SHAKER EXCITATION TUTORIAL

Considerations and Problems

Young Engineer's Program - IMAC 2001

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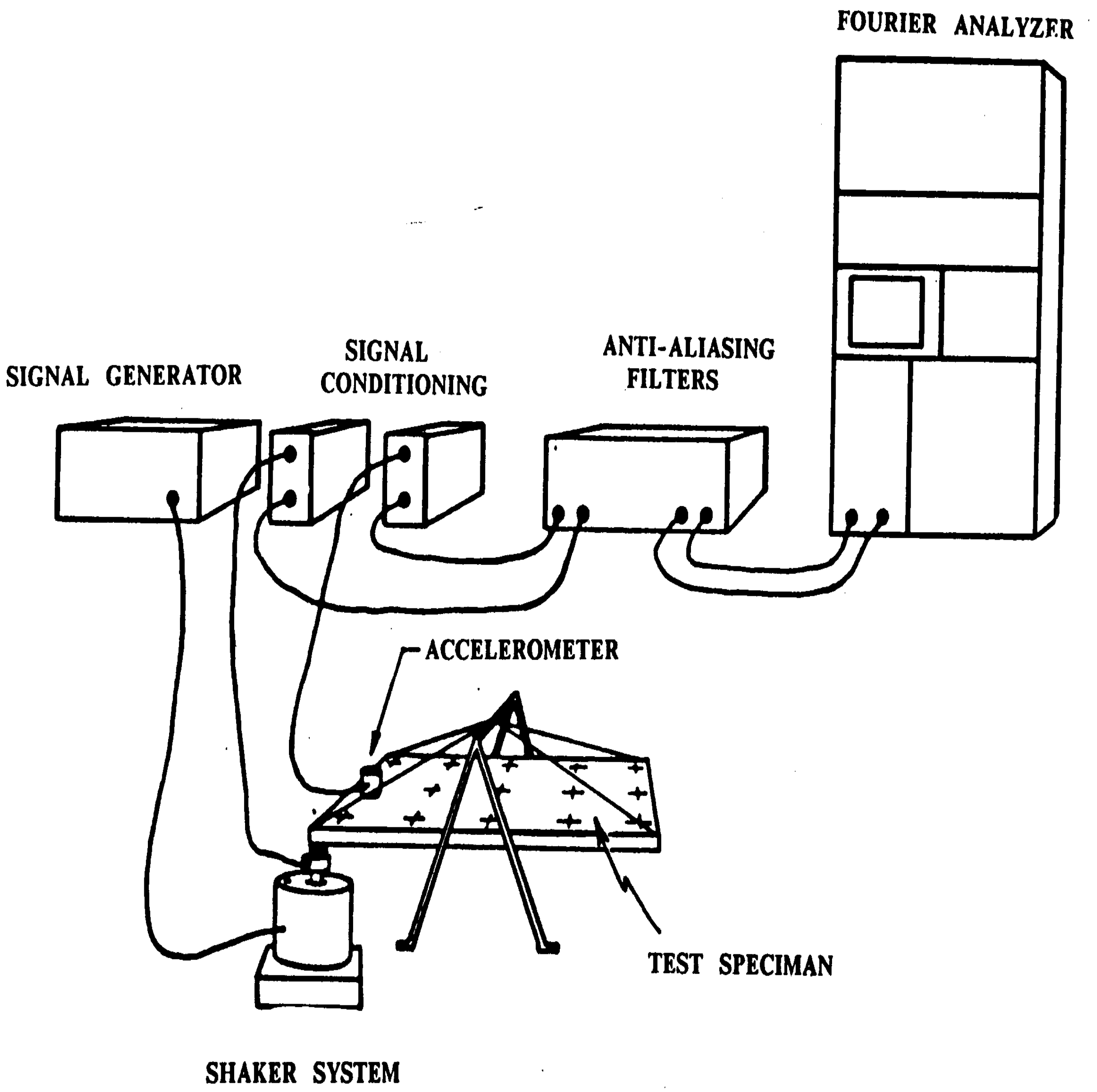
Shaker Excitation for Experimental Modal Analysis



Typical Shaker Excitation Test Setup Schematic

Shaker Excitation for Experimental Modal Analysis

Test Set-up for Shaker Excitation

- ***Physical Connections, Alignment***
- ***Instrumentation***
- ***Single Vs. Multiple Shakers***
- ***Excitation Signal Type***
- ***Digital Signal Processing***
- ***Data Quality***
- ***Post-Test Considerations***
    - ***Modal Parameter Estimation***

Shaker Excitation for Experimental Modal Analysis

Key Issues

- ***Estimate Frequency Response Functions (FRFs) Suitable for Modal Parameter Estimation***
  - ***Minimize Digital Signal Processing Errors (Leakage!)***
  - ***Minimize Small Structural Nonlinearities***
  - ***Multiple Reference FRF Data***
- ***Frequency Range and Resolution***

Shaker Excitation for Experimental Modal Analysis

Basic Assumptions

- ***Linearity***
- ***Time Invariance (Stationarity, Consistency)***
- ***Observability***
- ***Reciprocity***

Error Considerations

- ***Variance Error: Averaged value equals expected value***
- ***Bias Error: Averaged value not equal to expected value***

Shaker Excitation for Experimental Modal Analysis

Test Object Configuration

- ***Fixed Boundary Conditions***
- ***Free Boundary Conditions***
  - ***Shock Cord***
  - ***Foam Rubber***
  - ***Air Suspension***
- ***Realistic Boundary Conditions***
  - ***Match Impedance(s) at Boundaries***
- ***Mass Loaded Boundary Conditions***

Shaker Excitation for Experimental Modal Analysis

Other Test Configuration Considerations

- ***Test Fixturing***
  - ***Interaction with Test Object***
- ***Test Object***
  - ***Number of References***
    - ***Fixed Excitation/Response Locations***
  - ***Location of References (Shakers)***

Shaker Excitation for Experimental Modal Analysis

Instrumentation

- ***Shaker Type (electromagnetic, hydraulic, etc.)***
    - ***Shaker Control Capability (force matching vs. motion matching)***
    - ***Specifications***
        - ***Force Amplitude Range (static vs. static + dynamic)***
        - ***Frequency Range***
- ***Signal Source (noise, DAC, etc.)***

Shaker Excitation for Experimental Modal Analysis

Physical Connections - Shaker to Structure

- ***Mount Force Transducer on Test Object (glue, screw, vacuum, etc.)***
- ***Connect Force Transducer to Shaker with Stinger (quill, etc.)***
    - ***Stiff in Direction of Excitation***
    - ***Weak in Transverse Directions***
    - ***No Moments or Side Loads on Force Transducer***
    - ***No Moments or Side Loads on Shaker***

  Minimize Shaker Fixture Motion/Resonances

Shaker Excitation for Experimental Modal Analysis

Data Quality Issues

- ***Force Level (High/Low Amplitude, Improper Frequency Content)***
- ***Loose Exciter Connection (Stinger)***
- ***Load Cell, Shaker Connection Not Perpendicular to Test Object***
- ***Load Cell Not Aligned with Response Transducer at Connection***
- ***Low Battery Power in Transducer Signal Conditioning***
- ***Loose Cable Connections***
- ***Cables Vibrating, Bad or Intermittent Cables***
- ***Electrical and/or Radio Frequency Noise on Data***
    - ***Ground Loop***
    - ***50/60 Hertz Noise***
- ***Rattles in Test Object***
- ***Unmeasured Inputs***

Shaker Excitation for Experimental Modal Analysis

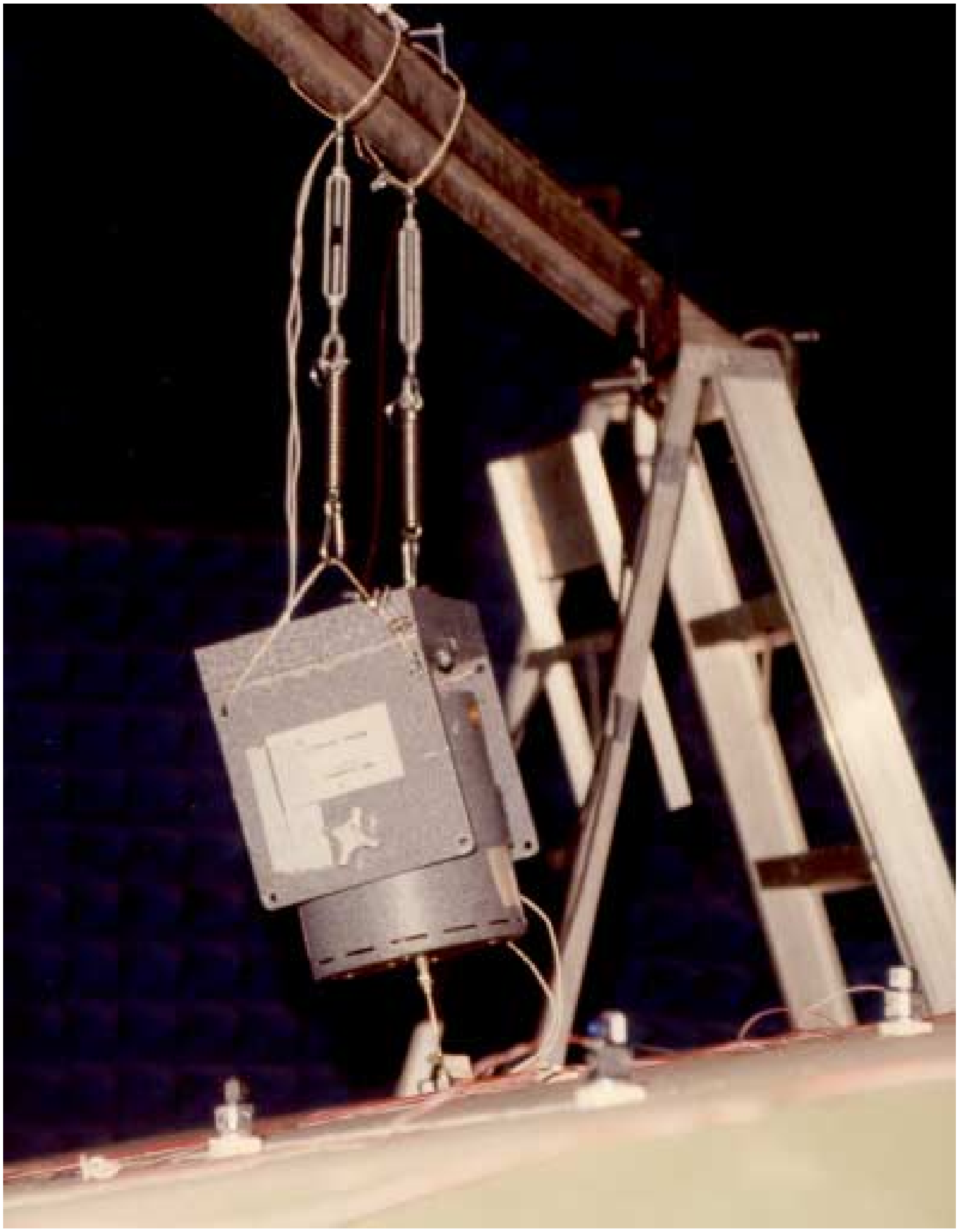
Data Quality/Consistency

- ***Monitor Typical Measurements***
    - ***Frequency Response Functions for Noisy Data, Rattles, Frequency Shifts, Amplitude Changes***
    - ***Driving Point Frequency Response Function***
    - ***Cross Point Frequency Response Function***
- ***Reciprocity Check***
    - $H_{pq} = H_{qp}$
- ***Monitor Force Spectrum of Each Input***
    - ***Equipment Failure, Loose Stinger(s)***
- ***Monitor Force Correlation Characteristics for Multiple Inputs***

Test Set-Up Examples

Test Set-Up Examples

Test Set-Up Examples



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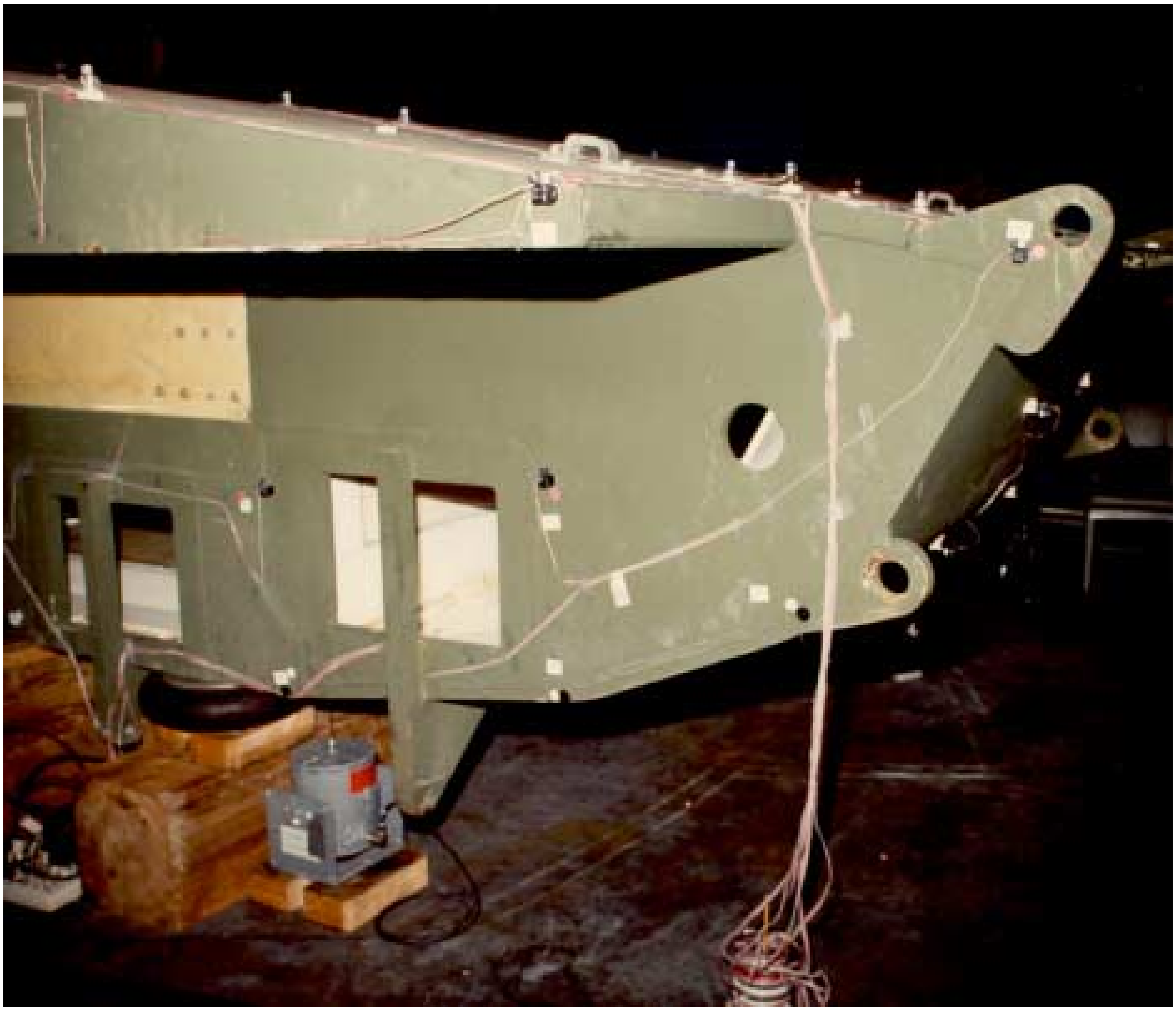

Test Set-Up Examples

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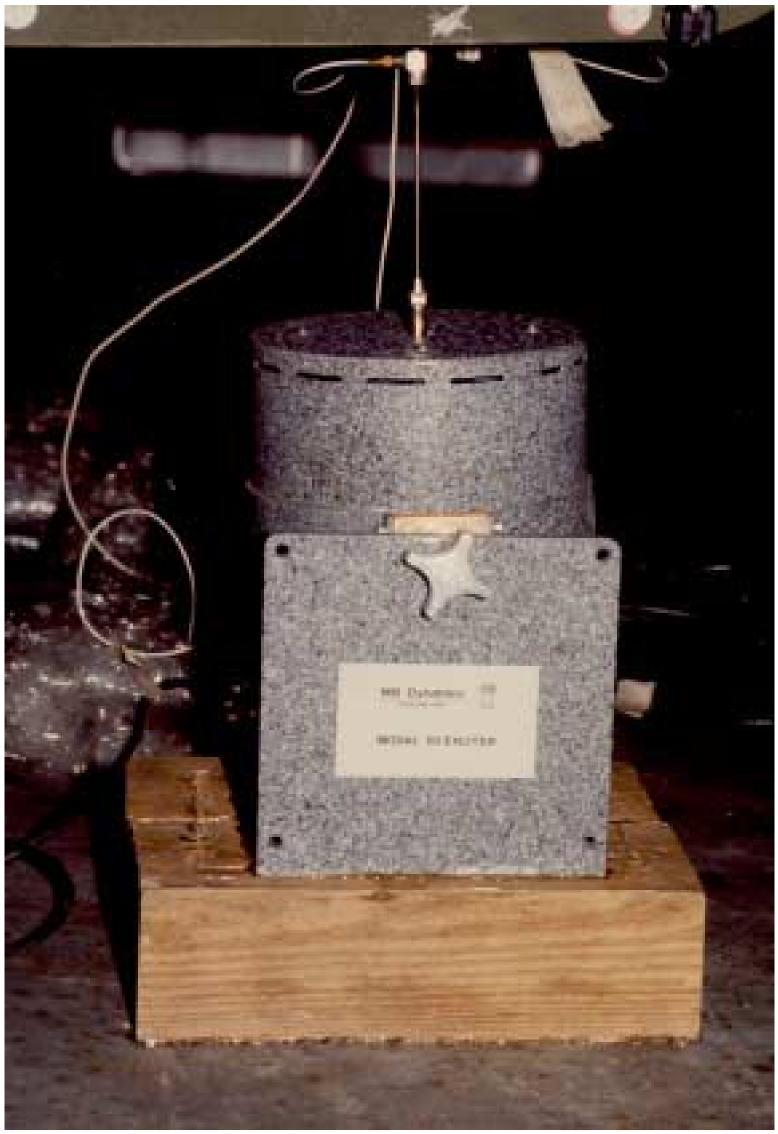
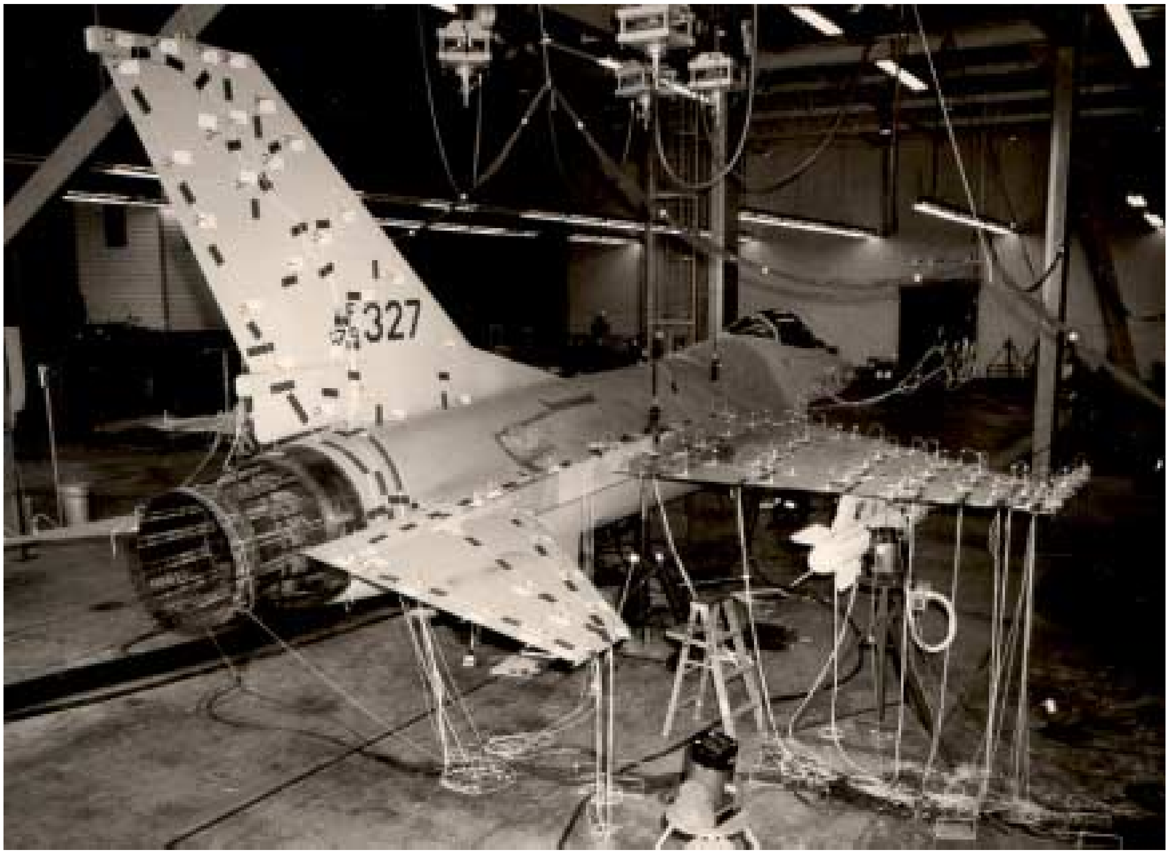
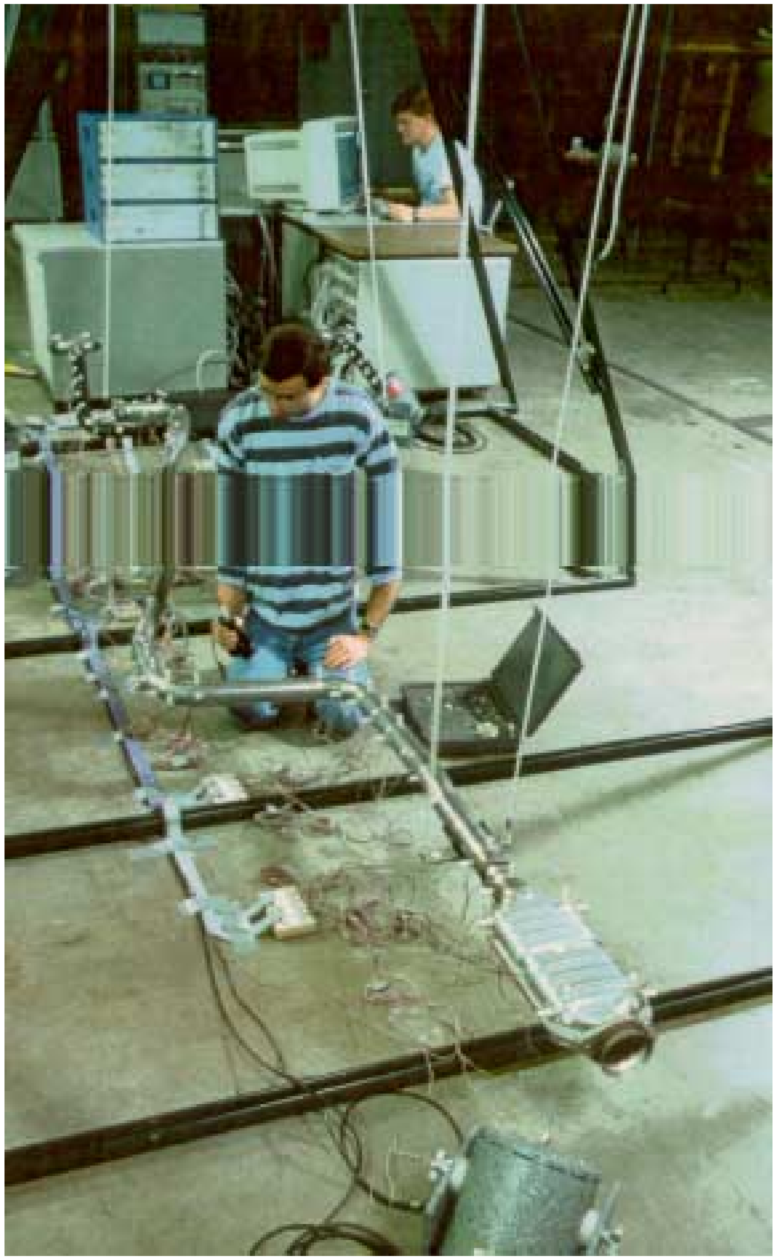


Test Set-Up Examples

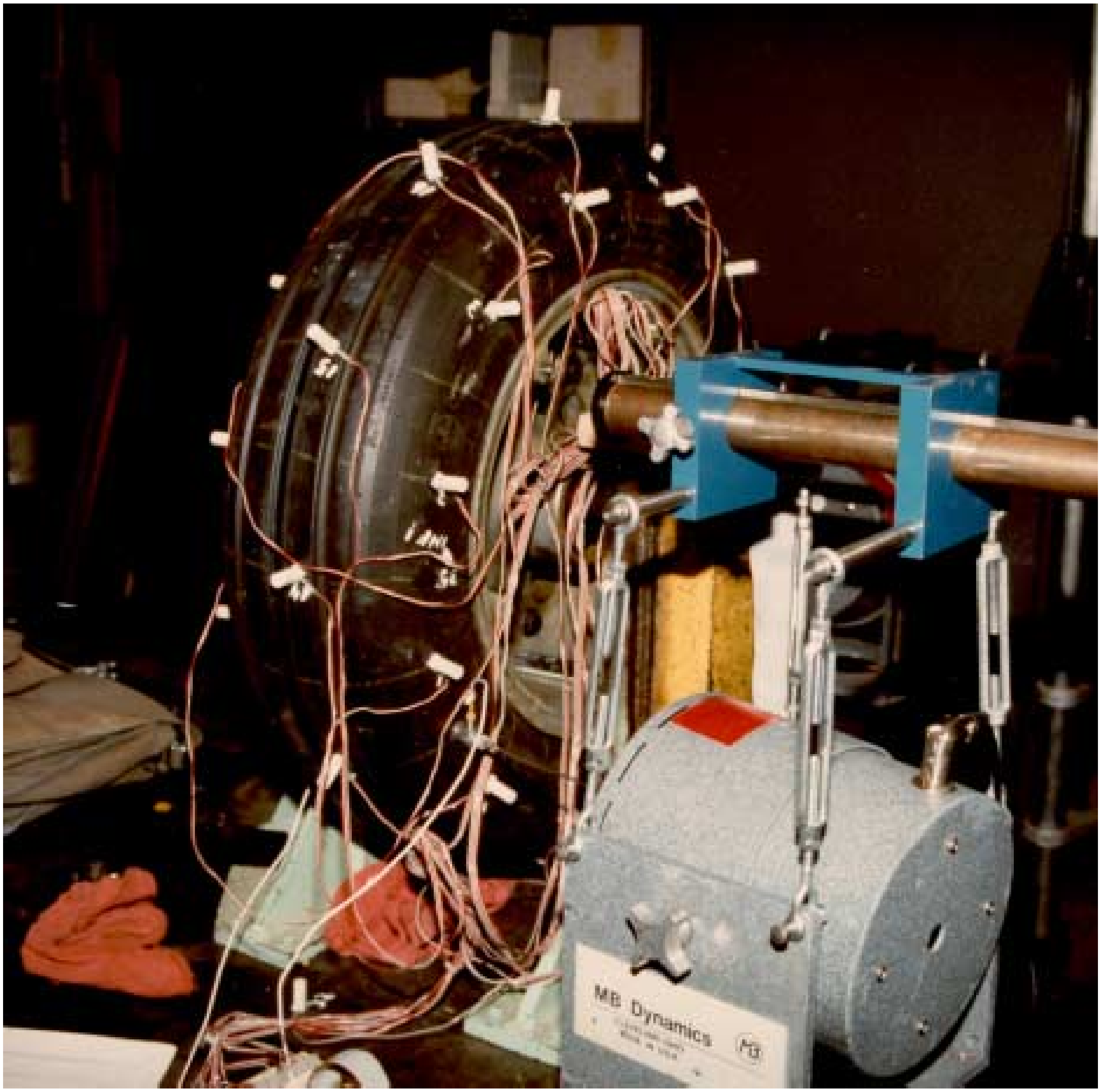


Test Set-Up Examples

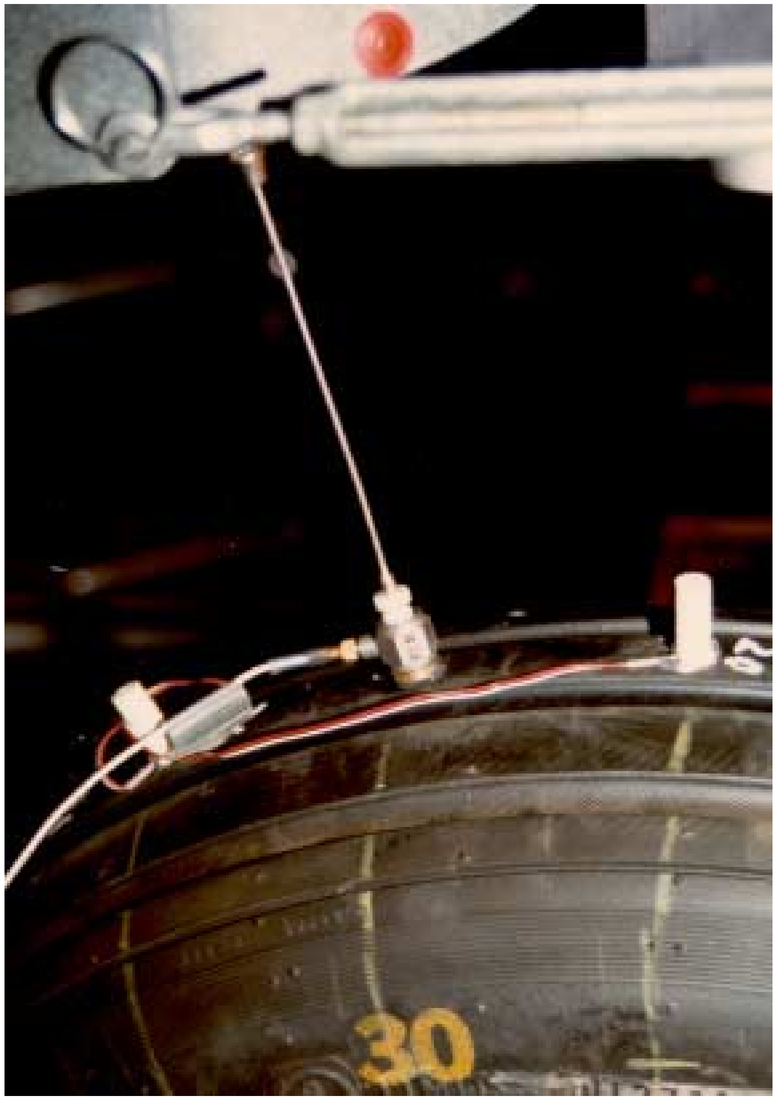
Test Set-Up Examples



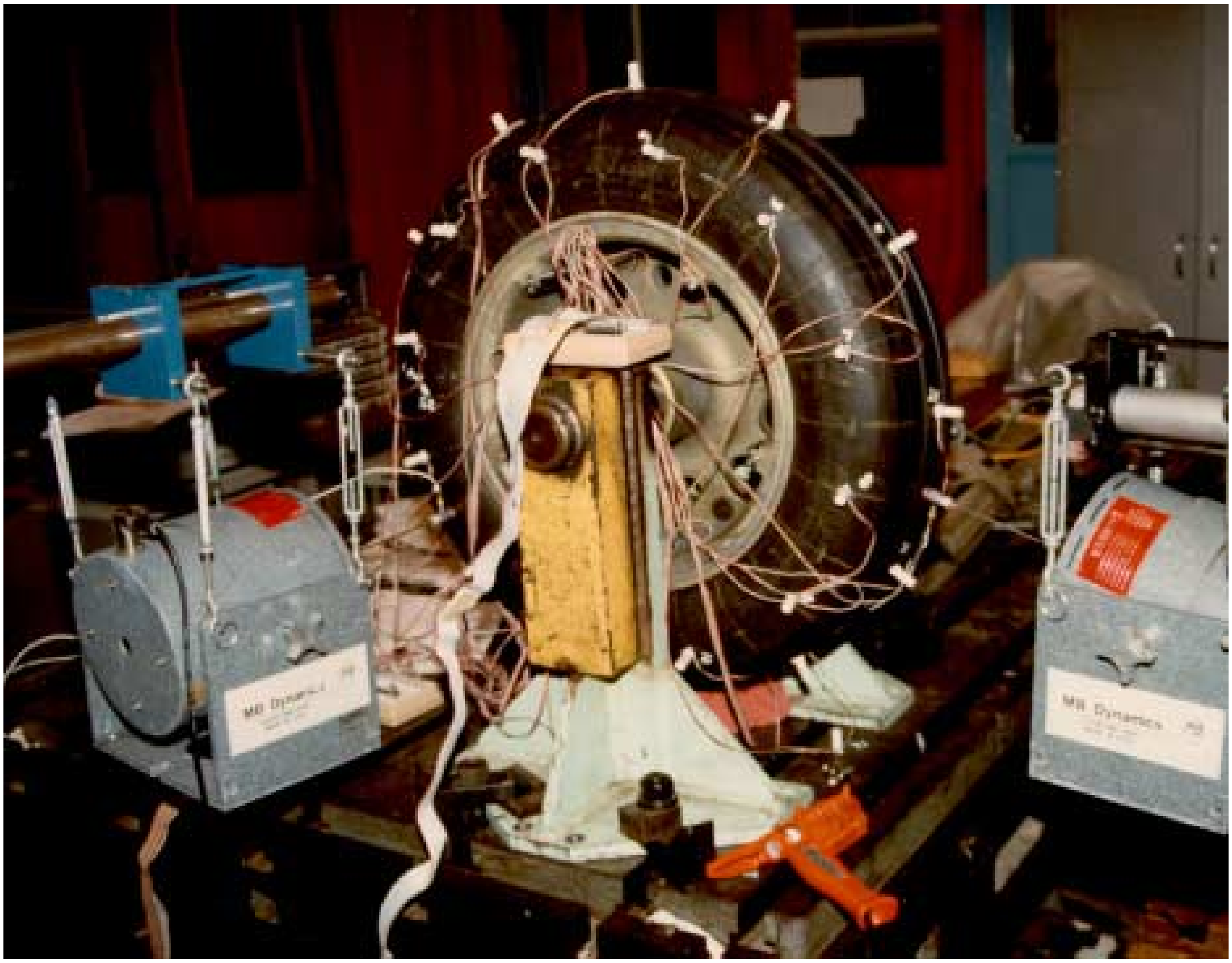
Test Set-Up Examples



Test Set-Up Examples



Test Set-Up Examples



Test Set-Up Examples

Test Set-Up Examples

Excitation Signal Considerations

The type of excitation signal used to estimate frequency response functions depends upon several factors. Generally, the excitation signal is chosen in order to minimize noise while estimating the most accurate frequency response function in the least amount of time. With the advent of the FFT, excitation signals are most often contain broadband frequency information and are limited by the requirements of the FFT (totally observed transients or periodic functions with respect to the observation window).

Classification of Excitation Methods

- ***Steady State***
    - ***Slow Swept Sine***
    - ***Stepped Sine***
- ***Random***
    - ***True Random***
- ***Periodic***
    - ***Fast Sine Sweeps***
    - ***Pseudo Random***
    - ***Periodic Random***
- ***Transient***
    - ***Burst Random***
    - ***Impact***
- ***Operating***

Excitation Signal Characteristics

RMS to Peak Ratio - ***This ratio is formed by taking the RMS value of the excitation signal over the observation time period (T) compared to the largest value (positive or negative) in the time period (T). Generally, good excitation signals have larger RMS to peak ratios.***

Signal to Noise Ratio - ***This ratio is formed by taking the RMS value of the excitation signal over the observation time period (T) over the RMS value of the noise over the same time period (T). Generally, good excitation signals have larger signal to noise ratios.***

Distortion - ***Distortion refers to the ability of the excitation signal, when averaged, to allow nonlinear characteristics in the data to be preserved. Generally, since experimental modal analysis is a linear process, excitation signals that minimize distortion are considered more favorably. Nonlinear characteristics must be identified by other experimental or analytical techniques.***

Excitation Nomenclature

In order to explain the way in which excitation signals are created and sent to the shaker, particularly in random testing, a number of nomenclature issues must be explained.

Delay Blocks - ***The number of contiguous blocks of excitation that take place without the associated input and output data being acquired are referred to as the delay blocks (**N_d**).***

Capture Blocks - ***The number of capture blocks refers to the number of contiguous blocks of time data (excitation (input) and response (output)) that are recorded or captured for each average (**N_c**).***

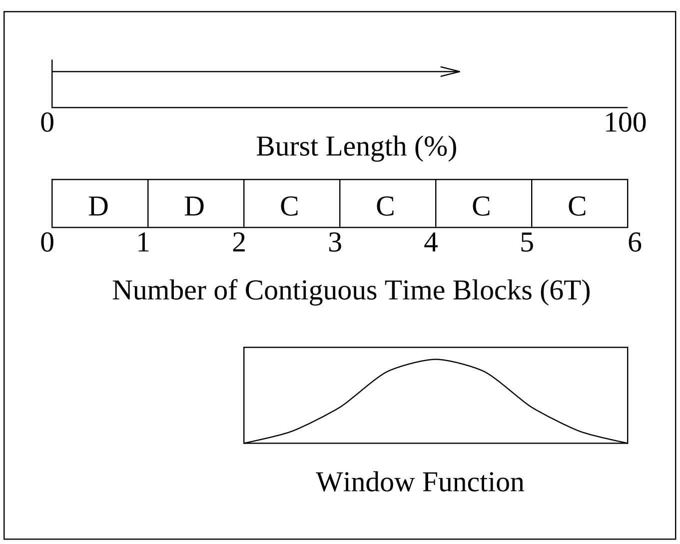
Average (Ensemble) - ***The average or ensemble refers to the total collection of contiguous time blocks that contribute to each power spectral average. The total time of each average is equal to the sum of the number of delay blocks (**N_d**) plus the number of capture blocks (**N_c**) times the observation period (T) which is the same for all delay and capture blocks.***

Burst Length - ***Burst length is the percentage (0 to 100%) of the average or ensemble time that the excitation signal is present.***

Excitation Nomenclature

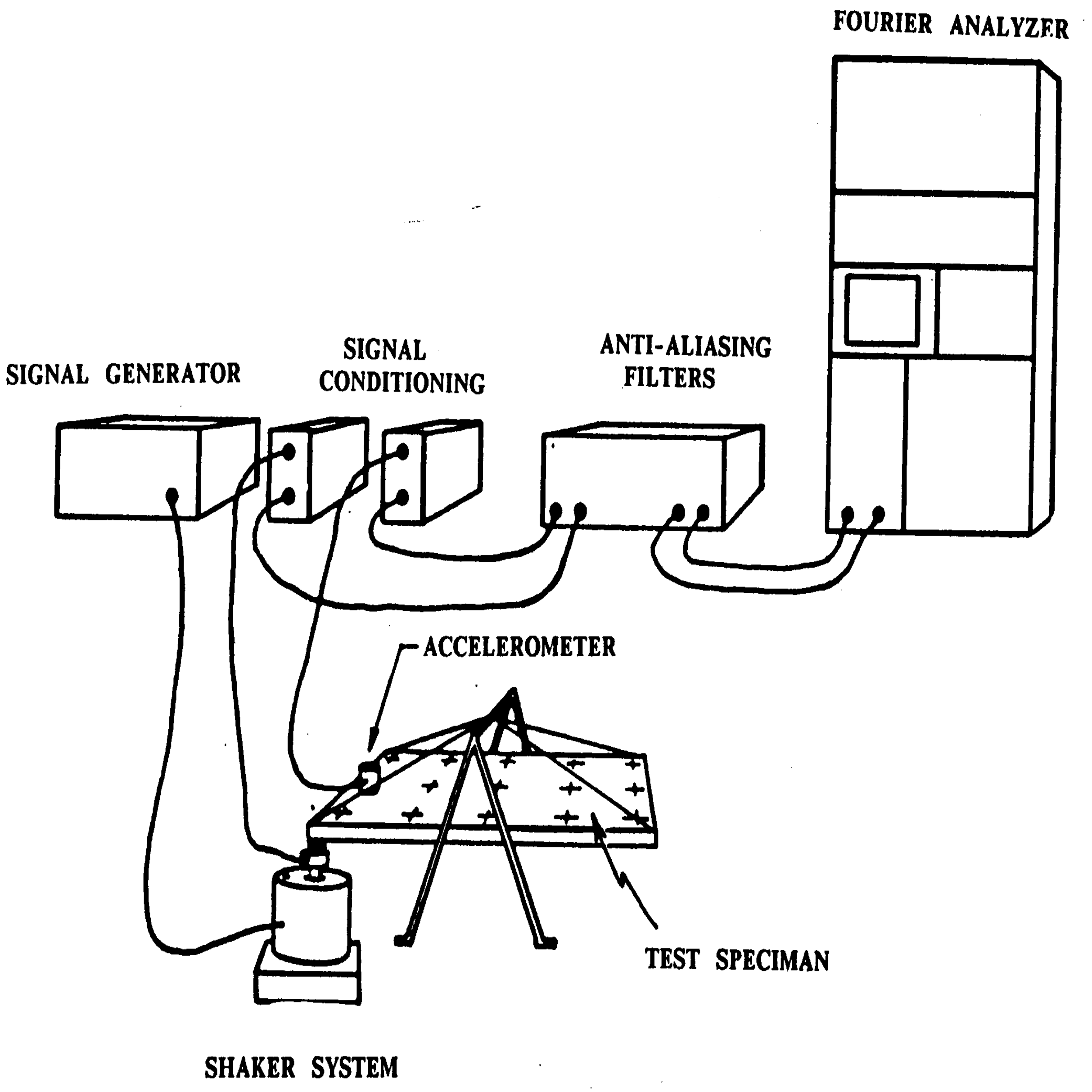
Power Spectral Averages - ***The number of power spectral averages (N_{avg} or N_a) is the number of auto and cross spectra that are averaged together to estimate the FRF measurements.***

In order to clarify the preceding terminology, the following figure is a schematic representation of the number of contiguous blocks of time domain data contributing to one power spectral average. In this example, the two blocks marked "D" represent delay blocks and the four blocks marked "C" represent capture blocks. The total time for each power spectral average is, therefore, six contiguous blocks of time data ($6 \times T$ seconds of data).



Total Contiguous Time Per Power Spectral Average

Random Excitation Methods

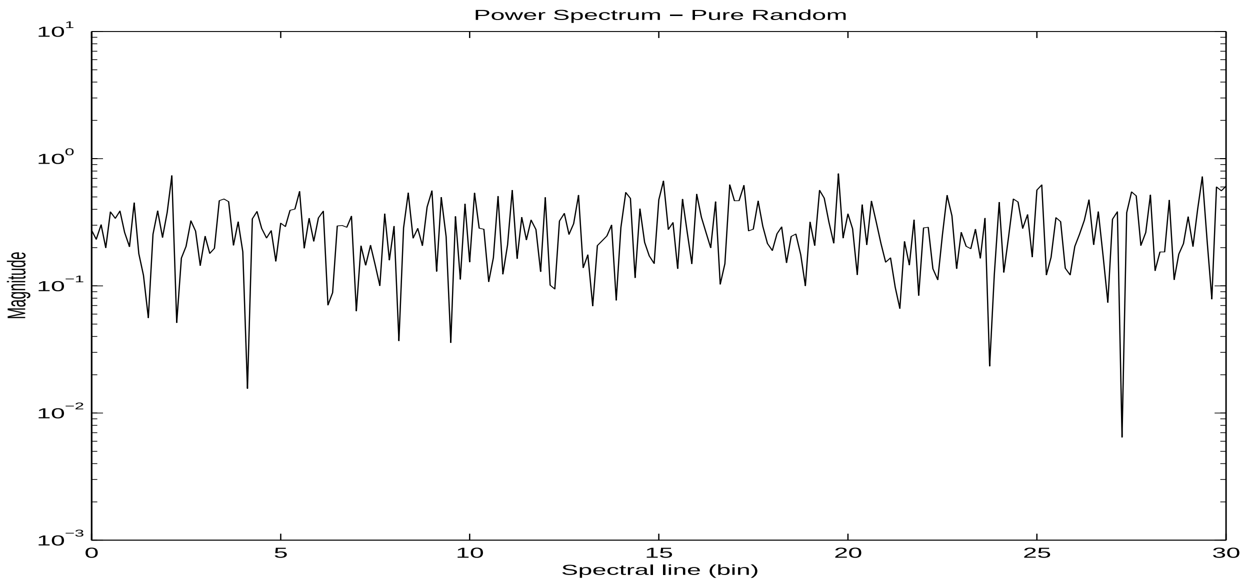


Typical Random Excitation Test Setup

Pure Random

- ***Advantages:***
  - ***Fair general excitation type***
  - ***Fair signal to noise ratio***
  - ***Fair RMS to peak ratio***
  - ***Reduces distortion***
  - ***Good measurement test time***
  - ***Works well with Zoom***
- ***Disadvantages:***
  - ***Leakage a serious problem***
  - ***More averages required***
  - ***Poor characterization of non-linearities***
- ***Typical DSP Window***
  - ***Hanning Window***

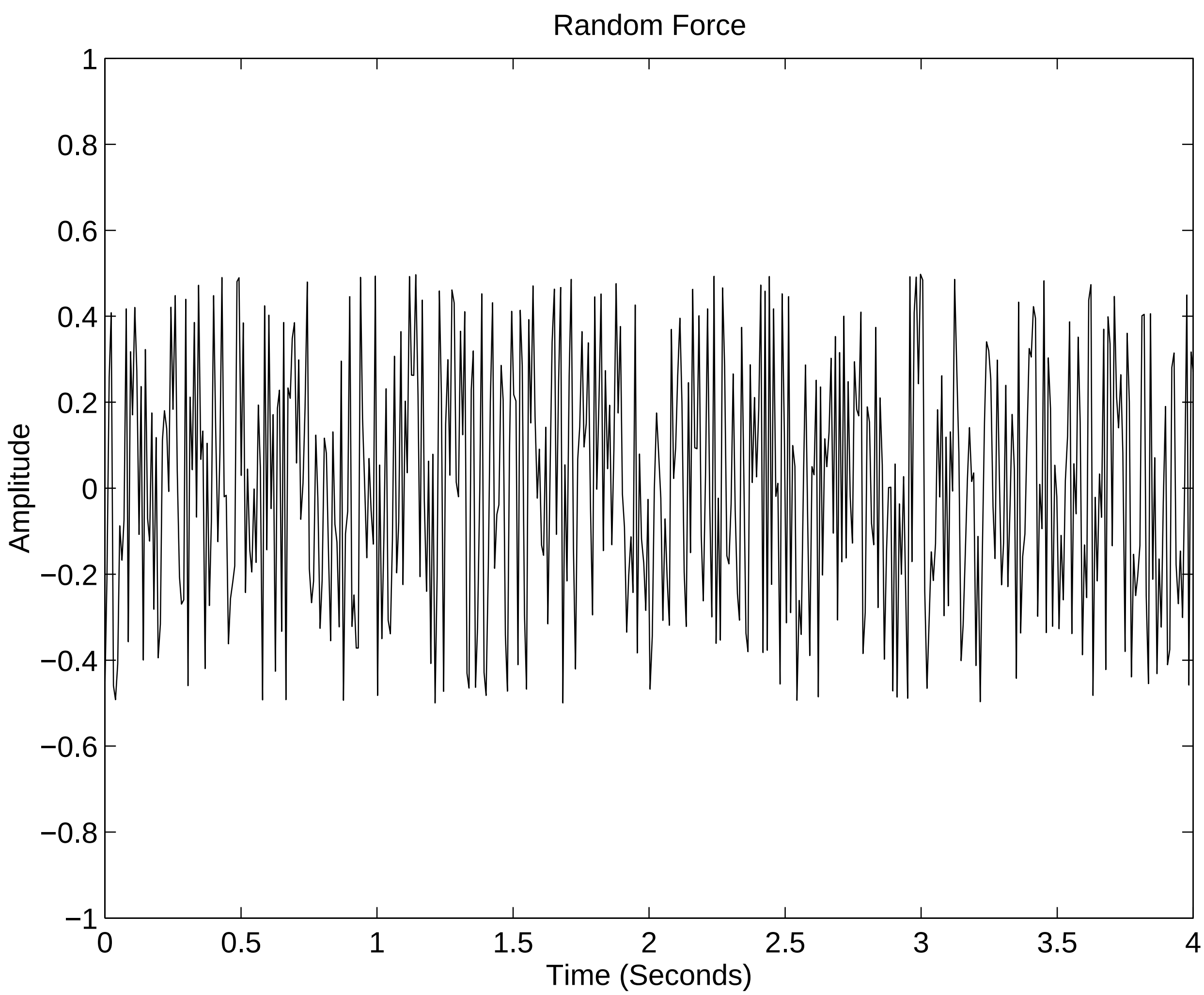
Pure Random



Signal Energy Content - Pure Random

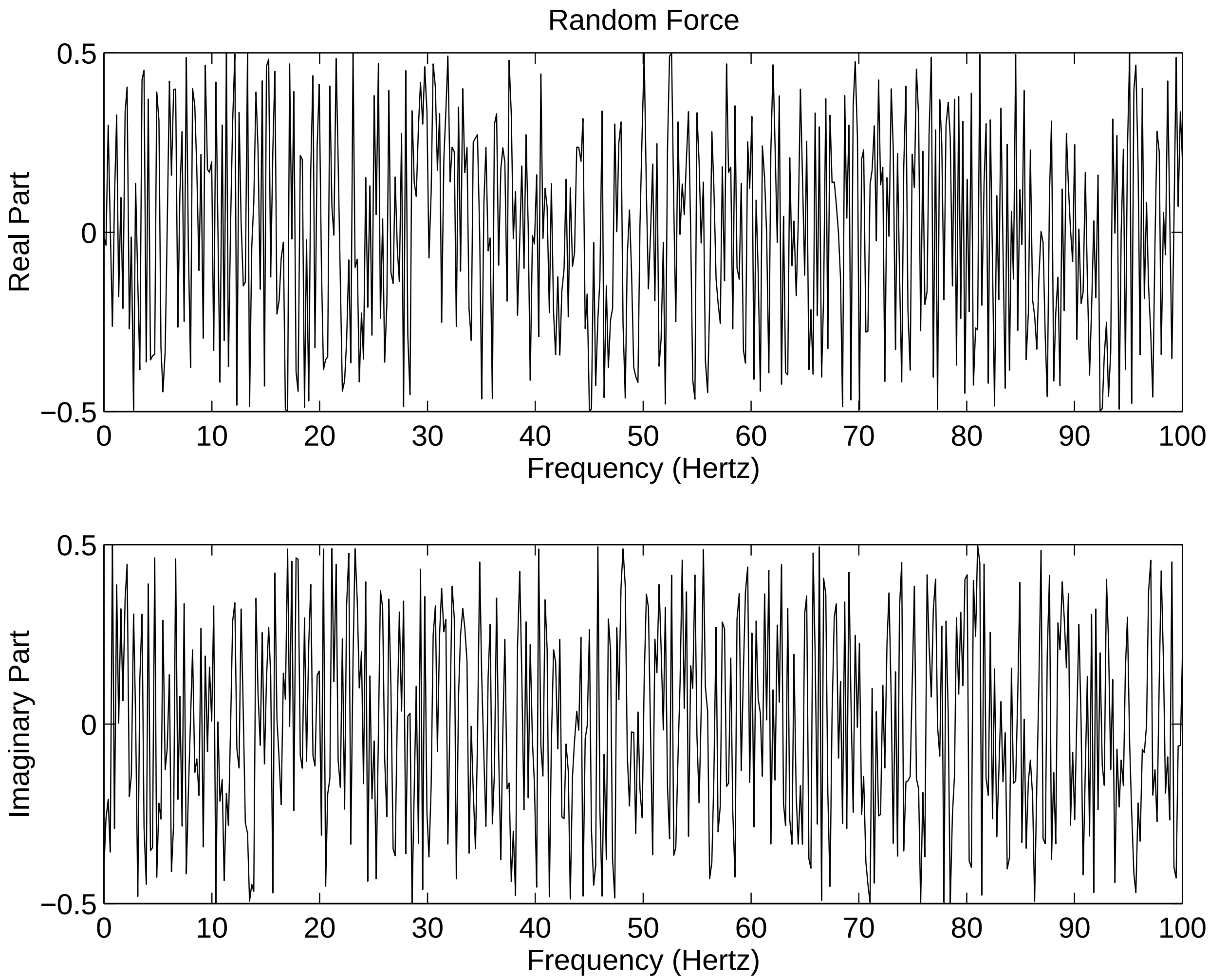
Pure Random

Typical Random Signal - Time Domain



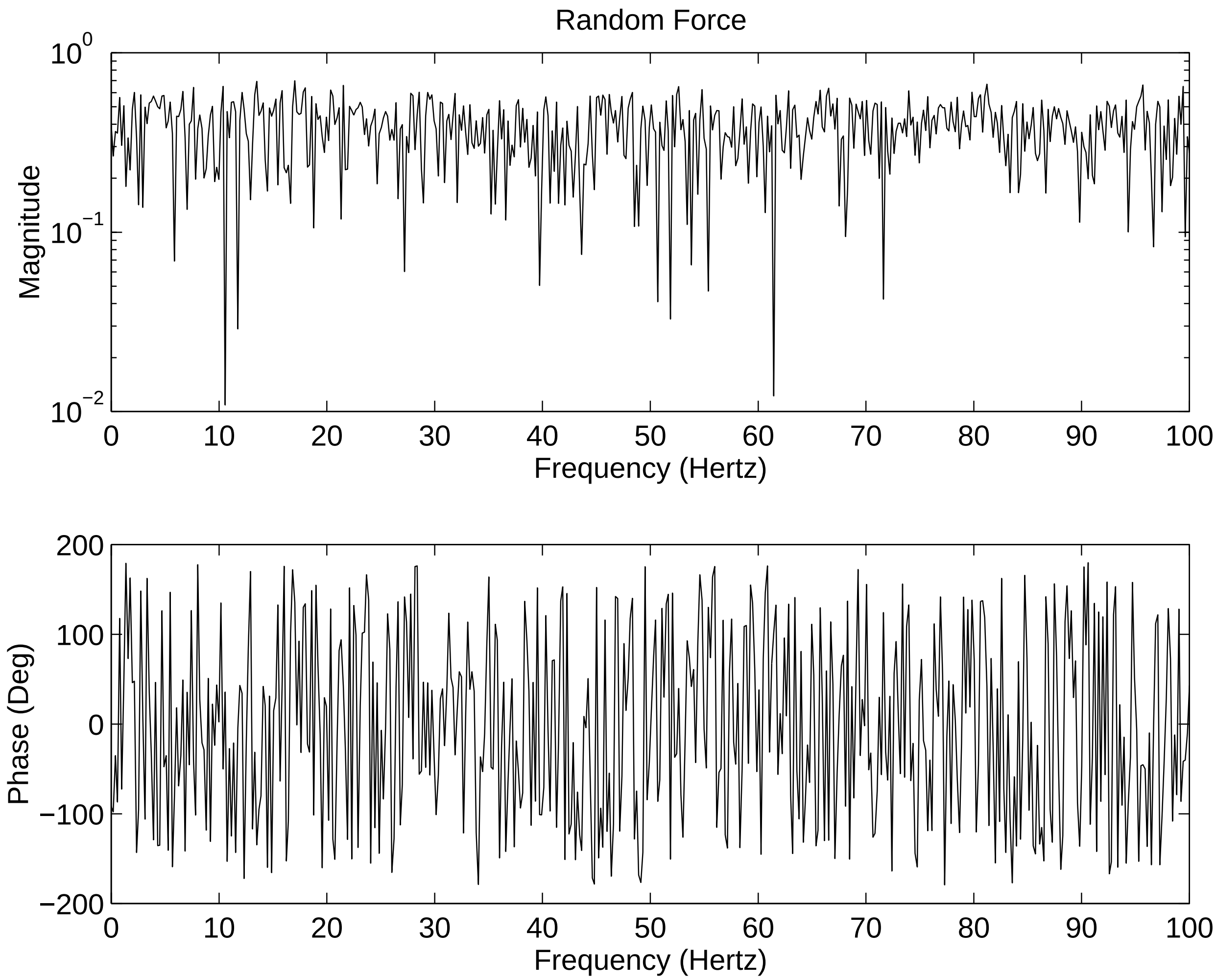
Pure Random

Typical Random Signal - Frequency Domain



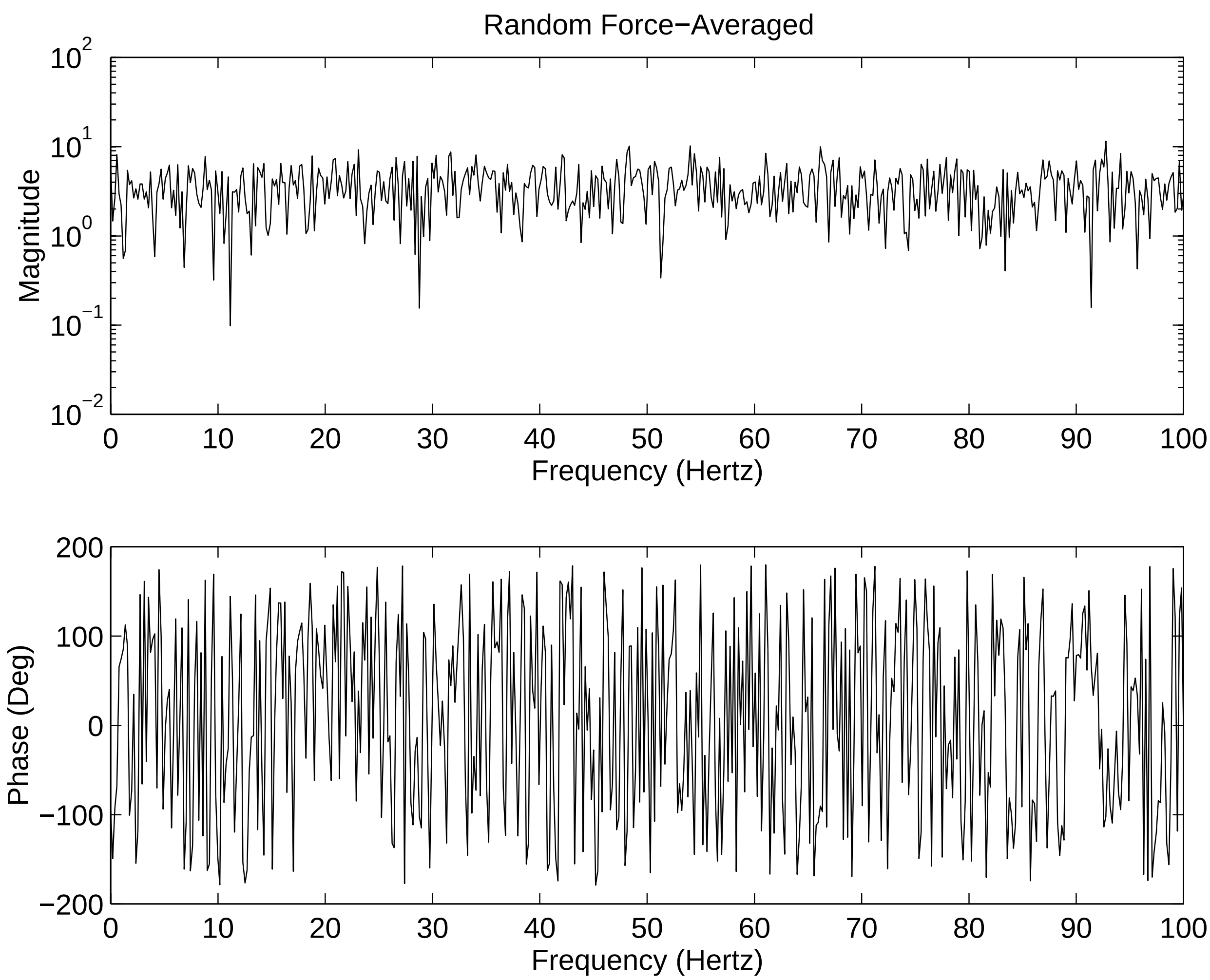
Pure Random

Typical Random Signal - Frequency Domain



Pure Random

Typical Random Signal - Frequency Domain

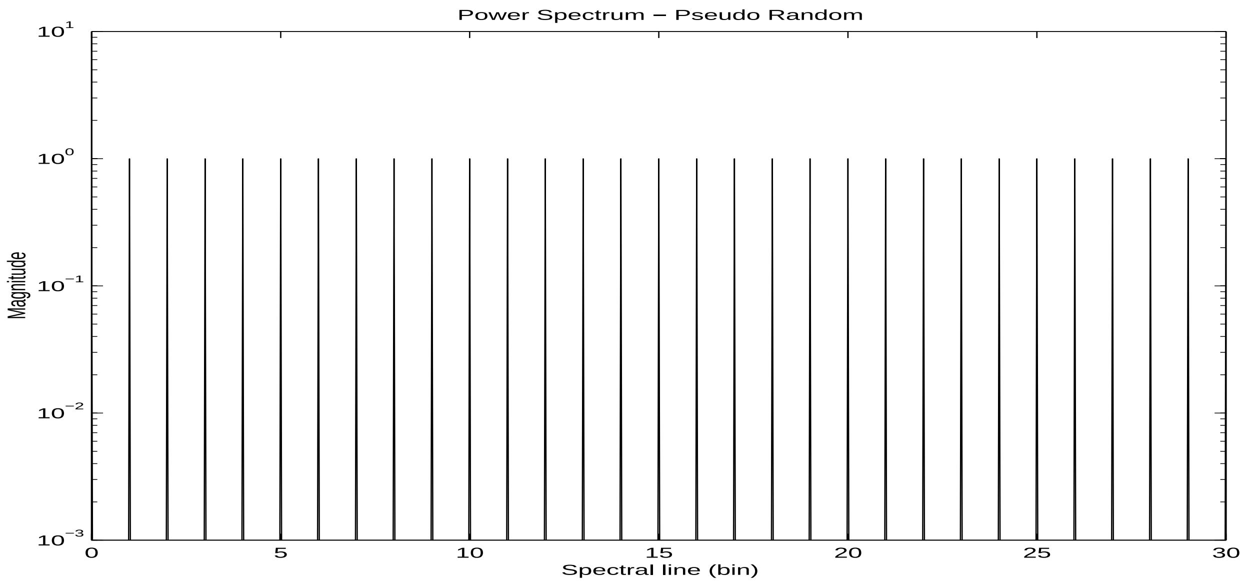


Pseudo Random

A pseudo random excitation signal is a random time domain signal that is constructed from a limited sequence of random numbers. Conventionally, the pseudo random excitation signal is constructed in the frequency domain with a uniform amplitude, random phase spectrum at the discrete frequencies of the measurement. Therefore, a single time block of the pseudo random excitation signal has energy at all frequencies of the measurement.

- ***Advantages:***
  - ***Minimum leakage***
  - ***Fair signal to noise ratio***
  - ***Fair RMS to peak ratio***
  - ***Good measurement test time***
- ***Disadvantages:***
  - ***Non-linear systems generate periodic noise***
- ***Typical DSP Window***
  - ***Uniform Window***

Pseudo Random

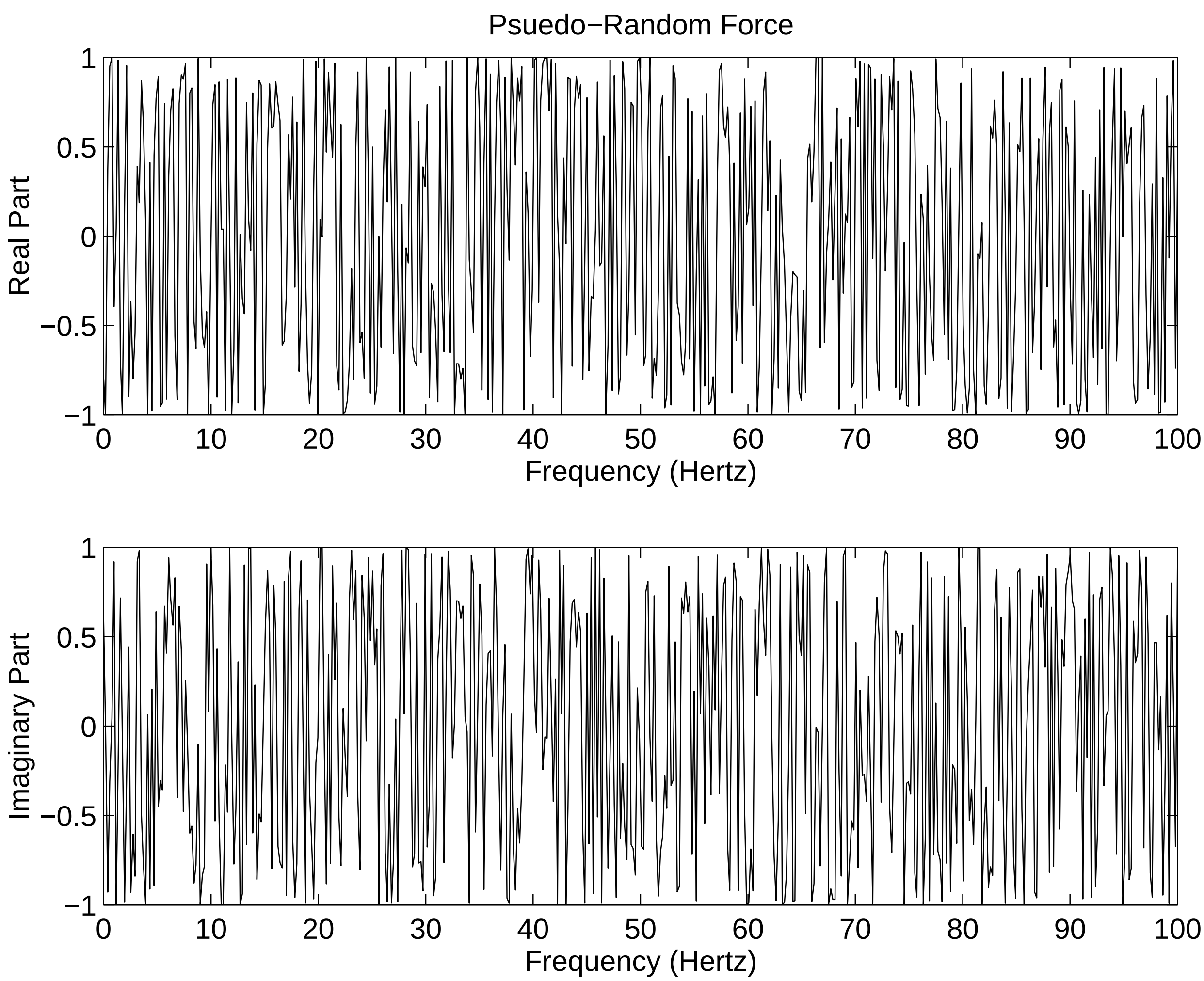


Signal Energy Content - Pseudo Random

The pseudo random excitation signal is applied to the exciter repetitively. While the excitation signal is periodic in the observation window (T), the response will not become periodic until the startup transient has decayed to zero. At this time, one or more averages are taken.

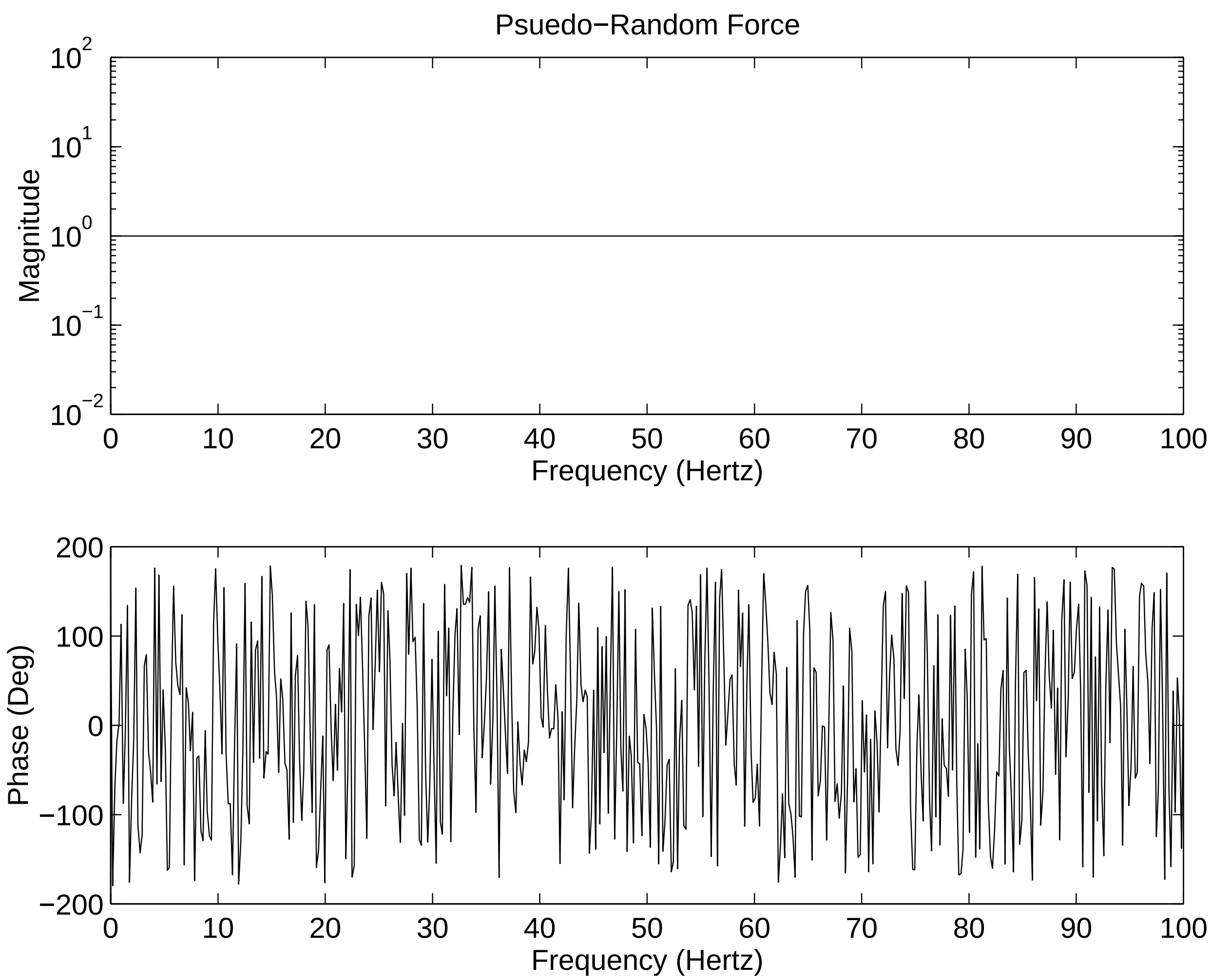
Pseudo Random

Typical Pseudo Random Signal - Frequency Domain



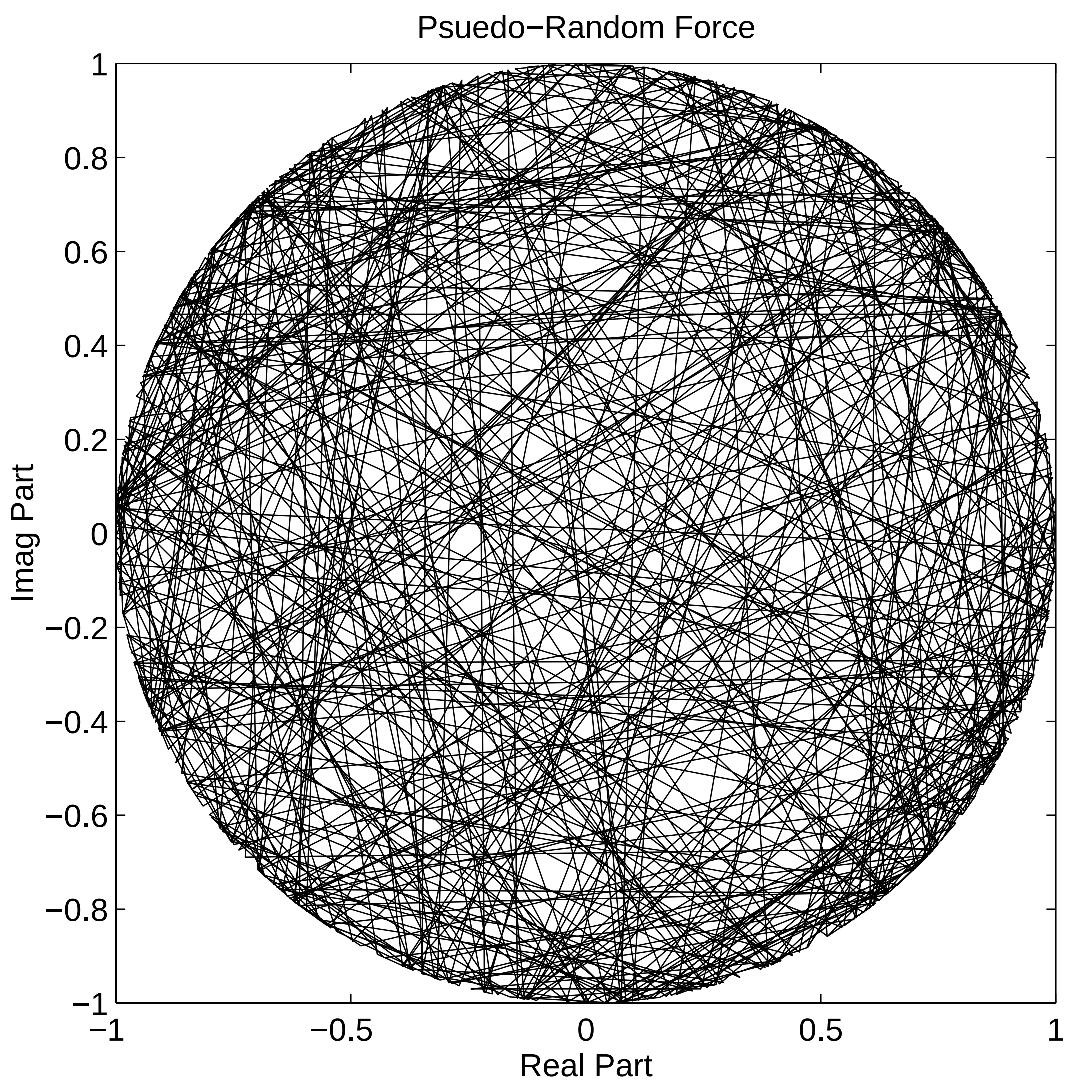
Pseudo Random

Typical Pseudo Random Signal - Frequency Domain



Pseudo Random

Typical Pseudo Random Signal - Frequency Domain

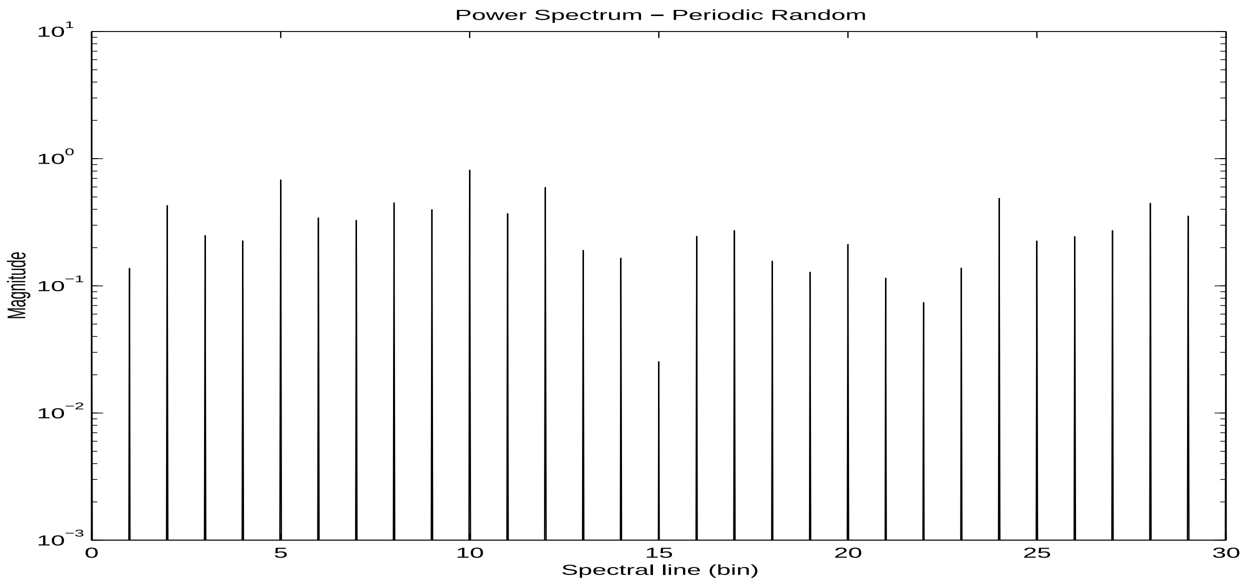


Periodic Random

A periodic random excitation signal is a random time domain signal that is constructed from an unlimited sequence of random numbers. Conventionally, the periodic random excitation signal is constructed in the frequency domain with a random amplitude, random phase spectrum at the discrete frequencies of the measurement. Therefore, a single time block of the periodic random excitation signal does not have energy at all frequencies of the measurement.

- ***Advantages:***
    - ***Minimum leakage***
    - ***Fair signal to noise ratio***
    - ***Fair RMS to peak ratio***
    - ***Reduces distortion***
    - ***Fair measurement test time***
- ***Disadvantages:***
    - ***Slower than other periodic excitations***
    - ***Special hardware needed***
- ***Typical DSP Window***
    - ***Uniform Window***

Periodic Random



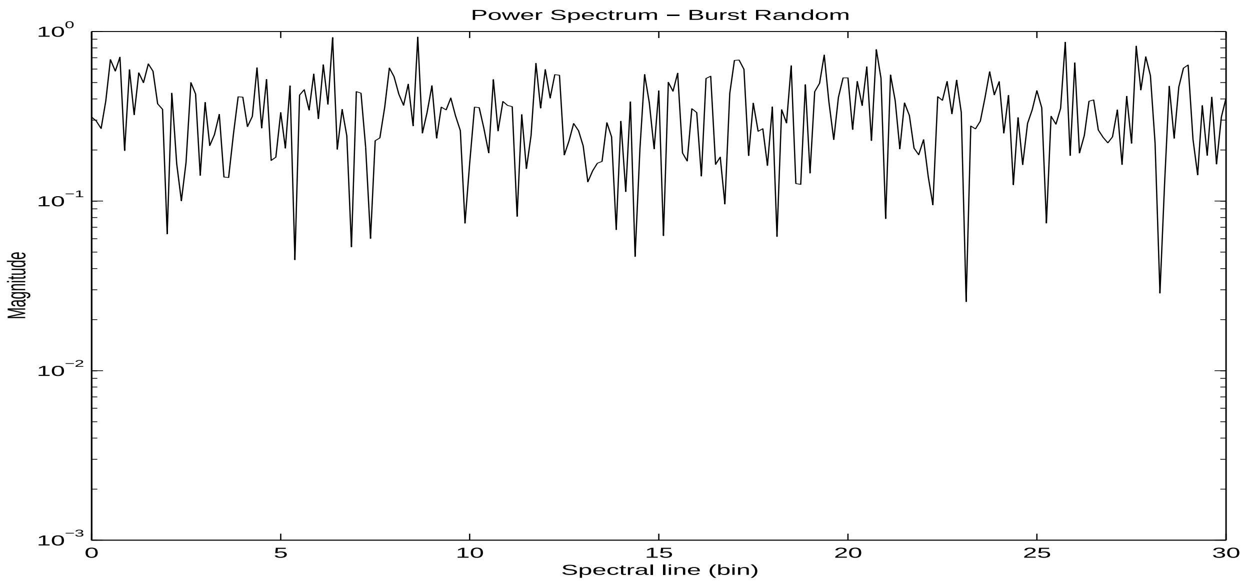
Signal Energy Content - Periodic Random

The periodic random excitation signal is applied to the exciter repetitively; while the excitation signal is periodic in the observation window (T), the response will not become periodic until the startup transient has decayed to zero. After sufficient time has elapsed to allow for both the input and output to become periodic, the first average of data is taken. This process is repeated until sufficient averages have been taken.

Burst Random

- ***Advantages:***
  - ***Good general excitation***
  - ***Minimum leakage***
  - ***Fair signal to noise ratio***
  - ***Fair RMS to peak ratio***
  - ***Reduces distortion***
  - ***Good measurement test time***
- ***Disadvantages:***
  - ***Special hardware needed***
    - ***Voltage feedback excitation amplifier***
- ***Typical DSP Window***
  - ***Uniform or Exponential Window***

Burst Random



Signal Energy Content - Burst Random

Burst Random

Exciter Systems:

Exciter systems, particularly electromagnetic, attempt to match the excitation signal to some physical characteristic of the exciter. Typically, this means that the displacement, velocity or acceleration of the armature of the shaker will attempt to match the excitation signal. Note that this is normally an open loop control process; no attempt is made to exactly match the excitation signal.

Voltage Feedback:

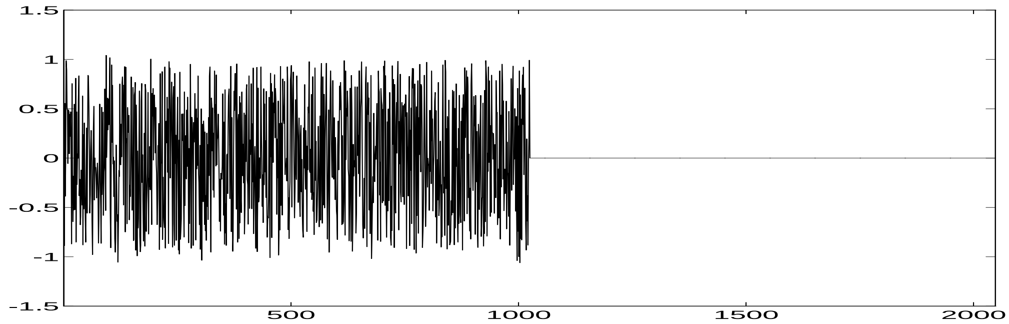
Voltage feedback refers to the types of amplifiers in the exciter system that attempt to match the voltage supplied to the shaker to the excitation signal. This effectively means that the displacement of the armature will follow the excitation signal. Therefore, if a zero voltage signal is sent to the exciter system, the exciter will attempt to prevent the armature from moving.

Current Feedback:

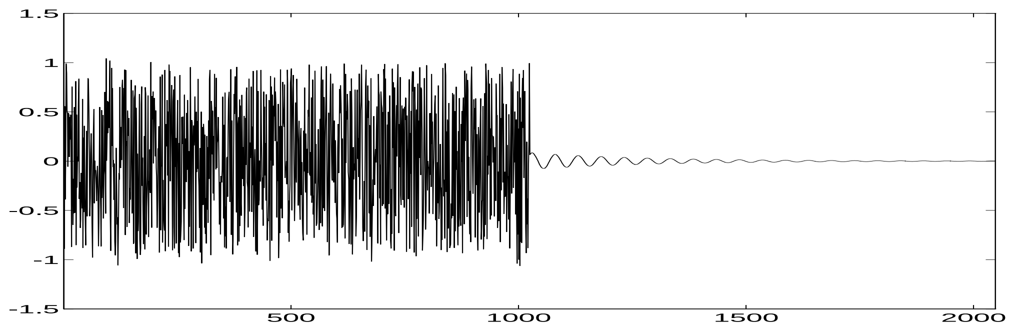
Current feedback refers to the types of amplifiers in the exciter system that attempt to match the current supplied to the shaker to the excitation signal. This effectively means that the acceleration of the armature will follow the excitation signal. Therefore, if a zero voltage signal is sent to the exciter system, the exciter will allow the armature to move, preventing any force to be applied by the exciter system.

Burst Random

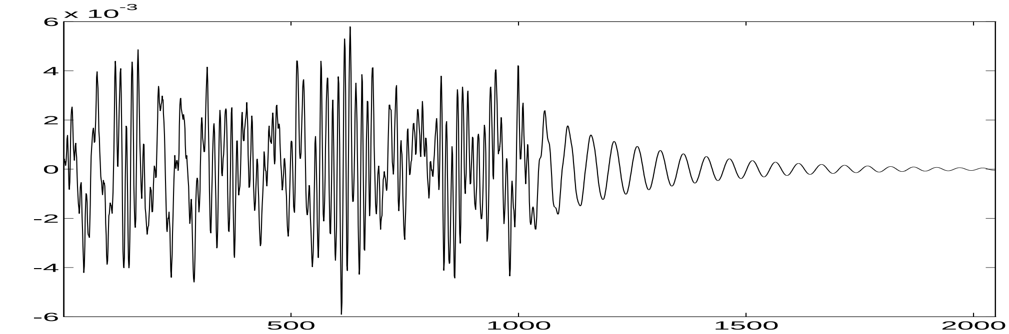
Signal to shaker



Signal from load cell (Voltage Feedback)

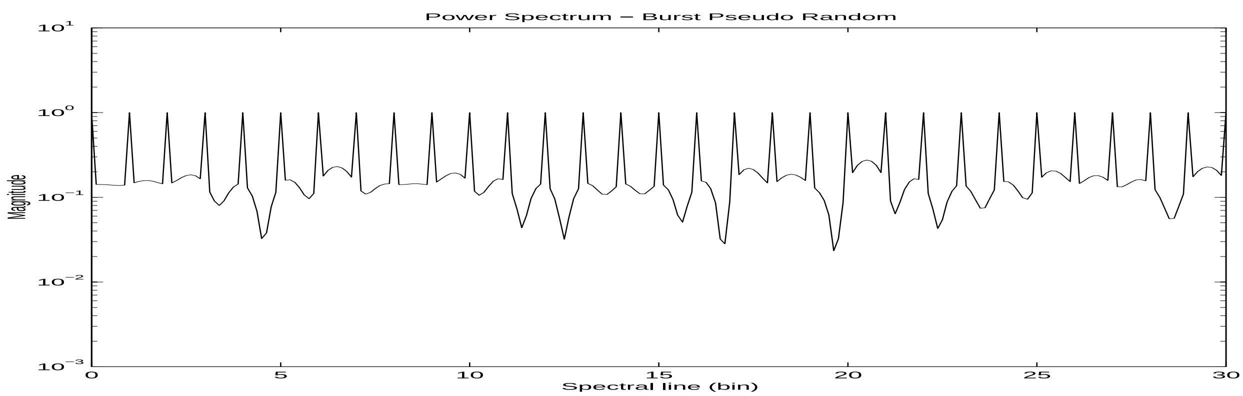


Signal from accelerometer

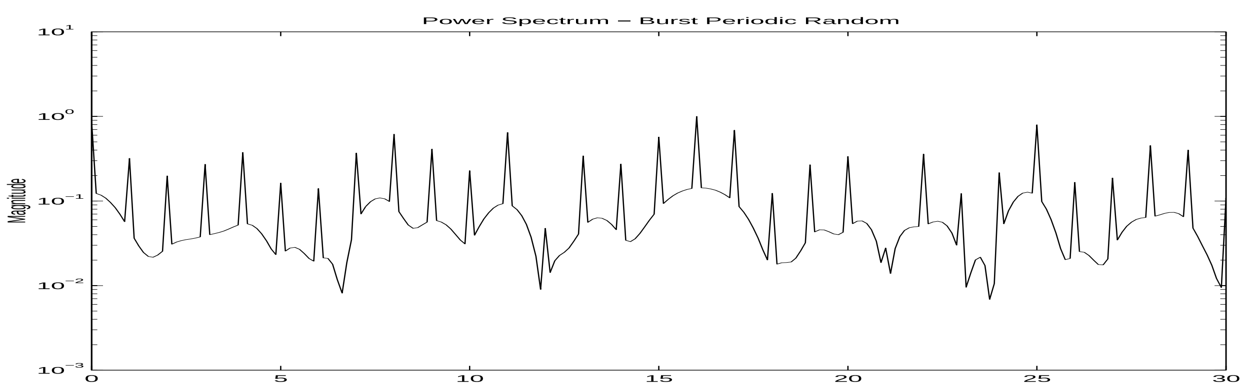


Hybrid Random Excitation Methods

Several random excitation methods have recently been demonstrated that are hybrid methods involving combinations of burst random and pseudo random, burst random and periodic random together with cyclic averaging.



Signal Energy Content - Burst Pseudo Random



Signal Energy Content - Burst Periodic Random

Shaker Excitation for Experimental Modal Analysis

Summary of Excitation Signal Choices

Excitation Signal Characteristics							
	Steady State Sine	Pure Random	Pseudo Random	Random	Periodic Chirp	Impact	Burst Random
Minimize Leakage	No	No	Yes	Yes	Yes	Yes	Yes
Signal-to-Noise Ratio	Very High	Fair	Fair	Fair	High	Low	Fair
RMS-to-Peak Ratio	High	Fair	Fair	Fair	High	Low	Fair
Test Measurement Time	Very Long	Good	Very Short	Fair	Fair	Very Short	Very Short
Controlled Frequency Content	Yes	Yes *	Yes *	Yes *	Yes *	No	Yes *
Controlled Amplitude Content	Yes	No	Yes *	No	Yes *	No	No
Removes Distortion	No	Yes	No	Yes	No	No	Yes
Characterize Nonlinearity	Yes	No	No	No	Yes	No	No

* Special Hardware Required

Shaker Excitation for Experimental Modal Analysis

Summary/Conclusions/Discussion