeter
DT0	delayed time-zero
EPROM	erasable programmable read-only memory
HIC	head injury criterion (a number computed to indicate the severity of head injury expected from an acceleration input)
MHz	megahertz
ms	milliseconds
mV	millivolts
PPM	parts-per-million
RAM	random access memory
rms	root-mean-square
SAE	Society of Automotive Engineers
SPSW	signal processing software (refers to software developed to analyze SWG output waveforms)
SWG	signal waveform generator
TDAS	test data acquisition system
T0	time-zero
TTL	transistor-transistor-logic
μs	microsecond

PART I

SIGNAL WAVEFORM GENERATOR PERFORMANCE SPECIFICATIONS

1. DESCRIPTION

This report provides important information for users of the NHTSA signal waveform generator (SWG) and for those organizations that would perform testing to certify the accuracy of SWG signals.

The SWG is used in testing to verify that the performance of a DOT crash and sled test contractor's data acquisition system (DAS) meets certain requirements of the Society of Automotive Engineers (SAE) recommended practice "Instrumentation for Impact Test" (SAE J211/1 MAR95) [1], as required by DOT contract specifications.

The evaluation test of a crash test facility DAS is performed by providing precise electrical signals at the sensor interface (input) to the DAS and recording those signals with the DAS. The recorded signals are processed by special purpose signal processing software to measure the quality of DAS performance. The test contractors are required to set up their DAS in the same manner as for a regular crash test except that a NHTSA furnished SWG is connected to the sensor interface to provide the input signals. The SWG provides precise waveform and time reference inputs to the DAS for testing and is described in detail in the SWG operator's manual [2].

The SWG functions by storing the precision waveforms digitally in erasable programmable read-only-memory (EPROM). When a test is performed, the waveform data is read out of EPROM 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 provides a total of 20 output channels. Sixteen of the output channels provide precision waveforms at signal levels and source impedances representative of bridge circuit transducer outputs. These 16 channels are called "data" channels in this specification. Two of the output channels provide the same waveforms at relatively high voltage signal levels for SWG check-out use and are called "check-out" channels in this specification. Two output channels provide a time reference signal and are called "time reference" channels in this specification.

1.1 SWG OUTPUT LEVELS

Signal output levels from the data channels are switchable between a high level, ±100 mV, labeled "piezo electric" and a low level, ±10 mV, labeled "strain gage." The check-out channels have corresponding full scale output voltage levels of ±5.0 volts and ± 0.5 volt. The time reference channels are transistor-transistor-logic (TTL) compatible.

The 16 data channels each present an equivalent source impedance of approximately 350 ohms and provide an ungrounded differential output. The two check-out channels provide "single ended" outputs.

1.2 CALIBRATION OUTPUTS

After the SWG is powered up and it completes its self test, all waveform outputs are at the zero level. This is the zero level calibration voltage from each output. Pressing the "calibration" button produces a positive or negative full scale calibration voltage level at each waveform output. Full scale calibration level is defined as the SWG output voltage level that represents a full scale value of the measurand being simulated. Calibration output polarity is determined by the setting of the "calibration mode" switch.

1.3 WAVEFORM OUTPUTS

The SWG provides two precision waveform sequences simultaneously, shown in Figure 1-1. Each waveform sequence is available on eight of the data channels and one of the check-out channels. Each waveform sequence consists of the following, in the order specified: rectangle, half-sine, stair, sum-of-sines, and crash waveforms.

The Group 1 waveform sequence contains the X components of the half-sine and crash waveforms and the Group 2 waveform sequence contains the Z components of these waveforms. The rectangle and stair waveforms are used to measure channel time accuracy, amplitude accuracy, and amplitude overshoot. The half-sine pulse 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 data recorded on that channel.

1.3.1 Rectangle Waveform

The rectangle waveform consists of a square wave that alternates between the plus and minus full scale calibration levels. The duration of each positive level is 5.978 milliseconds (ms) and the duration of each negative level is 4.026 ms. Positive-going leading edges occur at 10.004 ms intervals starting at zero ms (time-zero). Negative-going leading edges occur at 10.004 ms intervals starting 5.978 ms after time-zero. The rectangle waveform consists of ten complete cycles. The duration of the rectangle waveform is 99.979 ms because the last cycle of the rectangle waveform is 0.061 ms shorter than the other nine. The exact timing of all of the waveforms has been incorporated into the SWG signal processing software (SPSW).

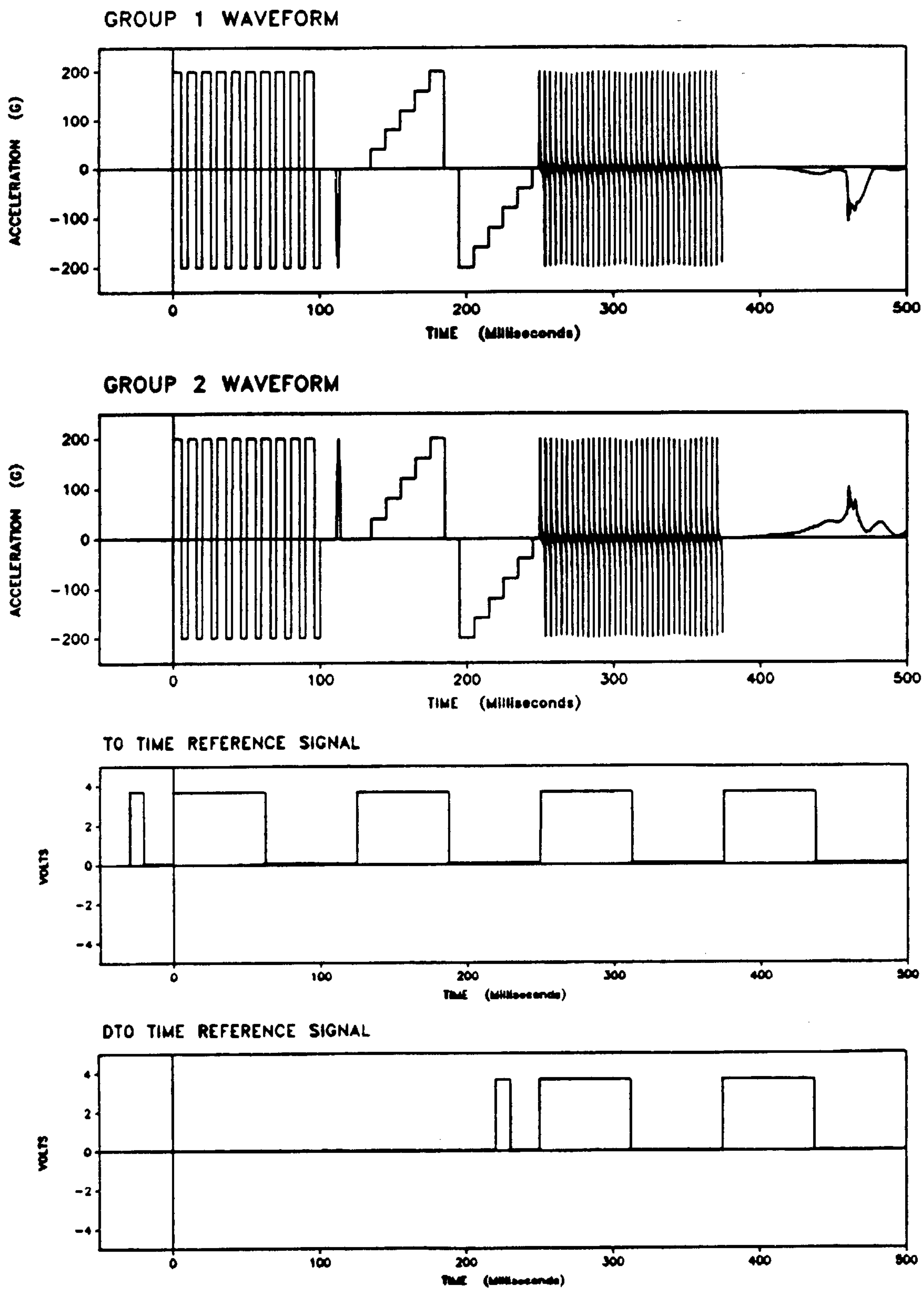

FIGURE 1-1 SWG WAVEFORM OUTPUTS

1.3.2 Half-Sine Pulse

The half sine pulse waveform shares the test waveform segment with the rectangle waveform. The peak value of each half sine pulse is the corresponding full scale calibration level. The width or duration of each half sine pulse is 2.989 ms. The Group 1 waveform sequence has a negative half sine pulse and the Group 2 waveform sequence has a positive half sine pulse. Both half-sine pulse components are synchronized in time. The half-sine pulse was designed to simulate a short duration impact which is often found in actual crash test data.

1.3.3 Stair Waveform

The stair waveform, which is used to measure amplitude linearity, starts at zero signal level and after 10.004 ms proceeds toward the positive full scale calibration level in five 20% of full-scale increments, each having a 10.004 ms duration. The waveform then returns to zero signal level for 9.943 ms after which it drops to the negative full-scale calibration level for 10.004 ms. At this time it proceeds toward the zero signal level in five 20% of full-scale increments, each of 10.004 ms duration except the last at zero level. Total duration of the waveform is 124.974 ms.

1.3.4 Sum-of-Sines Waveform

The sum-of-sines waveform is a sinusoidal composite consisting of the sum of 14 sinusoids. The frequencies of the sinusoids are the 14 consecutive integer harmonics of the lowest (fundamental) frequency. Each sinusoid in the summation has the same amplitude. The fundamental signal frequency is 273.4375 Hz. Therefore, the signal frequencies are 273.4375, 546.875, ..., 3828.125 Hz. The peak values of the sinusoidal composite signal are the full-scale calibration level. The duration of the sinusoidal composite is 124.2265 ms. This provides approximately 34 full cycles of the lowest frequency signal. These signal frequencies coincide with 14 of the output frequencies of the analyzing 2048-point discrete Fourier transforms when the sampling intervals are 75, 100, and 125 microseconds. Until recently, these same sampling intervals were used by all NHTSA crash and sled test contractors. Since then, the SWG SPSW has been adapted to process the same sum-of-sines waveform sampled at different time intervals.

1.3.5 Crash Pulse

The crash pulse waveform consists of the "X" and "Z" components of actual dummy head acceleration crash pulse data from a vehicle-to-barrier crash test. The "X" component is in the same test waveform sequence as the "X" component of the half sine pulse and the "Z" component is in the other test waveform sequence. The head injury criteria (HIC) value of the resultant pulse achieved by the vector summation of the "X" and "Z" components is 929.54.

1.4 TIME REFERENCE OUTPUTS

The time reference outputs 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 starts when the "record" switch on the SWG control panel is pressed and 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.

The "delayed time zero" (DT0) time reference signal provides the same time reference information for situations in which only the last two waveforms in the sequence are to be recorded. The measured time durations of each pulse in the T0 and DT0 outputs are shown in Figure 1-2.

1.5 PHYSICAL DESCRIPTION

The SWG is 12.7 x 10.1 x 9.2 inches in size, weighs 12 pounds, and is designed to be used at crash test facilities by facility personnel. A photograph of the SWG is shown in Figure 1-3.

1.5.1 Control Panel

Five lights on the SWG control panel indicate the following:

Warm-up	The SWG is going through its programmed warm-up sequence.
Fail	The SWG has failed its internal self-test procedure.
Ready	The SWG has passed its self-test and will produce waveforms or calibration voltages on command.
Calibration	The SWG is producing calibration voltages on its data and check-out terminals.
Recording	The SWG is producing precision waveforms on its data and check-out terminals.

Three rotary switches on the SWG control panel perform the following functions:

Transducer Type	Controls waveform output voltage level.
Time Zero Polarity	Controls the polarity of the time reference pulses.
Calibration Mode	Controls the polarity of the calibration voltages.

Two momentary contact, push button switches on the SWG control panel perform the following functions:

Recording	Controls the start of waveform production.
Calibration	Controls the production of calibration voltages.

One toggle switch on the SWG control panel controls the application of AC power to the SWG.

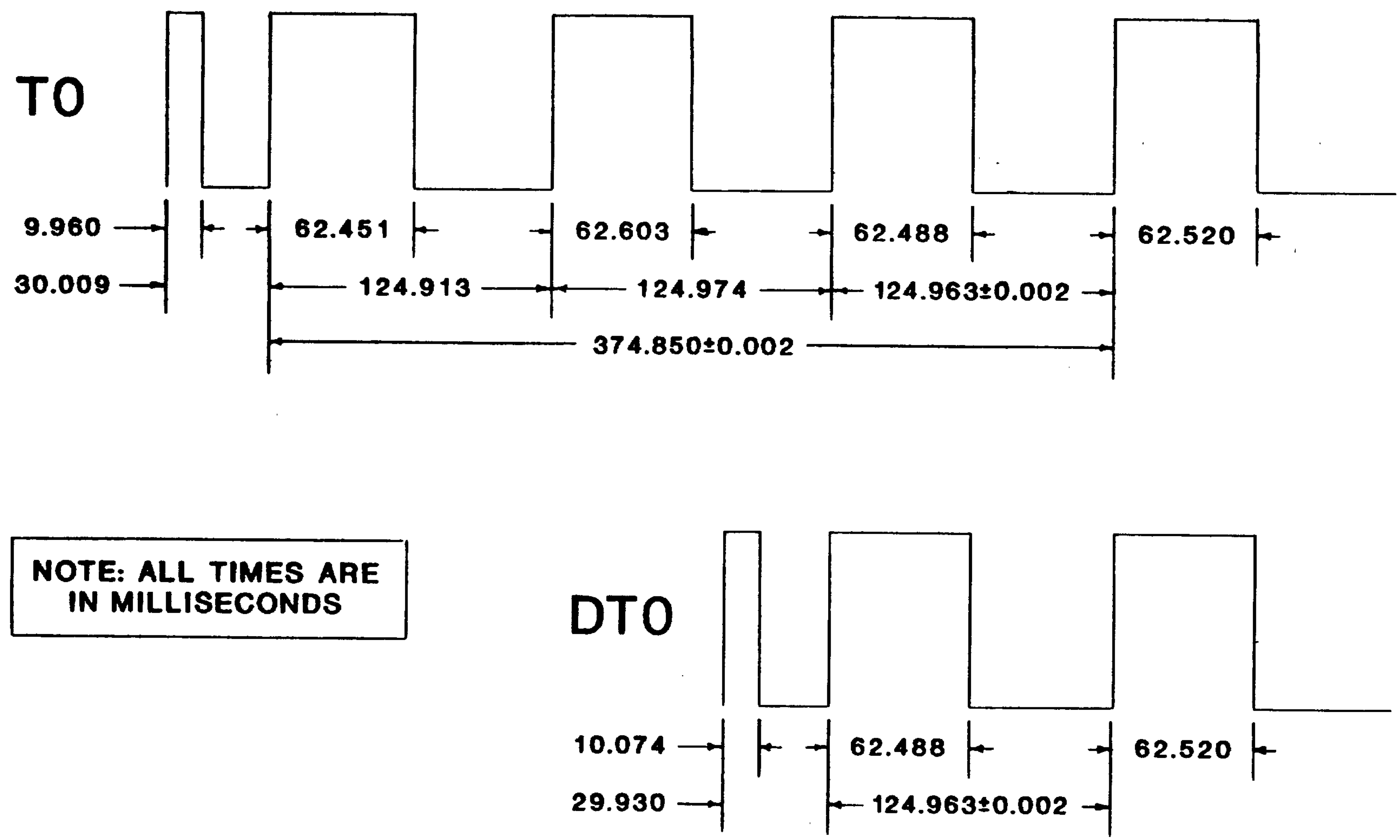

FIGURE 1-2 TIME REFERENCE SIGNAL TIMING SUMMARY

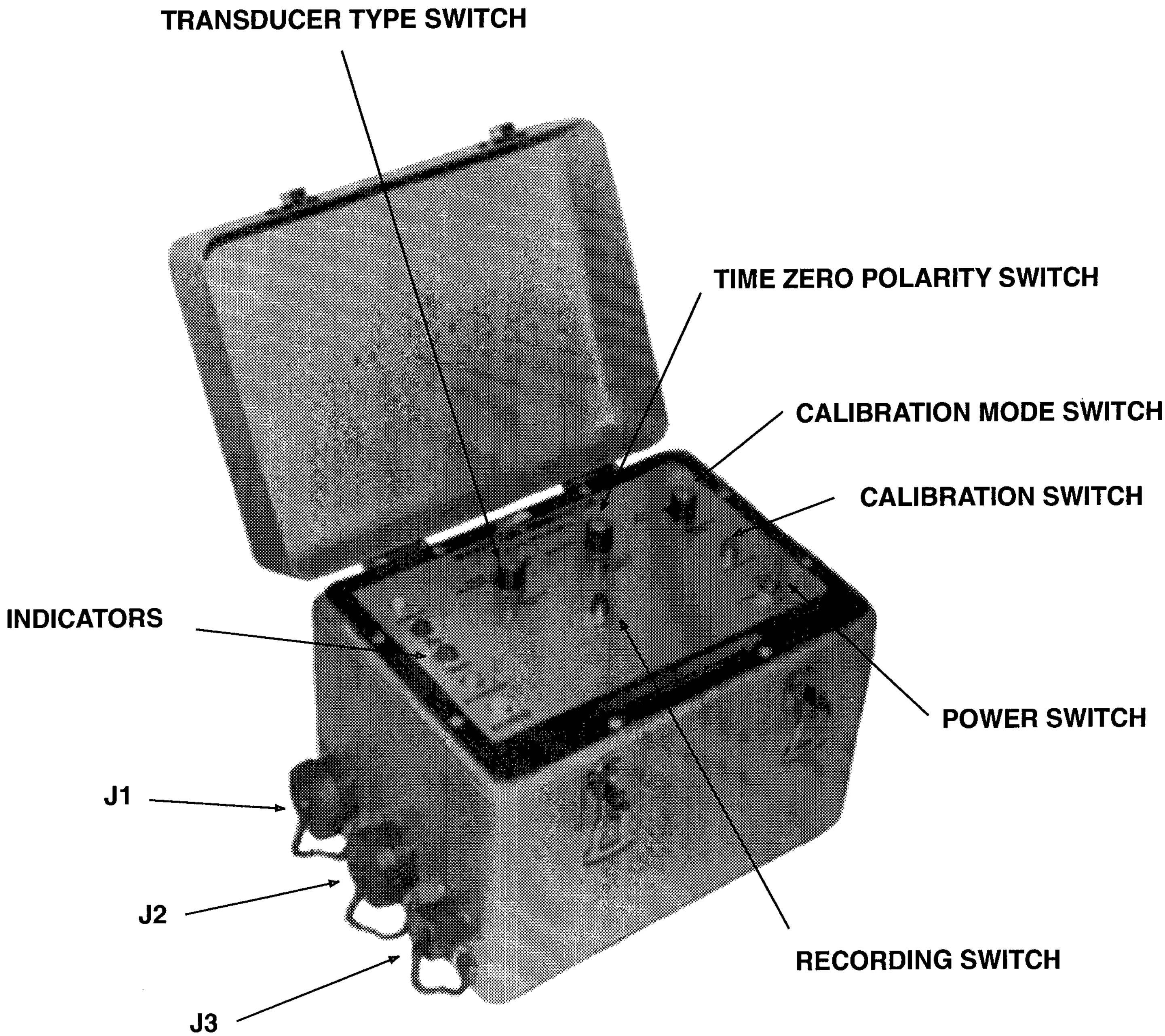

FIGURE 1-3 GENERAL OVERVIEW OF THE WAVEFORM GENERATOR INSTRUMENT

1.5.2 <u>Remote Control</u>

The SWG will accept TTL-compatible signals to control generation of waveforms, generation of a calibration signal, and polarity of the calibration signal. The remote control voltages are applied to the designated contacts of connector J3.

1.6 POWER REQUIREMENTS

The waveform generator is powered from a 117 VAC 60 Hz power source. Instructions are provided in the SWG operator's manual [2] for changing the power supply input to accept 230 VAC 50 Hz power.

1.7 OPERATING ENVIRONMENT

The waveform generator meets all of its performance specifications while operating in an ambient temperature range of -10°C to 50°C.

1.8 SELF-TEST FUNCTIONS

Each time SWG power is turned on, the waveform generator performs the following self tests:

1) Function of control panel indicator lamps
2) Zero and full scale output of the DAC are within ±30 mV of the required level.
3) Checksum of precision waveform memory to assure that waveform storage is correct.

If these tests are passed, the SWG will be in the ready mode, indicated by illumination of the READY light.

If the SWG fails any of the self tests, the FAIL indicator light and a combination of the other indicators will flash to indicate the type of failure, and the SWG will not produce waveforms or calibration voltages. The failure codes are as follows:

1) FAIL and CALIBRATION flash to indicate DAC output voltage is out of tolerance.

2) FAIL, READY, and one other light flash to indicate a checksum error in the Group 1 EPROMs.

3) FAIL, READY, CALIBRATION, and one other light flash to indicate a checksum error in the Group 2 EPROMs.

2. ACCURACY

The stated accuracy available from the SWG is based on the results of certification testing of all ten SWGs.

2.1 TIME REFERENCE

The time reference (data clock) of the waveform generator is accurate to within 7 parts per million (PPM) over the ambient temperature range of -10°C to +50°C. The 7 PPM accuracy implies a maximum time reference error of ±3.5 μs during the 0.5 s waveform duration.

2.2 AMPLITUDE

The generator output waveforms, which are used to measure amplitude accuracy, are accurate to within ±0.1% of the full scale calibration level at the "piezo resistive" setting and within ±0.6% of the full scale calibration level at the "strain gage" setting.

2.3 CALIBRATION OUTPUTS

The zero offsets of the data channels are less than ±0.25 mV and of the check-out channels less than ±105 mV. The full scale calibration voltage at each data channel output is 100±0.4 mV at the high level and 10±0.4 mV at the low level. The full scale calibration voltage at each check-out channel output is 5±0.12 V at the high level and 0.5±0.12 V at the low level.

2.4 OUTPUT NOISE

The root-mean-square value of the noise component of the SWG output signals is less than 0.05% of full scale at the "piezo resistive" setting and less than 0.15% of full scale at the "strain gage" setting.

2.5 FREQUENCY RESPONSE

The amplitude frequency response of the SWG is "flat" (zero attenuation with frequency) to within ±0.03 dB from 273 to 2838 Hz.

2.6 PROCESSING SOFTWARE

The SWG signal processing software used to evaluate the recorded waveforms has been coordinated with the measured waveform time intervals to within ±2 μs for the time reference signals, the rectangle, half-sine, and stair waveforms.

PART II

SIGNAL WAVEFORM GENERATOR CERTIFICATION REQUIREMENTS

Part II describes the measurements, measurement equipment, measurement procedures, and measured SWG performance required to certify that the outputs of each SWG are sufficiently precise to serve as a reference to qualify a DOT crash test contractor's data acquisition system.

3. REQUIRED MEASUREMENTS

3.1 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.

The second through the fifth factors are related to the first by software control. Therefore, only the first, and one of the second through fifth factors need be checked for SWG certification. The fourth and fifth factors are checked automatically in processing the test data collected from the SWG.

3.1.1 Clock Frequency

The frequency of the SWG crystal clock oscillator is measured because it is this oscillator that establishes the SWG timing reference.

3.1.2 Waveform Timing

Any indication of excessive channel-to-channel time difference or excessive errors in waveform timing indicates an SWG malfunction.

3.2 AMPLITUDE ACCURACY

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

3.2.1 Calibration Level

The positive and negative calibration voltages at both "piezo resistive" and "strain gage" settings from all SWG output channels are measured to confirm that each channel output is providing the correct calibration voltage level. "Zero" output voltages at both output level settings are also measured to establish "zero" offsets.

3.2.2 Waveform Amplitudes

Measurement of waveform accuracy is the primary measurement in the SWG certification process. The SWG analog waveform outputs are recorded using a precise test data acquisition system (TDAS). This TDAS must be sufficiently precise that its errors are significantly smaller than the error tolerance for the SWG. The recorded average calibration outputs, waveform data files, and time reference files are processed using the SWG SPSW which is available from the NHTSA Office of Crashworthiness Research, telephone 9202) 366-4850.

A detail description of and instructions for the use of the SWG SPSW are contained in the SWG SPSW documentation [3]. Although the specific program for processing the SWG certification test data is different from the program used for processing crash test DAS evaluation test data, the procedure for its use is very nearly the same. The few more steps that are required are explicitly directed by the program when it is used.

3.3 FREQUENCY RESPONSE

For the SWG to perform an accurate measurement of frequency response, the amplitude frequency response of the SWG must be "flat" (no significant attenuation with frequency) at all signal frequencies (273 to 3828 Hz).

4. MEASUREMENT EQUIPMENT REQUIREMENTS

4.1 TIMING ACCURACY

4.1.1 Clock Frequency

The frequency counter used to measure SWG crystal clock oscillator frequency shall be accurate to 1 part per million (PPM). Its time interval measurement shall be accurate to one microsecond (μs). Many frequency counters are available that have this capability. The Fluke 1910A-04 and PM6662/-3-, the Hewlett-Packard 5386A-004, the Keithley 775A/51/52, the Keithly Metrabyte PCIP-CNTR/TCXO, and the Tektronix CMC251 satisfy this requirement.

4.1.2 Waveform Timing

The waveform timing is measured using the TDAS described below.

4.2 AMPLITUDE ACCURACY

4.2.1 Calibration Voltage Levels

A 4½ digit digital multimeter (DMM) that maintains its errors for DC voltage measurements to no greater than ±0.1% of reading or ±20 μV, whichever is greater, will be sufficient for this measurement. Digital multimeters that meet this requirement include the Fluke 8050A, the Keithley 175A, and the Simpson 460-6.

4.2.2 Test Data Acquisition System (TDAS)

The TDAS used to measure waveform accuracy shall meet the following salient performance requirements:

1. The test data acquisition system (TDAS) shall be in the form of an "option board" that fits into the option slot of and functions in an IBM compatible personal computer. The model of the PC that is used will determine which DAS option boards are usable.

2. The TDAS shall be able to operate in the following externally clocked sweep mode: after an external clock pulse is applied to the TDAS, the TDAS will sample each one of a sequence of at least four channels once and then wait for the application of the next external clock pulse before repeating the sampling sequence. The time interval between externally applied clock pulses is expected to be 30.5 μs. The time interval between the sampling of each input channel in the sequence shall be adjustable to 5.0 μs. The time elapsed between the external clock pulse and the sampling of the two analog input channels shall be at least 20 μs. The two digital input channels shall be sampled before the analog input channels. (In the present SWG certification testing setup used at the Volpe Center, six channels are sampled at 5 μs intervals. The data from the first two are

ignored, the third and fourth channels sampled are the digital time reference inputs, and the fifth and sixth channels are the analog inputs.)

3. The duration of each data acquisition run will be 530 milliseconds which will result in the collection of 17,377 samples from each channel sampled. The data from four of the input channels, 69,508 samples, will have to be transferred to PC RAM or stored in on-board RAM.

4. The TDAS shall have the capability of acquiring data continuously after being started from a software command or an external trigger pulse.

5. Sample interval in all modes shall be adjustable over a range of from 5.0 μs per sample to 5.0 ms per sample.

6. At least 12-bit words shall be produced by the analog-to-digital conversion process.

7. The TDAS accuracy shall be ±0.03% of full range while meeting the above requirements.

8. The TDAS shall have at least two channels of programmable output capability. These output channels may be either analog or digital in nature. They will be used to drive two TTL inputs on the SWG. (Alternatively, a separate I/O board may be used.)

9. It will be necessary to acquire and average two sets of approximately 8000 samples of data from each of two channels and then acquire 17,377 samples from each of four channels within the time interval of approximately 5 seconds. Either the TDAS shall have the capability to average two sets of 8000 data values from each of two input channels in real time or near real time or the averaging shall be accomplished by the PC at a later time from data acquired and stored during the 5-second time interval.

10. The TDAS or the host PC and its software shall have the capability to translate the acquired data to ASCII format and write the data to disk storage.

11. The TDAS shall have the capability of accepting analog input signals in the range ±2.5, ±5.0, or ±10.0 volts.

Microstar Laboratories of Redmond, WA provides a plug-in option board that satisfies these specifications and requires only a basic IBM PC compatible host. It is possible that plug-in option boards from Keithly Metrabyte (Taunton, MA), Computer Boards (Mansfield, MA), Data Translation (Marlboro, MA), or RC Electronics (Goleta, CA) will perform the same functions when plugged into a more advance model of IBM compatible PC.

4.2.3 <u>Test Interface Electronics</u>

To utilize the full dynamic range of the TDAS when measuring "sensor level" outputs from the SWG, two instrumentation amplifiers are required to amplify the ±100 mV and ±10 mV outputs to the full input range of the TDAS. These amplifiers must be fast and accurate. Amplifier settling time shall be less than 15 μs to settle from a 20 mV step (-10 mV to +10 mV or +10 mV to -10 mV) to 0.01% of final value when amplifier gain is set to 250. Amplifier nonlinearity errors shall be less than ±0.03% of full scale when amplifier gain is set to 250. The Burr-Brown INA110 and the Analog Devices AMP02 meet these requirements. Very likely there are other integrated circuit instrumentation amplifiers that will meet these requirements. The gain of these amplifiers shall be adjusted so that full scale SWG output voltage plus noise is slightly less than full scale TDAS input voltage range. At the same time the output noise of these amplifiers shall be as small as possible. It would be desirable to keep rms output noise to less than 0.05% of full scale voltage.

To test the timing of the SWG outputs to within the accuracy of one 30.5 μs SWG DAC output sampling interval, it is necessary to prepare the SWG for testing as described in section 5.1 below.

The DAC strobe signal is a 50% duty cycle square wave that is active whenever the SWG is powered. Furthermore, when the waveforms are being produced, the update time interval for the DAC is 30.5 μs. But at all other times, the update interval for the DAC is one-fourth of 30.5 μs or 7.625 μs. The mechanism available to synchronize the sampling of the TDAS to the SWG output is to feed the SWG DAC strobe pulse into the external clock input of the TDAS. Since the DAC strobe signal is always active, the DAC strobe signal seen by the TDAS has to be gated so as to start the TDAS sampling when the waveform outputs are produced. The time reference input can be used to start the DAC strobe signal to the TDAS. Gating logic that will do this task is shown in Figure 4-1.

4.3 FREQUENCY RESPONSE

Frequency response is computed from the data acquired by the TDAS described above. The SWG signal processing software (SPSW) used for processing the data acquired by the TDAS determines amplitude frequency response from the recorded sum-of-sines waveform.

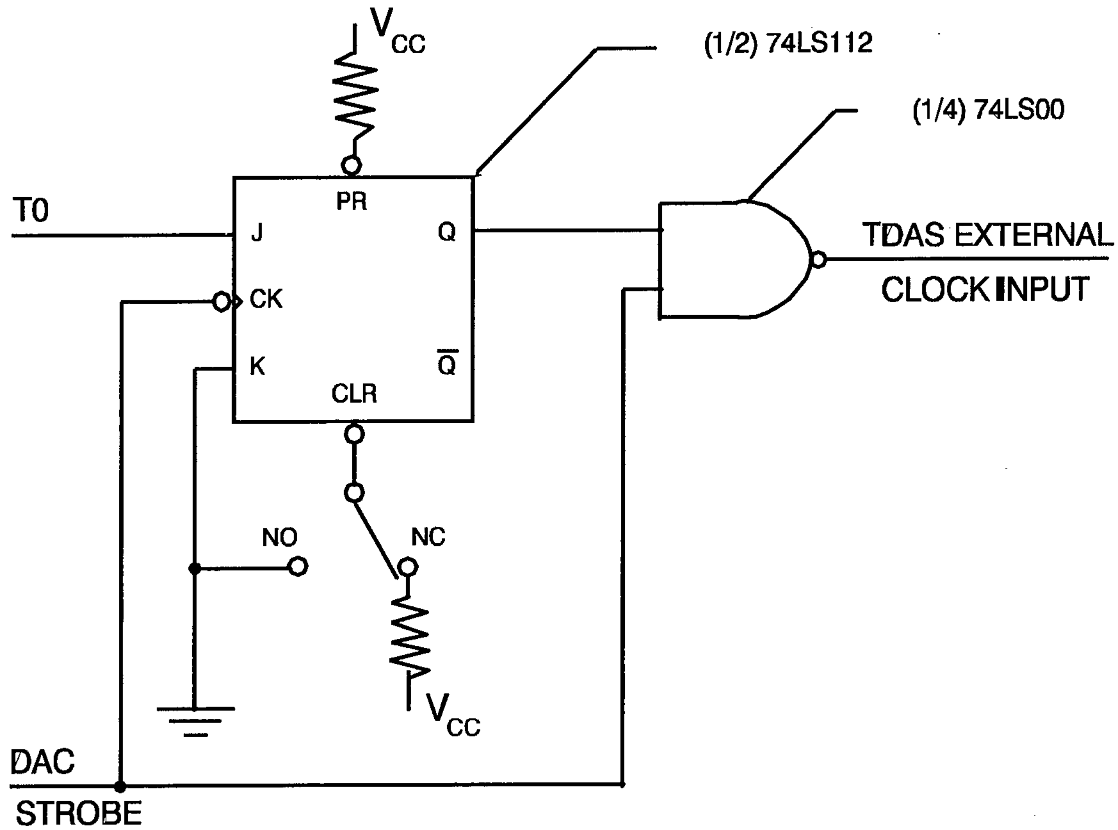

FIGURE 4-1 GATING LOGIC

5. MEASUREMENT PROCEDURES

5.1 PREPARATION OF SWG FOR TESTING

The timing of the SWG outputs is to be tested to within the accuracy of one 30.5 µs SWG DAC output update interval. Therefore, it is necessary to synchronize the TDAS sampling to the DAC strobe signal.

1. To gain access to the DAC strobe signal, 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.
2. Connect wires from W1-50 to J1-pin H and from W1-56 to J1-pin J. Use of coaxial cable for these connections is recommended. W1-50 carries the DAC strobe signal and W1-56 is a ground connection. J1 is the group 1 waveform output connector.
3. Finally, reassemble the SWG before testing. Now the DAC strobe signal can be transmitted from the SWG by coaxial cable.

5.2 TIMING ACCURACY

5.2.1 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.
7. Connect a return lead from the frequency counter to the SWG chassis.
8. Wait at least 30 minutes for readings to stabilize.
9. After the frequency display becomes stable, record the T2 output frequency.
10. Remove probes, remove power, and reassemble the SWG.

5.2.2 Waveform Timing

See Section 5.3.3 below.

5.3 AMPLITUDE ACCURACY

5.3.1 Calibration Voltage Levels

1. Apply power to the DMM (or digital multimeter) 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 level output voltage and positive and negative calibration voltage levels.

4. With the "transducer type" switch in the "strain gage" position, record zero level output voltage 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. Record zero level output voltage and positive and negative calibration level voltages for the transducer type set to "piezo resistive" and to "strain gage" positions.

8. Repeat step 7 for the SWG "High Level Group 2" output.

9. Remove probes and power from the DMM and the SWG.

5.3.2 Calibration and Data Acquisition Program

A 12-bit analog-to-digital converter (ADC) will produce a number that corresponds to the voltage applied to its input. This number will range from -2^{11} (-2048) to 2^{11}-1 (2047) or some binary multiple of these numbers. The Microstar DAP 2400/5, used for testing the SWG at the Volpe Center produces numbers that vary from -32768 to 32752. The SWG SPSW used for SWG certification testing requires the SWG zero and positive full scale values from the ADC as input before performing the analysis.

The calibration and data acquisition process is programmed so that once started, all calibration and waveform data is acquired during an interval less than two seconds long. The remote control inputs of the SWG are used to initiate the production of calibration voltages and waveforms.

- Program the TDAS or the PC to provide a TTL high level on the SWG "calibration initiate" remote control input for 0.6 seconds to obtain the full scale output voltage levels from the SWG.

- Program the TDAS to start data acquisition of the calibration outputs from a group 1 waveform channel and a group 2 waveform channel long enough to acquire 8000 data points from each channel at a 30.5 μs sampling interval.

- Program the TDAS or the PC to average each set of 8000 points and print the averages.

- Program the TDAS or the PC to set the remote "calibrate initiate" input to zero.

- Program the TDAS to acquire 8000 data points of the zero output levels from each waveform group channel, calculate the averages of these zero values, and print the average values.

- Program the TDAS to sample each input channel once each time it receives a pulse on its external clock input. Assuming that six input channels will be sampled once during every 30.5 μs interval, assign TDAS input channels 0 and 1 to TDAS input connection 3 (shorted to ground).

- Assign TDAS input channel 2 to TDAS input connection S4 (DT0).

- Assign TDAS input channel 3 to TDAS input connection S0 (T0).

- Assign TDAS input channel 4 to TDAS input connection S1 (Group 1 waveform).

- Assign TDAS input channel 5 to TDAS input connection S2 (Group 2 waveform).

By assigning the input channels in this order, a 20 μs time delay is built in between the SWG DAC strobe pulse and the first sampling of an analog data channel to provide the instrumentation amplifiers time to settle before their outputs are sampled.

The next stage of the program is for the TDAS to be armed to start collecting SWG waveform data when it starts to receive external clock pulses. Then program the TDAS or the PC to provide a TTL high level to the SWG remote "recording initiate" control input for approximately 1 ms. All of the above programming is in effect, one program.

Once the test interface electronics module is reset, a command from the PC keyboard starts the process which then proceeds automatically. An annotated program for the Microstar DAP 2400/5 TDAS is provided in the Appendix. Although the averaging of 8000 samples of the calibration voltage and zero output level are now specified, the program for the DAP 2400/5 was written to collect and average 16,000 samples of each voltage level.

The reference above and in the following text to input connections and input channels is used as an example of how to create the required 20 μs delay. By way of explanation, the input connection is the actual hardware location to which the wires containing the various signals are attached. The input channels are a creation of the software that are sampled in numerical order starting with channel zero. The assignment statements use software to connect the input connections to the input channels.

5.3.3 Data Acquisition and Processing Procedure

1. This procedure assumes that a Microstar DAP 2400/5 board (TDAS) has been installed and configured in the host PC/XT/AT/386/486 compatible computer.

2. Connect the SWG Time Zero (T0) output to TDAS input connection 0 and to the test interface electronics T0 input.

3. Connect the SWG DAC strobe signal to the test interface electronics DAC strobe input.

4. Connect the test interface electronics TDAS sync output to the TDAS 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 TDAS 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 TDAS input connection 2.

7. Short TDAS input connection 3 by connecting a wire from input connection 3 to ground.

8. Connect the SWG Delayed Time Zero (DT0) to TDAS input connection 4.

9. Connect TDAS analog output A0 to the SWG remote "calibrate initiate" control input.

10. Connect TDAS analog output A1 to the SWG remote "recording initiate" control input.

11. Apply power to the TDAS, the test interface electronics, and the SWG, in that order. Applying power to the equipment in any other order could destroy the input amplifiers of the unpowered equipment.

12. 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 SWG "calibration mode" switch to "manual positive."

13. Following the TDAS instructions, set up the TDAS to convert the recorded data to ASCII and write them to hard disk.

14. Press and release the reset button on the test interface electronics and start the TDAS data acquisition process.

15. After TDAS processing and recording of the sampled data is complete, follow TDAS instructions to close the logged disk file.

16. Print the first part of the logged data file. Embedded in this printout will be the average zero and calibration values for both waveform channels. Record the zero and calibration values for use in processing the data.

17. Edit the logged data file to remove the program listing header and any non-ASCII characters from the file.

18. Set the SWG transducer type switch to the "strain gage" setting, switch the instrumentation amplifiers to high gain, and repeat steps 13 through 17.

19. A program to process these data on the PC, SWGCPRC2.FOR, is available from the NHTSA Research & Development, Office of Crashworthiness Research, Safety Systems & Analysis Division (NRD-11). SWGCPRC2.FOR accepts the outputs of the DAP 2400/5 directly as inputs (once the program listing header has been removed).

6. CERTIFICATION REQUIREMENTS

The following paragraphs specify the SWG performance required for certification in terms of specific test results. If the SWG under test fails to satisfy these specifications, it shall be repaired and retested before being placed in service.

6.1 TIMING ACCURACY

The frequency of the T2 crystal clock oscillator shall be 4,000,000 ±40 Hz.

6.2 AMPLITUDE ACCURACY

6.2.1 Calibration Level

It would be desirable for the voltage tolerances for zero level voltage outputs to be ±0.25% of nominal full scale calibration level and the positive and negative calibration voltage levels to be within ±2% of the nominal full scale values. While some of these tolerances have been achieved, many have not. Table 6-1 provides the envelope of measured values for all ten SWGs tested. Note that the 5 and 0.5 volt level outputs are used primarily to observe waveform outputs on an oscilloscope, and are not used directly for testing crash test data acquisition systems, the meeting of the desired voltage level tolerances for these outputs is not as critical as it is for the 10 and 100 mV level output signals. Since the errors observed at the 10 mV full scale output level are as large as those observed at the 100 mV full scale output level, it is recommended that only the 100 mV full scale output level be used to test crash and sled test data acquisition systems.

TABLE 6-1 CALIBRATION VOLTAGE LEVELS AND TOLERANCES

Nominal Full Scale Output Level	Zero Offset Tolerance	Positive Calibration Level	Negative Calibration Level
5.0 V	±105 mV	4.998±0.12 V	-5.0±0.12 V
0.5 V	±105 mV	0.499±0.12 V	-0.5±0.12 V
100.0 mV	±0.25 mV	100.0±0.4 mV	-100.±0.4 mV
10.0 mV	±0.25 mV	10.0±0.4 mV	-10.±0.4 mV

6.2.2 Waveform Amplitudes

The accuracy requirements will be specified by waveform type. The processed data is available from the report files derived from the processing of each waveform.

6.2.2.1 Rectangle Waveform

1. Time deviation from theoretical time shall be no greater than ±31 μs.

2. Steady-state amplitude deviation from theoretical shall be less than ±0.1% at the "piezo resistive" setting and less than ±0.6% at the "strain gage" setting.

3. Amplitude overshoot relative to calculated steady-state amplitude shall be less than 0.1% at the "piezo resistive" setting and less than 0.6% at the "strain gage" setting.

6.2.2.2 Half-Sine Waveform

1. Channel-to-channel time difference shall be less than ±10 μs.

2. "X" component time deviation shall be less than ±31 μs.

3. "Z" component time deviation shall be less than ±31 μs.

4. HIC deviation shall be less than ±0.6%.

6.2.2.3 Stair Waveform

1. Time deviation from theoretical time shall be less than ±10 μs.

2. Steady-state amplitude deviation from theoretical shall be less than ±0.1% at the "piezo resistive" setting and less than ±0.6% at the "strain gage" setting.

3. Steady-state amplitude deviation from best fit straight line shall be less than ±0.25%.

4. Amplitude overshoot relative to calculated steady-state amplitude shall be less than 1% at the "piezo resistive" setting and less than 5% at the "strain gage" setting. [Note: Since the SWG has no overshoot, this measurement becomes a measure of the peak noise on the SWG output signal.]

6.2.2.4 Crash Waveform

The crash waveform HIC error shall be less than ±0.6% to confirm that the crash waveform produced is of acceptable quality.

6.3 FREQUENCY RESPONSE

The computed amplitude ratio at all 14 signal frequencies shall be less than ±0.05 dB at the "piezo resistive" setting.

APPENDIX

TDAS CERTIFICATION TEST PROGRAM LISTING

#RESET	Clear memory.
#PIPES P0,P1,P2,P3,P4, P5,P6,P7,P8,P9	Define FIFO buffers called pipes.
#STRING A1 = “AVG1=“	Define character string A1.
#STRING A2 = “ AVG2=“	Define character string A2.
#ODEF A 1	Define output procedure A with one output channel.
>SET 0 A0	Assign output channel 0 to analog output connector A0.
>TIME 30.5	Set output update rate.
>CYCLE 2	Repeats reading data from input pipe every two samples.
>DIRECT(P0,0)	Assign input pipe P0 to internal channel 0.
>END	End of output procedure A.
#IDEF B 2	Define input procedure B with two input channels.
>SET 0 S1	Assign input channel 0 to analog input connector S1.
>SET 1 S2	Assign input channel 1 to analog input connector S2.
TIME 15.25	Set input sample interval to 15.25 µs.
COUNT 32000	Set total number of samples to be acquired to 32000.
AVERAGE(0,16000,P2)	Average 16000 samples from channel 0 and send average value to pipe P2.
AVERAGE(1,16000,P3)	Average 16000 samples from channel 1 and send average value to pipe P3.

APPENDIX (cont.)

END	End of input procedure.
PDEF C	Define processing procedure C.
FORMAT(A1,P2,A2,P3)	Transfer character strings A1 and A2 and data from pipes P2 and P3 to the output device.
END	End of procedure C.
#IDEF D 6	Define input procedure D with six input channels.
>CLOCK EXTERNAL	Requires external clock pulse to start sampling sequence.
>SET 0 S3	Assign input channel 0 to analog input connector S3 (shorted to ground).
>SET 1 S3	Assign input channel 1 to analog input connector S3 (shorted to ground).
>SET 2 S4	Assign input channel 2 to analog input connector S4 (DT0).
>SET 3 S0	Assign input channel 3 to analog input connector S0 (T0).
>SET 4 S1	Assign input channel 4 to analog input connector S1 (group 1 waveform).
>SET 5 S2	Assign input channel 5 to analog input connector S2 (group 2 waveform).
>TIME 5	Set input sample interval to 5 μs.
>COUNT 104262	Set total sample count to 104262.
>DIRECT(2,P7)	Transfer data from input channel 2 to pipe P7.
>DIRECT(3,P6)	Transfer data from input channel 3 to pipe P6.
>DIRECT(4,P4)	Transfer data from input channel 4 to pipe P4.
>DIRECT(5,P5)	Transfer data from input channel 5 to pipe P5.
>END	End of input procedure D.

#PDEF E	Define processing procedure E.
>FORMAT(#,P4,P5,P6,P7)	Transfer the sample number along with the data from pipes P4, P5, P6, and P7 to the output device.
>END	End of procedure E.
#ODEF F 1	Define output procedure F with one output channel.
>SET 0 A1	Assign output channel 0 to analog output connector A1.
>DIRECT(P8,0)	Transfer data from pipe P8 to output channel 0.
>TIME 1000	Set output update interval to 1000 μs.
>CYCLE 2	Repeat reading data from pipe P8 after two samples.
>END	End of procedure F.
#ODEF G 1	Define output procedure G with one output channel.
>SET 0 A1	Assign output channel 0 to analog output connector A1.
>TIME 1000	Set output sample interval to 1000 μs.
>CYCLE 2	Repeat reading data from pipe P9 after two samples.
>DIRECT(P9,0)	Transfer data from pipe P9 to output channel 0.
>END	End of procedure G.
#FILL P0 16384 16384	Put two samples of a number into pipe P0 that will cause the digital-to-analog converter (DAC) to produce an output voltage of 2.5 volts.
#START A	Start process A.
#PAUSE 100	Pause for 100 ms to allow process A to get started.
#START B,C	Start process B and C.
#PAUSE 600	Pause for 600 ms to allow processes B and C to complete data acquisition and averaging the data.

#STOP	Stop processes A, B, and C.
#PAUSE 1	Pause for 1 ms.
#FILL P0 0 0	Fill pipe P0 with two samples of zero value. This will cause the DAC reading this pipe to produce a zero output.
#PAUSE 1	Pause for 1 ms.
#START A	Start process A.
#PAUSE 100	Pause for 100 ms to allow process A to get started.
#START B,C	Start processes B and C.
#PAUSE 600	Pause for 600 ms to allow processes B and C to complete data acquisition and averaging the data.
#STOP	Stop processes A, B, and C.
#PAUSE 1	Pause for 1 ms.
#FILL P8 16384 16384	Fill pipe P8 with two samples of a number that will cause the DAC to produce an output voltage of 2.5 volts.
#FILL P9 0 0	Fill pipe P9 with two samples of zero value. This will cause the DAC to produce a zero output voltage.
#START D,E,F	Start processes D, E, and F.
#PAUSE 1	Pause for 1 ms.
#STOP F	Stop process F.
#PAUSE 1	Pause for 1 ms.
#START G	Start process G.
#PAUSE 1	Pause for 1 ms.
#STOP G	Stop process G.

REFERENCES

1. Society of Automotive Engineers, Inc., "Instrumentation for Impact Tests," SAE J211/1 MAR95, March 1995, 11 p in SAE Handbook.

2. MGA Research Corporation, Operator's Manual for Waveform Generator Model RPG-6236-A, U.S. Department of Transportation, National Highway Traffic Safety Administration, Washington, DC, February 1988, DOT-HS-807-218, 36 p.

3. MGA Research Corporation, Waveform Generator Signal Processing Software, U.S. Department of Transportation, National Highway Traffic Safety Administration, Washington, DC, September 1988, DOT-HS-807-312, 172 p.