Frequently Asked Questions About TMS 2100E11 Modal Shaker

A selection of frequently asked questions on electrodynamic exciters and related excitation topics.

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2. When do I need to use inertial masses? What frequency does it become important to use the inertial masses?
3. How critical is alignment to shaker performance?
4. What is the best way to align the shaker when setting up a test?
5. Why does my shaker have multiple force ratings?
6. At what time during a modal test set up should the shaker be attached to the structure?
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What is the advantage of a through-hole armature?

With conventional vibration testing using a shaker with a traditional mounting platform design, the test article is directly attached to the top surface of the armature with some base excitation applied, usually monitored by controlling some prescribed acceleration. The device under test (DUT) is normally subjected to some operating environment, generic spectrum or some excessive environment to determine if the equipment is suitable for the intended service. A typical configuration is shown.

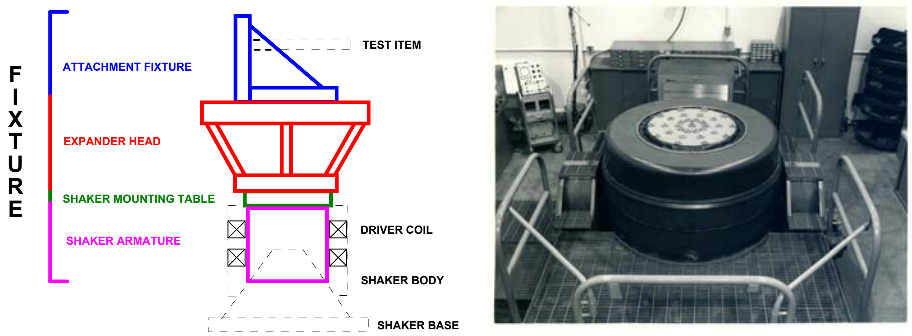

Figure 1 – Typical shaker qualification configuration

In the early days of modal testing with shaker excitation, smaller shakers were used to apply some low level excitation to be able to measure a frequency response function. Usually the shaker was attached with a long rod, commonly referred to as a stinger or quill, in order to impart force to the structure. (The purpose of the stinger was to try to dynamically decouple the shaker from the structure.)

Because these traditional shakers were typically used for base excitation, the armature attachment configuration was not optimal. Usually, some type of left-right thread arrangement was made or some type of collar was designed to enable an easier attachment to the shaker. It was a rather difficult arrangement no matter how the connection was made. In addition, there had to be some thought given to shaker position and actual length of stinger needed. If a different length stinger was needed, then the shaker needed to be reoriented and realigned as different stinger lengths were used for the modal test. Overall, the set up of the shaker for a modal test was very difficult and cumbersome.

Due to all these problems, some thought was given to specific design configurations that were better suited for modal testing applications. This gave rise to the through-hole armature with a chuck and collet design (like gripping a drill bit on a hand drill) that enabled very easy attachment of the shaker to the modal test article. A long stinger can be slid into the shaker's through-hole armature, threaded to the force transducer attached to the test article, properly aligned, and then clamped down with the chuck and collet at the appropriate length. These components are shown as an exploded view in Figure 2 below, and a video demonstrating actual installment is posted at http://www.youtube.com/watch?v=VP_X-8TUtOU. This design also accommodates stingers of different lengths if needed. This arrangement is so simple that it is difficult to imagine having to set up the test without this important feature.

Figure 2. Exploded view of shaker, two-part chuck, collet, stinger and force transducer.

When do I need to use inertial masses? What frequency does it become important to use inertial masses?

Many times it is difficult to support a shaker from a floor-mounted fixture, such as the Model 2050A lateral excitation stand shown in Figure 3 below. In these cases, the shakers may be hung from a support cable attached above the test article. Often masses are attached to the base of the shaker trunnion to provide more inertia to push against for improved performance, typical only an issue at very low frequency in the sub-10 Hz range.

Figure 3 – Typical shaker excitation set up

How critical is alignment to shaker performance?

The alignment of the shaker is very important. Significant misalignment may cause damage and/or unnecessary wear to the shaker armature due to resulting side loads. In addition, the forces imparted to the structure will be measured incorrectly due to transverse load components, and the measured response functions will not be correct. This alignment issue causes difficulty in any shaker test. Care must be taken to provide the best alignment possible to attain the best possible measurements.

(In a future update of this FAQ, measured frequency response functions will be included to show the distortion that may commonly result due to poor alignment.)

What is the best way to align the shaker when setting up a test?

In setting up a shaker test, typically the stinger is slid into the shaker's through-hole armature with the force transducer or impedance head attached to the end of the stinger. With the shaker collet loosened, the stinger can be extended in and out of the armature to obtain the desired length. Once this is done then the force gage or impedance head mounting pad can be affixed to the structure; the mounting pad is often attached using dental cement, two-part quick epoxy or a

Loctite adhesive. Often a piece of foil adhesive tape is first adhered to protect the surface of the test article, with the mounting pad bonded to the tape.

If the alignment is correct, the shaker stinger will easily unthread from the force transducer or impedance head AND also thread right back in without any binding or difficulty whatsoever. This should be accomplished without the stinger putting side load onto the shaker armature, sliding easily within the chuck and collet assembly, which assures that the shaker and stinger are properly aligned.

At times there may be a threaded mating hole in the structure for mounting the force gage or impedance head and attaching the shaker. Alignment in these situations is much more difficult, requiring that the shaker and/or the test article be moved such that the fixed threaded hole places the stinger exactly in the correct position. The main point is that the shaker must be aligned such that the stinger can be very easily threaded in to the force gage or impedance head with no difficulty or binding whatsoever.

Why does my shaker have multiple force ratings?

Shakers actually only have one maximum force rating. However, shaker systems (i.e. the electrodynamic exciter paired with a specific power amplifier with accessories like a cooling package) have different system ratings. For example, the 2100E11 modal shaker has a maximum force rating of 100 lb pk. To attain this maximum force rating, the shaker must be driven by an amplifier with adequate power, for example, the 2100E18 power amplifier, which is rated at 1000 W. Additionally, to attain this maximum force rating without damaging the shaker, forced air cooling must be supplied to the shaker to dissipate the heat generated from the current flowing through the coils using, for example, the 2050E03 cooling package.

For typical modal applications, lower input force levels are desired. Therefore, the shaker can be used with an instrumentation amplifier, for example the 2050E05 power amplifier delivered with the K2100E11 system kit. This system solution includes certain features of interest to modal test engineers, such as a constant voltage / constant current selection on the amplifier output, and a safety interlock that can be connected to the mechanical limit switches which prevent any over travel of the shaker armature. Given the 500 W power rating of the 2050E05 power amplifier, the maximum attainable output force level of the system (i.e. the 2100E11 driven by the 2050E05) is only specified at 35 lb pk.

At what time during a modal test set up should the shaker be attached to the structure?

When performing experimental modal analysis with shakers, generally all the accelerometers are mounted and cables are run from the structure to the data acquisition system before the shakers are attached to the test article. The shaker setup, stinger attachment, and alignment are usually the last steps in the process. If attached before the rest of the instrumentation is set up on the structure, the shaker could be damaged due to settling of the structure on its soft supports or shifting of the structure during the course of test set up. This will cause misalignment of the shaker/stinger set up which may lead to incorrect measurements. As a result, the shaker is generally the last item to be set up and aligned when performing modal testing.

Should I disconnect the stingers while not testing?

Whenever a modal test is performed using shaker excitation, the shakers should be disconnected from the structure while data is not being acquired, whether it is between different test configurations or during periods of inactivity, for example over a lunch break or overnight. There are many reasons for this. During the set up of the test, there may be some shifting or settling of the test article. Commonly, airbag soft support systems are used to provide a free-free boundary condition during testing. These may lose air over time, shifting the structure. Additionally, elastic shock cord (bungee) will creep in length over a period of time. In between tests, there may be some reconfiguration of the test article for multiple sets of test data. For instance, a vehicle's gas tank may be empty in one test and then filled in another test. Because of this, there may be a general shifting or redistribution of mass in the system, which in turn causes shifting of the test article relative to the original alignment of the shakers to the structure.

If the shakers are attached during down time between tests while the structure undergoes necessary reconfigurations, there may be side loads applied to the stinger attaching the shaker to the structure and the alignment of the system may be disturbed. These side loads will potentially bend the stingers, or worse, cause damage to the shaker armature. In addition, it may become difficult to disassemble the stinger from the structure once the alignment has been disturbed.

If the shakers are disconnected during periods between test cycles, it will be obvious if any misalignment has occurred upon reattaching the shakers for the next set of tests. If the original shaker alignment is disturbed, then the shakers must be realigned in order to provide a proper attachment to the system.

What is a trunnion? What can I do with it?

The trunnion is a very important component of the shaker system. It is the "U" shaped support base that supports the electrodynamic shaker body itself. The 2100E11 shaker trunnion allows the shaker to be rotated in place and provides convenient mounting holes for hanging from a lateral excitation stand, for example the 2050A shaker stand. Without a trunnion, it is very difficult to set up a shaker for modal testing. The trunnion allows the shaker to be configured in different skewed orientations and angles for excitation. Skewing the input force can be particularly important for exciting structures with vertical and lateral modes that are highly uncoupled. The trunnion is also beneficial when aligning the shaker to the structure for modal testing.

Figure 4 – TMS 2100E11 modal shaker with trunnion and easy-turn handles

How do I mount my shaker to the floor?

When setting up for shaker testing, the shaker must be aligned with the structure in order to excite the structure in the desired direction. Most times the shaker force levels used are very low in amplitude with no need to bolt the shaker to the floor or another mounting arrangement. However, there may still be some vibration that transmits back through the base to the floor. In these cases, friction against the floor alone may not be enough to stabilize the shaker and it should be firmly affixed to the floor. For low levels of force, hot glue around the base is typically adequate. In instances where hot glue is not sufficient the shaker may be attached with bolts or a clamping arrangement to the floor.

Another possibility when exciting at low force levels is to sit the shaker trunnion onto sand bags or rubber mats. This approach may be quicker/easier that applying hot glue, but does not always work good enough to maintain proper alignment since the shaker can still vibrate out of place. If shaker base vibration is observed, make sure that the shaker alignment is checked during the sequence of testing to assure that misalignment is not introduced. In addition, the driving point frequency response functions should be routinely checked to make sure that no significant change in the system has occurred.

My shaker is vibrating out of place during the test, what should I do?

If the shaker is vibrating out of place, misalignment of the stinger and armature will likely be introduced into the system. As discussed previously, proper alignment is critical to good quality measurements as well as preventing damage to the shaker itself. Therefore, it is necessary to attach the shaker firmly to a base if exciting at levels that result in the shaker “walking about” during testing. In most cases hot glue provides a temporary bond of the shaker to the floor, solving this issue. Please reference the previous discussion on proper floor mounting techniques if this occurs.

What's the best way to support my shaker to provide lateral inputs to my structure?

Usually a shaker stand such as the Model 2050A Lateral Excitation Stand (shown in Figure 4 below) or equivalent is used. The shaker needs to be supported at four separate points to allow appropriate horizontal motion of the shaker (as shown). At very low frequencies (below 5 to 10 Hz range), inertial weight is added to enhance the performance of the shaker system. These are generally heavy metal blocks that bolt onto the trunnion base, providing additional inertial mass for the exciter to push against while generating force input to the test structure.

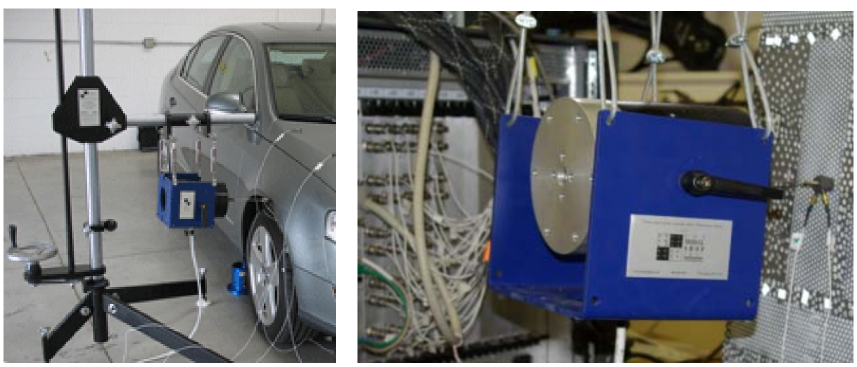

Figure 5 – Typical shaker measurement set up examples

What are the most common practical failures in a shaker installation/operation?

Misalignment of the stinger is often a significant problem in modal testing. Given a large enough misalignment, the shaker armature coil windings will be damaged due to scraping. More commonly, misalignment results in distortion and poor quality measured frequency response functions, which are uncharacteristic representations of the true system. At times this will cause difficulties in estimating modal parameters from data that has been contaminated with poor shaker alignment. This type of measurement contamination is often overlooked because of other issues related to many inconsistencies in the test structure system due to noise, nonlinearities and other effects. It is all too easy to overlook this simple measurement issue due to other commonplace factors.

The main problem with shaker misalignment is that the force transducer or impedance head transmits transverse loads that do not align with the sensing axis of the transducer normal to the surface. This causes a distortion of the actual measured force that is applied to the structure. It is very important to make the best possible measurement and alignment is an important part of that process.

Another problem will result when the structure is too compliant at the point of shaker attachment. As a result, the shaker may not have enough stroke for the actual structure displacement observed during testing. While displacement is one effect, consider the shaker coil's velocity limitations (5.2 ft/s, around 62 ips for the 2100E11) as well. In these cases the structure wants to deflect (especially at resonant frequencies) and the shaker cannot "keep up" with the actual displacement/velocity of the structure. This causes a "force dropout" in the input force spectrum, especially at resonant frequencies. Many times this will be referred to as impedance mismatch between the shaker and structure. In order to remedy this, typically the shaker will need to be moved to another suitable input location where the structure is not as compliant, yet still adequately excites all the modes of interest.

What type of maintenance does my shaker require?

- **Normal wear and tear. What to do?**
- **Broken/cracked flexure. What to do?**
- **Misaligned armature. What to do?**
- **Shorting of coils. What to do?**

The 2100E11 shaker is a sealed device requiring little or no regular maintenance if the operating instructions described in the user manual are followed. Normal wear and tear of the shaker can be addressed by cleaning the shaker body of debris. Pressurized shop air (through the body's vent holes) can be used to blow any free particles from the internals that may scrape the armature. Before attempting further inspection or service on the 2100E11 Modal Shaker, always disconnect the drive cable of the shaker from the power amplifier.

Damage to the armature's flexure suspension due to either mechanical or electrical overdrive of the shaker may be handled by replacing the damaged flexure element with a new one (spares supplied in the shaker accessory kit). The moving armature is suspended in the gap of the magnetic field circuit by four sets of two radial flexures. Sixteen vertical flexures provide axial support as well as lateral and rotational restraint of the armature assembly. Use a screwdriver to remove the four screws that hold the shaker cover and inspect the armature suspension for damaged flexures. Damaged, fatigued flexures will show a white discoloration, typically near the mounting points. Use the 3 mm allen hex wrench (supplied in the shaker accessory kit) to replace a damaged flexure with a new one. Check that the armature is properly centered in the gap and moving without interference before replacing the shaker cover and attempting to use the shaker. For special alignment procedure, please contact The Modal Shop.

Repair of damage to the coil, exciter body or magnet core should not be attempted in the field. Regarding the health of the coil, the 2100E11 should have a DC impedance between 3 to 4 ohms. Check the shaker impedance with a multi-meter for a short or open circuit. If the measured impedance is below 3 ohms, then some of the coils windings are shorted and the performance of the shaker will lessen. If the measured impedance is infinite, then the coil windings are open. In both cases, the unit should be sent back to The Modal Shop for repair.

The 2100E11 has an internal 10A fuse to protect the coil in the event of an electrical overdrive of the shaker. Use a screwdriver to remove the four screws that hold the shaker cover. Inspect the electrical wiring and replace the 10A fuse with a new one (spare supplied in the shaker accessory kit). Do not attempt to replace the fuse with a higher current fuse as it won't protect the shaker in the case of another electrical overdrive.

Amplifier related questions

What is the difference between the constant current and constant voltage settings on the shaker amplifier? What applications are best for each?

Most shakers for general use are set up with current amplifiers. When using some of the more common shaker excitations techniques used today for modal testing, this does not provide for good frequency response measurements. This is especially true for burst random excitation which is very widely used in modal testing with single or multiple shakers. When using burst random excitation, the response of the system needs to decay to zero before the end of the sample interval of the FFT analyzer time capture. With current amplifiers, the armature of the shaker coil is allowed to freely float after the excitation is terminated. For very lightly damped systems, the excitation and response may linger on well beyond the sample interval.

However, when the amplifier is set up as a voltage amplifier then the back EMF effect (the electromotive force caused by the structure motion driving the shaker armature through the coil) provides resistance to the armature and helps to cause the system response to decay more quickly. This may seem to be inappropriate because it seems that the shaker system is then supplying damping to the measurement, but is not an issue as long as the force is measured for the entire measurement. Then the correct input-output relationship is measured. (It is also important to note here that the force needs to be measured and not the electrical parameters of the amplifier in order to make the correct measurement.)

My amplifier has a current monitor output. What is it for?

In some general shaker qualification type testing, it is common that the current may track reasonably well with the actual force applied to the structure. As a result a current monitor is often provided by the amplifier to make an easy measured force estimate. However, there no substitute for measuring the actual force imparted to the structure during modal testing. Also, the force must be directly measured when using an amplifier set in voltage mode. For modal applications, use of the current output is not considered to be an accurate representation of the force applied to the structure in either mode, particularly higher frequencies where dynamics within the stinger/force transducer setup assembly may cause errors that would be undetected by monitoring the current only.

How well does the amplifier current output correlate with the excitation force?

In some cases, the force and current may track together but this is not always the case. Therefore, it is important to always measure the actual force imparted to the structure during shaker testing when measuring frequency response functions. Use a dynamic piezoelectric force transducer, such as a PCB 288D01 impedance head (ideal for modal driving point measurements) or PCB 208 series force transducer for accurate force measurements.

Can I use amplifier current output to accurately estimate the excitation force input to the test structure?

For applications of general vibration testing with large shakers, current is generally considered to be a fairly good estimate of the force applied to the system. However, for modal testing, the shaker is set up with a stinger to attach the shaker to the structure. The stinger assembly may also affect system dynamics. As a result, the force transducer or impedance head should always be measured on the structure side of the stinger in order to measure the force directly imparted to the structure. It is imperative to use a force transducer to measure the actual force imparted to the structure. There is no substitute for measuring the actual force.

What is the importance of the frequency specification of the amplifier?

Depending on the frequency range to be tested, the amplifier frequency range must also be considered to insure that the excitation signal provided to the shaker is properly conditioned. If not, the amplifier itself may induce significant distortion into the shaker's drive signal, compromising the quality of the measurement.

Stinger related questions

Why should I use stingers?

Stingers, sometimes also called quills, are required to perform modal testing with shakers. The shaker head should never be directly attached to the structure for modal testing. This would provide very poor frequency response measurements for modal testing. If the shaker were to be directly attached to the structure, there would be significant dynamic effects of the shaker imposed onto the structure, resulting in a dramatically altered frequency response function.

Basically, the stinger decouples the shaker system from the structure and applies force to the structure. The stinger is designed to be rigid in the axial direction and flexible in the lateral direction. Force transducers measure axial force but still transmit forces into the structure through the transducer's stiff casing. Therefore, any sideloads transmitted to the structure by the stinger through the force transducer are unmeasured and contribute noise on the measurement. A stinger that is properly designed, selected and aligned will reduce or eliminate this.

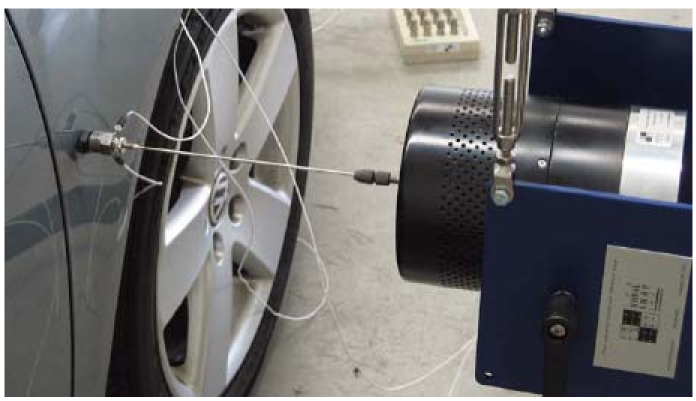

Figure 6 – A typical shaker measurement set up with stinger

Of course the shaker's dynamic subsystem will never be perfectly decoupled and there will practically always be some slight cross-axis force input to the structure. The intent of the stinger design is to be very stiff in the axial direction and extremely compliant to lateral loads to minimize this situation. The best stinger for minimizing any affects of cross-axis force input is a piano wire stinger, such at The Modal Shop model K2160G, which utilizes the through-hole armature design of a modal shaker allowing the wire to be pretensioned to "push" force into the test structure. The piano wire is completely flexible in the lateral direction, making it the optimal choice. Another alternative is a thin rod stinger design, such as The Modal Shop 2150G12, which also utilizes the through-hole armature design. Since this design is a stiff rod (rather than a wire) it does transmit some amount force laterally. However, this style of stinger does not need to be pretensioned, and thus greatly simplifies setup. As a result it is more commonly used as an acceptable compromise of performance and ease-of-use.

The affects of the stinger assembly's lateral stiffness on the overall system is very dependent on the stiffness of structure being tested. If the structure itself is very stiff, then this is often not a serious concern. However, when the structure is very flimsy or has a significant amount of rotational effect at the attachment point of the stinger then these lateral loads can become very important and a source of large measurement error. In addition, these rotational effects generally become more important at higher frequencies so it is always difficult to determine that actual impact on the overall results. One easy way to determine the effects of the stinger lateral and rotational effects is to make several test runs with the length of the stinger varying by +/- 10% and observe the change in the measured drive point frequency response.

How do piano wire stingers work? How are they pre-tensioned?

Piano wire stingers are an excellent way to circumvent the problems with lateral stiffness associated with conventional stingers. Essentially the piano wire has no lateral stiffness to speak of. The piano wire is pretensioned with a load that is greater than the alternating load to be applied; a preload of 3 to 4 times the range is considered reasonable. The piano wire is fed through the core of the through-hole shaker armature so it is critical to have a modal shaker that is designed to accommodate this. A simple preload can be applied with weights or an elastic tie-down strap. With the weight applied, the collet is used to clamp the tensioned piano wire. As long as the applied load during shaker excitation is less that the preload, then the piano wire is an excellent way to transmit force and conduct a modal test, eliminating the effects of lateral stiffness in conventional stingers.

How short (or long) should I make my stingers?

The length of the stinger can be an issue in performing a modal test. Given too short of a stinger, the structure will be less decoupled from the excitation system and there will be some dynamic effects of the shaker on the dynamics of the structure. Given too long of a stinger, the stinger will buckle within the frequency range of interest and insufficient force will be transmitted to the structure. The effects of this would be evident the force transducer's power spectrum measurement. Ideally, the stinger is set up as long as possible to maintain lateral flexibility but still short enough to transmit axial force without buckling.

(In a future update of these FAQ, additional information with quantified example data will be provided for further understanding of this topic.)

What is the useable frequency range for force input based upon stinger type and length?

The length of the stinger can be an issue in performing a modal test. Given too short of a stinger, the structure will be less decoupled from the excitation system and there will be some dynamic effects of the shaker on the dynamics of the structure. Given too long of a stinger, the stinger will buckle within the frequency range of interest and insufficient force will be transmitted to the structure. The effects of this would be evident the force transducer's power spectrum measurement. Ideally, the stinger is set up as long as possible to maintain lateral flexibility but still short enough to transmit axial force without buckling.

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Why should I use a "modal" stinger (thin rod type, like models 2150 or 2155) instead of threaded rod stinger?

The modal stingers are professionally made with the specific intent of being used for modal testing. They are intended to be used with modal shakers that are equipped with a through hole armature design with a chuck and collet for clamping the stinger. The stinger can easily slide in the chuck's collet until aligned and attached to the force transducer or impedance head, then tightened in place like you would a drill bit. The thin rod is very weak in the lateral direction, minimizing the transmission of transverse force inputs. The model 2150 series is just 1/16" diameter while the model 2155 series is 3/32" diameter, each with a 10-32 threaded stud brazed on the end to connect to the force transducer or impedance head attached on the test structure. An ordinary threaded rod with a conventional shaker (not specifically designed for modal testing) can be used but the set up and alignment are often difficult and cumbersome to use. Since these stinger designs are threaded throughout, attaching them to a tapped hole at both the test structure and the shaker armature, at the same time, is rather difficult. These are also typically much stiffer in the lateral direction, generating transverse force inputs, a significant source of measurement error.

How many degrees of misalignment can a standard stinger absorb at what inaccuracy level?

The stinger is intended to be used to transmit force only along the axis of the stinger. It is very difficult to identify the exact level of inaccuracy that can be absorbed by a stinger. The thicker the stinger, the more misalignment it can physically support, but the more transverse force will be input into the system resulting in measurement error. The thinner the stinger, the more likely that any misalignment with bend the stinger, damaging it. However, since stingers are (relatively) inexpensive and intended to essentially be a mechanical fuse in your test setup, it is better to error in this direction. If you continue to bend stingers, damaging them beyond usage, it would follow that you have too much misalignment. At some point the quality of the measured data is suspect as well; however, this is dependent not just on the stinger but also on the structure under test and the frequency range to be considered.

(In a future update of these FAQ, additional information with quantified example data will be provided for further understanding of this topic.)

When do I use the graphite composite tube around the nylon 10-32 threaded rod stinger?

The graphite composite tube around the threaded rod is intended to provide additional stiffness to the stinger. Often times these are shipped together and they are installed and used "as is" for modal testing. Many times the graphite composite tube provides too much lateral stiffness and may cause distortion of the measurement system. One way to determine the effect is to test the structure with and without the graphite composite tube and further compare these results with a longer stinger configuration. If there is no difference in any of the measured drive point frequency response functions then there is no concern. But if there are differences then some assessment of the measured functions and which stinger system is most appropriate for the modal test needs to be identified.

Sensor related questions

What is the proper mounting technique for the force transducer?

A very important consideration when mounting force transducers is recognition that force transducers are "directional". This means that force transducers are designed to accurately measure force on only one of its two mounting faces, for example labeled "TOP" and "BASE" on the PCB model 208 series. This is shown in Figure 7 below, showing a 208 series force transducer mounted to a 2155G12 rod style stinger. Note that for this model force transducer the "TOP" of the unit is the designed sensing surface and should be mounted directly to the test article. Some transducers, like the PCB model 288D01 impedance head, have an indication of exactly which side to mount to the structure. In any case, please consult the force transducer's user manual for identifying which mounting surface is intended to measure the force accurately. This is due to the fact that the force transducer itself has mass and stiffness. They are designed and calibrated to read force accurately on one of its mounting faces, and thus need to be installed accordingly.

Figure 7. PCB 208 series force transducer, shown installed on a TMS 2155G12 modal stinger

Another important consideration is that the force transducer should always be mounted directly to the test structure, between it and the stinger and shaker assembly. If the force gage is mounted on the exciter side, as shown in the illustration in Figure 8, then the dynamics of the stinger become part of the measured function. This is generally only an issue when using conventional shakers for modal applications because modal shakers have the through-hole armature design and would not accommodate mounting the force transducer in such a fashion.

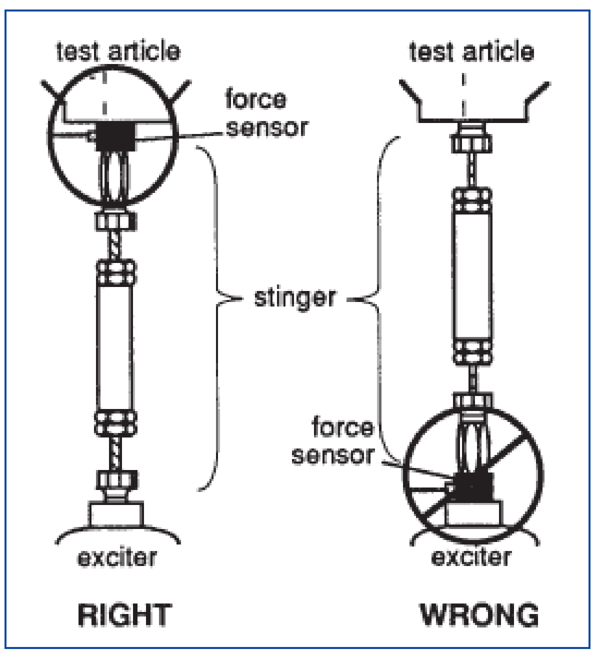

Figure 8 – A typical stinger setup showing proper force transducer location relative to the test article, threaded stinger rod and exciter.

The force transducer is usually mounted using a threaded adhesive mounting base, firmly attached to the test structure using dental cement or quick dry epoxy. Dental cement is ideal because it is extremely stiff, providing rigid attachment within the frequency range of typical modal testing. If the test structure can be drilled and tapped with an appropriate thread, directly attaching the force transducer to the structure is the best solution.

What is an impedance head? Why should I use it?

An impedance head, like PCB Piezotronics model 288D01, is a transducer that measures both force and resulting response in one device. Today, this is typically an accelerometer and force transducer but in the past it was a velocity transducer and force transducer (which is where the name impedance head comes from and has lingered on even today even though velocity is no longer measured). This is a critical measurement in experimental modal analysis and it is recommended that impedance heads be used in most cases. A combination of a separate force transducer and accelerometer, mounted next to each other, is often used instead, but the convenience of measuring the driving point with a single transducer and validating reciprocity between input locations is best obtained with an impedance head.

Modal Excitation general questions

What is the correct amplitude level for modal testing applications?

The excitation levels for modal testing are usually reasonably low. There is no need to provide large force levels for conducting a modal test especially if appropriate response transducers (accelerometers) are selected with good sensitivity and resolution, as well as high quality, high resolution (24 bit technology standard in today's commercial offerings) data acquisition systems. The level only needs be sufficient enough to make good measurements. In fact larger force levels tend to overdrive the structure, exciting nonlinear characteristics of the structure and providing poorer overall measurements than with lower level force tests. For this reason on larger structures, it is often desired to use multiple shakers at lower force levels to more evenly distribute force than a single shaker at a high level.

How many shakers should I use in my modal test?

The number of shakers is often a difficult one to answer. Often we are limited by the total number of output sources in the data acquisition system or shakers available in the test lab for modal testing. Usually two to four shakers are sufficient for most tests, particularly when testing larger structures like automobiles or aircraft. Generally test with more than five shakers are rare. Ultimately, there needs to be enough shakers acting as reference locations that are positioned so that all of the modes of the structure are adequately excited and observed, and good frequency response measurements are obtained. This includes having multiple shaker/reference locations to resolve repeated roots and/or closely spaced modes.

How do I use an impact hammer to determine the proper position and alignment of my shakers for modal testing?

The proper locations for shakers are heavily dependent on the frequencies and mode shapes to be extracted. Their location should be at points of adequate displacement in each of the modes of interest. It is common to perform pretest analysis using an impact hammer, like the PCB model 086 series, and an accelerometer to determine suitable "active" locations at each of the modes of interest. Impact hammers are very convenient because the provide hand-held freedom and flexibility to rove around the structure to test a large number of "trial points" to get an idea of the structural response. Then shakers can be setup at the necessary locations to adequately observe all of the modes simultaneously.

The location of the shaker is called the reference location for a modal test. If an inappropriate location is selected then some of the modes may not be adequately excited and measured. This is another reason why multiple input shaker tests are conducted. But even with a MIMO test arrangement, much consideration needs to be given to the appropriate shaker reference locations. Suffice it to say that all of the modes need to be adequately excited by the reference location selected.

What's the advantage of the different common excitation techniques – random, burst, chirp, sine, etc.?

The main excitation technique commonly used in modal testing today is burst random, used more often than others such as random, sine chirp and digital stepped sine. These are discussed with some brief comments. (Other techniques such as pseudo-random, periodic random, burst chirp and others are variations on these signals and are not discussed at length here.)

Random excitation was one of the first excitation techniques used because it was simple to create. The problem with random excitation is that the signal is never periodic in the sample interval of the FFT measurement and requires a window (commonly a Hanning window) to mediate the effects of leakage. Unfortunately, even with a window applied, the frequency response measurement suffers from leakage especially at the resonant peaks of the measurement.

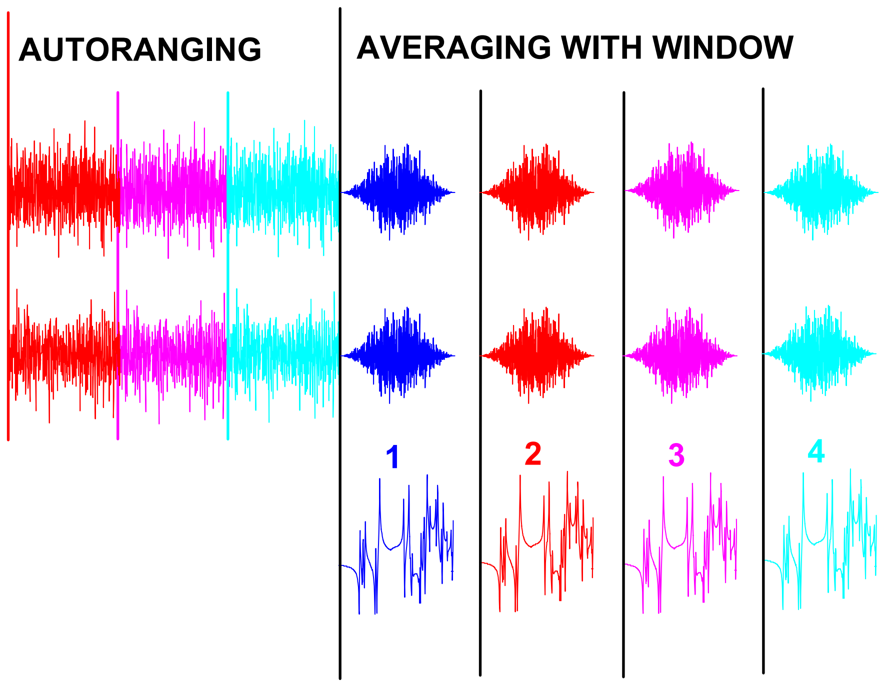

Figure 9 – A typical measurement sequence for random excitation

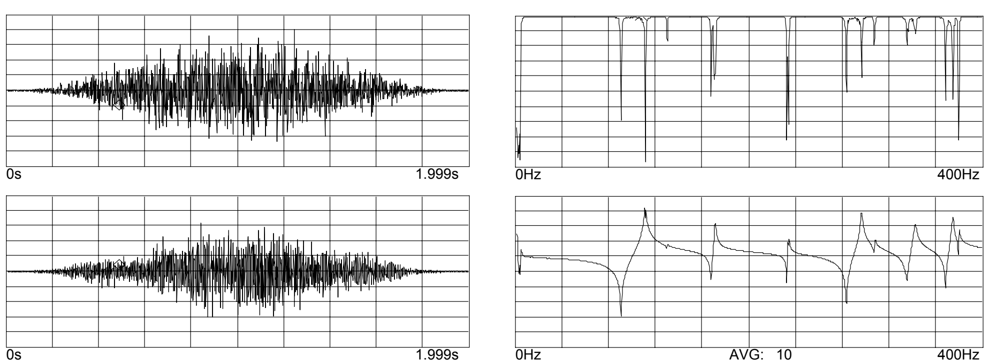

Figure 10 – Input and output random time with FRF and coherence

Sine chirp is an excellent technique for testing on systems that are fairly linear. This signal is a very fast swept sine where the frequency is swept from low frequency to high frequency within the time of one sample of the FFT analyzer. As a result, the signal is periodic in the sample interval once steady state response is achieved. This signal does not require any windows and does not suffer from leakage.

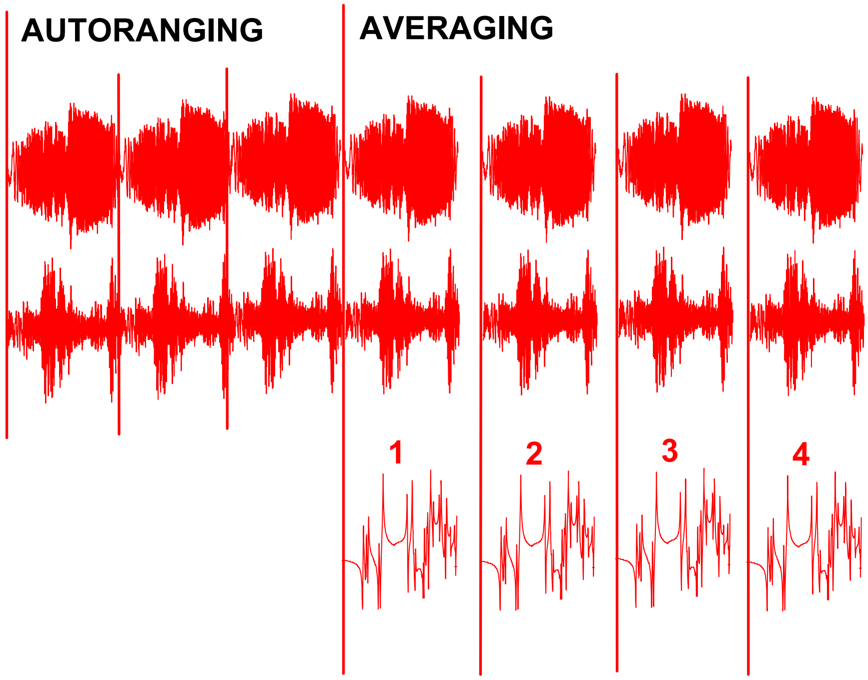

Figure 11 – A typical measurement sequence for sine chirp excitation

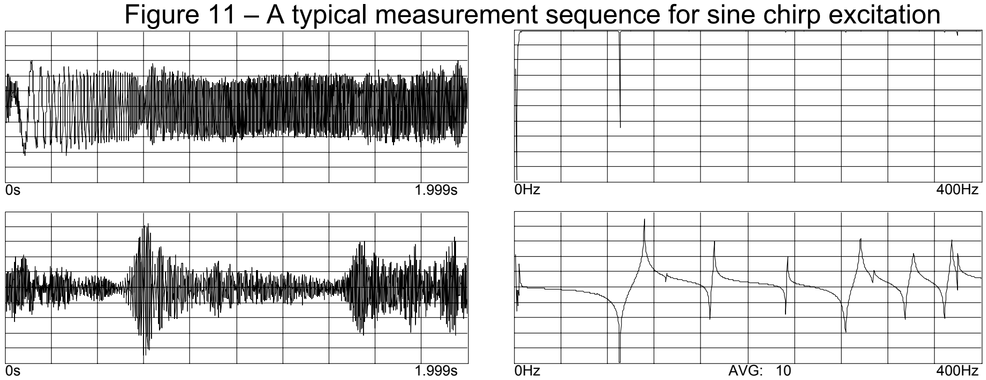

Figure 12 – Input and output sine chirp time with FRF and coherence

Burst random excitation was developed in the early 80s and has remained as one of the more commonly used excitation techniques for experimental modal testing. The vast majority of all shaker modal tests today employ burst random technique.

Burst random is formed as follows. A random excitation is generated but is only applied for a portion of the data block. In this way, the excitation signal is totally observable within one sample interval of the FFT analyzer and there is no need for the use of windows since there is no leakage associated with the captured signal. (Note: Providing that the response measured on the structure is also totally observable within one sample interval of the FFT analyzer then there is no need for the use of windows since there is no leakage associated with the captured signal.) However, once the excitation is turned off, the structural response will die exponentially depending on the damping associated with the structure. If the response of the structure does not die out within one sample interval, then the burst should be shortened such that the response does end before the end of the sample interval. The burst can be controlled by specifying the percentage of the block over which the excitation is to be applied. Generally, this can be accomplished with most structures.

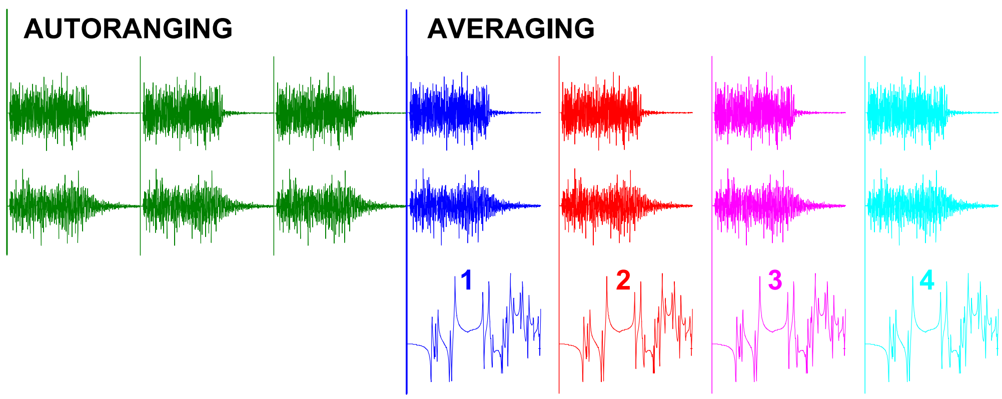

Figure 13 – A typical measurement sequence for burst random excitation

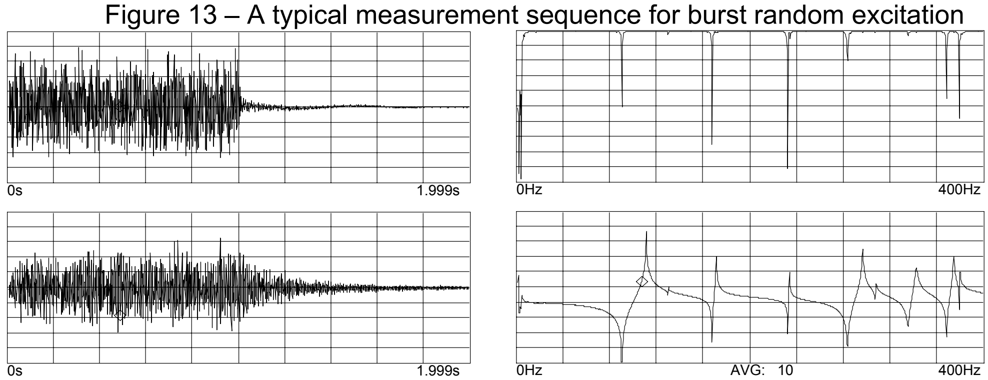

Figure 14 – Input and output burst random time with FRF and coherence

Why bother with Mulitple Input Multiple Output (MIMO) testing? Why can't you just run a Single Input Single Output (SISO) test several times?

Multiple Input Multiple Output (MIMO) testing requires the use of multiple shakers to excite the structure with uncorrelated signals supplied to each of the shakers. This requires that all the shakers be simultaneously attached to the structures for the modal test, as well as separate independent uncorrelated output sources from the data acquisition system.

While it seems possible to test the structure with one shaker and then move that shaker to all the different shaker locations, it turns out that conducting the test in this manner typically results in an inconsistent set of frequency response functions. This can be due to a variety of reasons such as an inconsistent mass load distribution from roving transducers or environmental changes altering the structure's mass and stiffness properties. When the different sets of data are combined, the resulting frequency responses are not as consistent as when all the data is collected simultaneously. The best measurement results have been achieved when acquired all of the test data in a "single snapshot" eliminating any issues related time invariance or structure stationarity.

To illustrate this, a reciprocal frequency response measurement was taken with one shaker and then the test was repeated by moving the shaker to the other location to retake the measurement from the reciprocal location. The measurement was taken using a random and burst random to illustrate the differences. Notice that the random signal has more variance and suffers from leakage even though a Hanning window was used. The second measurement was made using a burst random excitation. Both of these measurements were made with a SISO approach. Clearly there is a difference in the two measurements shown; these two measurements should be exactly the same.

This measurement was repeated with a MIMO approach. Again a random excitation with a Hanning window and a burst random excitation were used. The variance using the random excitation can still be seen in the measurement even using the MIMO approach. Notice that the burst random MIMO approach provides the best measurement overall with a good frequency response where reciprocity is observed in the measurement.

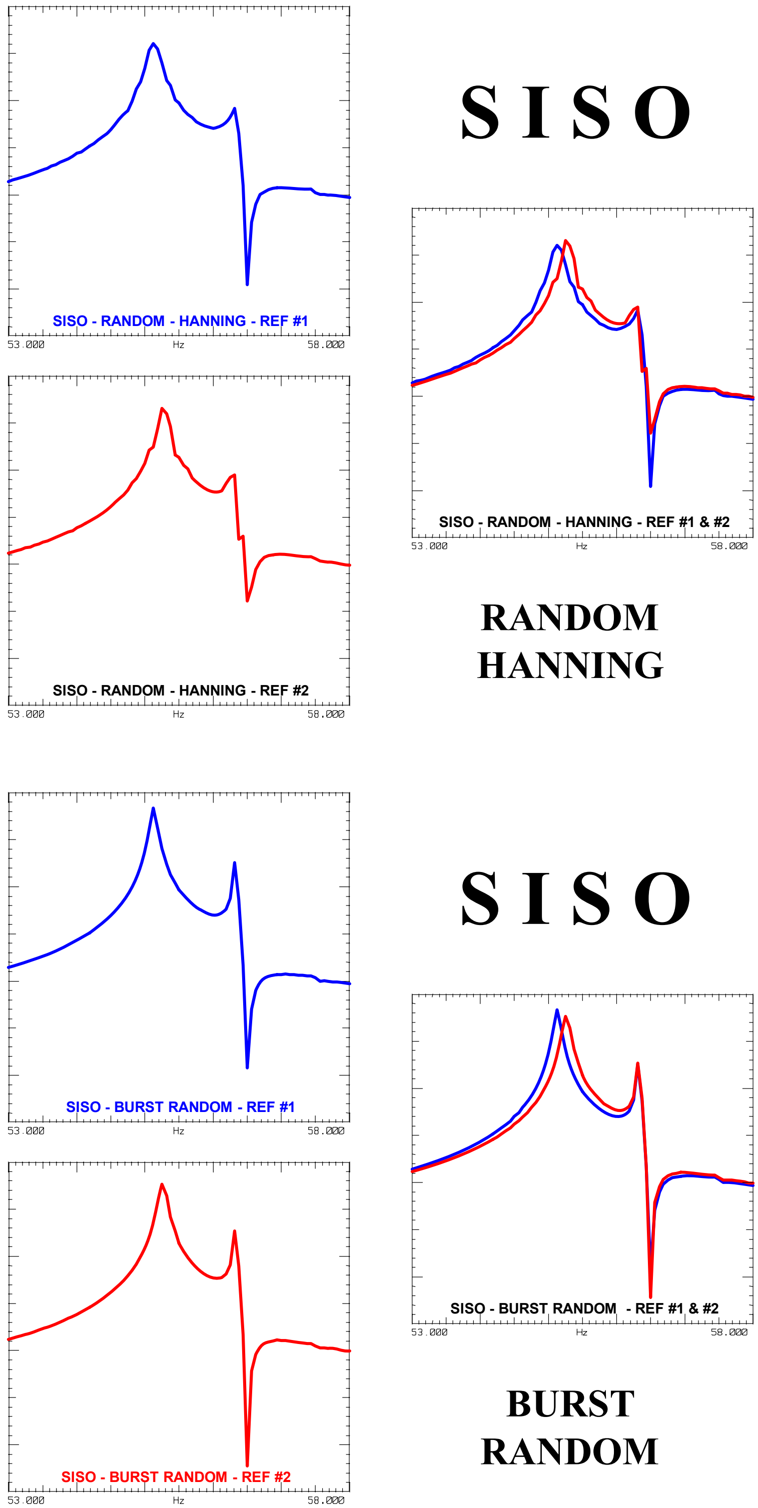

Figure 15 – SISO Reciprocity FRF with Random (top) - Burst Random (bottom)

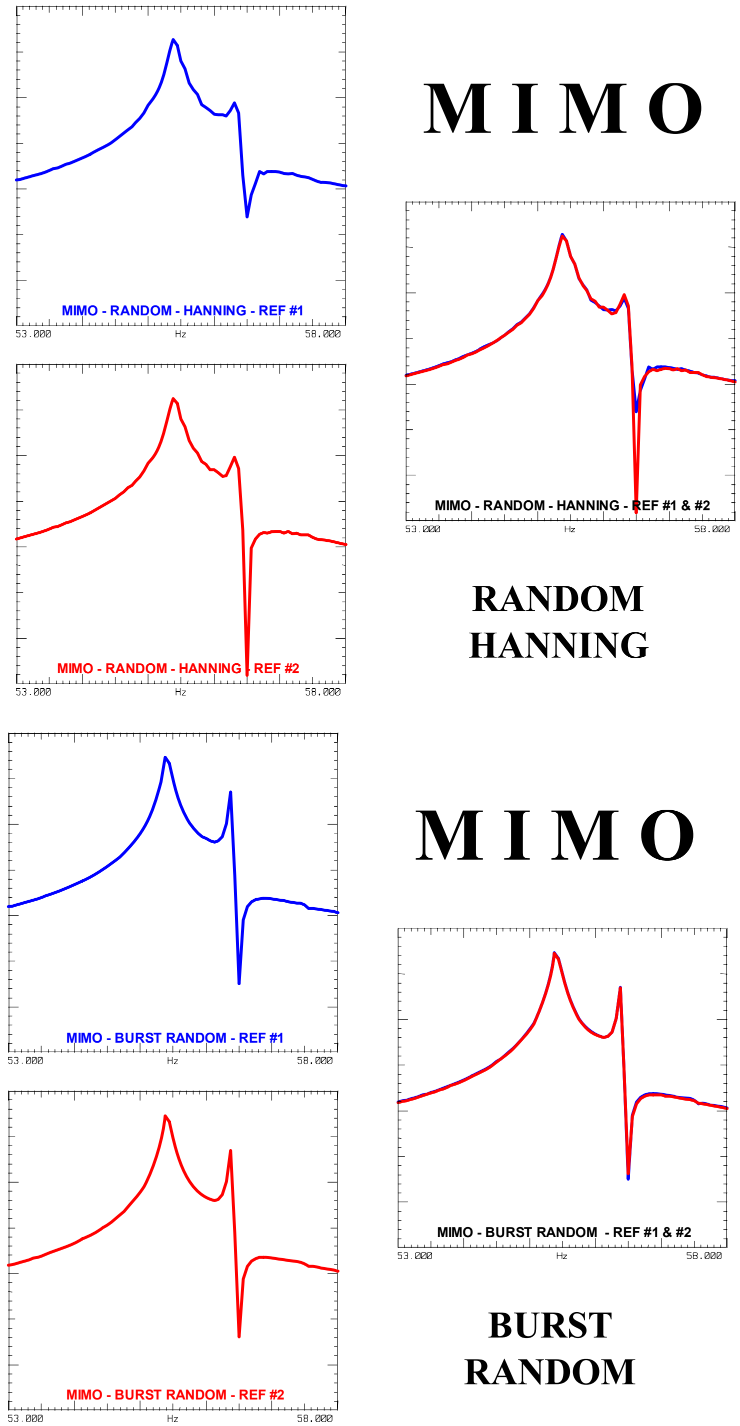

Figure 16 – MIMO Reciprocity FRF with Random (top) - Burst Random (bottom)