Deducing Electronic Unit Internal Response during a Vibration Test Using a Lumped Parameter Modeling Approach

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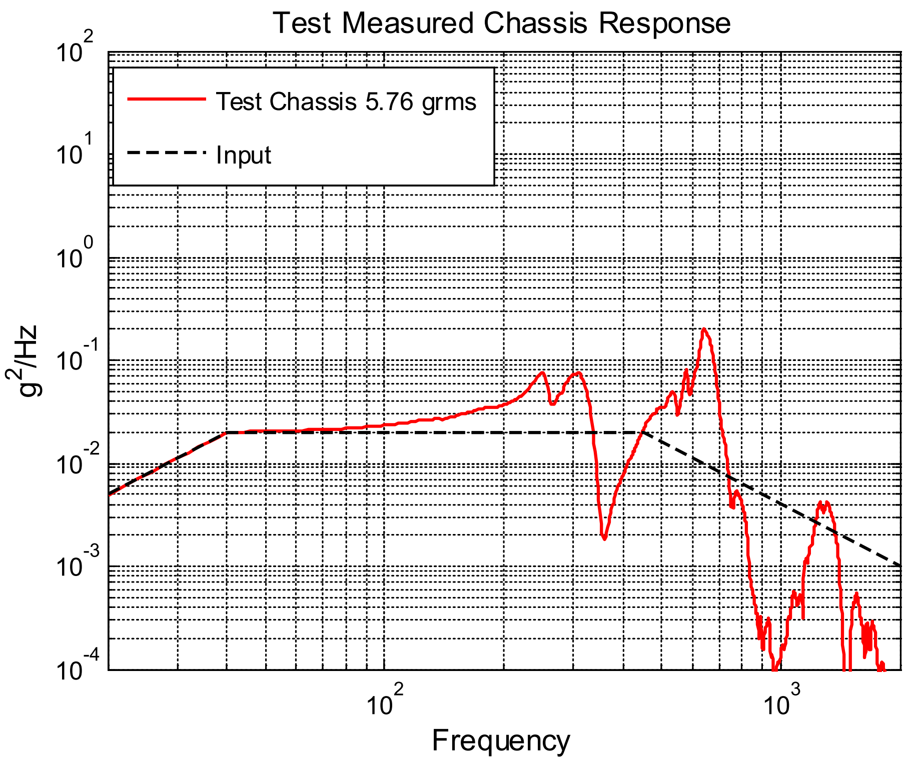
Overview

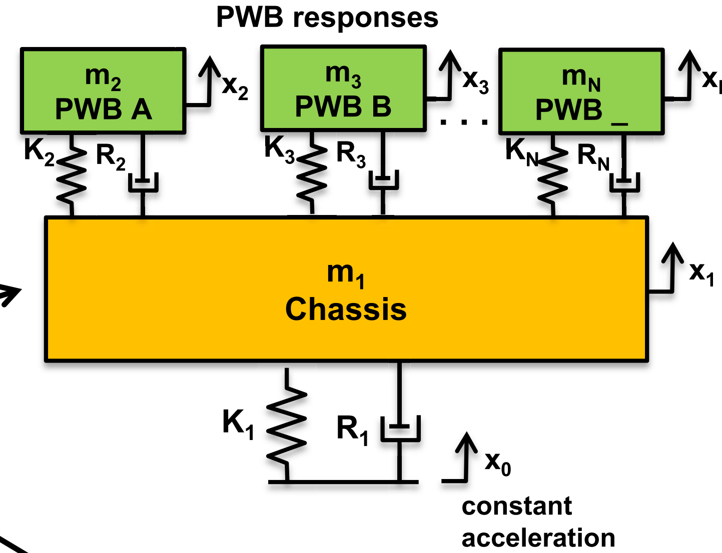
- Basic approach using model to deduce internal dynamics from external measurement
- Model development
- Two DOF illustration of parametric influence of model parameters
- Demonstration and correlation with test data
- Conclusions and future development

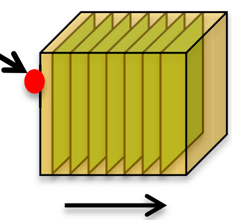
Motivation

- Accurately estimate random vibration test response of PWBs when only external measurements are available
  - *Current approximation methods such as use of Miles equation can result in significant over- or under-estimation (do not account for coupled response)*
- During testing – Indirect observability of unit internal PWB dynamics from external test measurement
- After testing – Forensic interpretation of test data
  - *Anomaly resolution*
  - *Design validation*
- Design stage – Quick prototyping of electronics unit dynamics for early design
  - *This approach would supplement but not replace a detailed finite element model (FEM)*

Basic Approach







- Spectral shape of chassis response is a unique signature from dynamic coupling with mounted oscillators
- Lumped parameter model of chassis and PWBs created by tuning model parameters to approximate chassis test response signature

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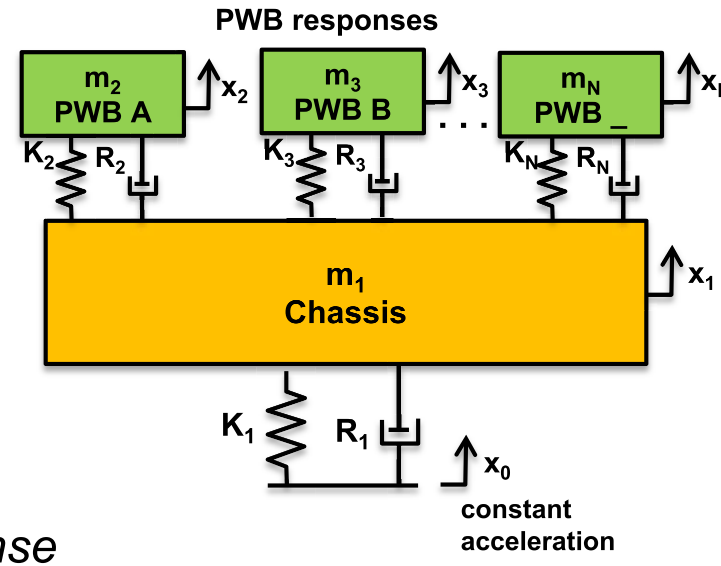
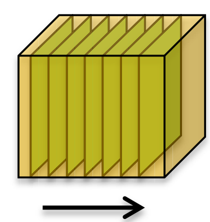
Basic Approach

- Assumptions
  - *Fixed base excitation normal to PWBs*
  - *PWBs independently supported by chassis*
  - *Damping assigned to discrete elements*
  - *Model elements approximate c.o.g. response of structural elements in fundamental mode*
- Limitations
  - *Approximates only fundamental modal response of structural element*
  - *Restricted to linear response*
  - *Ambiguity in correlating chassis spectral feature to response of specific PWB*
  - *Methodology still under development*
    - Needs more rigorously defined implementation rules and parameters
    - Needs further correlation with test data and finite element models





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Representation of Element Effective and Residual Mass

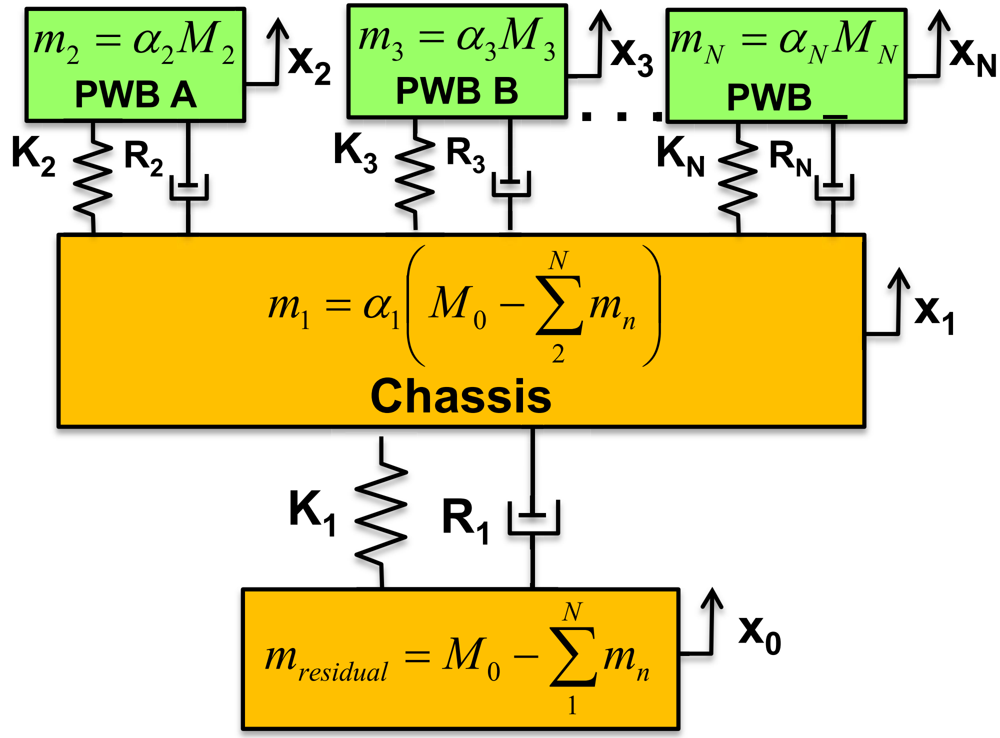
Element Total mass M_n

Element Effective modal mass
$m_n = \alpha_n M_n$

Dynamically participating in proportion to mode shape

Residual mass
$M_{res} = M_{unit} - \Sigma m_n$

Moves along with input in rigid body motion



(M_0 = total unit mass)

- *α_n = Modal mass participation factor for element n*
- *Adapted from Bamford, Wada (1971)*
  - *Differs: model DOF correspond to discrete structural elements (chassis, PWBs) rather than modes*

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Model Development: Parameter Assignment

Model DOF	Structural Element	Mass	Effective Modal Mass	Fundamental Frequency	Quality Factor
1	Chassis	$M_1 = M_0 - \sum_{n=2}^{N} m_n$	$m_1 = \alpha_1 M_1$	f_1	Q_1
2	PWB 1	M_2	$m_2 = \alpha_2 M_2$	f_2	Q_2
3	PWB 2	M_3	$m_3 = \alpha_3 M_3$	f_3	Q_3
:	:	:	:	:	:
N	PWB N-1	M_N	$m_N = \alpha_N M_N$	f_N	Q_N

- Model parameters m_n, f_n, Q_n initial value assignments based on
  – *Available unit information (actual measurements, structural analysis documentation)*
  – *Best estimates*
  – *Reasonable values based on experience*

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N-dimensional Linear System of Equations

$$\begin{vmatrix} 1-a_1(\omega)-\sum_{n=2}^{N}\gamma_n a_n(\omega) & \gamma_2 a_2(\omega) & \gamma_3 a_3(\omega) & \cdots & \gamma_N a_N(\omega) \\ a_2(\omega) & 1-a_2(\omega) & 0 & \cdots & 0 \\ a_3(\omega) & 0 & 1-a_3(\omega) & \cdots & 0 \\ \vdots & \vdots & \vdots & \ddots & \vdots \\ a_N(\omega) & 0 & 0 & \cdots & 1-a_N(\omega) \end{vmatrix} \begin{vmatrix} z_1(\omega) \\ z_2(\omega) \\ z_3(\omega) \\ \vdots \\ z_N(\omega) \end{vmatrix} = \begin{vmatrix} -a_1(\omega) \\ 0 \\ 0 \\ \vdots \\ 0 \end{vmatrix}$$

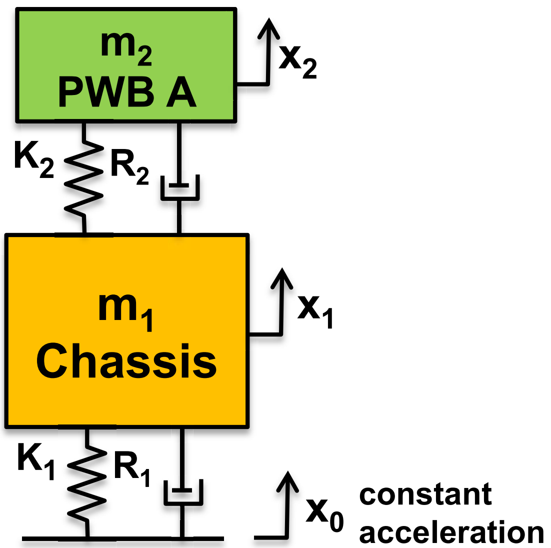
$$a_n(\omega) = j\frac{\omega_N}{\omega Q_N} + \left(\frac{\omega_N}{\omega}\right)^2 \qquad \gamma_n = \frac{m_n}{m_1}$$

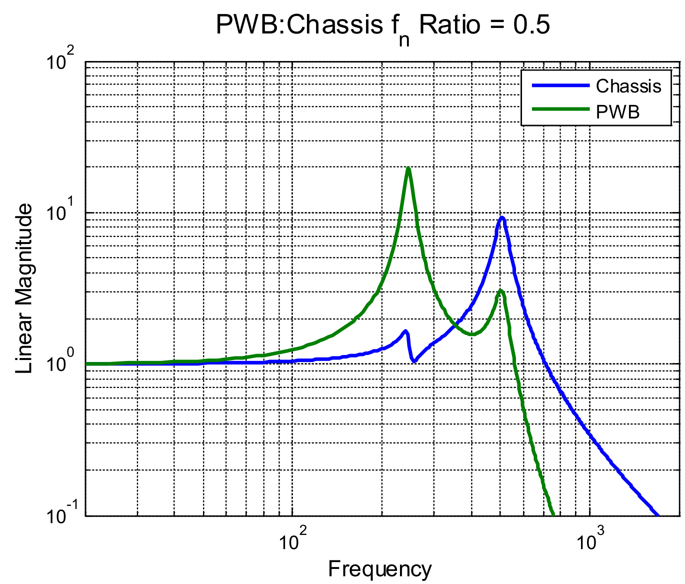
Solutions $z_n(\omega)$ = normalized frequency response functions for DOF

2 DOF Parametric Studies

Illustrate spectral influence of model parameters

- 2 DOF = Chassis + 1 PWB
- Coupled response studies
  1. *Ratio of uncoupled resonance frequencies f_2/f_1 for m_2/m_1=1/10 (small unit)*
  2. *Ratio of uncoupled resonance frequencies f_2/f_1 for m_2/m_1=1/30 (medium sized unit)*
  3. *PWB Q value*





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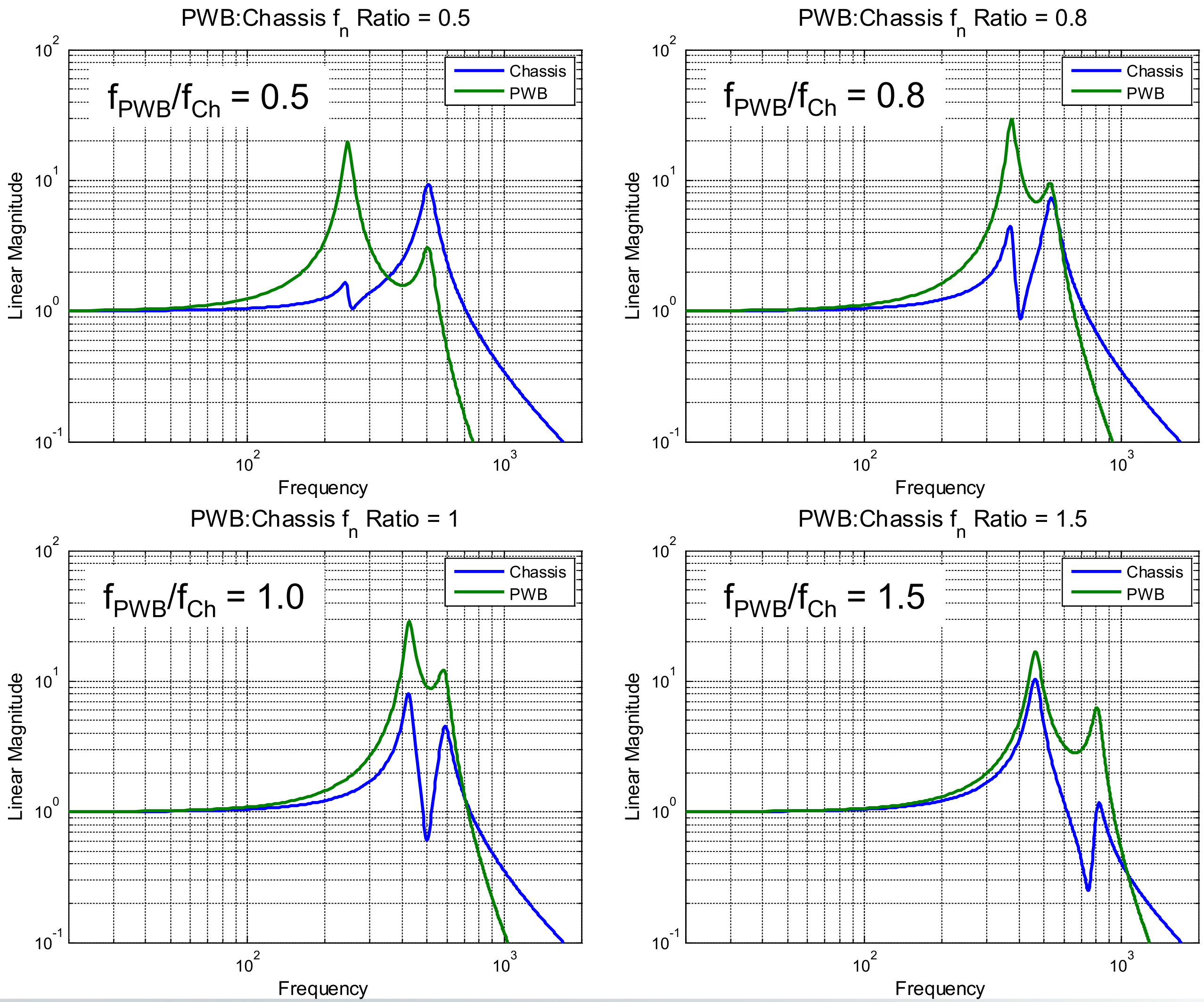
Study 1: PWB/Chassis f_n Ratio Spectral Influence

Relatively small unit – PWB/Chassis mass ratio = 1/10



PWB Q = 25
Chassis Q = 10

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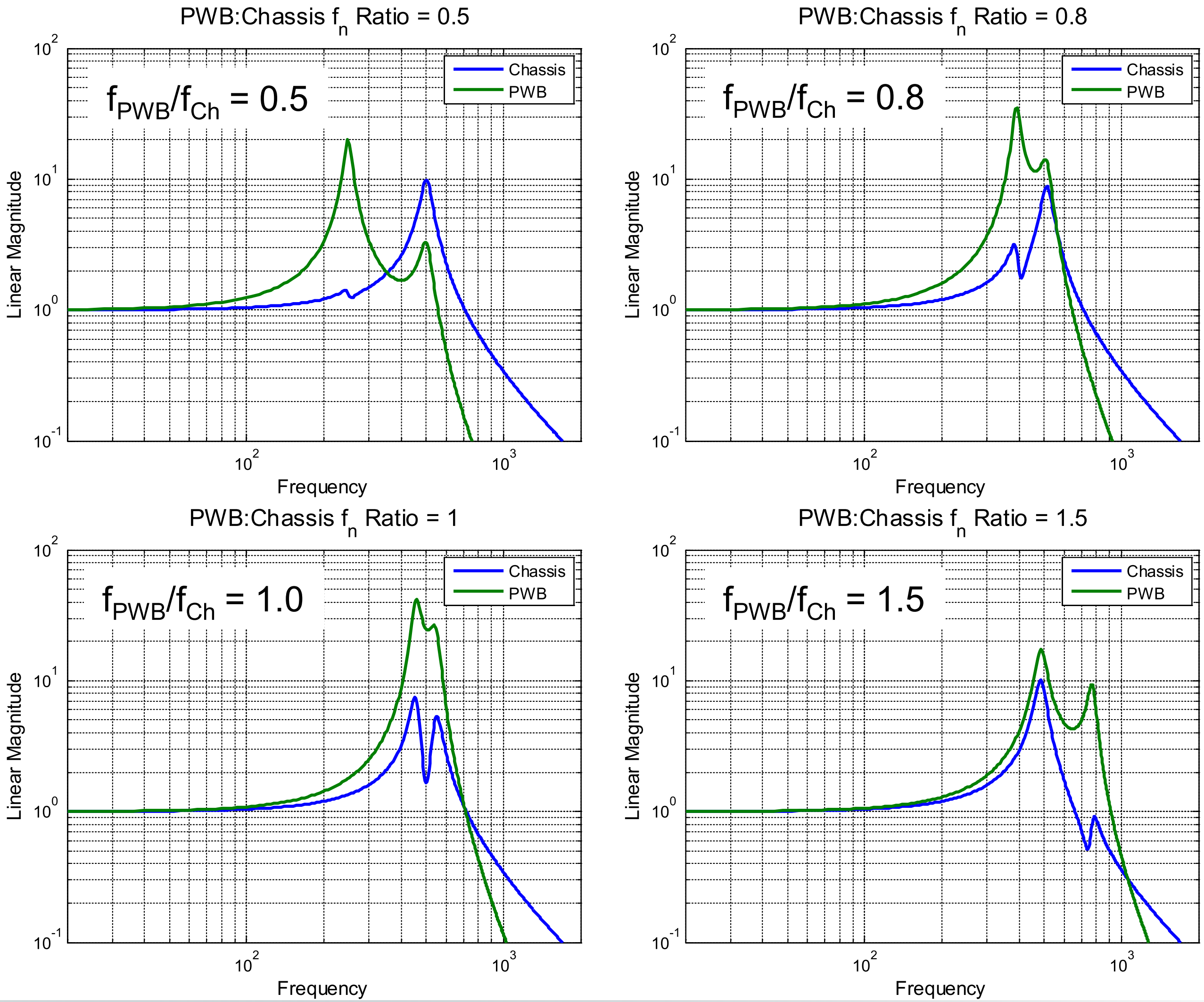
Study 2: PWB/Chassis f_n Ratio Spectral Influence

Medium-sized unit – PWB/Chassis mass ratio = 1/30



PWB Q = 25
Chassis Q = 10

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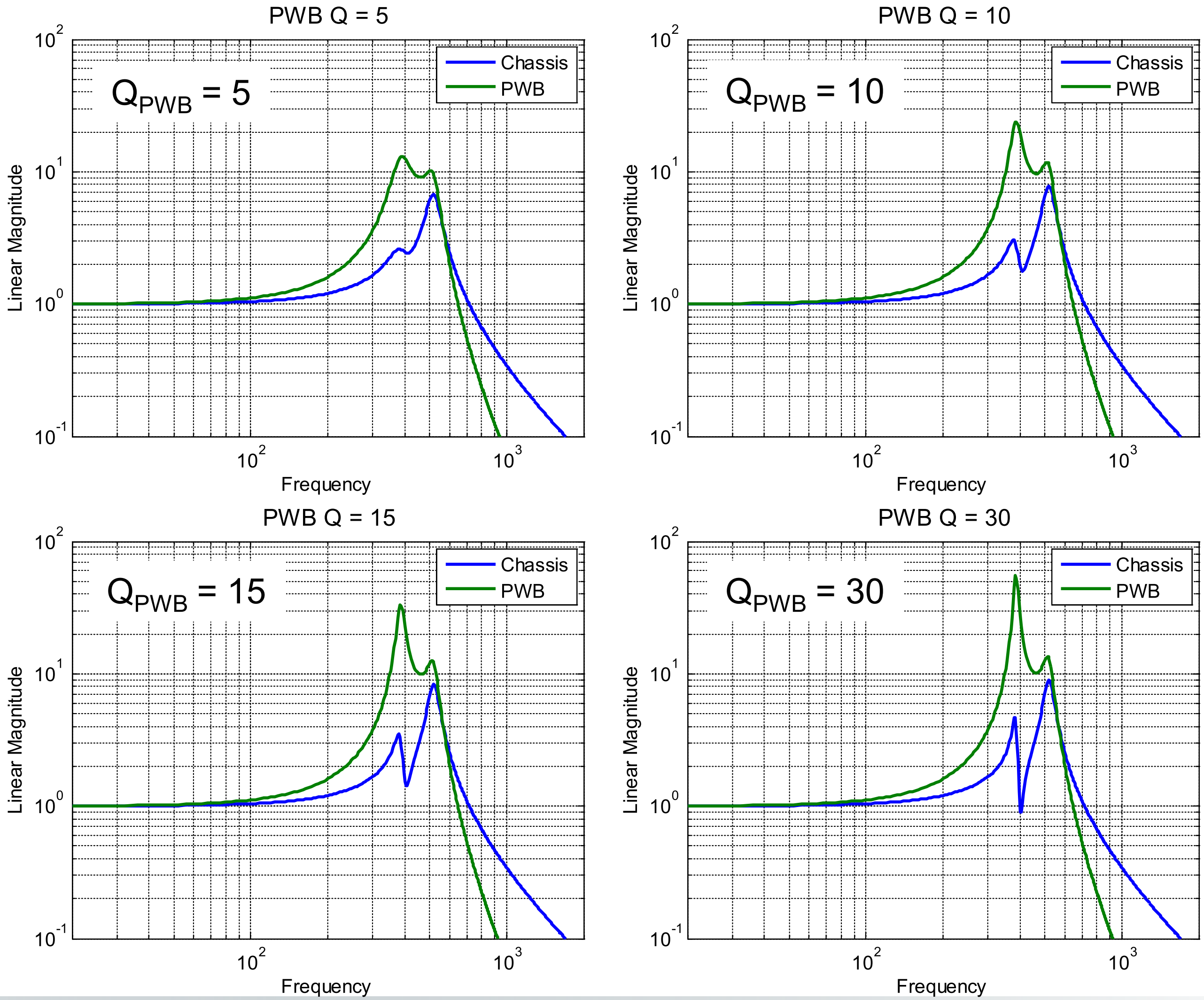
Study 3: PWB Q Value Spectral Influence



Chassis Q = 10
m_{PWB}/m_{Ch} = 1/10

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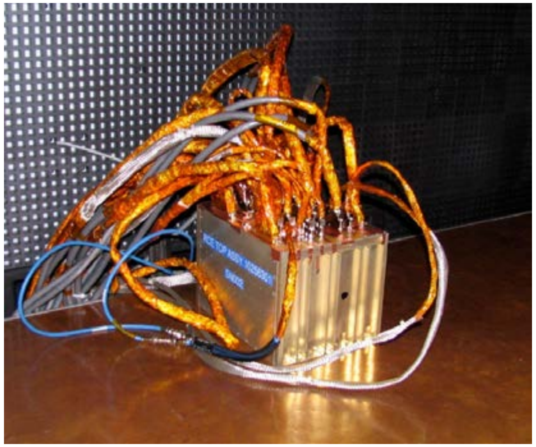
Demonstration Using Test Data

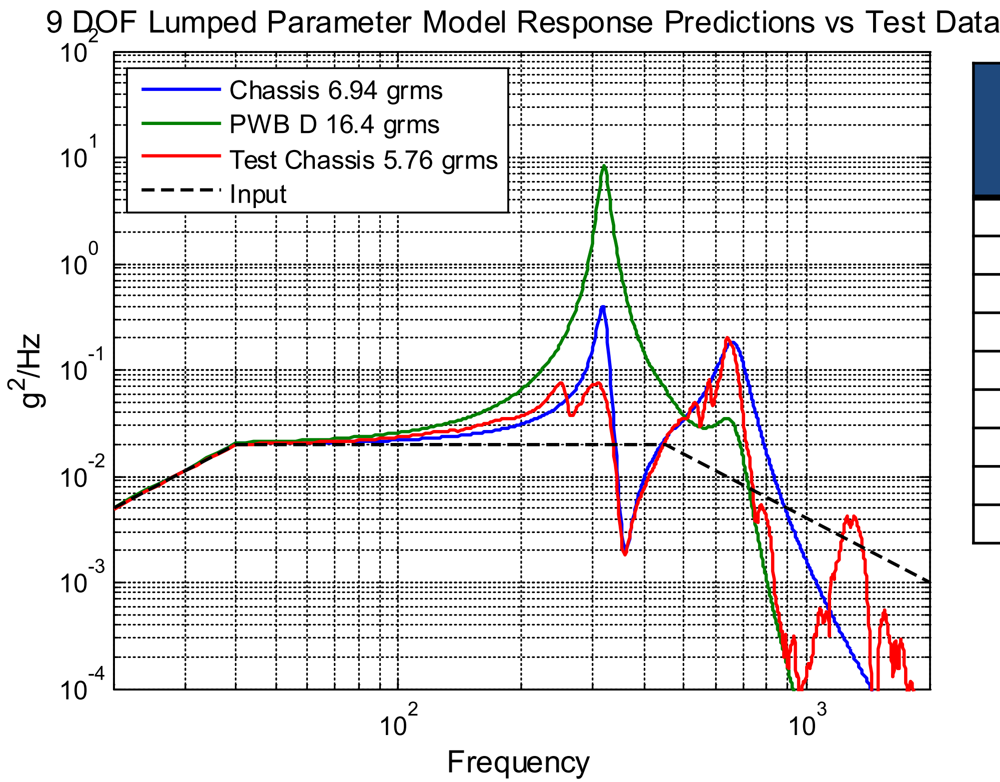
- Test article
  - *28 lb. (12.7 kg) electronics unit with 8 full-span PWBs*
  - *Random vibration test (force limited) performed in 2008*
  - *Accelerometer instrumentation*
    - 1 PWB (D) near center of board
    - Chassis at approximate c.o.g. height



PWB	Frame Weight lbs (kg)	CCA Weight lbs (kg)	PWB Weight lbs (kg)	FEM modal frequency (Hz)
A	1.10 (0.50)	1.70 (0.77)	2.80 (1.27)	218
B	0.94 (0.43)	1.39 (0.63)	2.33 (1.06)	228
C	0.50 (0.23)	1.00 (0.45)	1.50 (0.68)	223
D	0.50 (0.23)	1.00 (0.45)	1.50 (0.68)	213
E (copy of D)	0.50 (0.23)	1.00 (0.45)	1.50 (0.68)	213
F	0.50 (0.23)	1.00 (0.45)	1.50 (0.68)	213
G	0.50 (0.23)	0.90 (0.41)	1.40 (0.64)	228
H (spare)	0.59 (0.27)	0.78 (0.35)	1.36 (0.62)	NA

Data obtained from unit structural analysis documentation

9 DOF Model Approximation



Model Uncoupled Parameters

Model Element	Weight lbs (kg)	Mass Partic. Factor *α_n*	Uncoupled Resonance *f_n* (Hz)	Q
Chassis	*	0.45	595	6.0
PWB A	2.80 (1.27)	0.30	358	15.0
PWB B	2.33 (1.06)	0.30	358	15.0
PWB C	1.50 (0.68)	0.42	358	17.0
PWB D	1.50 (0.68)	0.42	358	17.0
PWB E	1.50 (0.68)	0.42	358	17.0
PWB F	1.50 (0.68)	0.42	358	17.0
PWB G	1.40 (0.64)	0.42	358	17.0
PWB H	1.36 (0.62)	0.42	358	17.0

Chassis response:
Measured = 5.76 g_{rms}
Predicted = 6.94 g_{rms}

- Test external chassis response (red)
  - *Low level (-6 dB) test run used for model correlation*
  - *Test data normalized to nominal input spectrum to eliminate spectral noise*
- Predicted random vibe responses = $|z_n(\omega)|^2$ x Input PSD (interpolated)

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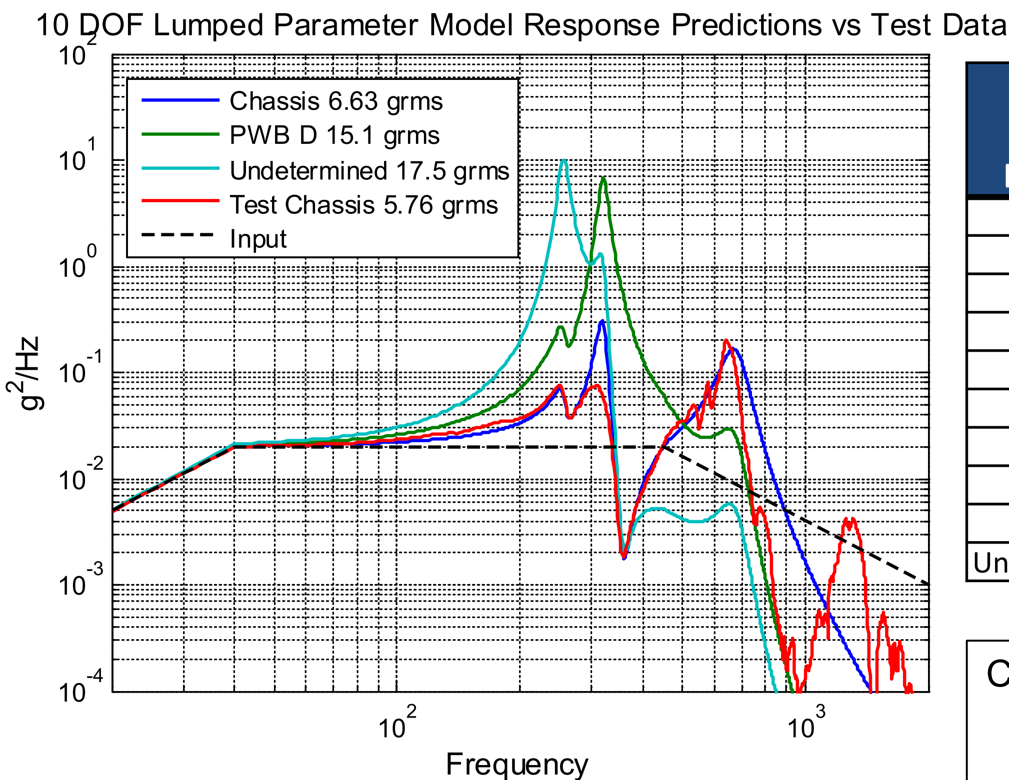
10 DOF Model Approximation



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PWB F	1.50 (0.68)	0.42	358	17.0
PWB G	1.40 (0.64)	0.42	358	17.0
PWB H	1.36 (0.62)	0.42	358	17.0
Undetermined	2.50 (1.13)	0.40	260	14.0

Chassis response:

Measured = 5.76 g_{rms}

Predicted = 6.63 g_{rms}

Predicted PWB D accel. = 15.1 g_{rms}

Predicted PWB D rel. defl. = 1.15 $mils_{rms}$ (29.2 μm_{rms})

- Notch in chassis response at 260 Hz predicted with undetermined structural element of 2.5 lbs., Q = 14

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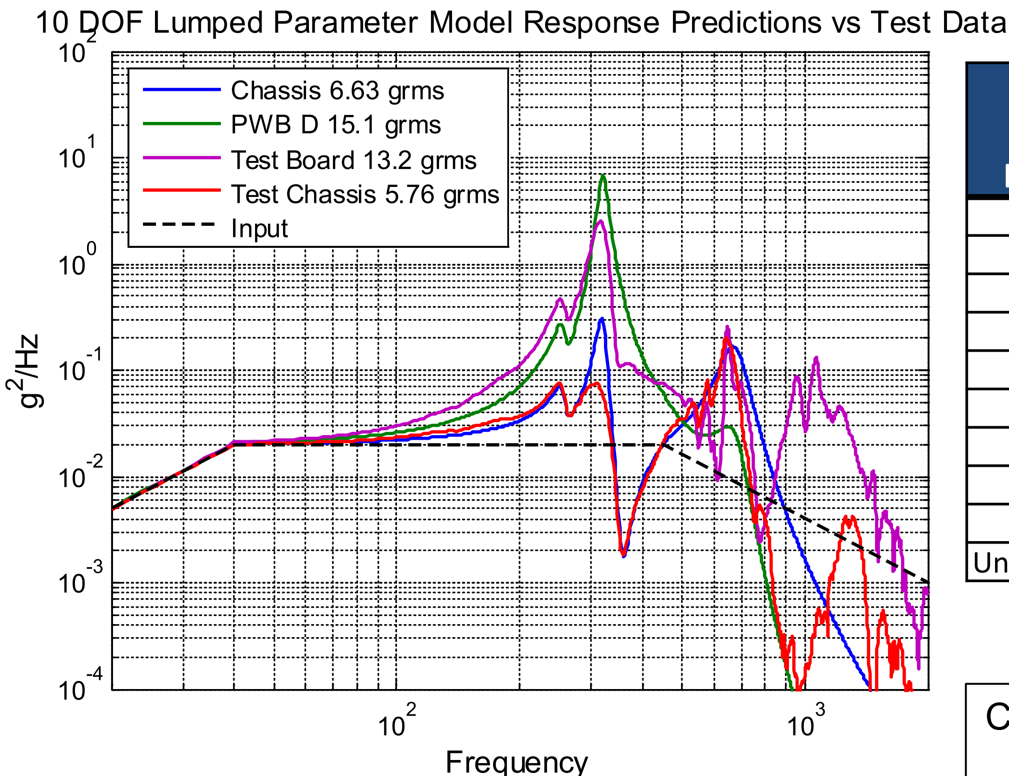
PWB Response: 10 DOF Model vs. Test Measurement



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PWB F	1.50 (0.68)	0.42	358	17.0
PWB G	1.40 (0.64)	0.42	358	17.0
PWB H	1.36 (0.62)	0.42	358	17.0
Undetermined	2.50 (1.13)	0.40	260	14.0

Chassis response:

Measured = 5.76 g_{rms}

Predicted = 6.63 g_{rms}

PWB D response

Measured = 15.1 g_{rms}

Predicted = 13.2 g_{rms}

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Conclusions

- Lumped parameter modeling is a viable approach for deducing internal board random vibration test responses given only external chassis response measurement
  - *Reasonable correlation of model predictions with test data*
  - *Model can be rapidly developed and tuned to provide quick results*
  - *Due attention must be made to assumptions and limitations*
  - *More development needed to ensure reduce uncertainties in application*

- Empirical alternative to application of crude approximation methods such as application of Miles Equation

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Future Development

- Additional correlation of approach with test data and finite element models
- Incorporate test force measurements along with chassis response as test data observables of internal dynamics
- Explore extension to transient response for application to shock test response predictions for electronic units
  - *Limited to spectral range dominated by structural response (typically <1000Hz)*
- Develop similar modeling approaches for broader range of application

Acknowledgements

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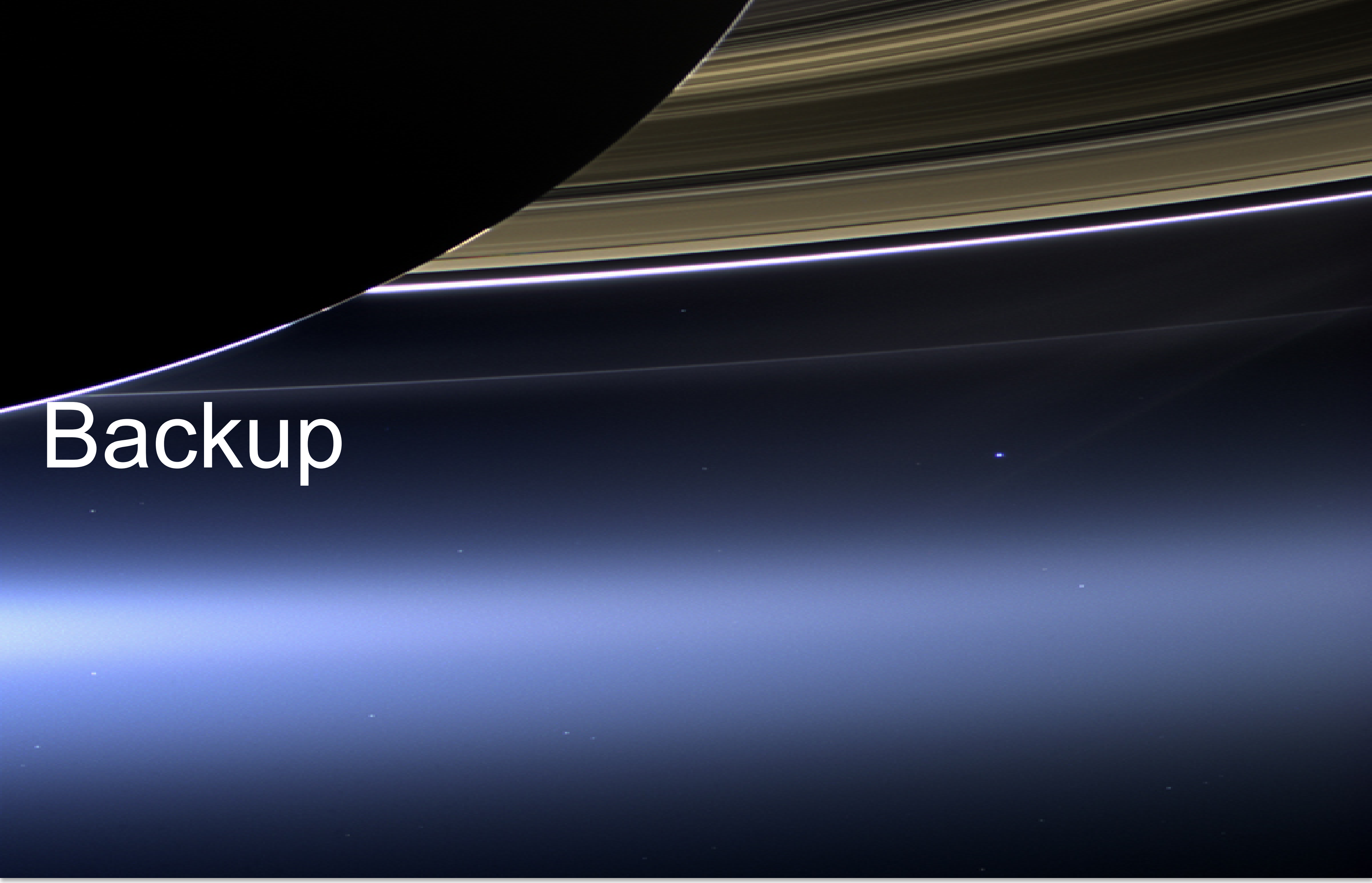
  - *Test conductor for electronic unit used in demonstration*
- Steven Carlson, for Jet Propulsion Laboratory
  - *Structural analyst for electronic unit used in demonstration*
- David C. Sandkulla, The Aerospace Corporation
  - *For collaboration in adapting the lumped element approach to modeling electronic box dynamics*

Backup



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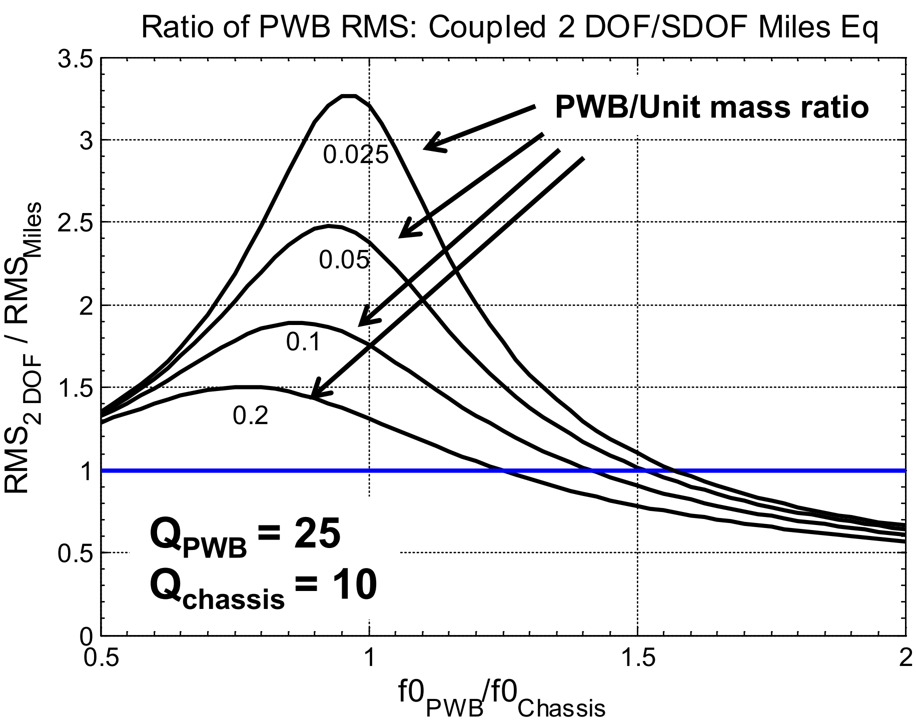
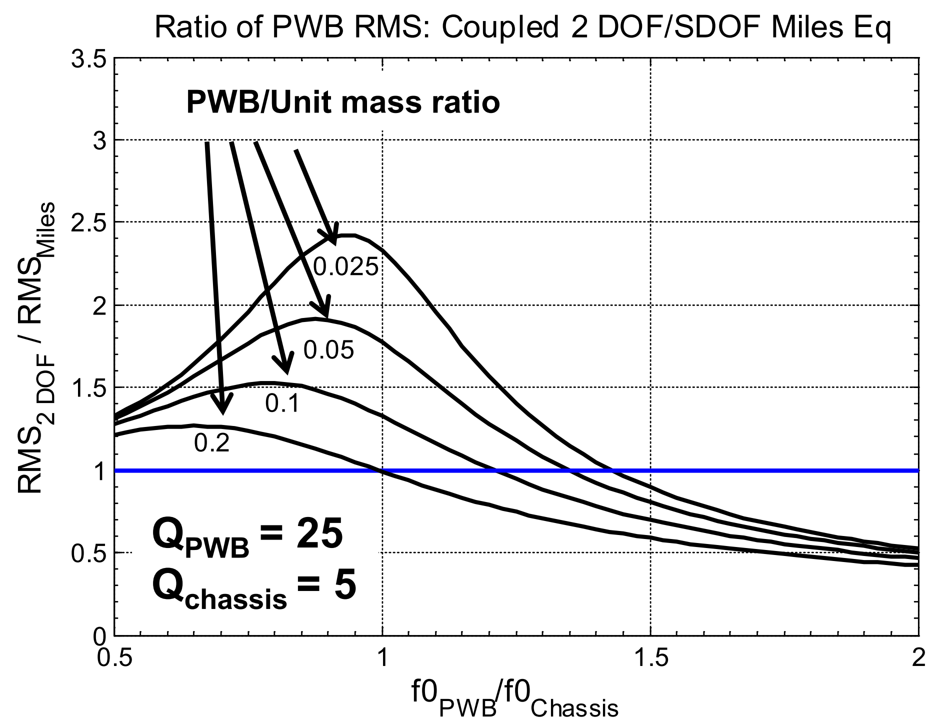
RMS: Coupled PWB Response Based on 2 DOF Model





- *Coupled relative RMS response of first bending mode (whether g's or mils) can be significantly greater than a simple SDOF Miles Equation would predict*
- *Degree of amplification dependent on relative mass ratio, f0 ratio, Q*

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