MEscope Application Note 50

Rapid Test™ Using Two Uni-Axial Accelerometers

The steps in this Application Note can be carried out using any MEscope Package that includes the **VES-3600 Advanced Signal Processing** option. Check **Help | About** to verify authorization of this option.

Click here to download the MEscope Demo Project file for this App Note.

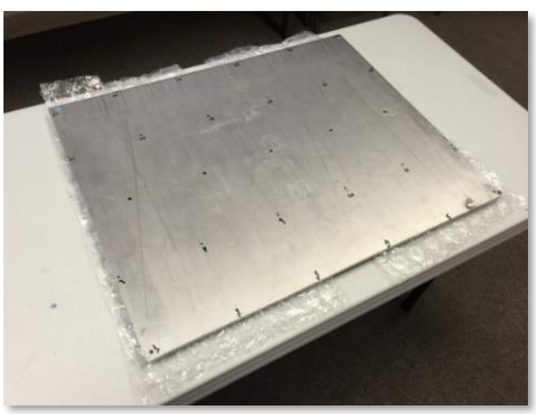
INTRODUCTION

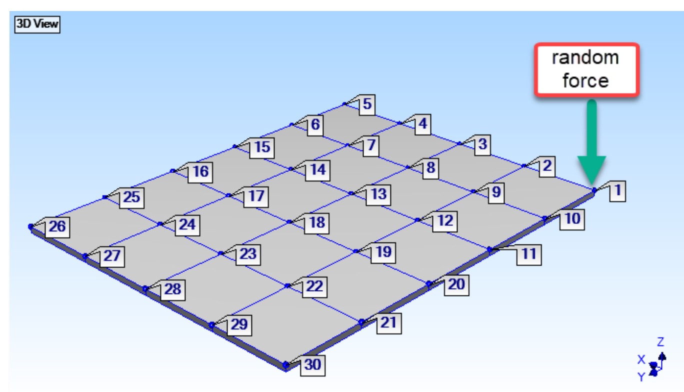
In this Application Note, a unique measurement and post-processing capability in MEscope will be used to calculate a single-reference set of FRFs from random response data acquired with ***two uni-axial accelerometers***. The acceleration responses at 30 points on the aluminum plate shown below will be simulated by applying a pure random force input at one corner of the plate and using a set of experimental FRFs to represent the dynamics of the plate. The random responses will be calculated using MIMO Modeling & Simulation, which is part of the VES-3600 Advanced Signal Processing option in MEscope.

Data acquisition from the aluminum plate ***will be simulated*** as if it were acquired using ***two uni-axial accelerometers*** and a 2-channel acquisition system. The Acquisition window in MEscope will be used to ***"acquire"*** data from a Data Block containing the random responses. The acquired data will be used to calculate a sequence of Transmissibility measurements, called a TRN chain. Finally, the TRN chain will be ***"seeded"*** with an FRF to yield a single-reference set of FRFs. A ***"round trip"*** will be completed by comparing the experimental FRFs with the FRFs derived from the TRN chain.

In a Rapid Test™, either or both accelerometers can be moved between acquisitions of data. One sensor can be ***"hopped over"*** the other in slinky fashion, or both can be moved, provided that a chain of Transmissibility's is calculated from the acquired data. The TRN chain is defined by the DOFs of the Transmissibility's. A TRN chain is formed when each Transmissibility has the same DOF as another Transmissibility.

More details of Slinky™ (TRN chain) testing are presented in **Technical Paper #72** from the Vibrant Web site.





OPENING THE PROJECT

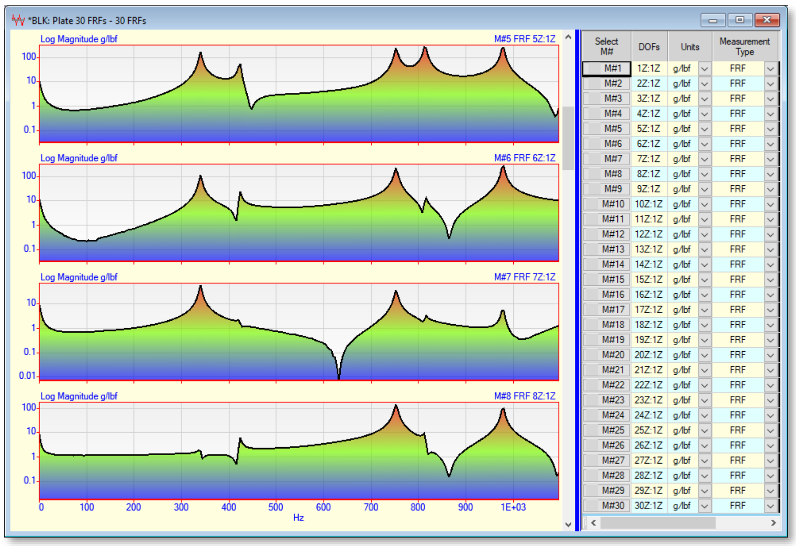
- Click here to download and then open **AppNote50.VTprj**

This Project contains an STR file, several BLK files, and multiple VSL script files with ***seven numbered Hotkeys***.

Experimental FRFs

To capture the dynamics of the aluminum plate, a ***roving impact test*** was performed on it with an accelerometer attached at one corner (DOF 1Z). The plate was impacted at 30 points in the vertical direction (DOFs 1Z to 30Z), and 30 FRFs were calculated between each impact DOF and the fixed reference response DOF 1Z.

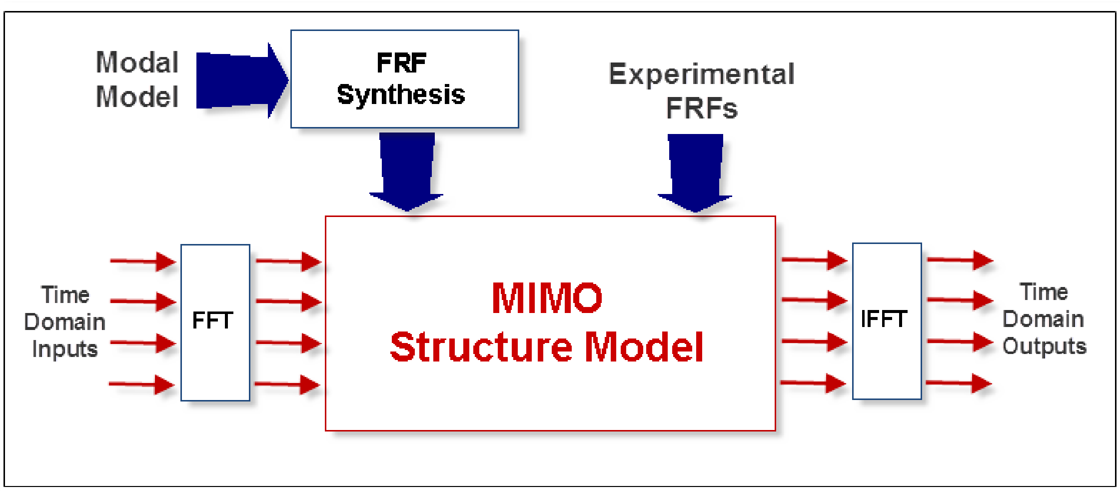
The log magnitudes of several FRFs derived from the impact test are shown in the figure below. The FRFs are stored in **BLK: Plate 30 FRFs** which is included in the Project file. The properties of the FRFs are also listed in the **M#s spreadsheet** to the right of the log magnitudes. The log magnitudes indicate that at least five resonances (modes of vibration) were excited over the frequency span of the FRFs.



Experimental FRFs from the Aluminum Plate

MIMO MODELING & SIMULATION

Using the FRFs as its dynamic model, a random excitation force will be applied at one corner of the aluminum plate (**DOF 1Z**). The random responses of the plate at DOFs 1Z to 30Z will be calculated using the **Transform | MIMO Outputs** command in MEscope. This calculation is depicted in the diagram below.



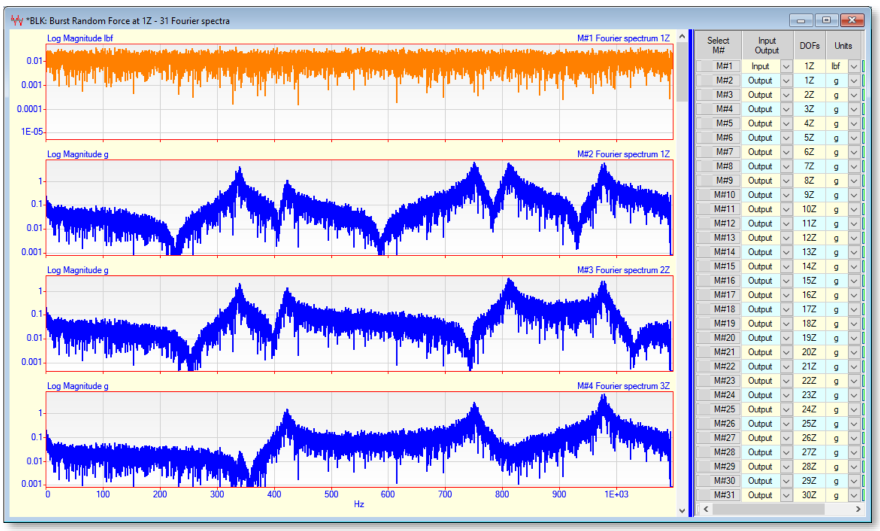
The **File | New | Data Block** command in MEscope was used to create a Data Block with a time waveform of the random force in it. A sequence of ***ten random time waveforms***, each with 2000 samples, was created as ***the random force Input*** at **DOF 1Z**. This Data Block (**BLK: Random Force at 1Z**) is included in the Project file.

The **Transform | MIMO Outputs** command will be executed in the **(BLK: Random Force at 1Z)** Data Block window, and the following steps will be carried out to calculate the response time waveforms caused by the excitation force,

1. The Fourier spectrum of the force is calculated by **Fourier transforming** its time waveform
2. Each experimental FRF is ***multiplied*** by the Fourier spectrum of the force Input to obtain the Fourier spectrum of each random Output
3. The time waveform of each random Output is calculated by **Inverse Fourier transforming** its Fourier spectrum

The Fourier spectrum of the random force Input and the Fourier spectra of several random Outputs are shown in the figure below. Each of these spectra has ***10,000 samples*** in it.

The random force time waveform (in **BLK: Random Force at 1Z**) was created with 20,000 samples, enough samples to calculate 10 Fourier spectra with 1000 samples each. When this data is ***"acquired"*** from the **BLK: Random Responses** Data Block by the Acquisition window, spectrum averaging will be used to remove the random noise from the response Output spectra.

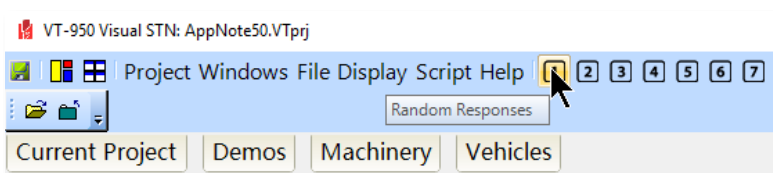


Fourier Spectra of Excitation Force & Three Random Responses

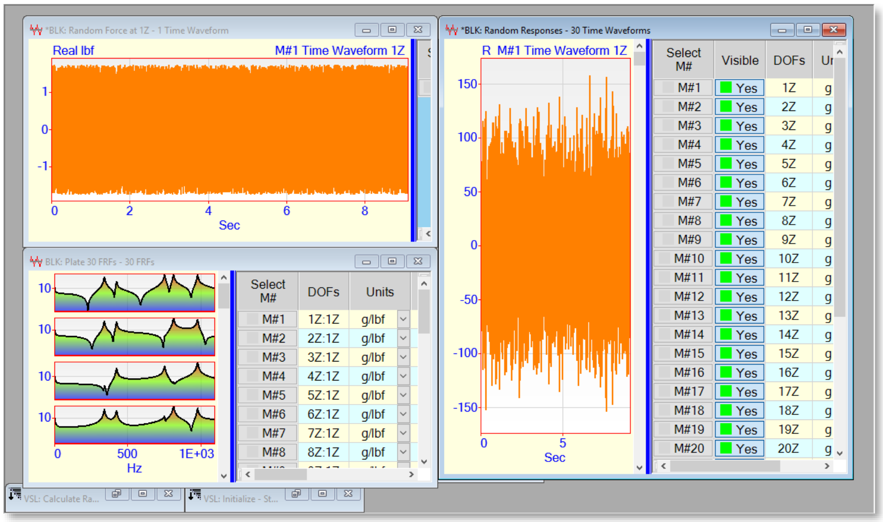
Step [1] Calculating Random Responses

To calculate the random responses due to the random excitation force,

- ***Press* Hotkey [1]** on the Toolbar as shown below. With the mouse pointer over this Hotkey, its Tool tip **"Random Responses"** is displayed

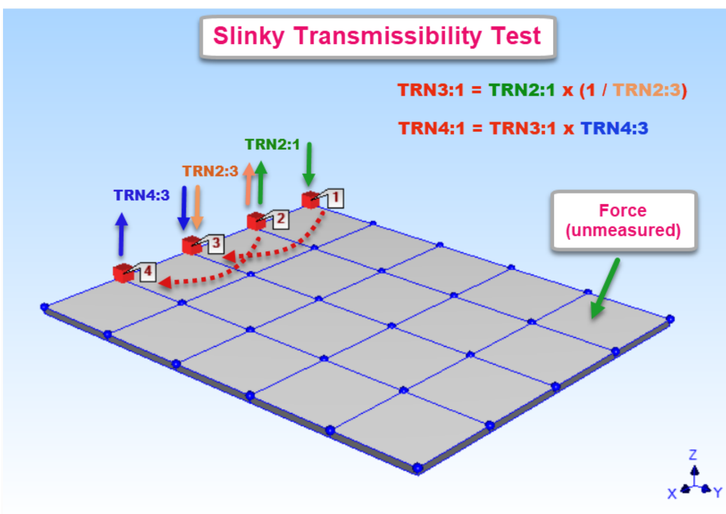


Pressing Hotkey [1] will execute a Script that calculates the 30 random response Outputs and displays them on the right side of the MEscope window as shown below. Data will be ***"acquired"*** from **BLK: Random Responses** when the Acquisition window in MEscope is connected to it.



Step [2] -Calculate the Slinky TRN Chain

Next, a Slinky TRN chain will be calculated by ***"acquiring"*** data from the Data Block **BLK: Random Responses**. A Slinky test using a ***pair of uni-axial accelerometers*** will be simulated by ***"simultaneously acquiring"*** random response data from the **BLK: Random Responses** Data Block corresponding to a pair of adjacent points on the plate. Each pair of responses is used to calculate a Transmissibility. This Slinky test procedure is depicted in the figure below.



Slinky Test

- ***Press*** **Hotkey [2]** on the Toolbar. With the mouse pointer over this Hotkey, its Tool tip **"Slinky TRN chain"** is displayed

The Acquisition window will ***"acquire"*** pairs of random responses from the Data Block **(BLK: Random Responses)** using 29 Measurement Sets. A Transmissibility is calculated between each successive pair of grid points on the plate.

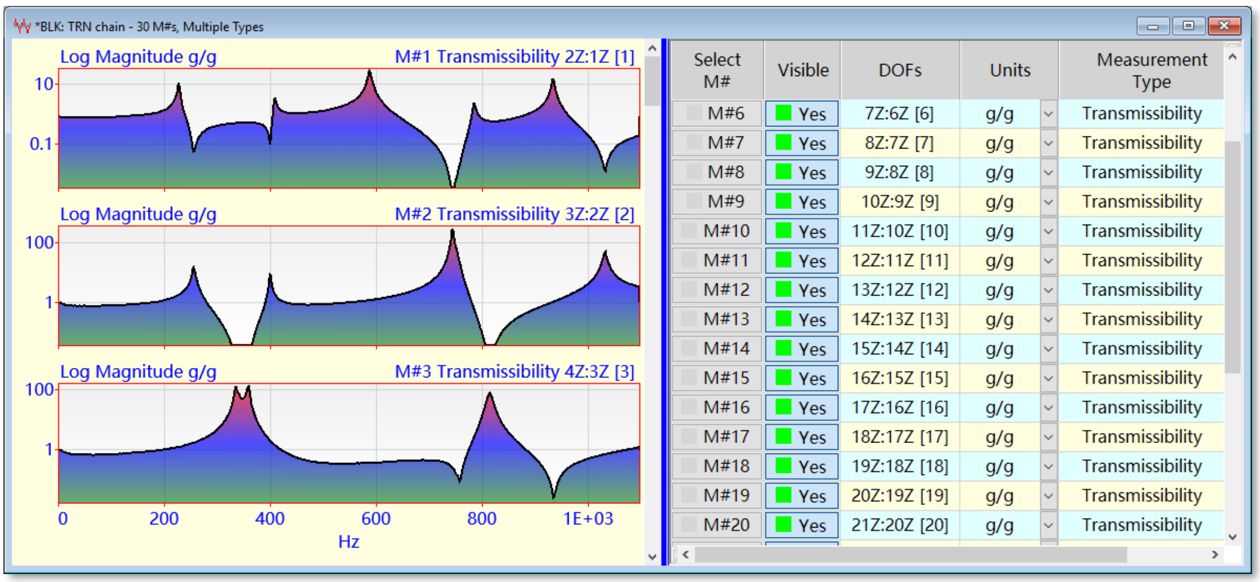
A Transmissibility is a ***cross-channel measurement***, defined as the Fourier spectrum of one response divided by the Fourier spectrum of another response.

A Transmissibility is calculated by dividing the Cross spectrum between two responses by the Auto spectrum of the denominator response.

Before calculating a Transmissibility, ***ten response Auto & Cross spectra*** will be averaged together to remove the random noise from the spectra. Each sampling window (2000 samples of response time waveform) must also have a ***Hanning window*** applied to it before transforming it to its Fourier spectrum.

> Because each random time waveform is ***non-periodic (not completely contained)*** within its sampling window, a Hanning window ***must be applied*** to each sampling window OF time waveform data ***before transforming it*** in order to ***minimize leakage effects*** in its Fourier spectrum.

Hanning windowing and spectrum averaging are both performed by the Acquisition window when it ***"acquires"*** data from the **BLK: Random Responses** Data Block. When Hotkey [2] is pressed, a TRN chain of 29 Transmissibility's is calculated between 29 pairs of accelerations using 29 Measurement Sets. Some of the Transmissibility's are displayed below.



TRN Chain from the Plate

> A Transmissibility is a ***different complex waveform*** than an FRF
>
> ***Peaks*** in a Transmissibility are ***not resonance peaks***
>
> Transmissibility's ***cannot be curve fit*** using an FRF-based curve fitting method to obtain mode shapes.

Notice in the **M#s spreadsheet** on the right above that each Transmissibility has units of **g/g**, and each Transmissibility also has a different Reference DOF. The Transmissibility's in the TRN chain are ***"chained together"*** because each Transmissibility has a Roving or Reference DOF that is the same as a DOF of another Transmissibility in the chain.

> **TRN chain**: Each Transmissibility in the chain has either a Roving or a Reference DOF that is the same as a DOF in another Transmissibility in the chain. A Transmissibility can be calculated from data that is acquired ***between any pair of DOFs*** provided that all Transmissibility's are chained together by their DOFs.

Step [3] – Seeding the TRN Chain

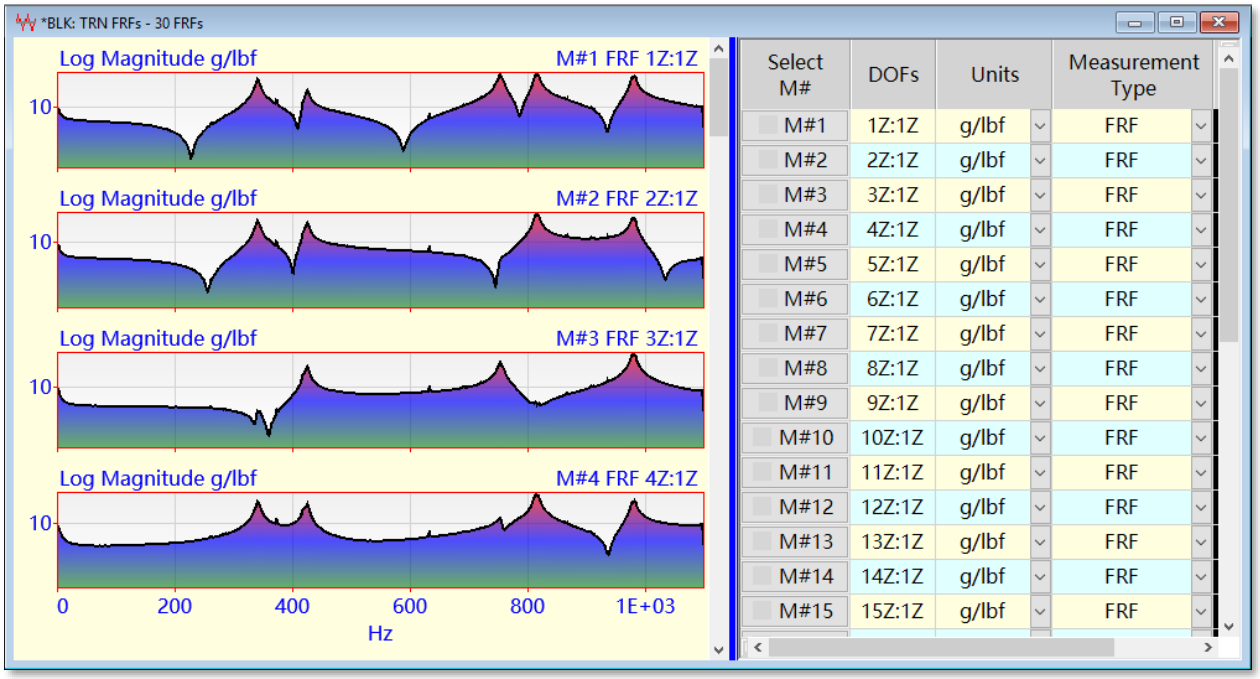
A single-reference set of FRFs will be calculated by ***"seeding"*** the TRN chain with an FRF. The Data Block **Transform | TRN Seed** command will be used to seed the TRN chain.

> The only requirement for seeding a TRN chain is that the ***Roving DOF of the seed match one of the DOFs*** of one of the Transmissibility's in the TRN chain

To seed the TRN chain,

- ***Press* Hotkey [3]** on the Toolbar. With the mouse pointer over this Hotkey, its Tool tip **"Seed with an FRF"** is displayed

After the TRN is seeded, a single-reference set of FRFs will be displayed on the right side of the MEscope window. Some of the FRFs derived from the TRN chain are shown below.



Single-Reference FRFs Derived from the TRN Chain

Step [4] – Comparing FRFs

A set of ***FRFs with a single reference*** DOF is required to display ODS's in animation, or to curve fit the FRFs and obtain mode shapes.

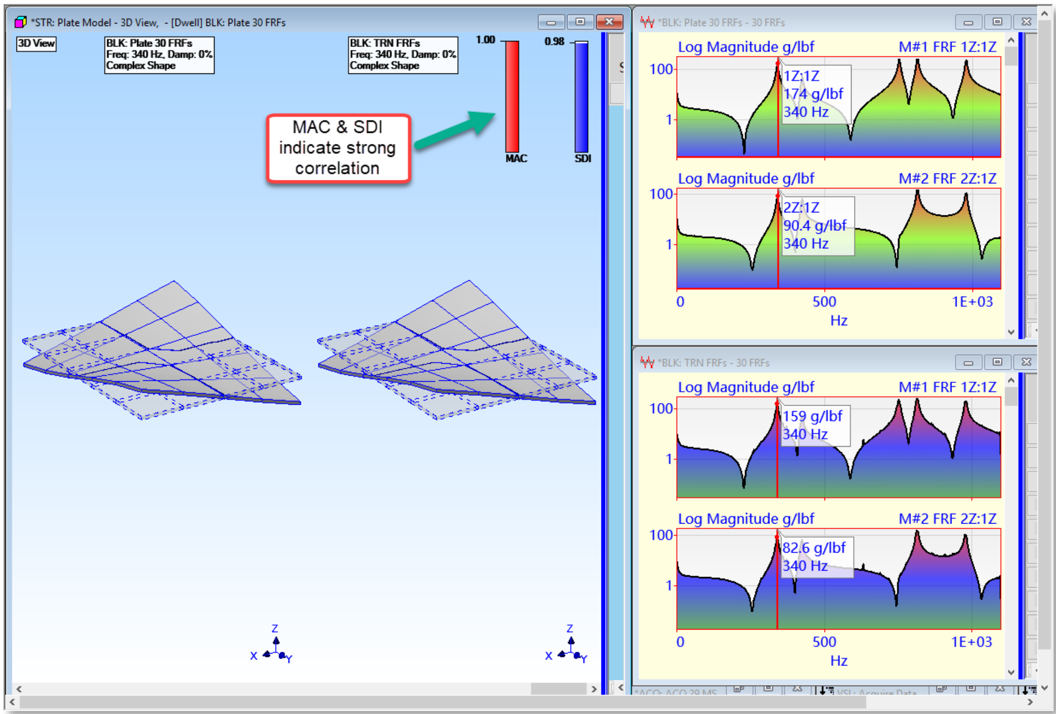
The FRFs derived from the TRN chain will be compared with the original FRFs in three different ways,

1. **Animated ODS Comparison**
2. **Data Block Correlation**
3. **M# Pair Correlation**

1. Animated ODS Comparison

To compare ODS's in animation between the Data Block of original FRFs **(BLK: Plate 30 FRFs)** and the Data Block of FRFs derived from the TRN chain **(BLK: TRN FRFs)**,

- ***Press* Hotkey [4]** on the Toolbar. With the mouse pointer over this Hotkey, its Tool tip **"Animate ODS's"** is displayed



Drag the cursor to each resonance peak in the FRFs to display its ODS. Notice in the figure above that **MAC =1** and the **SDI =0.98** between the **340 Hz ODS's** in the two Data Blocks. MAC indicates the ***co-linearity*** between two shapes, and SDI measures the ***difference*** between two shapes. Both metrics indicate a strong correlation between the ODS's at the 340 Hz resonant peak.

Step [5] - Data Block Correlation

The **Tools | Data Block Correlation** command calculates MAC & SDI values between the Y-axis values with matching DOFs ***at each sample*** in two Data Blocks.

The **Tools | Data Block Correlation** command requires that both Data Blocks have the ***same number of samples*** in them.

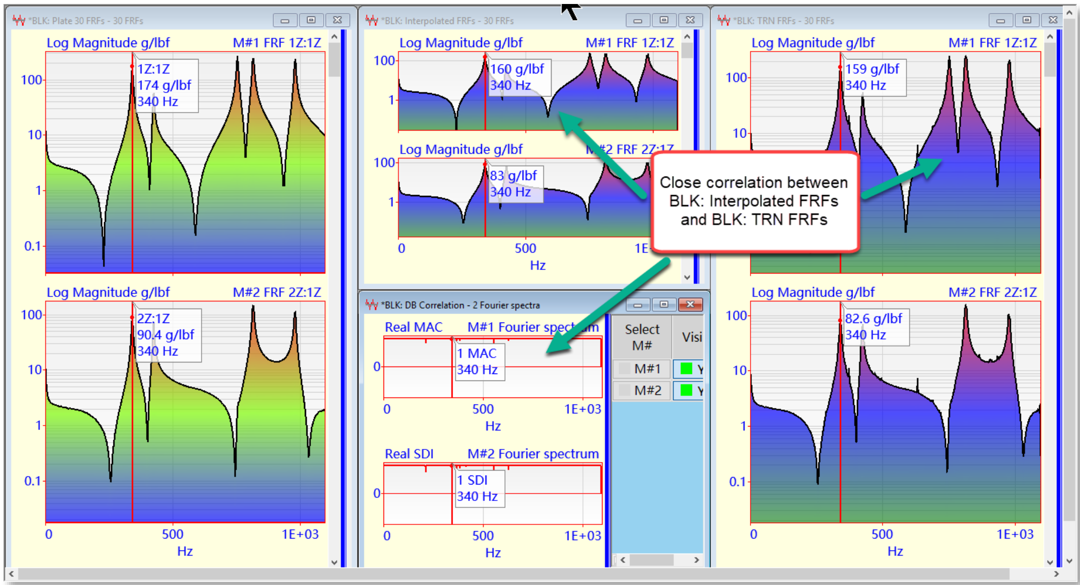
Each M# in **BLK: Plate 30 FRFs** has **275 samples** and each M# in **BLK: TRN FRFs** has **1000 samples**.

The **M#s | Paste from File** command ***interpolates the pasted M#s*** to match the X-axis samples of the Data Block into which the M#s are pasted.

In order to calculate MAC & SDI values between the **(BLK: Plate 30 FRFs)** and **(BLK: TRN FRFs)** Data Blocks, the Script connected to Hotkey [5] was written to paste **(BLK: Plate 30 FRFs)** into **(BLK: TRN FRFs)**, and then copy the ***interpolated M#s*** of **(BLK: Plate 30 FRFs)** into a different Data Block **(BLK: Interpolated FRFs)**.

- ***Press* Hotkey [5]** on the Toolbar. With the mouse pointer over this Hotkey, its Tool tip **"Data Block Correlation"** is displayed

When Hotkey [5] is pressed, the MAC & SDI results are put into a new Data Block. The new Data Block **(BLK: DB Correlation)** is displayed in the lower middle of the figure below. The MAC & SDI values indicate a ***strong correlation*** over the entire frequency span between the original Data Block of FRFs **(BLK: Plate 30 FRFs)** and the Data Block of FRFs **(BLK: TRN FRFs)** derived from the TRN chain.



Step [6] - M# Pairs Correlation

The **Tools | M# Pairs Correlation** command calculates MAC & SDI values between the Y-axis values of two M#s with matching DOFs in two Data Blocks.

The **Tools | M# Pairs Correlation** command requires that both Data Blocks have the ***same number of samples*** in them.

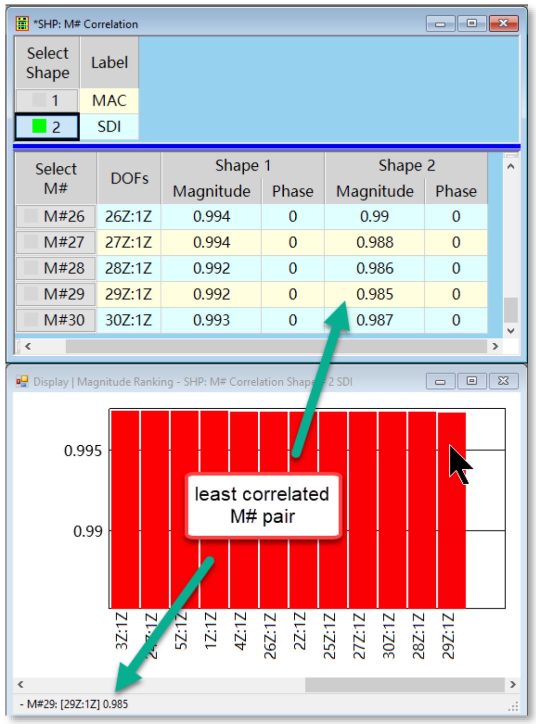
In order to calculate MAC & SDI values between the **(BLK: Plate 30 FRFs)** and **(BLK: TRN FRFs)** Data Blocks, the Script connected to Hotkey [6] was written to paste **BLK: Plate 30 FRFs** into **BLK: TRN FRFs,** and then copy the ***interpolated M#s*** of **BLK: Plate 30 FRFs** into a different Data Block **(BLK: Interpolated FRFs)**.

- ***Press* Hotkey [6]** on the Toolbar. With the mouse pointer over this Hotkey, its Tool tip **"M# Pairs Correlation"** is displayed

When Hotkey [6] is pressed, a new Shape Table **(SHP: M# Correlation)** is created which contains the MAC & SDI values between each pair of M#s with matching DOFs in Data Blocks **(BLK: Plate 30 FRFs)** and **(BLK: TRN FRFs)**.

(SHP: M# Correlation) is displayed in the upper middle of the figure below, and the **Magnitude Ranking** of its **M#s** in the lower middle. The MAC & SDI values indicate the ***same strong correlation*** between each **M#** of the **(BLK: Plate 30 FRFs)** and the **M#** with matching DOF in **(BLK: TRN FRFs)**.

SDI = 0.985 is the lowest SDI value among all matching M# pairs in the two Data Blocks (BLK: Plate 30 FRFs) and (BLK: TRN FRFs).



CONCLUSIONS

In this App Note, a Slinky™ test using two uni-axial accelerometers was simulated. This new testing method creates a chain of Transmissibility's called a TRN chain. A ***round trip*** was performed by starting with a set of FRFs with Reference DOF 1Z. Those FRFs were used to calculate the random responses of the plate to a random excitation force applied at DOF 1Z. The random responses of the plate where then ***"acquired"*** from a Data Block of time waveforms, 2 channels as a time to simulate the use of two uni-axial accelerometers.

A TRN chain of 29 M#s was calculated from the acquired data. The TRN chain was then seeded with an FRF, and a single-reference set of 30 FRFs with Reference DOF 1Z was derived.

Finally, the FRFs derived from the TRN chain were numerically compared with the original FRFs used to create the simulated random responses. Three different numerical comparisons were used between the two Data Blocks of original and derived FRFs

MAC & SDI

All three FRF comparisons used the **Modal Assurance Criterion (MAC)** and **Shape Difference Indicator (SDI)** metrics.

- Both MAC & SDI have values between 0 &1
- A MAC or SDI value ***greater than 0.9*** indicates a ***strong correlation*** between two shapes
- A MAC or SDI value ***less than 0.9*** indicates a ***weak correlation***.

All three MAC-based & SDI-based comparisons showed a ***strong correlation*** between the original FRFs and the FRFs derived from the TRN chain.

Step [7] - Review

To review all the steps of this App Note,

- ***Press*** **Hotkey [7]**