



CRYSTAL
INSTRUMENTS



MIMO Vibration Control System Overview

MIMO Vibration Control System | MIMO Testing

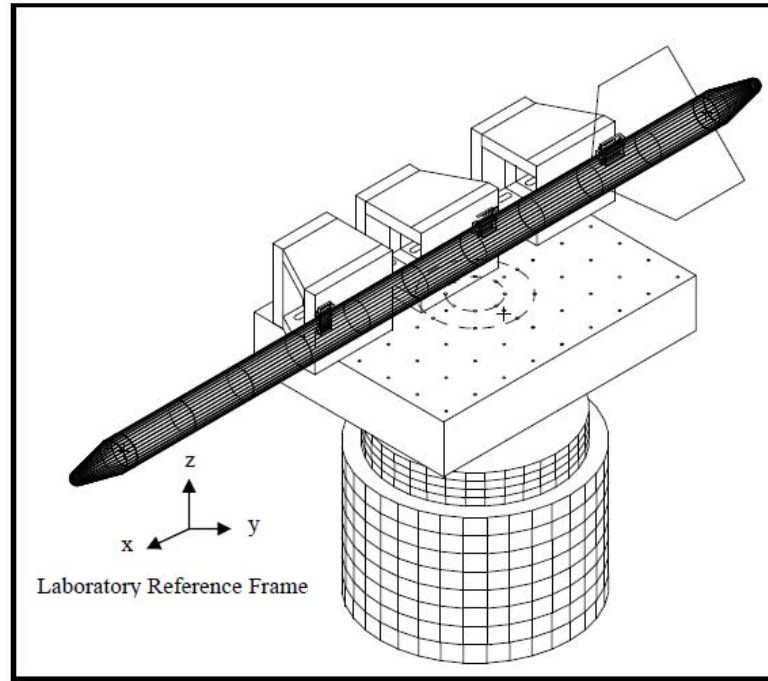
Multiple Shakers driving a single table to produce SDOF or MDOF vibration

- Large structure testing that cannot be excited with a single shaker without extensive fixturing
- Large structure testing with a single shaker does not provide sufficient force
- Tests that require simultaneous multi axis excitation (translation only)
- Tests that require simultaneous multi axis excitation with rotation
- MDOF testing is recommended when SDOF testing is inadequate to properly distribute the vibration energy to satisfy the specification

Terminology (MIL-STD-810G Method 527)

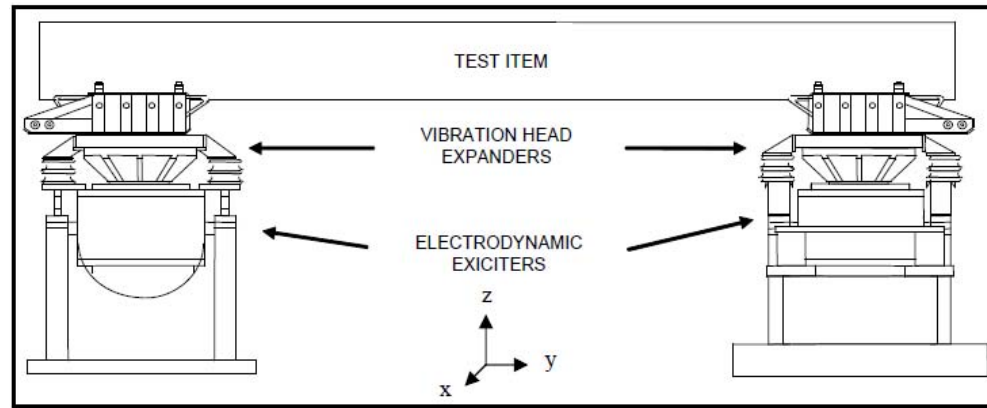
- Single-Degree-of-Freedom (SDOF)
- Multi-Degree-of-Freedom (MDOF)
- Single-Exciter (SE)
- Multiple-Exciter (ME)
- Single-Axis (SA)
- Multi-Axis (MA)
- MESA (multi-exciter, single-axis), MEMA (multi-exciter, multi-axis)
- SISO, MIMO

Single-Exciter/Single-Axis



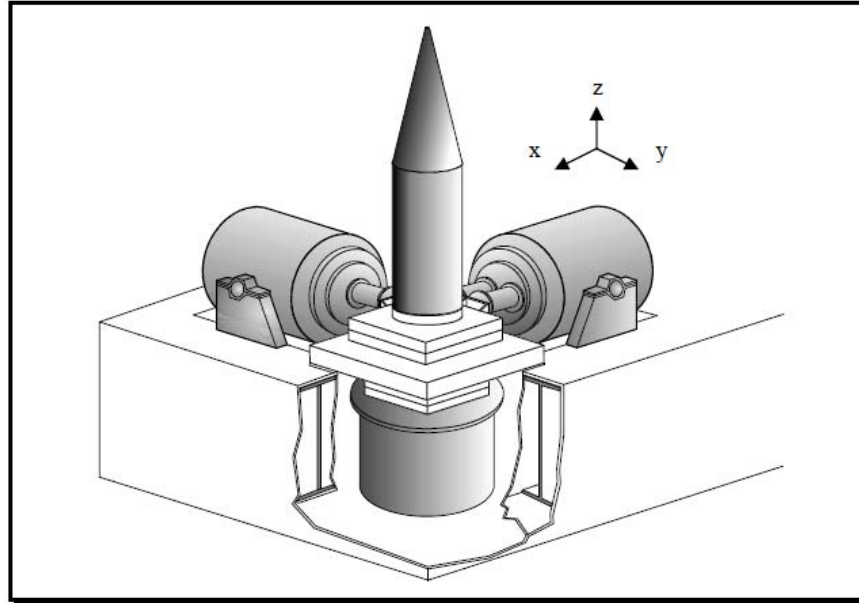
MIMO VCS | MIMO Testing

Multiple-Exciter/Single-Axis



MIMO VCS | MIMO Testing

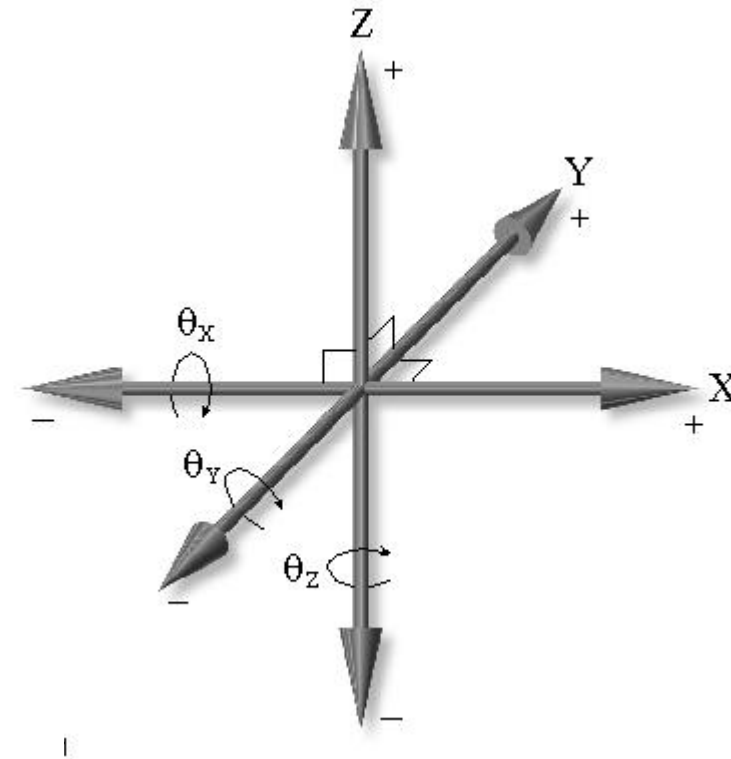
Multiple-Exciter/Multiple-Axis



Coordinate System Nomenclature

Degrees of Freedom (DOF)

- A rigid body has 6 degrees of freedom
 - 3 translation (X, Y, Z)
 - 3 rotations ($\theta_x, \theta_y, \theta_z$)
- Z vertical, X & Y horizontal



MIMO VCS | MIMO Testing

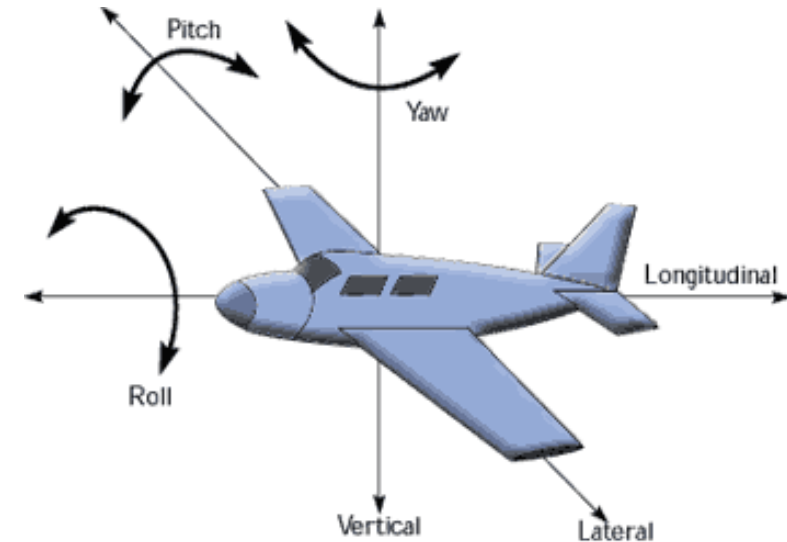
Degrees of Freedom

➤ Translation

- X, longitudinal
- Y, lateral
- Z, vertical

➤ Rotation

- around X, longitudinal roll
- around Y, lateral pitch
- around Z, vertical yaw



MIMO Testing Standards

- Mil-Std-810G Method 527
- IEST-RP-DTE022
- IEEE 344 Seismic Testing
- Transportation Time waveform Replication

MIMO VCS | MIMO Testing

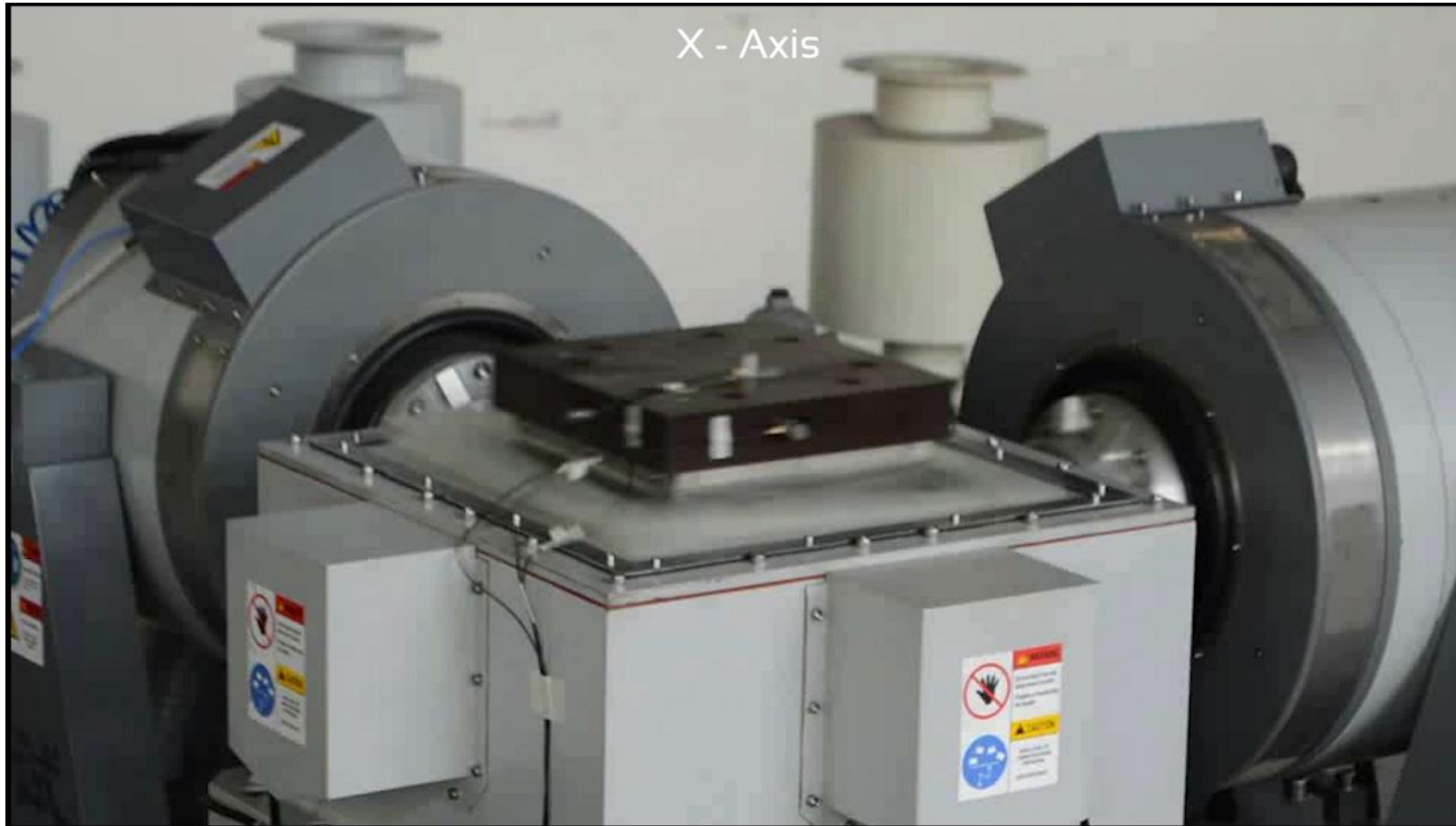
MIMO Testing Types

- MESA: Dual Shaker, push-push/Push-pull
- MEMA: Three-Axis shaker, other tables



MIMO VCS | MIMO Testing

3-Axis Shaker Table in Motion



MIMO Vibration Control System | Hardware Overview

Spider-80M

MIMO Vibration Controller System

- Modular, scalable, exchangeable.
- Support up to 8 output channels and 512 input channels.
- Usable together with strain measurement.



MIMO VCS Hardware | Spider-80M Main Specs

High Channel Count Vibration Test Control: scale up to 512 inputs

High Dynamic Range of Input : up to 160 dBFS

Inputs: 8 BNC connectors per front-end, voltage or IEPE, single-ended or differential, AC or DC coupling, 24-bit A/D converters, input range ± 20 volts, up to 102.4 kHz fs/ch

Outputs: up to 8 BNC connectors per front-end, 100 dB dynamic range, 24-bit A/D converters, ± 10 volts range

Channel Phase Match: Better than ± 1.0 degree up to 20 kHz among all channels

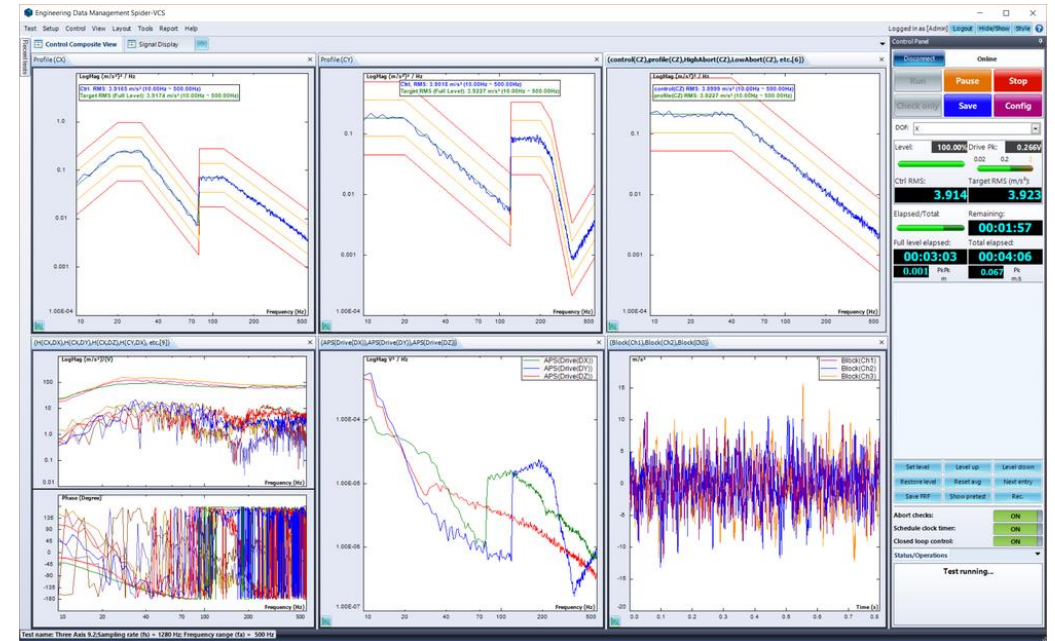
Computer Connections: 100 Base-T, RJ45 female connector supports connection to PC or network switch

Internal Memory: Flash memory for data storage is 4 GB per unit

MIMO Vibration Control System | Software Overview

MIMO VCS Software | Introduction

- Customizable layout and display supporting multiple monitors.
- Template-based reports
- Graphical tools and wizards are added to make setup a snap
- Interface has been arranged to make it logical and more useful
- Event-Action Rules, Abort-Sensitivity, and other features simplify operation
- One central location for all parameter setup

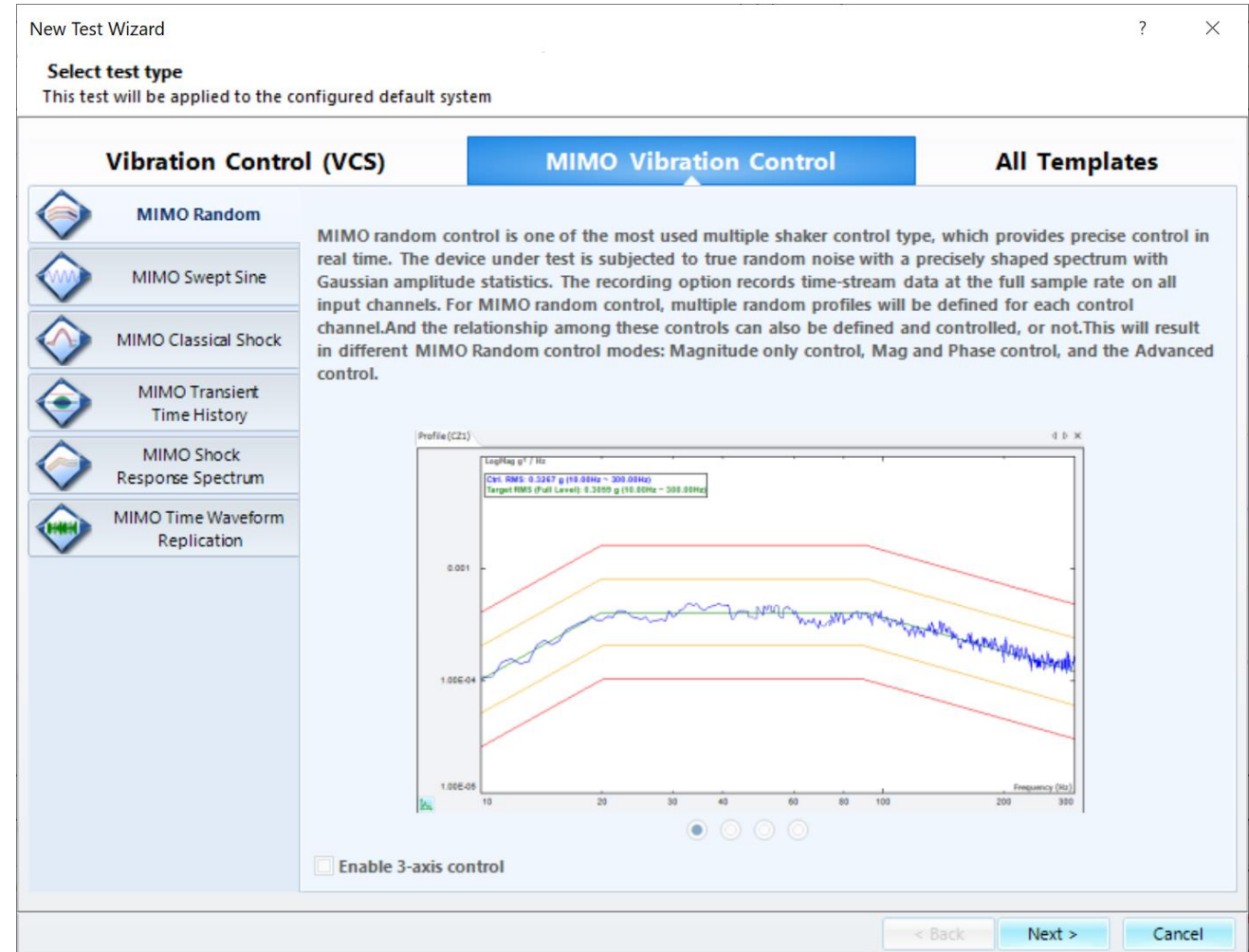


MIMO VCS Software | Safety Features

- Pre-test checks drives, sensor responses
- Shaker safety limits
- RMS limits for control signals
- Output voltage limiting
- Open loop, sensor failure detection
- Use limit channels with customized limit profile
- Channel overload and sensor overload detection

MIMO VCS Software | Overview Test Types

- MIMO Random
- MIMO Swept Sine
- MIMO Classical Shock
- MIMO Transient Time History
- MIMO Shock Response Spectrum (SRS)
- MIMO Time Waveform Replication (TWR)



MIMO VCS Software | Start Page

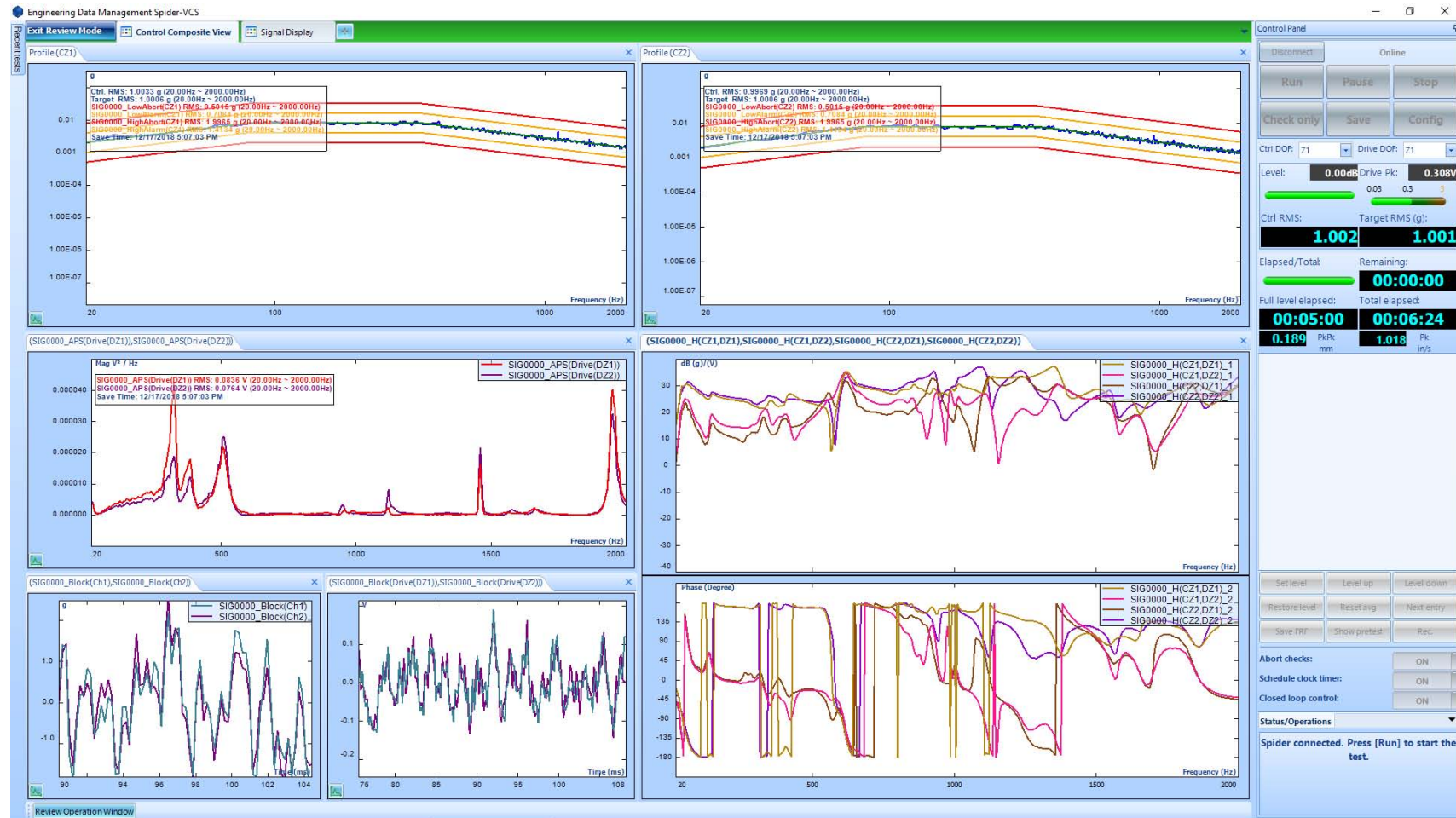
- Open a recent test
- Create a new test
- Log into an account
- View the list of Spider hardware



- In a MIMO Random test, the shakers are driven by wide band random signals.
- Feedback control adjusts the drive signals to generate responses that conform to the specified test profiles.
- The control algorithm calculates the inverse FRF matrix between the output drives and the input control channels. Besides the FRF update, the non-linear control helps correct the control errors.

MIMO VCS Software | MIMO Random

➤ Dual Shaker MIMO Random test: Same Profile in phase



MIMO VCS Software | MIMO Random

➤ Three-Axis Shaker MIMO Random test with Different Profiles, no phase control



Non-linear Control

- Enables the advanced control algorithm that compensates for non-linear response in the test system.
- Significantly improve the control performance for vibration tests on mechanical shaker systems.
- Should be left enabled for all tests unless advised otherwise by a manufacturer's service representative.



Advanced Settings

General

- ☐ Adjust High Alarm/Abort by level when it is less than 100% (0dB)
- ☐ Start notching when level is less than 100% (0dB)
- ☐ Reset average by level change
- ☐ Display Alarm/Abort with level
- ☐ Disable Control low limits while notching
- Abort ramp down rate (dB/s): 20
- ☒ Continue target level: 25.0 % (-12.0dB)
- Level change rate (dB/s): 20
- Adjust level step (dB): 0.82785

Performance optimization

- ☒ Non-Linear control
- ☐ Optimize displacement

Ramp-up rate

Slow ramp-up (about 2dB/s) Fast ramp-up (about 20dB/s) Fastest (about 60dB/s)

"Fastest" rate is not commonly used. Please make sure you're confident with the system's connections and there is no safety concerns.

Multi-resolution spectrum and random control

- ☐ Enable multi-resolution spectrum display
- ☐ Enable multi-resolution random control
- Cutoff frequency (Hz): Automatic (250)

Kurtosis control

- ☐ Enable kurtosis control
- Target kurtosis value (3 ~ 10): 3
- High pass cutoff (Hz): 5
- Max. histogram range (g): 3.3021
- Auto Est.

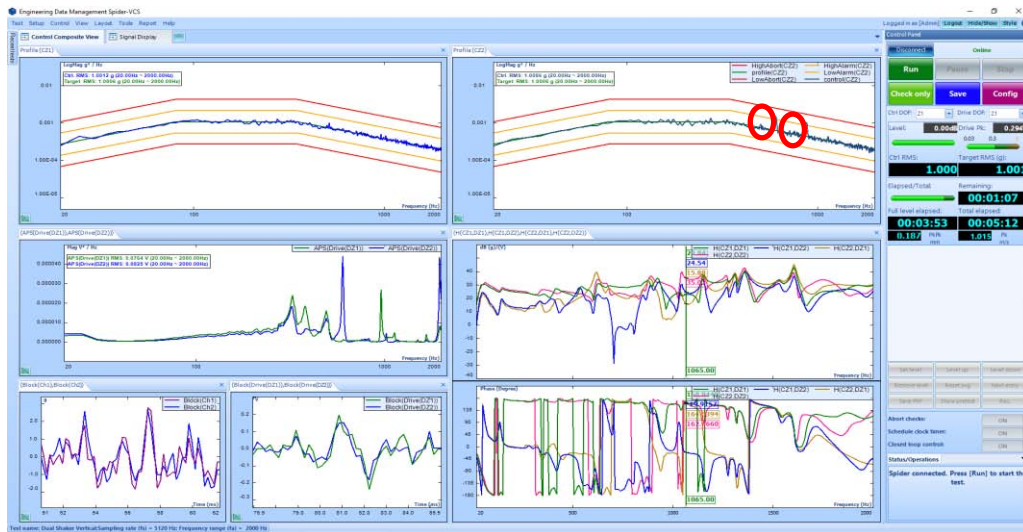
OK Cancel

Using Non-linear Control

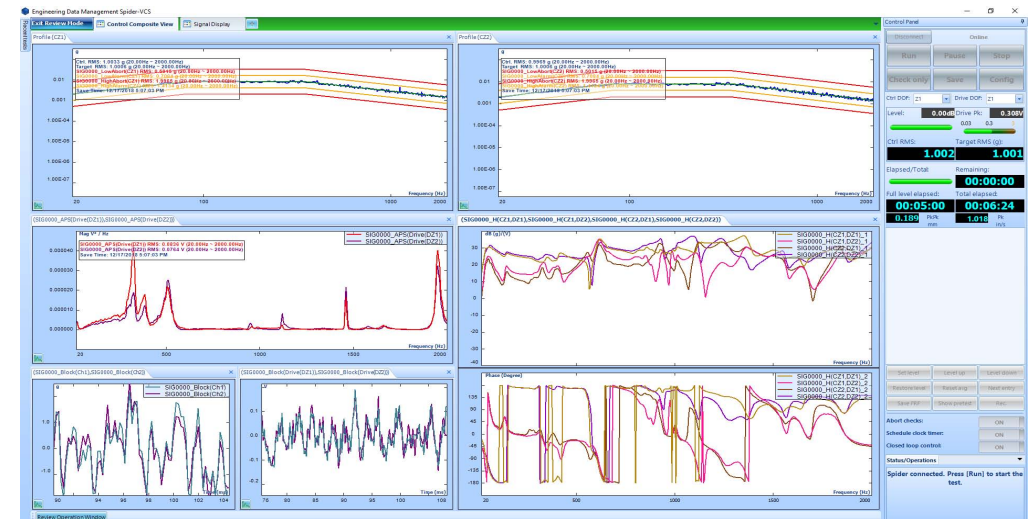
- When controlling the profiles with Mag/Phase, profiles are correlated. The FRF matrix cannot be updated. The non-linear control is the key to correct the control errors. It is also used with the Mag mode for the Mag control, when the FRF matrix can be updated to achieve fast control.
- A hydraulic driven shaker usually has very strong non-linear effect. The estimated transfer function does not completely represent the characteristics of the system. Enabling Non-Linear Control can increase the control accuracy so the control spectrum matches the profile better.
- When UUT has sharp resonances, the data windows applied in the data acquisition process introduces non-linear effect. To increase the control accuracy, turn on the Non-Linear Control option.

MIMO VCS Software | MIMO Random

➤ Non-linear control in action



Without Non-Linear Control



With Non-Linear Control

MIMO VCS Software | MIMO Random

➤ Multiple Channel Control Strategy

- Weighted Average
- Maximum
- Minimum

Test Configurations for 3 axis random demo114 [MIMO(Random)]

Test parameters

Shaker parameters

Test parameters

Pre-test parameters

Test profile

RMS limits

Run schedule

Limit channels

Event action rules

Miscellaneous

Lines: 400

DOF: 100

Average: 50

Overlap ratio: No Overlap

Delta frequency (Hz): 5.000000

Control strategy: **Weighted average**

Abort type: Magnitude abort

H update ratio (0.0~1.0): 0

Frequency range (fa)(Hz): Calculated by profile

Correction Control

Control channel	Control DOF	Correction	MCoh. Min.
1	X	<input checked="" type="checkbox"/> On	0.7
2	Y	<input checked="" type="checkbox"/> On	0.7
3	Z	<input checked="" type="checkbox"/> On	0.7

Abort sensitivity

0.0 Not Sensitive 0.5 1.0 Very Sensitive

Customize

Summary

Block T = 0.2 s dT = 0.000195313 s

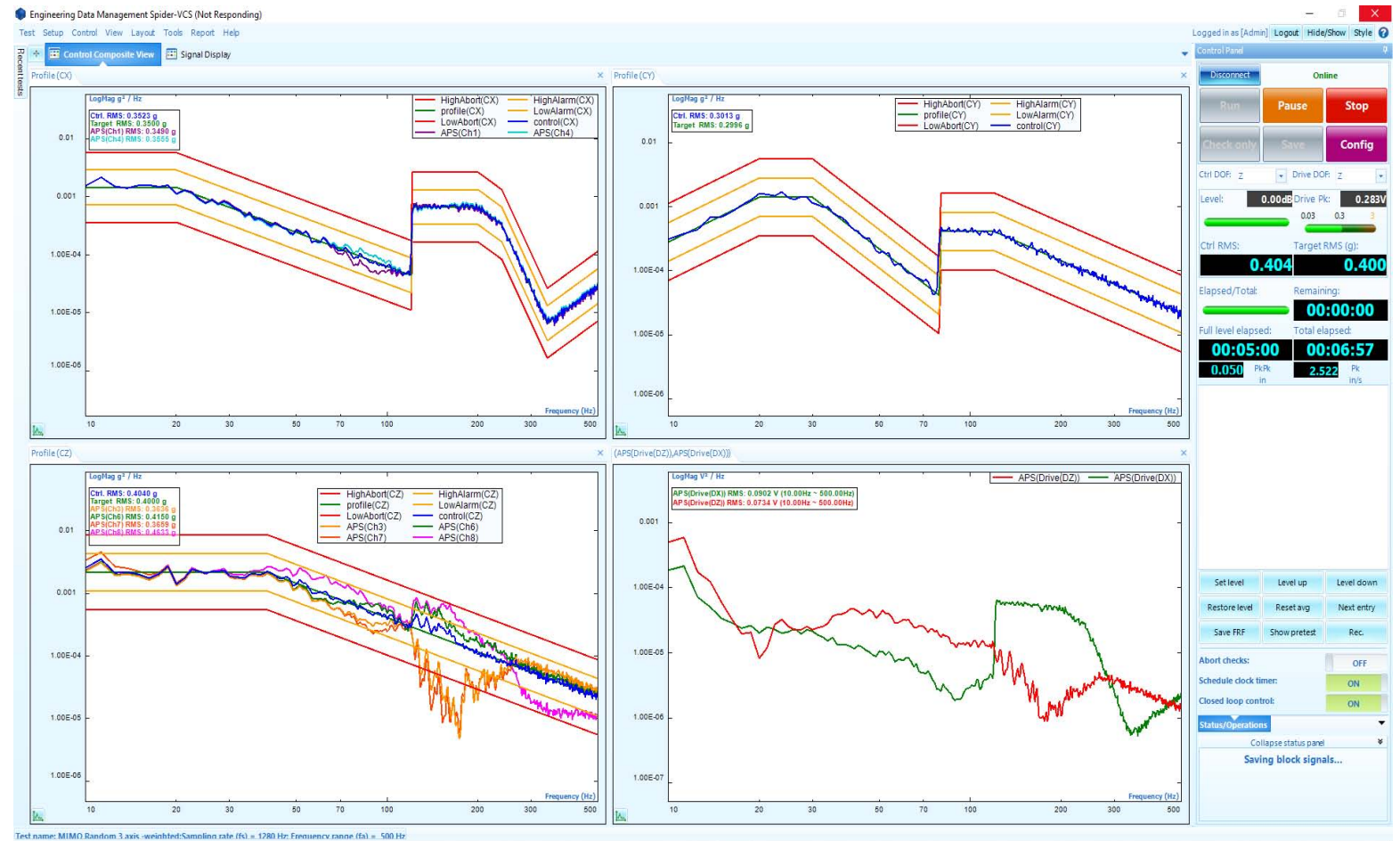
Sampling rate (fs) = 5120.00 Hz Frequency range (fa) = 2000.00 Hz

Config. library

OK Cancel

MIMO VCS Software | MIMO Random

➤ Multiple Channel Control : Weighted Average



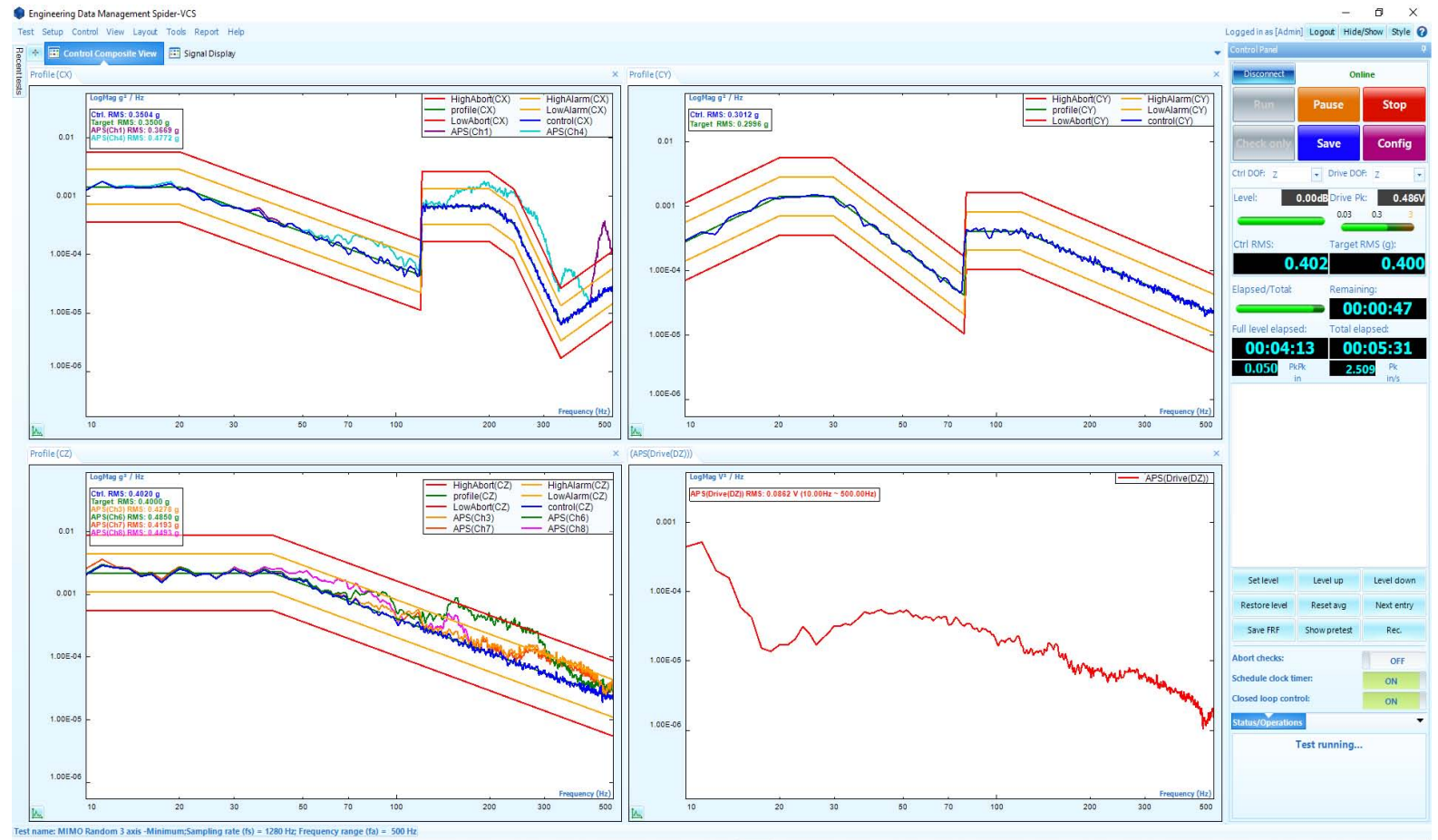
MIMO VCS Software | MIMO Random

➤ Multiple Channel Control : Maximum



MIMO VCS Software | MIMO Random

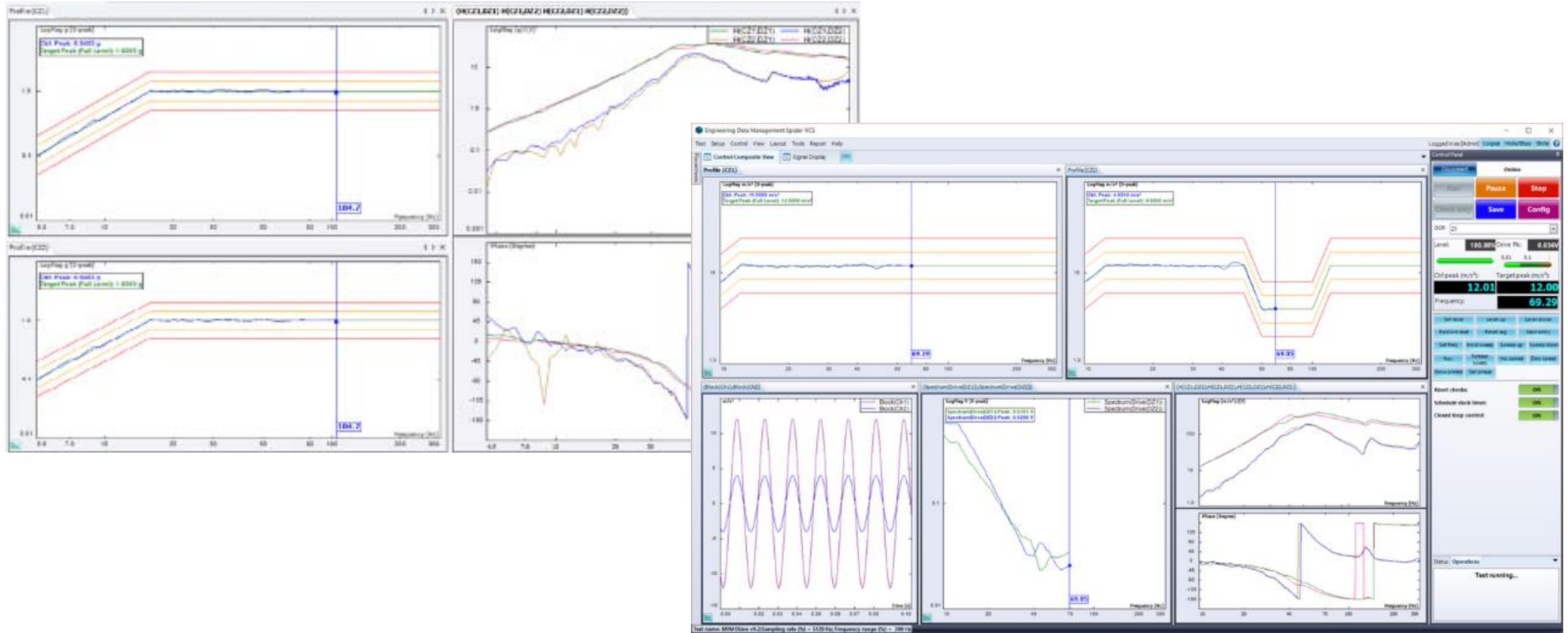
➤ Multiple Channel Control : Minimum



- MIMO Swept Sine test generates one frequency at a time and sweeps through a pre-set frequency range.
- Feedback from the control signals are then used to adjust the output drives such that the response signals of the UUT match the test profiles.
- Each test profile is a linear spectrum with the amplitude versus frequency. Mag or Mag/Phase mode can be used to define the profiles. The profiles can be the same, or different.

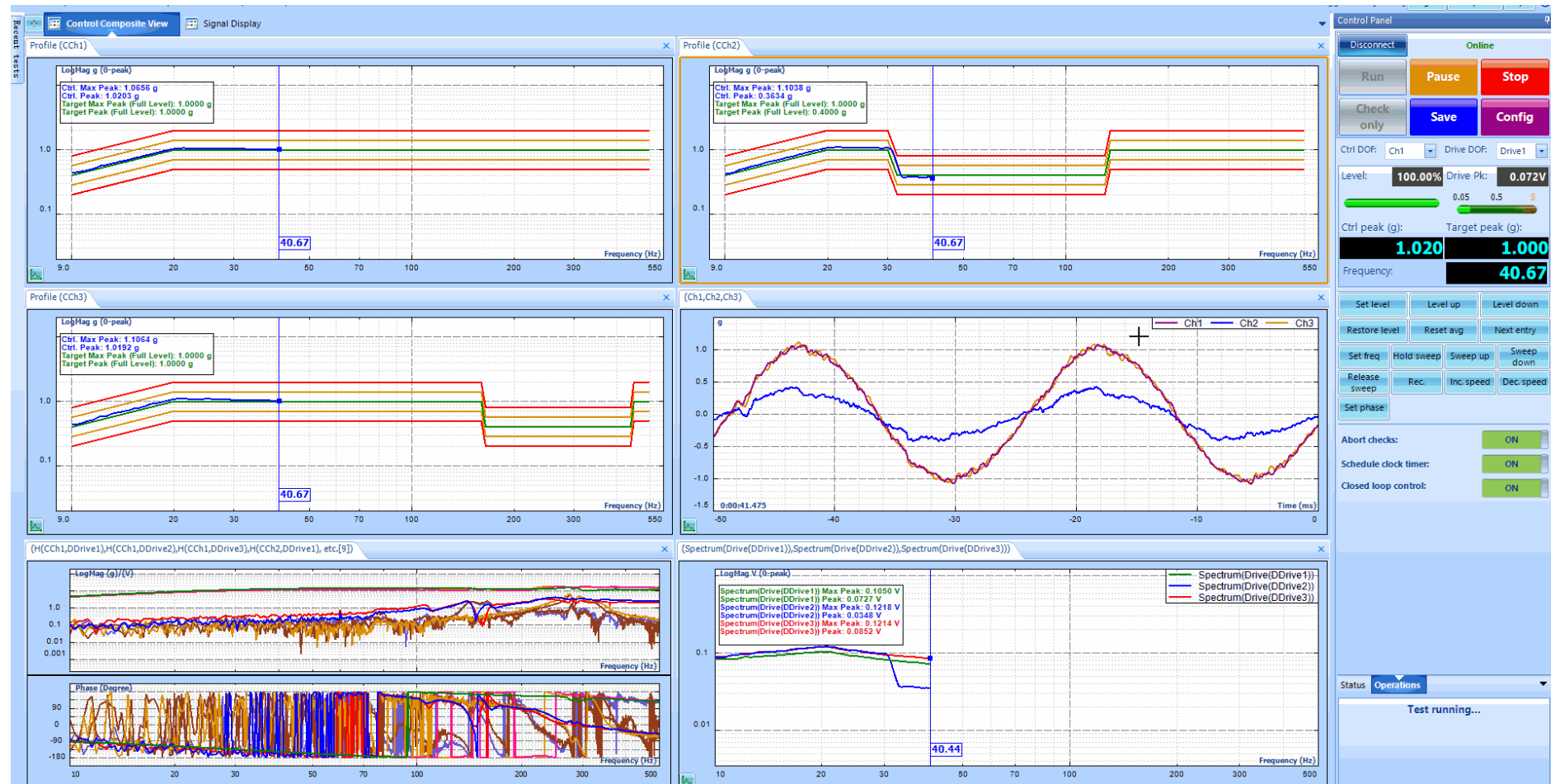
MIMO VCS Software | MIMO Swept Sine

➤ Dual shaker MIMO Sine test: Same vs. Different profiles



MIMO VCS Software | MIMO Swept Sine

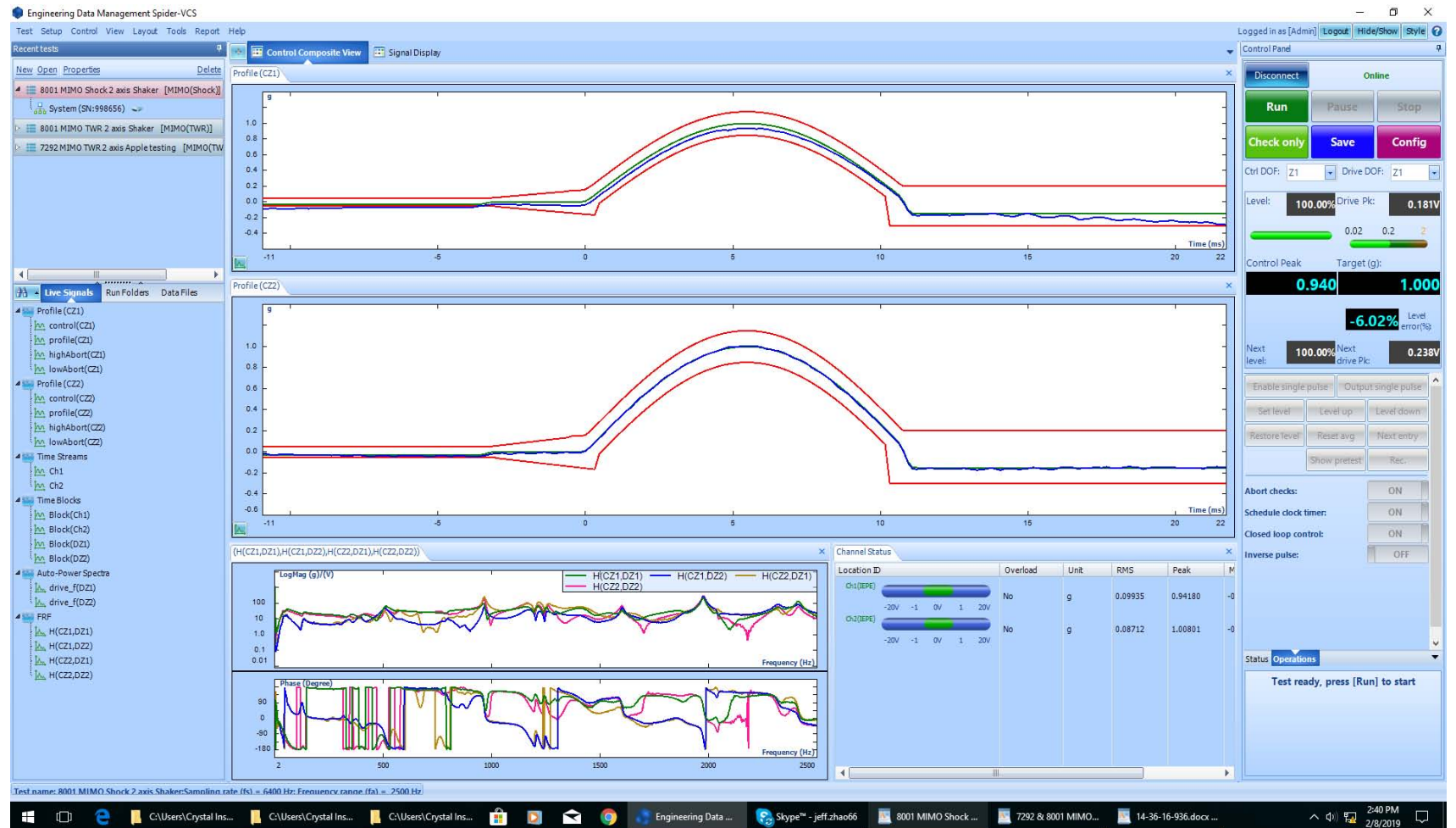
➤ Three-Axis Shaker MIMO Sine test with different profiles



- The Spider MIMO Classic Shock Vibration Control provides precise, real-time control and analysis for typical transient time domain signals.
- Classical pulse types include half-sine, haver-sine, terminal-peak sawtooth, initial-peak saw tooth, triangle, rectangle, and trapezoid.
- Dual or Three classic Shock waveforms can be defined and under control. These waveforms can be the same or different.

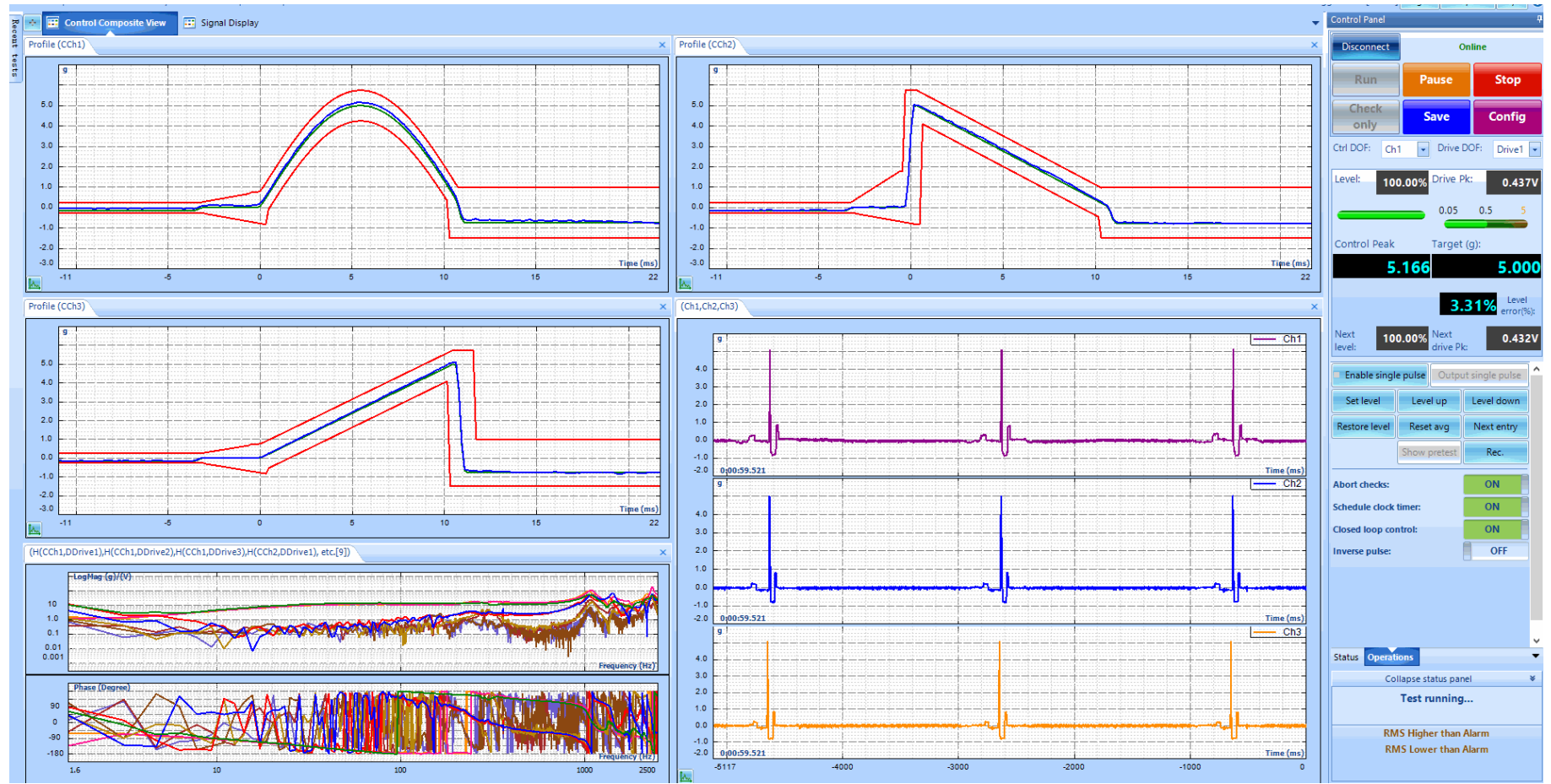
MIMO VCS Software | MIMO Classic Shock

➤ Dual Shaker MIMO Classic Shock test with same profiles



MIMO VCS Software | MIMO Classic Shock

➤ Three-Axis Shaker MIMO Classic Shock test with different profiles

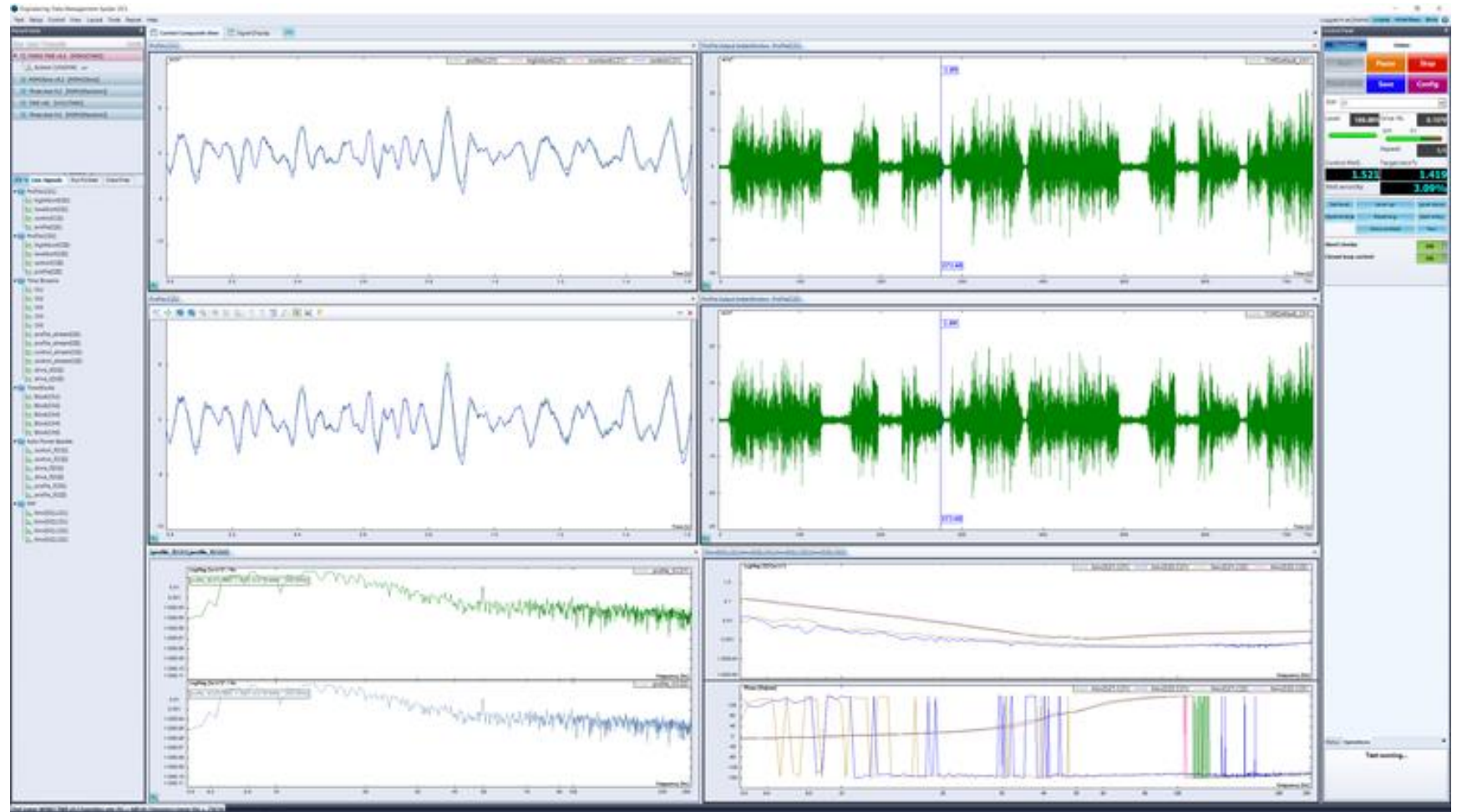


MIMO VCS Software | MIMO Time Waveform Replication (TWR)

- MIMO TWR provides precise, real-time control for long waveform duplication up to 1 billion data points!
- Multiple long waveforms can be duplicated precisely on the shaker just as they were recorded
- Includes Waveform Editor (EDM-WE), a flexible importing and editing tools for long waveform signals
- Allows the recording of time stream data at the full sample rate on all input channels
- Dual or three shakers can be under control and time data recording on master front-end

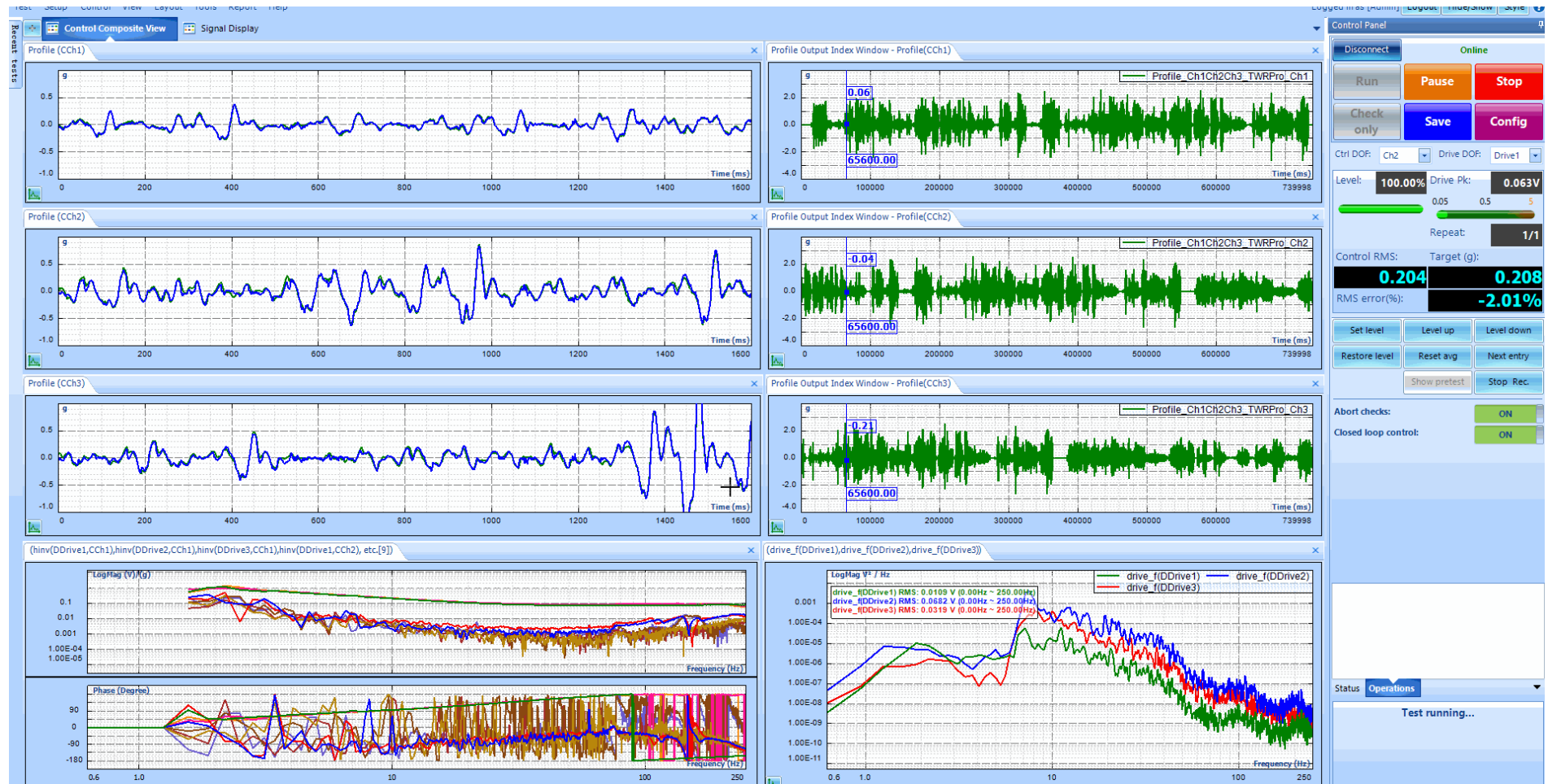
MIMO VCS Software | MIMO TWR

➤ Dual Shaker MIMO TWR test with same profiles



MIMO VCS Software | MIMO TWR

➤ Dual Shaker MIMO TWR test with Different profiles



MIMO VCS Software | Input Channel Table

- Input channel setup with customizable column selection
- Control DOF for Control channels
- Engineering unit assigned to each channel
- Automatically extract the TEDS sensor information
- Filter setup for each channel
- Sensor library with optional sensor calibration notification

Input Channels for MIMO Random 3axis 32 chan v18 [MIMO(Random)]

Fill Ex/Im Units Sensor Non-acceleration control Load from library Save to library Save as default Auto Fixed LocationID

Tip: Use Ctrl+c and Ctrl+v to copy and paste selected rows or cells.

	On/Off	Channel type	Location ID	Control DOF	Measurement quantity	Engineering unit	Sensitivity	Input mode	Sensor	Max. sensor range	High-Pass filter Fc (Hz)
1(M)	<input checked="" type="checkbox"/> On	Control	Ch1	X	Acceleration	g	100.00000 (mV/g)	AC-Single End		20.0000 (V)	2.0000
2(M)	<input checked="" type="checkbox"/> On	Control	Ch2	Y	Acceleration	g	100.00000 (mV/g)	AC-Single End		20.0000 (V)	2.0000
3(M)	<input checked="" type="checkbox"/> On	Control	Ch3	Z	Acceleration	g	100.00000 (mV/g)	AC-Single End		20.0000 (V)	2.0000
4(M)	<input checked="" type="checkbox"/> On	Monitor	Ch4		Acceleration	g	100.00000 (mV/g)	AC-Single End		20.0000 (V)	2.0000
5(M)	<input checked="" type="checkbox"/> On	Monitor	Ch5		Acceleration	g	100.00000 (mV/g)	AC-Single End		20.0000 (V)	2.0000
6(M)	<input checked="" type="checkbox"/> On	Monitor	Ch6		Acceleration	g	100.00000 (mV/g)	AC-Single End		20.0000 (V)	2.0000
7(M)	<input checked="" type="checkbox"/> On	Monitor	Ch7		Acceleration	g	100.00000 (mV/g)	AC-Single End		20.0000 (V)	2.0000
8(M)	<input checked="" type="checkbox"/> On	Monitor	Ch8		Acceleration	g	100.00000 (mV/g)	AC-Single End		20.0000 (V)	2.0000
9	<input checked="" type="checkbox"/> On	Monitor	Ch9		Acceleration	g	100.00000 (mV/g)	AC-Single End		20.0000 (V)	2.0000
10	<input checked="" type="checkbox"/> On	Monitor	Ch10		Acceleration	g	100.00000 (mV/g)	AC-Single End		20.0000 (V)	2.0000
11	<input checked="" type="checkbox"/> On	Monitor	Ch11		Acceleration	g	100.00000 (mV/g)	AC-Single End		20.0000 (V)	2.0000
12	<input checked="" type="checkbox"/> On	Monitor	Ch12		Acceleration	g	100.00000 (mV/g)	AC-Single End		20.0000 (V)	2.0000
13	<input checked="" type="checkbox"/> On	Monitor	Ch13		Acceleration	g	100.00000 (mV/g)	AC-Single End		20.0000 (V)	2.0000
14	<input checked="" type="checkbox"/> On	Monitor	Ch14		Acceleration	g	100.00000 (mV/g)	AC-Single End		20.0000 (V)	2.0000
15	<input checked="" type="checkbox"/> On	Monitor	Ch15		Acceleration	g	100.00000 (mV/g)	AC-Single End		20.0000 (V)	2.0000
16	<input checked="" type="checkbox"/> On	Monitor	Ch16		Acceleration	g	100.00000 (mV/g)	AC-Single End		20.0000 (V)	2.0000
17	<input checked="" type="checkbox"/> On	Monitor	Ch17		Acceleration	g	100.00000 (mV/g)	AC-Single End		20.0000 (V)	2.0000

Apply to Front-End OK Cancel

MIMO VCS Software | Shaker Parameters

- Shaker Configuration defines the Drive DOF for each drive channel
- Control DOF and Condition number selection
- Shaker information can be loaded and saved into library

Test Configurations for MIMO Random 3axis 32 chan v18 [MIMO(Random)]

Shaker parameters <<

Shaker parameters
Test parameters
Pre-test parameters
Test profile
RMS limits
Run schedule
Event action rules
Miscellaneous

Shaker configuration

Three-Axis Edit or save to a new configuration using the Edit parameters button.

Drives

Output Channel	Active	Drive DOF	Dir	Sigma clip	Drive limit(Volt Pk)	Shaker
1	<input checked="" type="checkbox"/> On	X	+	3	3	Default Shaker
2	<input checked="" type="checkbox"/> On	Y	+	3	3	Default Shaker
3	<input checked="" type="checkbox"/> On	Z	+	3	3	Default Shaker

Max. control DOF: Condition number threshold (%)

Shaker information

Manufacturer

Shaker name

Payload mass kg

Actual shaker limits used in this test

Force peak Newton

Acceleration peak g

Max. velocity m/s

Max. positive displacement mm

Max. negative displacement mm

Shaker orientation

Max. drive voltage peak V

Min. drive frequency Hz

Config. library

MIMO VCS Software | Test Parameters

Test Configurations for MIMO Random 3axis 32 chan v18 [MIMO(Random)]

Test parameters

Shaker parameters
Test parameters
Pre-test parameters
Test profile
RMS limits
Run schedule
Event action rules
Miscellaneous

Lines: 400 DOF: 100 Average: 50 Overlap ratio: 50%

Delta frequency (Hz): 1.250000 Abort type: Magnitude abort H update ratio (0.0-1.0): 0.3

Frequency range (fa)(Hz): Calculated by profile **Advanced settings**

Correction Control

Control channel	Control DOF	Correction	MCoh. Min.
1	X	<input checked="" type="checkbox"/> On	0.7
2	Y	<input checked="" type="checkbox"/> On	0.7
3	Z	<input checked="" type="checkbox"/> On	0.7

Abort sensitivity

0.0 Not Sensitive 0.5 1.0 Very Sensitive **Customize**

Summary

Block T = 0.8 s dT = 0.00078125 s
Sampling rate (fs) = 1280.00 Hz Frequency range (fa) = 500.00 Hz

Config. library **OK** **Cancel**

Test Configurations for MIMO Sine 3axis 32 ch v18 [MIMO(Sine)]

Test parameters

Shaker parameters
Test parameters
Pre-test parameters
Test profile
Check against shaker
Run schedule
Event action rules
Miscellaneous

Signal plot points: 2048 **Advanced settings**

Initial drive (Volts): 0.005

Sweep type: Logarithmic Oct/Min (Sweep speed)

Maximum drive during ramp-up and pre-test (Volts): 0.7

Abort type: Magnitude abort

Measurement strategy: Filter **More Info**

Filter type: Proportional Filter Bandwidth (%): 25

Abort sensitivity

0.0 Not Sensitive 0.5 1.0 Very Sensitive **Customize**

Config. library **OK** **Cancel**

Test Configurations for MIMO Shock spec [MIMO(Shock)]

Test parameters

Shaker parameters
Test parameters
Pre-test parameters
Test profile
SRS analysis
Shock abort limit
Limit channels
Run schedule
Event action rules
Miscellaneous

Average: 4 Interval between pulses (s): 1 Correction rate (0.0-1.0): 0

Drive limit (Volt Pk): 2 Level changing increment (dB): 0.83 **Advanced settings**

Abort sensitivity

0.0 Not Sensitive 0.40 1.0 Very Sensitive **Customize**

Summary

Block T/Size = 0.64 s / 4096 dT = 0.00015625 s
Sampling rate (fs) = 6400.00 Hz Frequency range (fa) = 2500.00 Hz

0.64 s

Config. library **OK** **Cancel**

Test Configurations for MIMO TWR 3axis v18 [MIMO(TWR)]

Test parameters

Shaker parameters
Test parameters
Pre-test parameters
Test profile
Limit channels
Run schedule
Event action rules
Miscellaneous

Block size: 1024 H update ratio (0.0 - 0.5): 0.00

Control strategy: Real Time

Level changing increment (dB): 0.83 **Advanced settings**

Correction control

Control channel	Control DOF	Correction	MCoh. Min.
1	X	<input checked="" type="checkbox"/> On	0.7
2	Y	<input checked="" type="checkbox"/> On	0.7

Abort sensitivity

0.0 Not Sensitive 0.75 1.0 Very Sensitive **Customize** 256 Points

Summary of the first profile

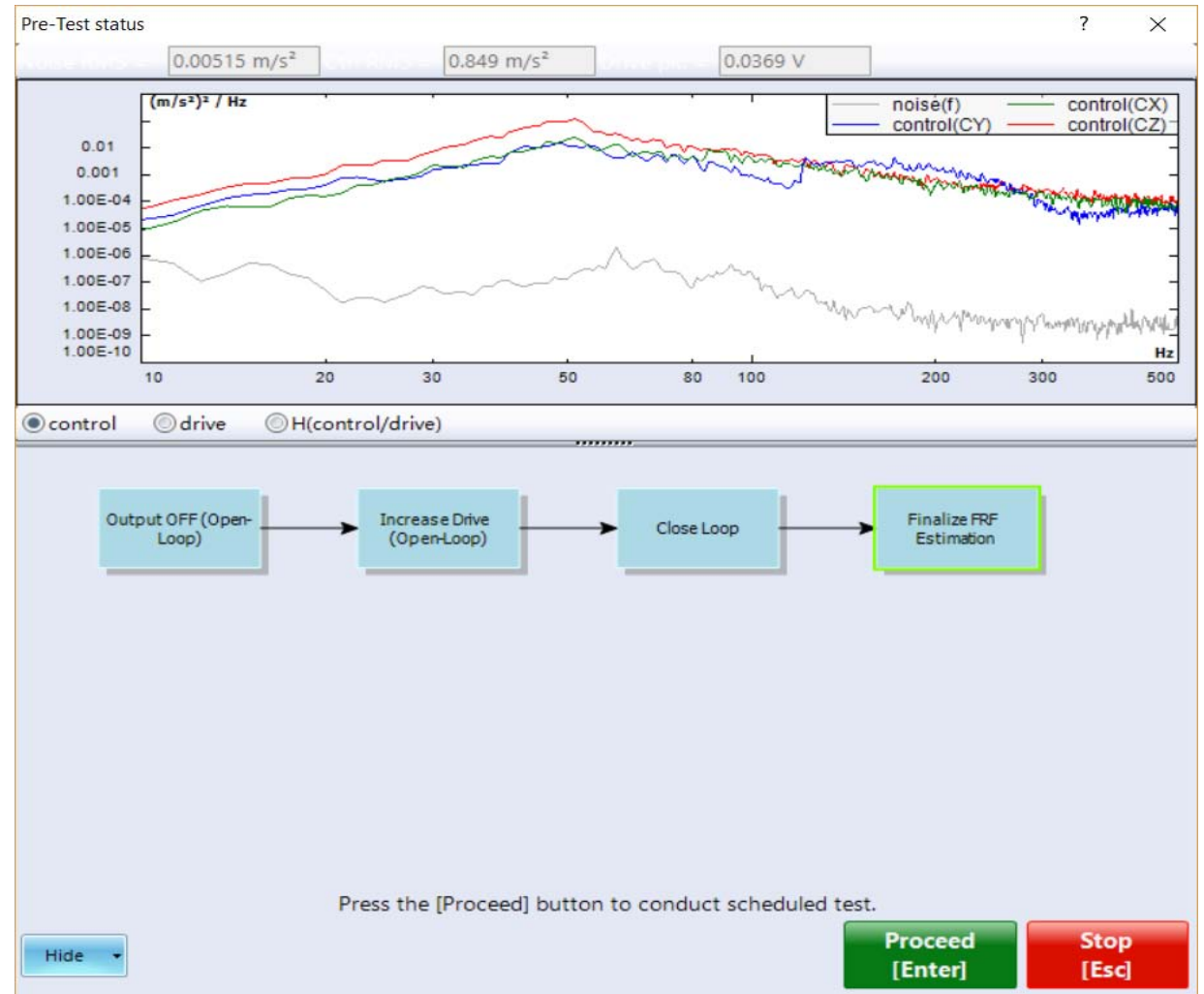
Block T/Size = 1.6 s / 1024 dT = 0.0015625 s
Sampling rate (fs) = 640.00 Hz Frequency range (fa) = 250.00 Hz dF = 0.63 Hz

Total time of the profile: 732.8 s

Config. library **OK** **Cancel**

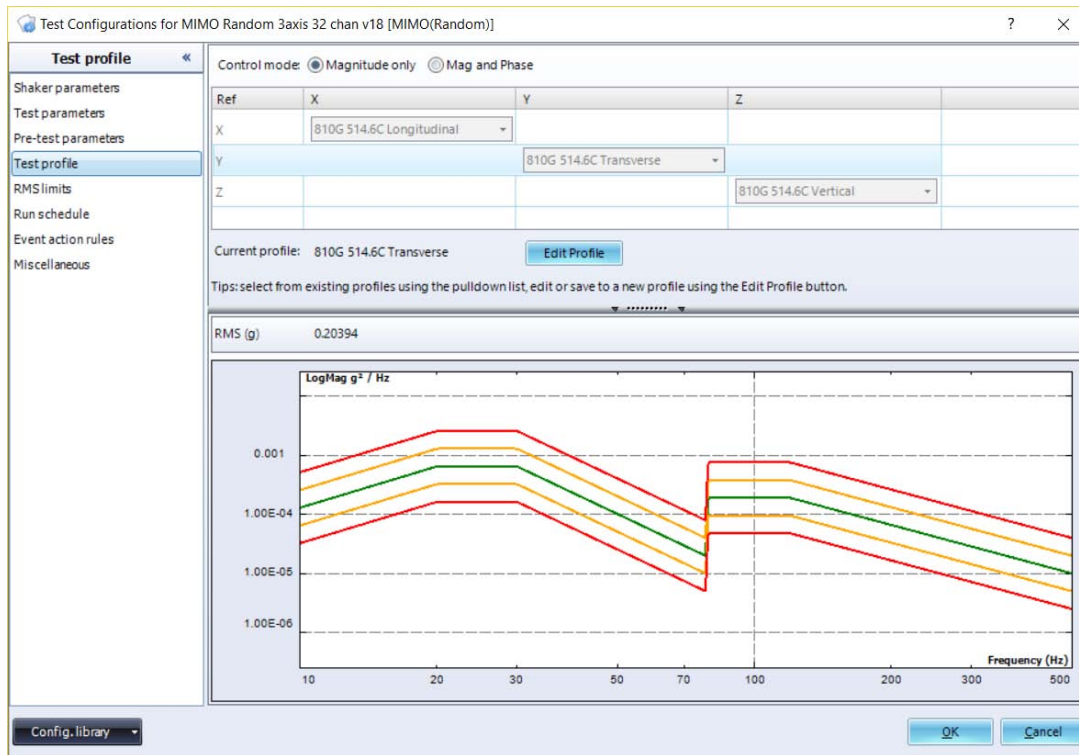
MIMO VCS Software | Pre-Test

- Broadband random signals from the output channels are used to measure the system FRF matrix of the control channels vs. all drives

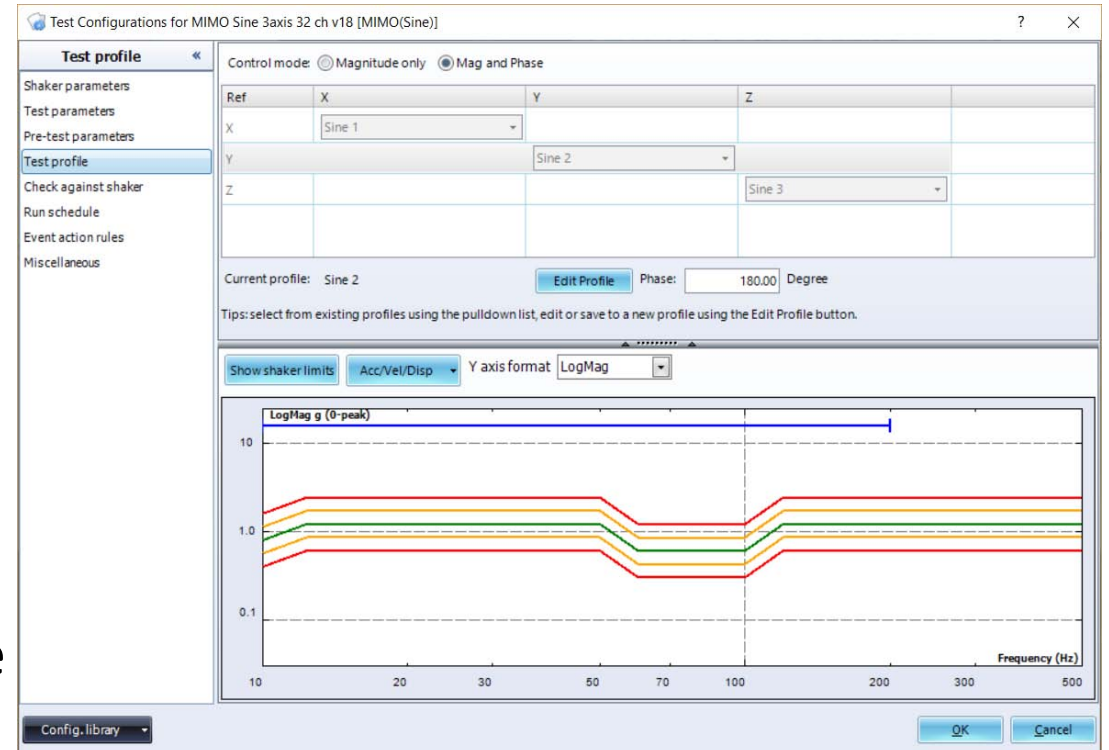


MIMO VCS Software | Test Profiles

MIMO Random



MIMO Sine

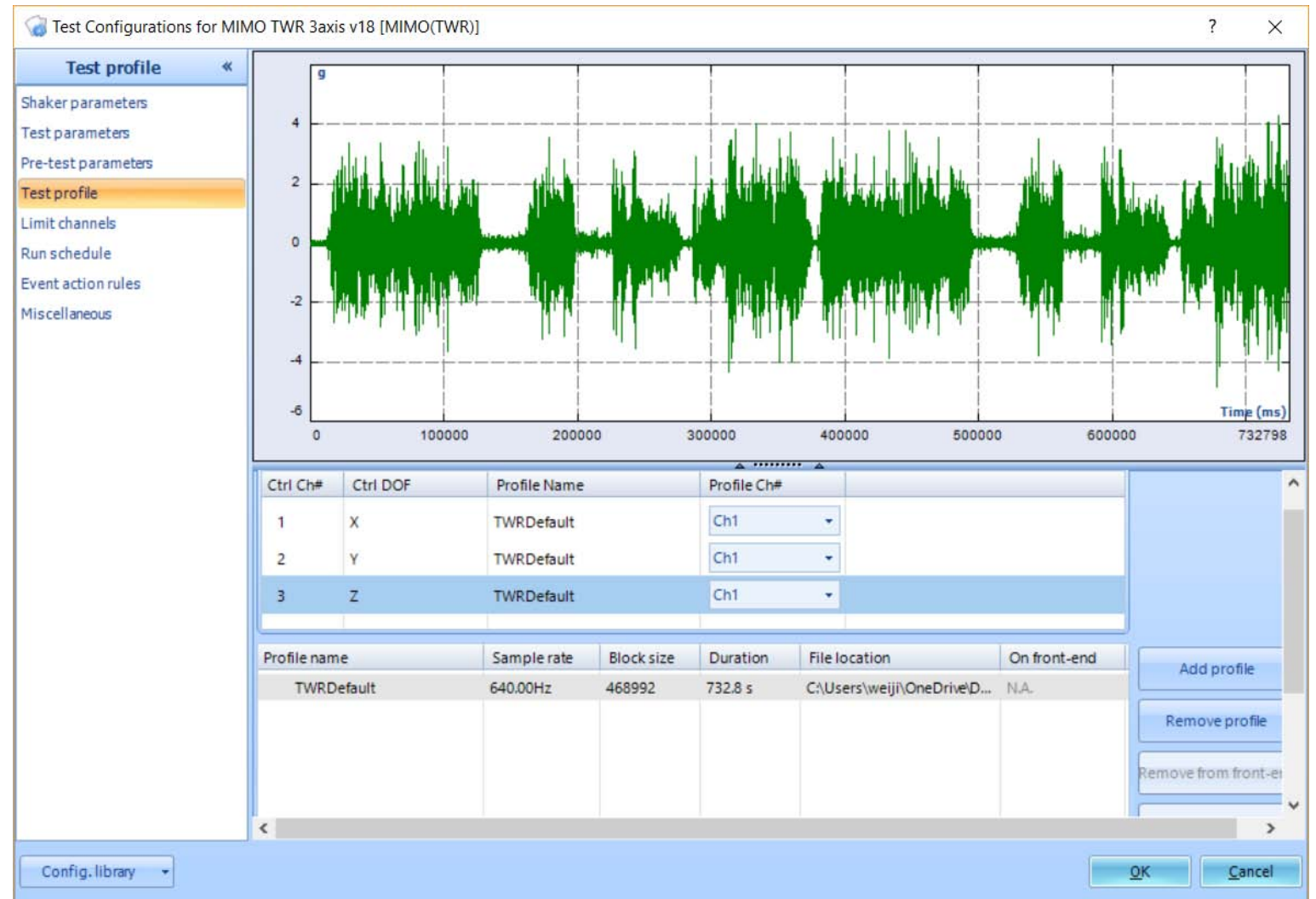


MIMO Classic Shock



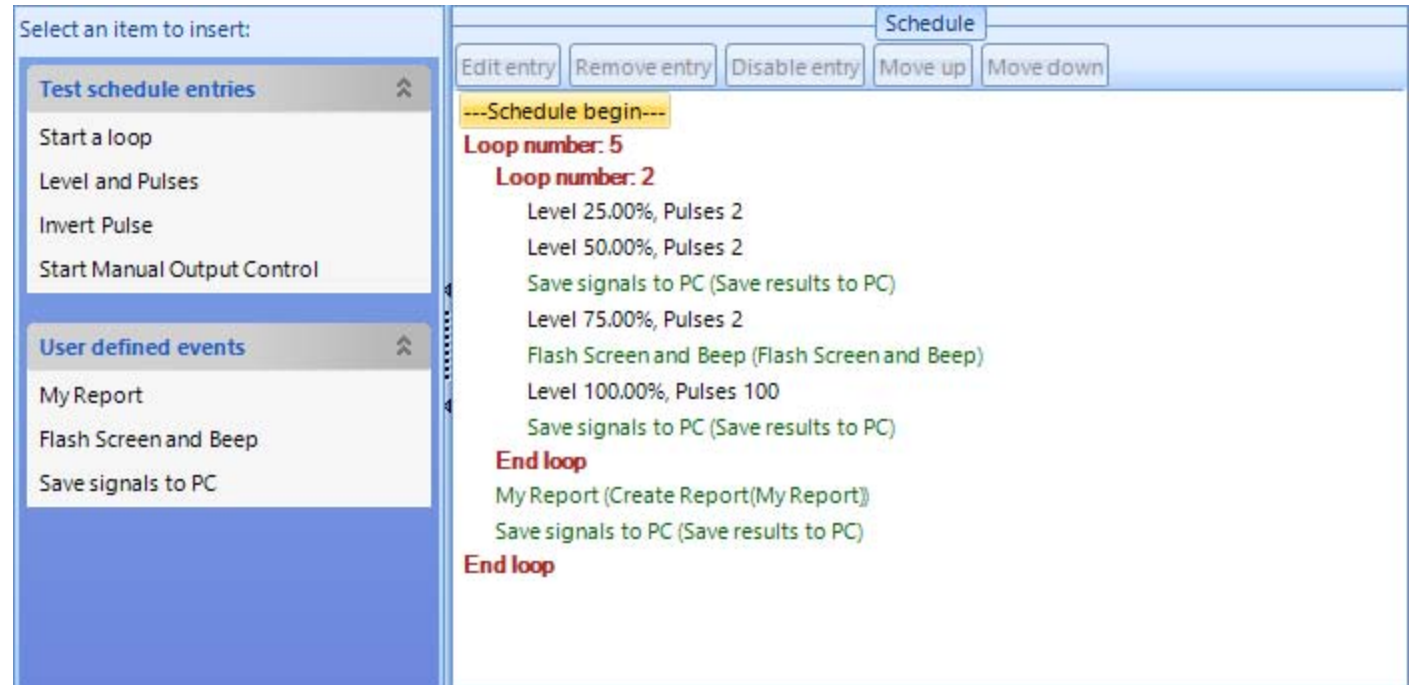
MIMO VCS Software | Test Profiles

MIMO TWR



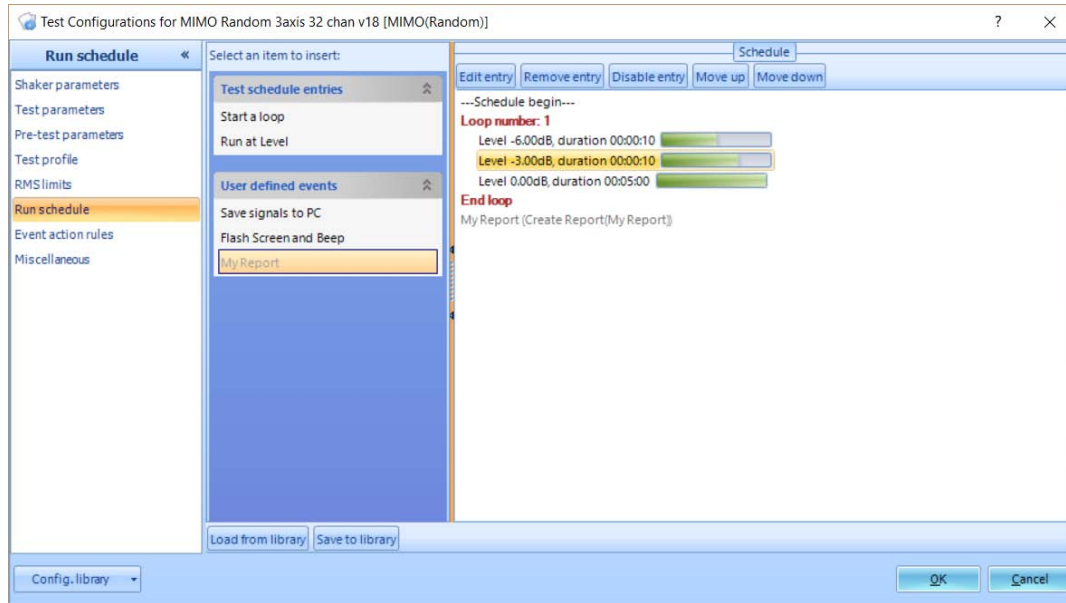
MIMO VCS Software | Run Schedule

- Run Schedule allows the test to be run automatically through a preset routine.
- This schedule can include loops and periods of running the test at a specified level and duration.
- The schedule can also activate any user-defined events defined in the Event Action Rules.

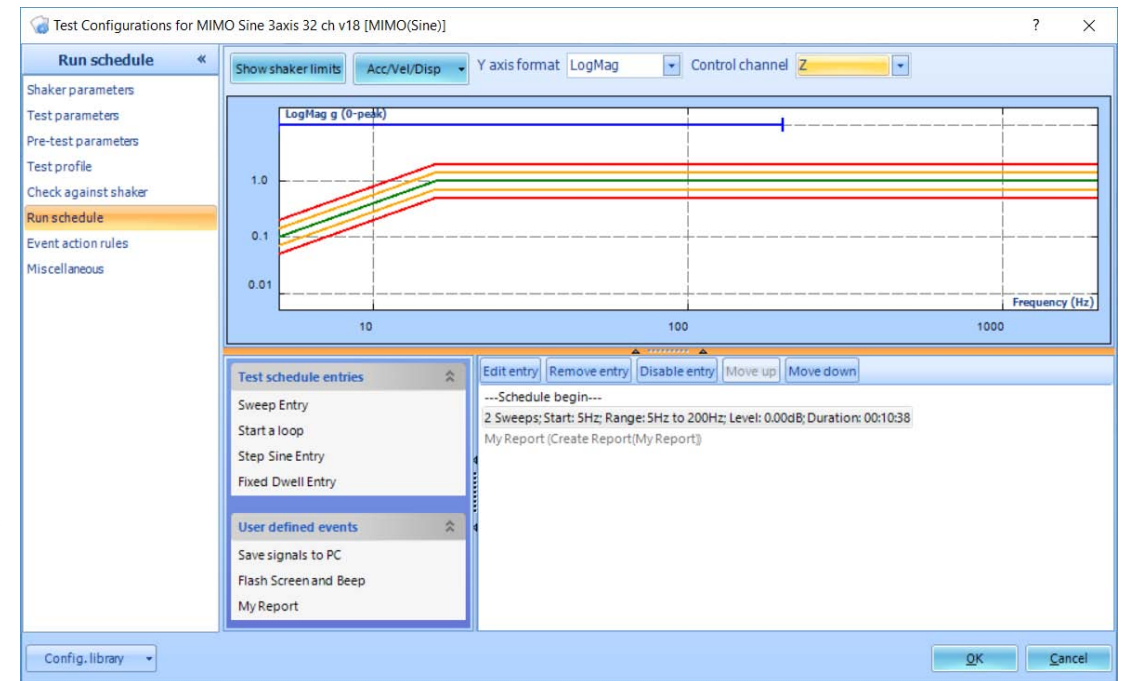


MIMO VCS Software | Run Schedule

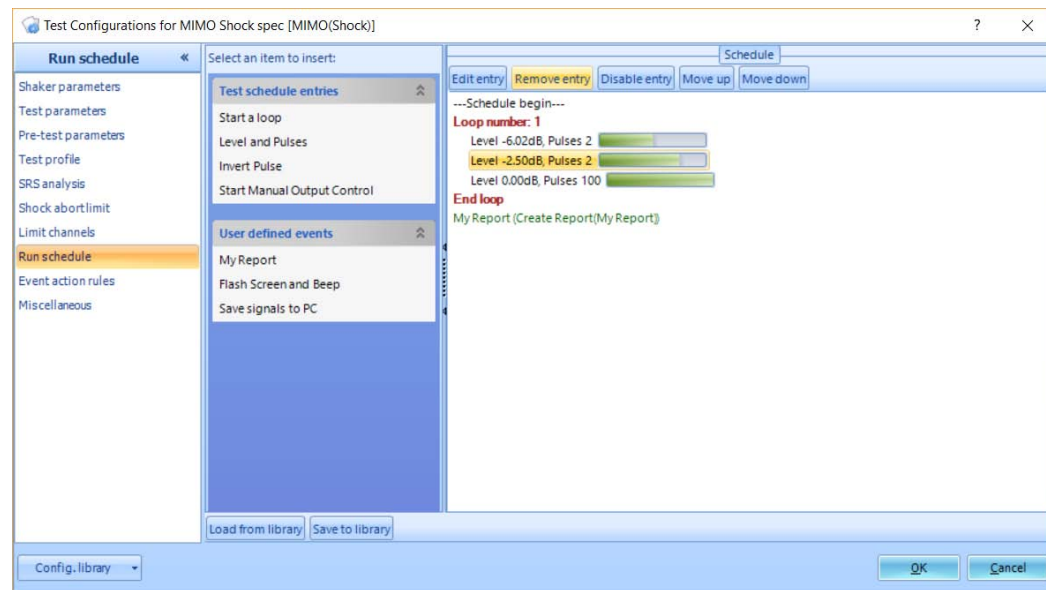
MIMO Random



MIMO Sine

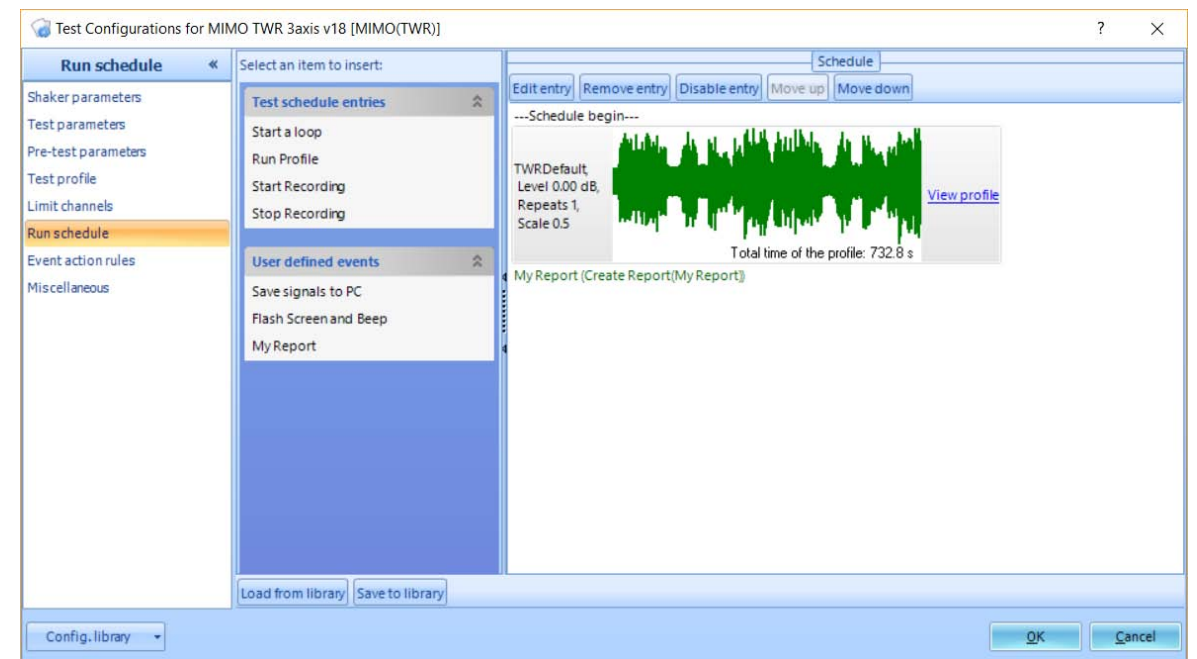


MIMO VCS Software | Run Schedule



MIMO Classic Shock

MIMO TWR



The End

Thank you!



GERÄTE UND SYSTEME FÜR
FORSCHUNG • ENTWICKLUNG • VERSUCH • SERVICE

ADM Messtechnik GmbH & Co. KG

Zum Wartturm 9 • 63571 Gelnhausen

Tel. (06051) 916557-1 • Fax 916557-9

sales@adm-messtechnik.de