AATT

Passive Wireless Vibration Sensing for Measuring Aerospace Structural Flutter

W. (Cy) Wilson & Jason P. Moore
NASA Langley Research Center

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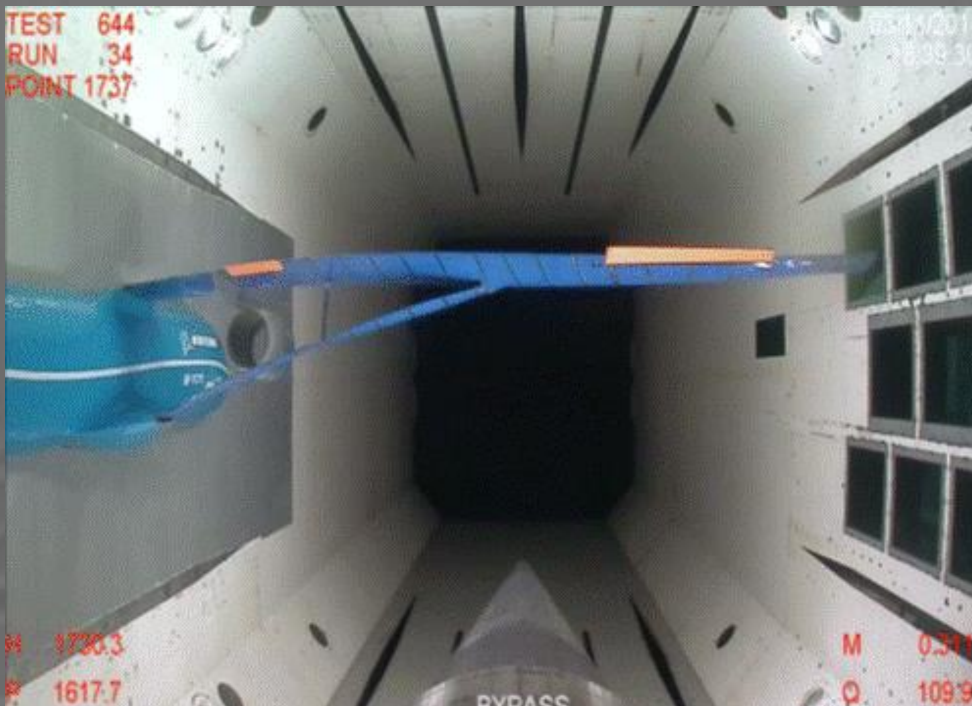
Outline

- Motivation
- Previous SAW Sensor Work
- SAW Results
- Microwave Experimental Setup
- Results
- Conclusions
- Funding/Partnership Opportunities

Motivation



The Advanced Air Transport Technology (AATT) Project is investigating flutter effects in aeroelastic wings.

A subprogram, the Subsonic Ultra-Green Aircraft Research (SUGAR), is examining the aeroelasticity of high aspect ratio truss-braced wings, which could reduce aircraft fuel consumption by 5~10%.

NASA is also investigating the behavior of light-weight flexible aircraft structures using the X-56 Multi-Utility Technology Testbed (MUTT) an unmanned aircraft system

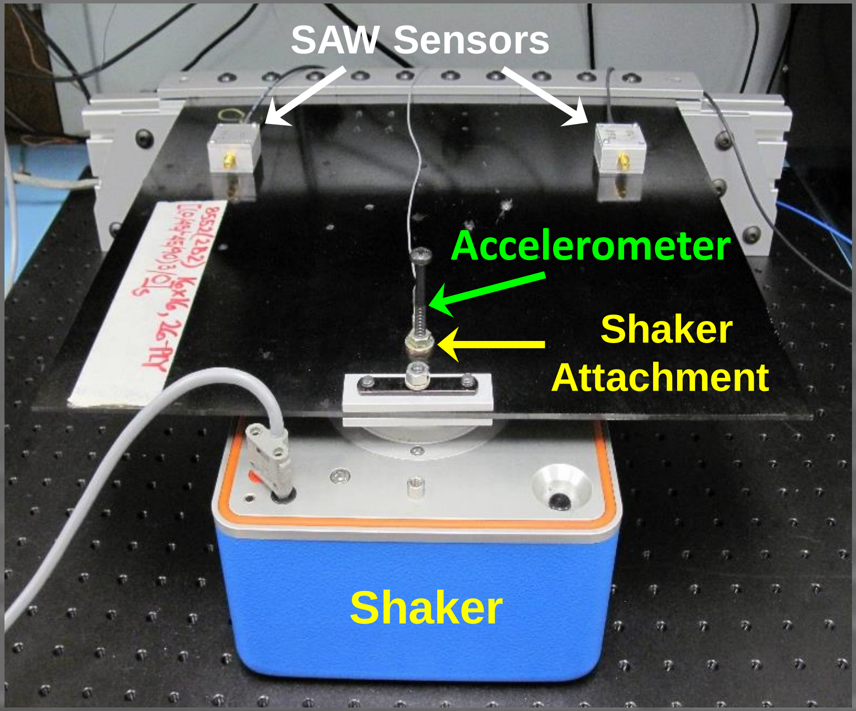
-Two center-bodies

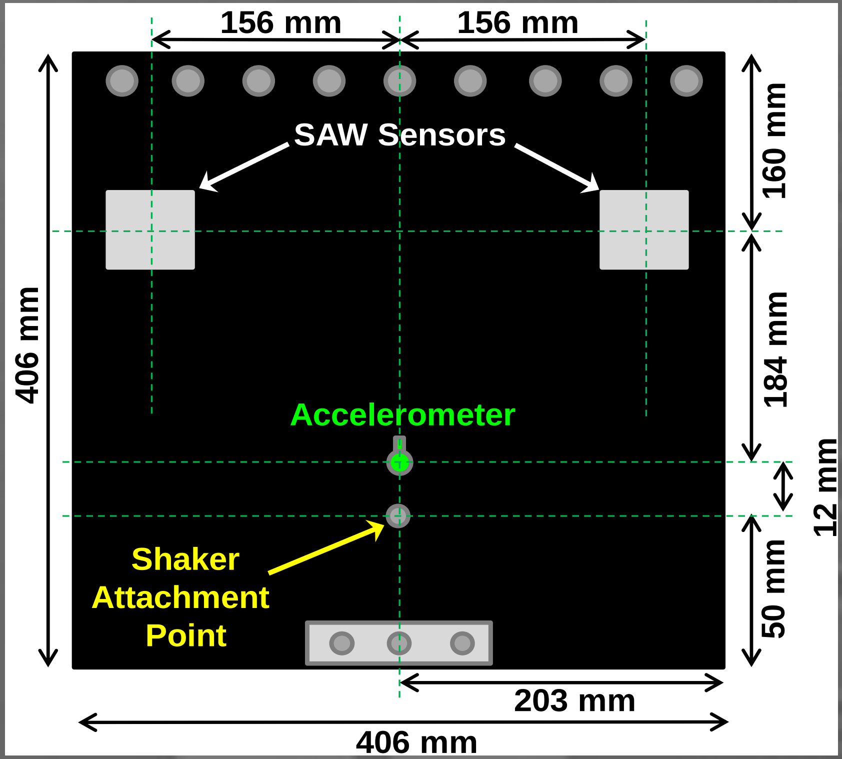
-Four sets of interchangeable wings of varying aeroelasticity.

Motivation

- Helios high altitude long duration aircraft.

CFRP Panel



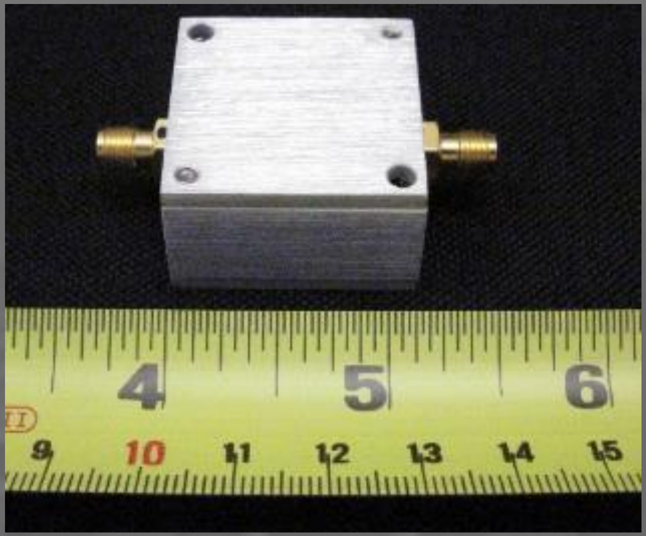


The SAW and accelerometer are mounted on top of the panel. The shaker is located at the free end of the cantilever underneath the panel.

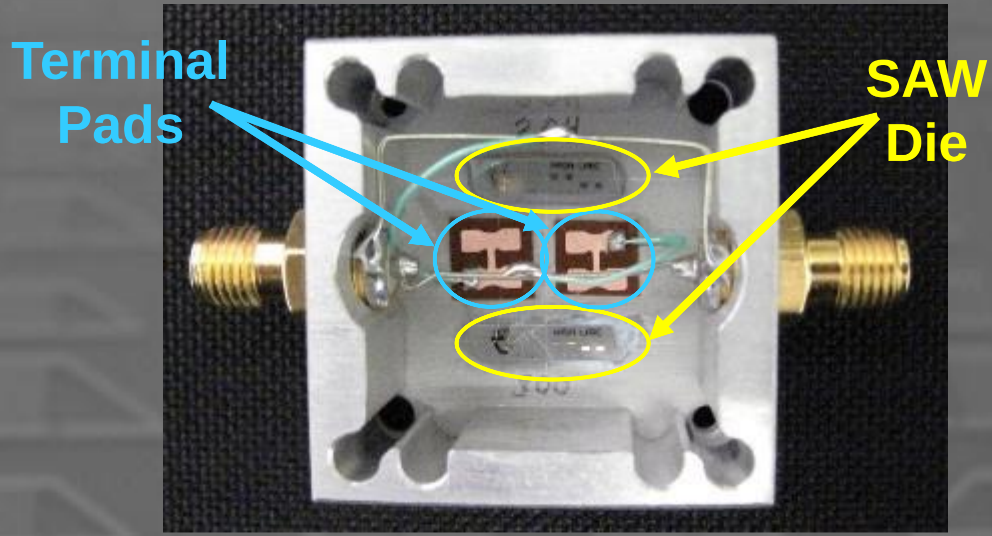
A diagram showing the location and distances of the sensors and the shaker attachment location.

Carbon fiber–reinforced polymer (CFRP) composite panel is 2.78 mm thick and was fabricated at NASA LaRC, it is a laminate of IM7/8552 is quasi-isotropic and is made up of IM7 fibers and 8552 prepreg with a 26 ply layup of $[(0/+45/-45/90)_3\ 0]_S$.

SAW Frequency Division Multiplexed (FDM) Sensor Modules



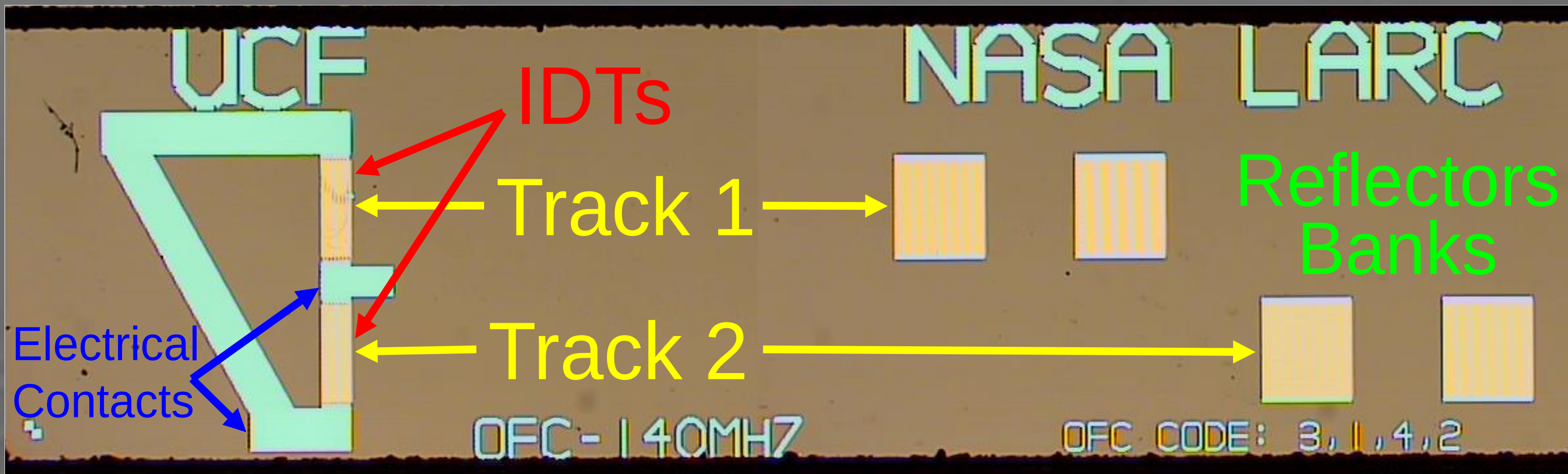
SAW sensor module
3.81cm x 3.81cm x 1.9cm
(1.5” x 1.5” x 0.75”)



Two SAW die bonded inside, and two SMA connections.

- The prototype FDM system has six SAW sensors (140, 172, 204, 236, 268, 300 MHz) in three modules. 140/236, 172/268, 204/300.
- One SAW sensor is bonded rigidly to the bottom of the package and is used for measuring strain (236, 268, 300)
- The other SAW sensor is bonded with a flexible bonding agent such as RTV that does not transfer strain (140, 172, 204), for measuring environmental effects.

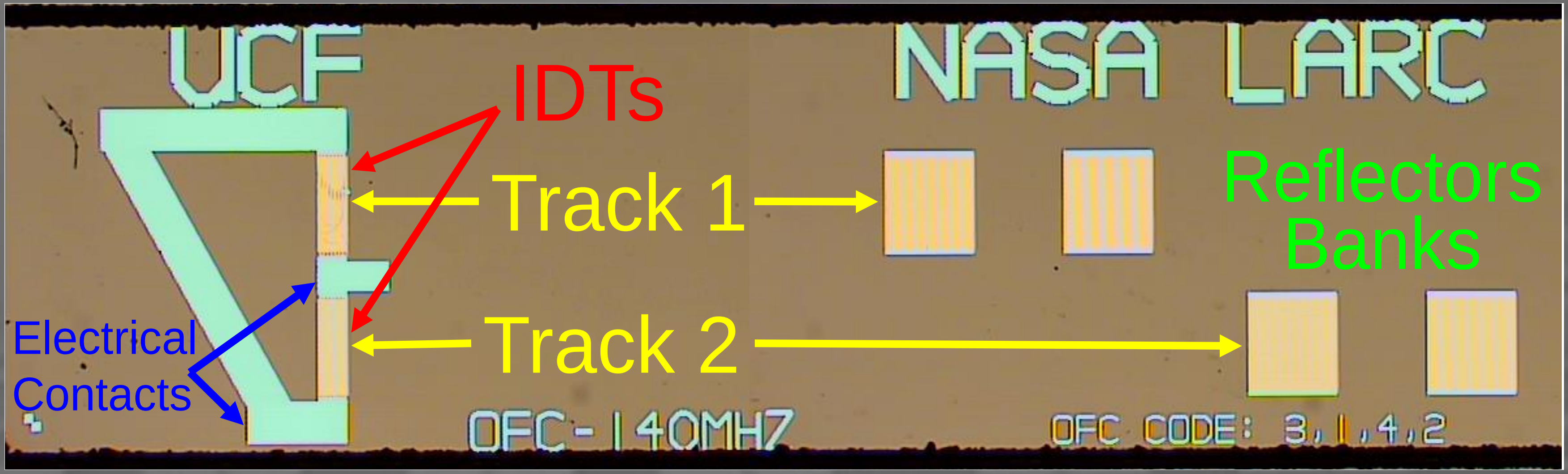
Surface Acoustic Wave Sensor



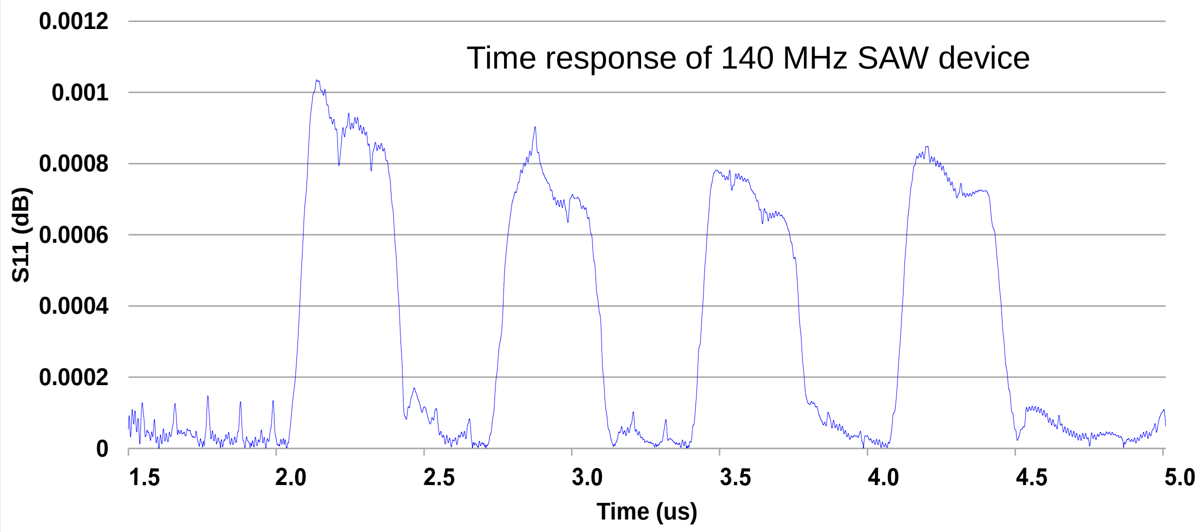
Time response of 140 MHz SAW device

- For this work the 236MHz device was used
- The sensor has four orthogonal frequency coded (OFC) reflector banks in two tracks,
- The IDTs have a wider bandwidth of 15 MHz, while each reflector has a bandwidth of 6MHz.
- The gratings in each track reflect a different frequency with an arrangement of f3, f1, f4, f2.
- The reflector center frequencies are f1=231.5, f2=234.5, f3=237.5, f4=241.5 MHz

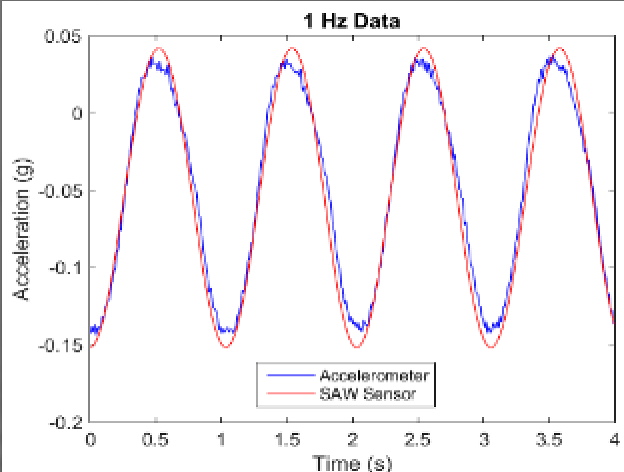
Surface Acoustic Wave Sensor

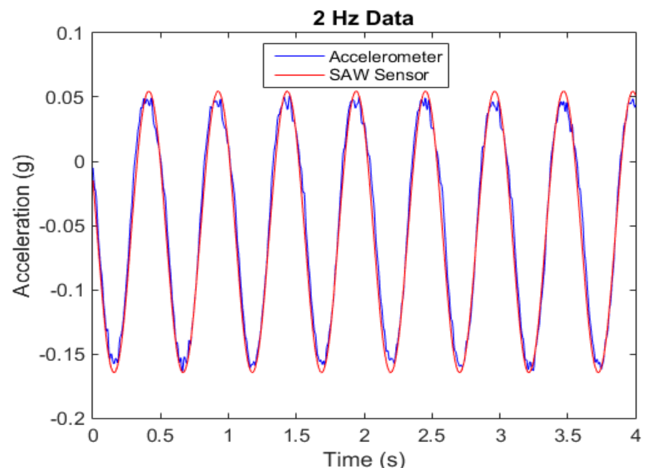


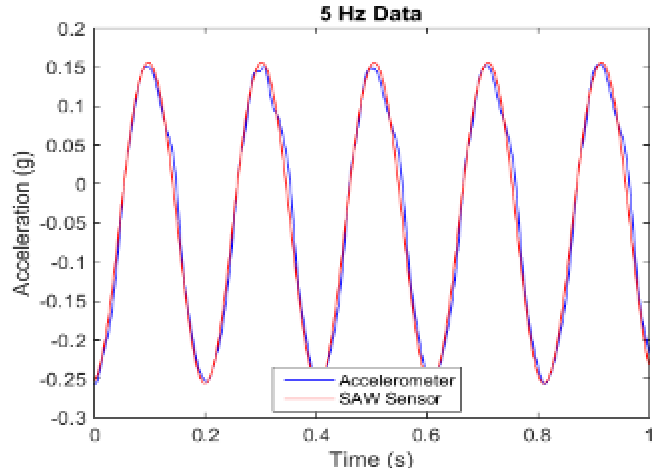
- Time Response for the four gratings.

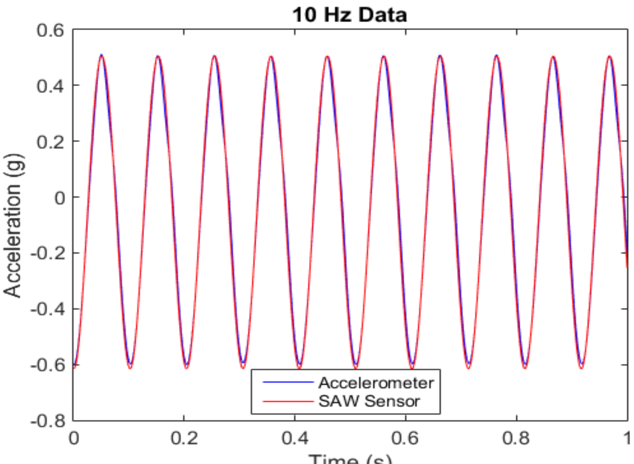


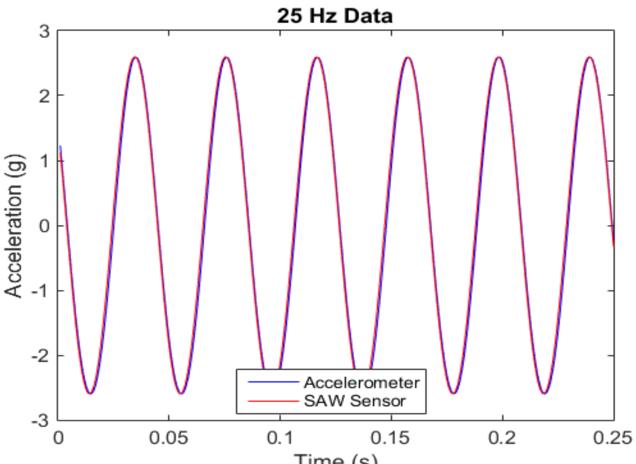
SAW Results

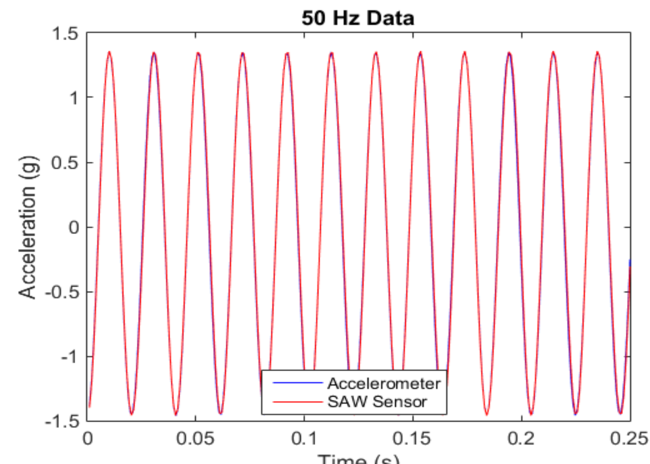

1 Hz Data
Acceleration (g)
Time (s)
Accelerometer
SAW Sensor
0.05
0
-0.05
-0.1
-0.15
-0.2
0
0.5
1
1.5
2
2.5
3
3.5
4


2 Hz Data
Acceleration (g)
Time (s)
Accelerometer
SAW Sensor
0.1
0.05
0
-0.05
-0.1
-0.15
-0.2
0
0.5
1
1.5
2
2.5
3
3.5
4

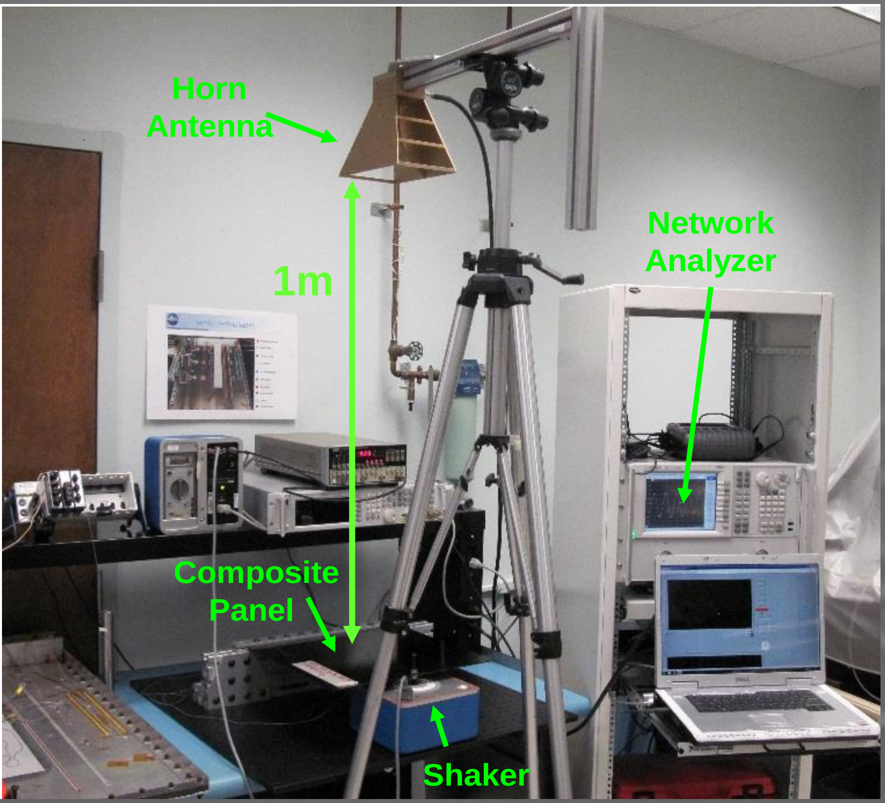

5 Hz Data
Acceleration (g)
Time (s)
Accelerometer
SAW Sensor
0.2
0.15
0.1
0.05
0
-0.05
-0.1
-0.15
-0.2
-0.25
-0.3
0
0.2
0.4
0.6
0.8
1


10 Hz Data
Acceleration (g)
Time (s)
Accelerometer
SAW Sensor
0.6
0.4
0.2
0
-0.2
-0.4
-0.6
-0.8
0
0.2
0.4
0.6
0.8
1

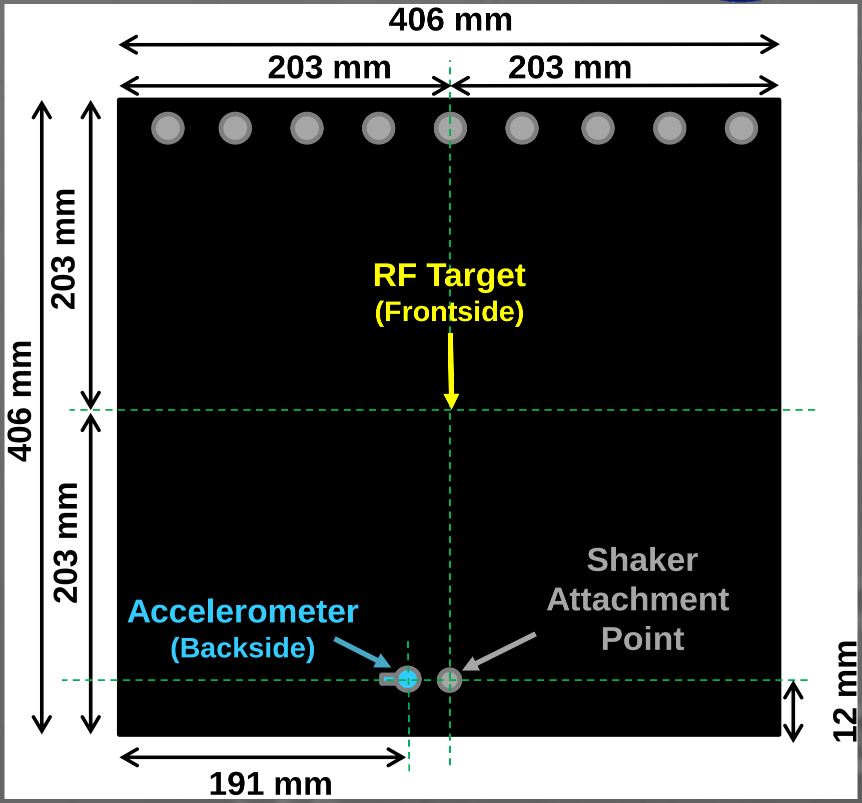

25 Hz Data
Acceleration (g)
Time (s)
Accelerometer
SAW Sensor
3
2
1
0
-1
-2
-3
0
0.05
0.1
0.15
0.2
0.25


50 Hz Data
Acceleration (g)
Time (s)
Accelerometer
SAW Sensor
1.5
1
0.5
0
-0.5
-1
-1.5
0
0.05
0.1
0.15
0.2
0.25

Microwave Test Setup

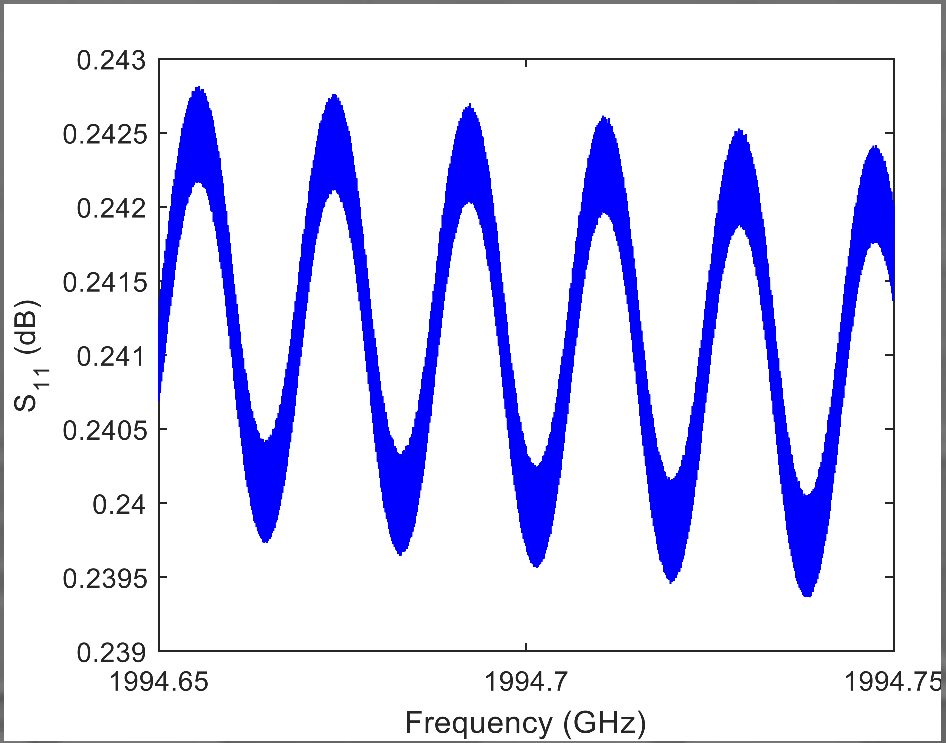


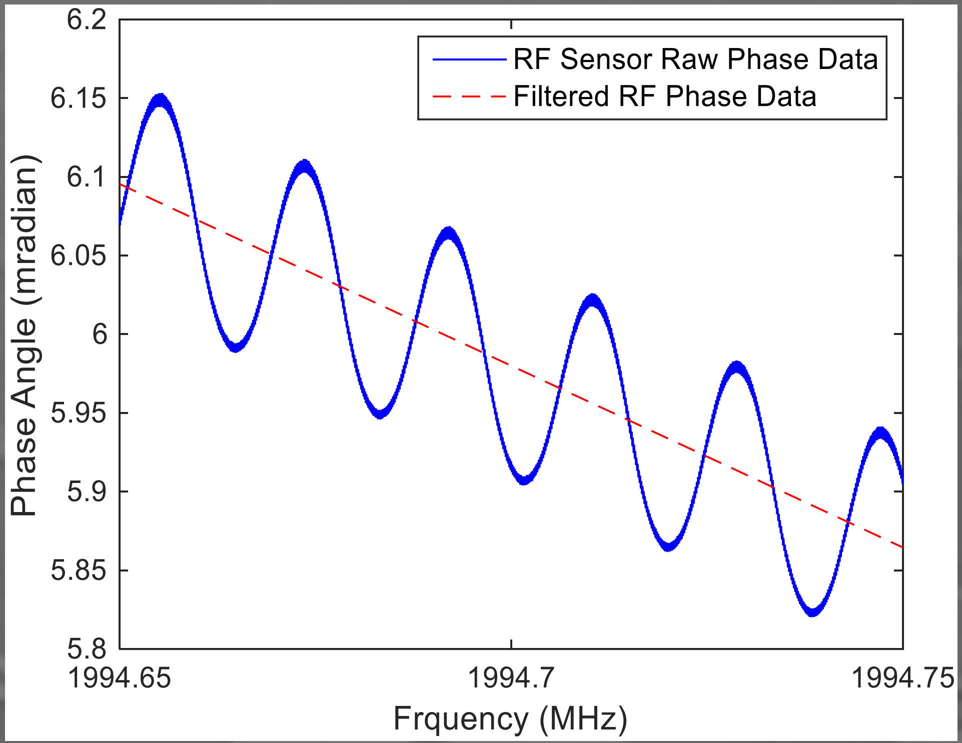
The test setup showing the network analyzer, the horn antenna, the composite test panel, and the shaker.



A diagram showing the location and distances of the accelerometer (underside), the RF target area and the shaker attachment location.

Raw Data

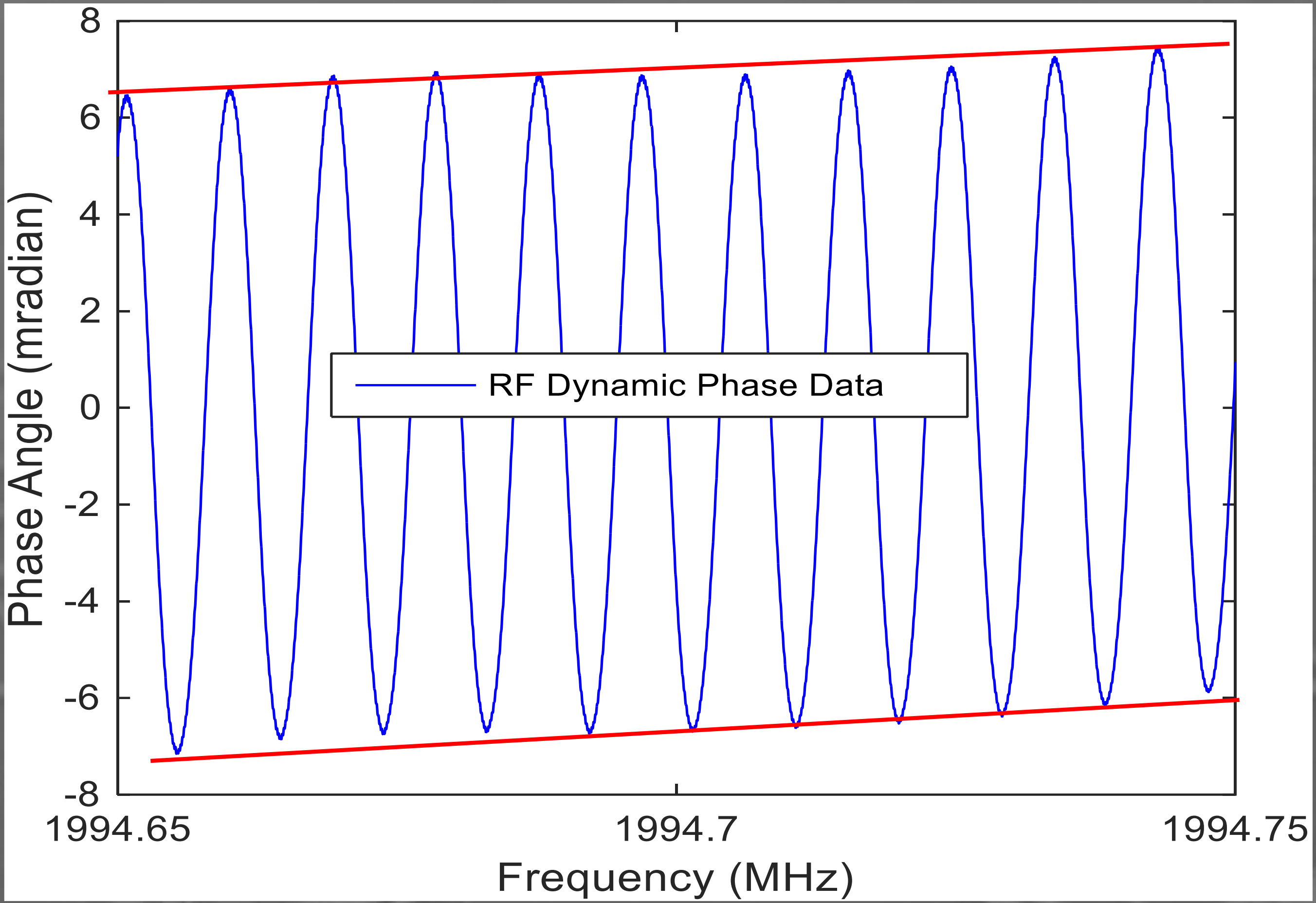




The raw S_{11} data with a 2 Hz sine wave.

The calculated phase data with a 2 Hz sine wave.

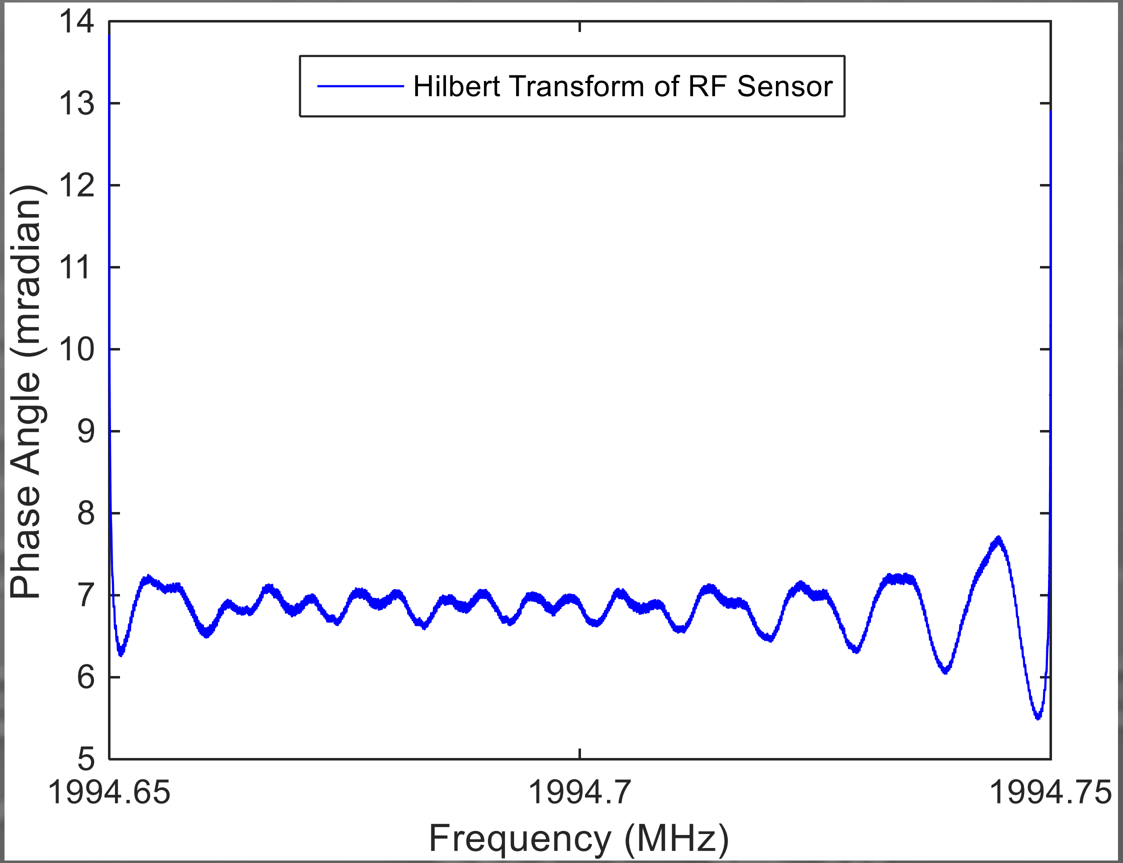
Delta Phase Response



The delta-phase data resulting from subtraction of filtered phase data (in red) from the raw phase data (in blue).

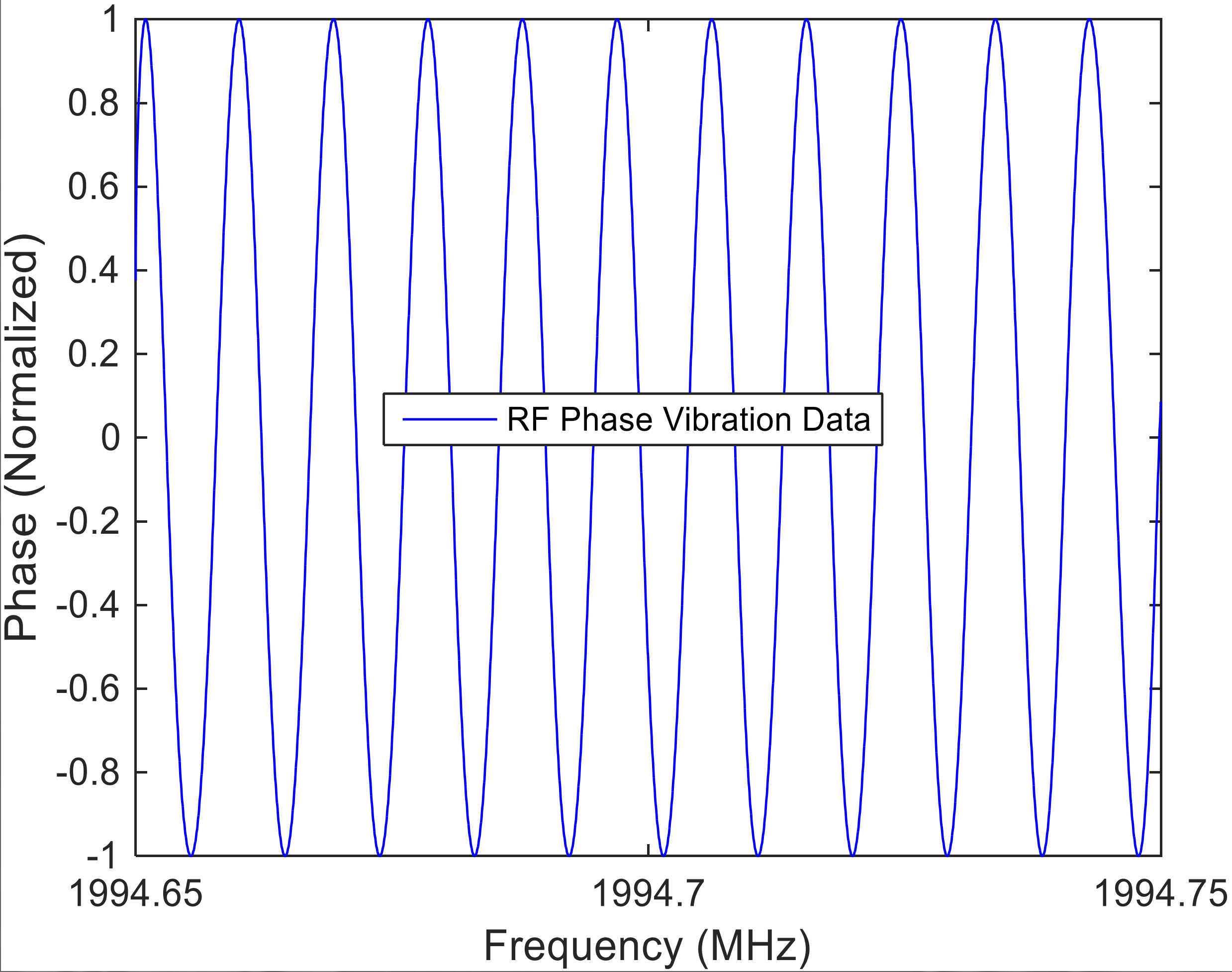
Hilbert Transform of Data

$$H\left[g(t)\right] = \frac{1}{\pi}\int_{-\infty}^{\infty}\frac{g(\tau)}{t-\tau}d\tau$$



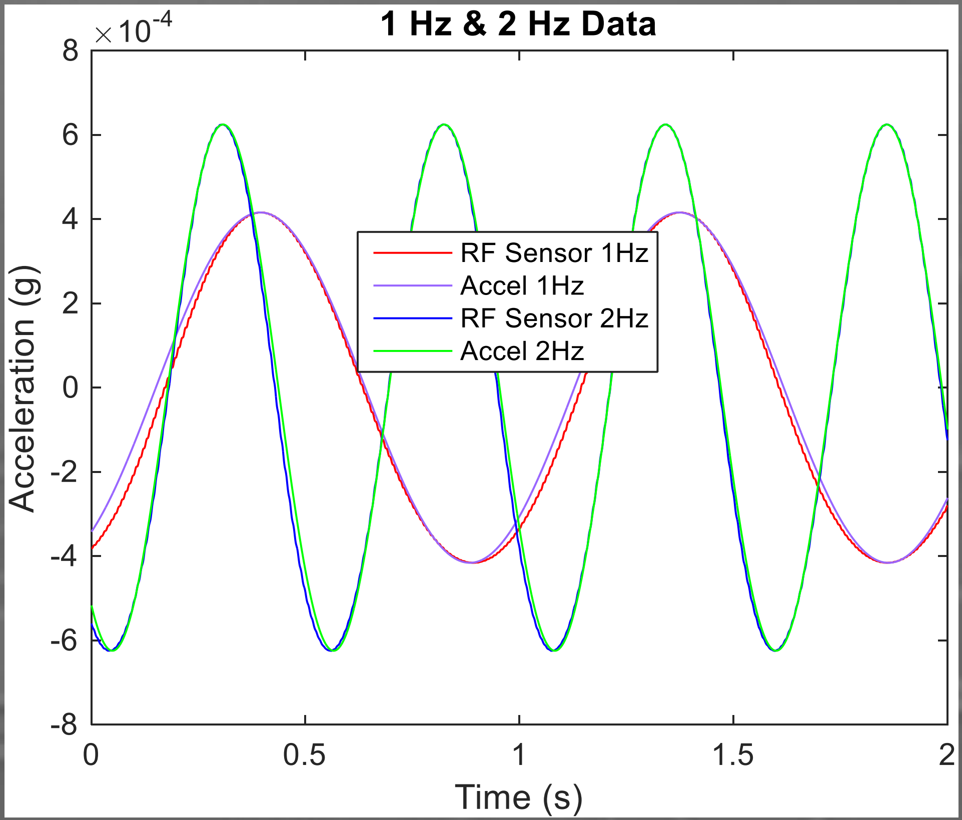
The absolute value of the Hilbert transform from the filtered delta-phase data

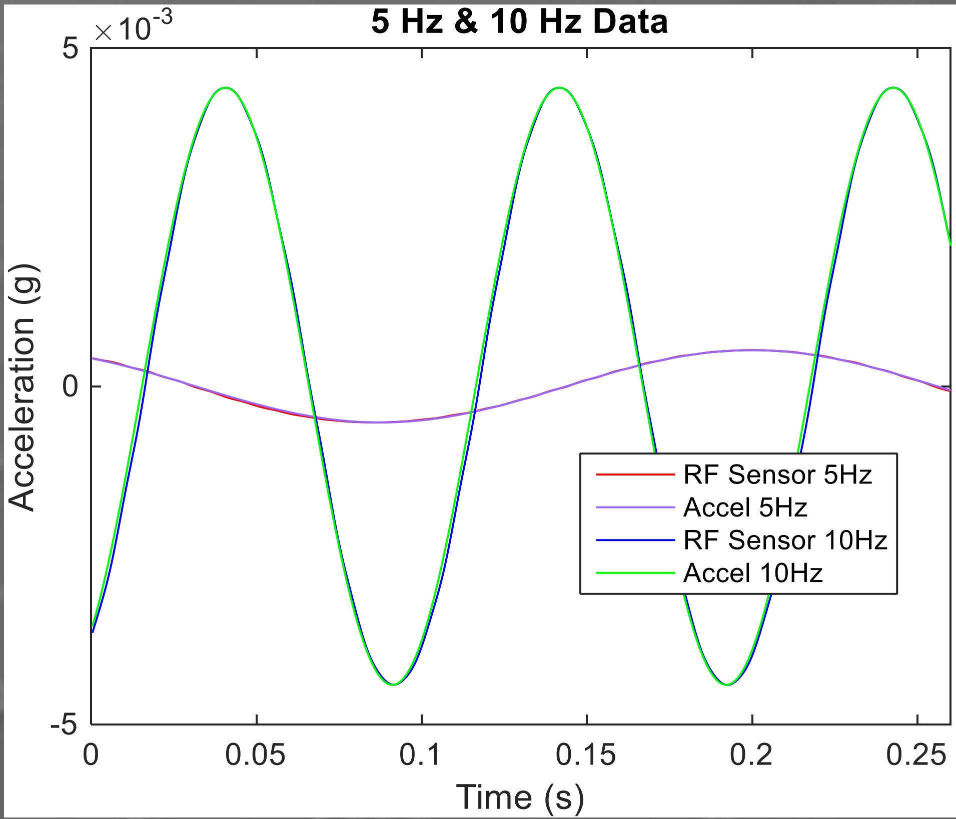
Vibration Data



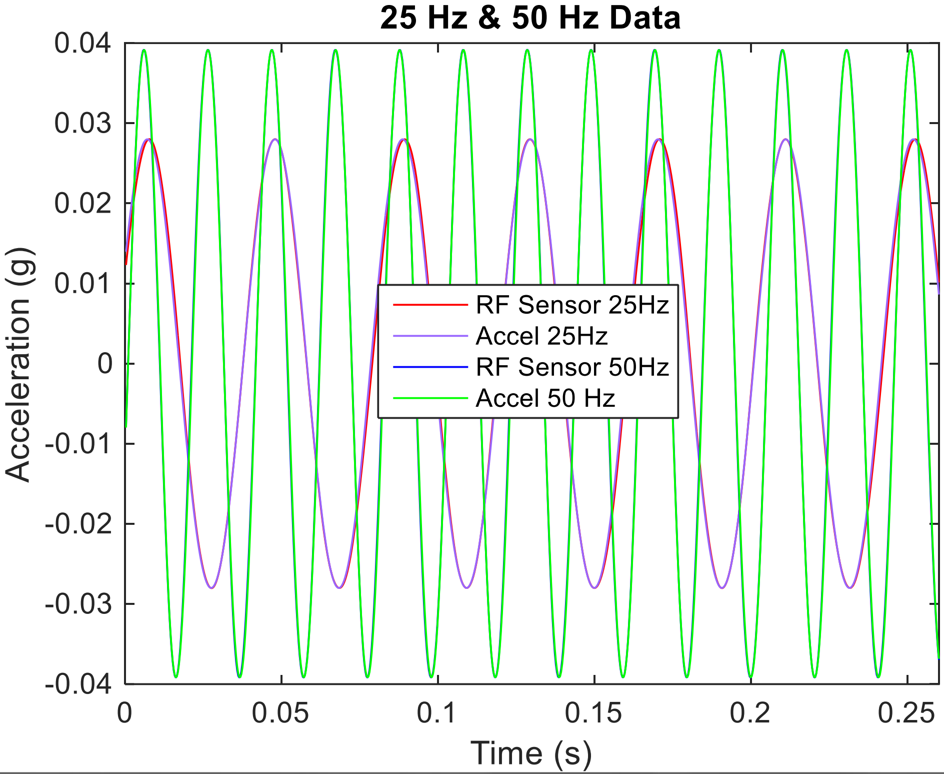
The vibration data, calculated by dividing the delta-phase data by the analytic signal (Hilbert transformed) data.

Results

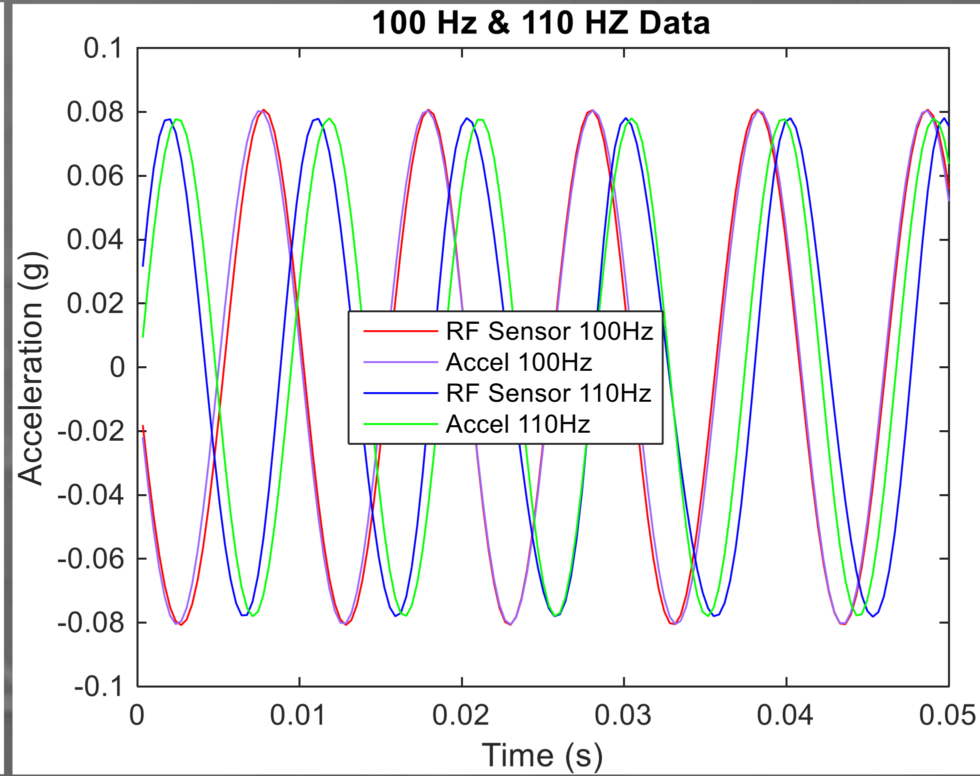

1 Hz & 2 Hz Data
×10^-4
Acceleration (g)
Time (s)
RF Sensor 1Hz
Accel 1Hz
RF Sensor 2Hz
Accel 2Hz


5 Hz & 10 Hz Data
×10^-3
Acceleration (g)
Time (s)
RF Sensor 5Hz
Accel 5Hz
RF Sensor 10Hz
Accel 10Hz

Results

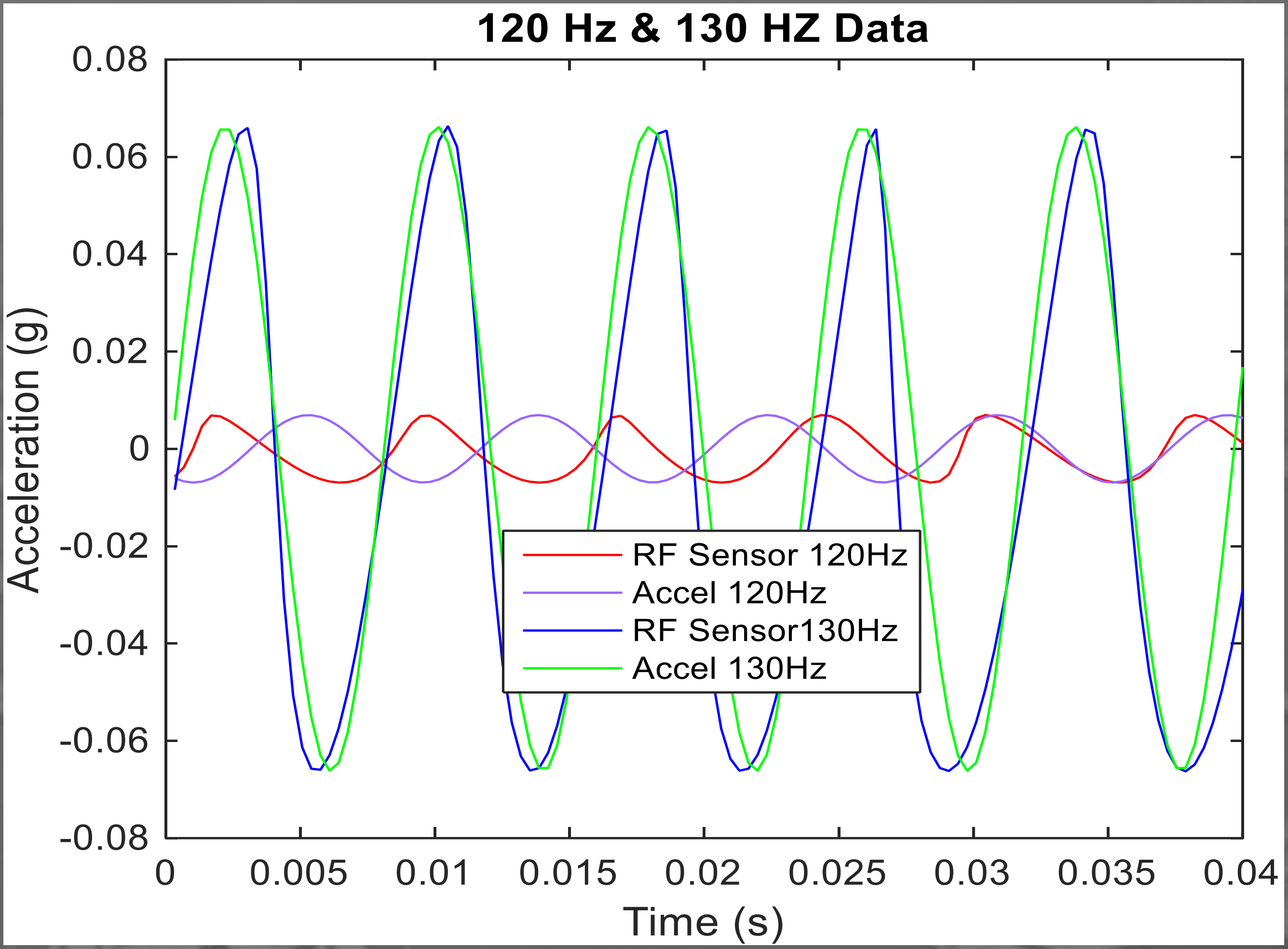


25 Hz & 50 Hz Data
Acceleration (g)
Time (s)
RF Sensor 25Hz
Accel 25Hz
RF Sensor 50Hz
Accel 50 Hz



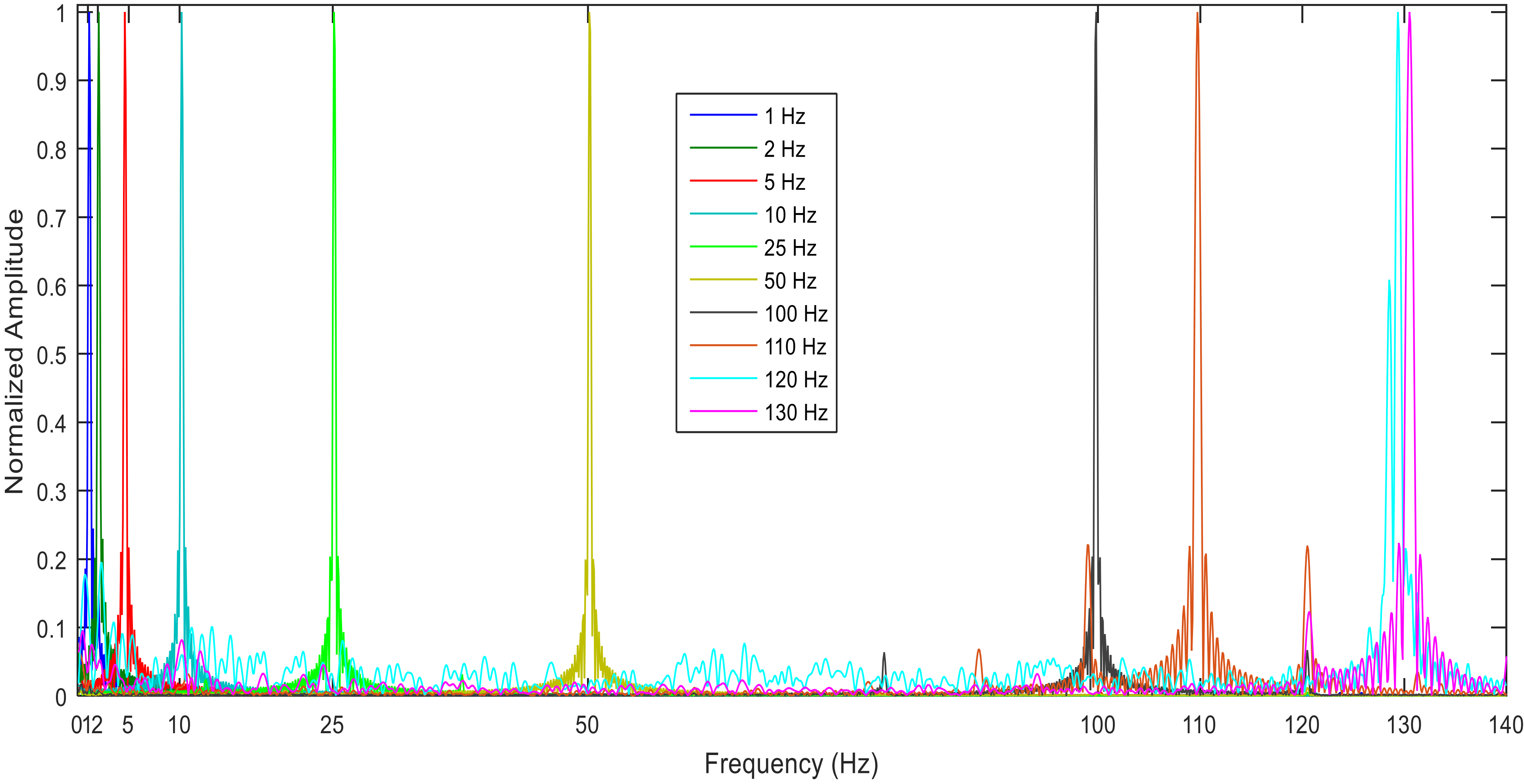
100 Hz & 110 HZ Data
Acceleration (g)
Time (s)
RF Sensor 100Hz
Accel 100Hz
RF Sensor 110Hz
Accel 110Hz

Results

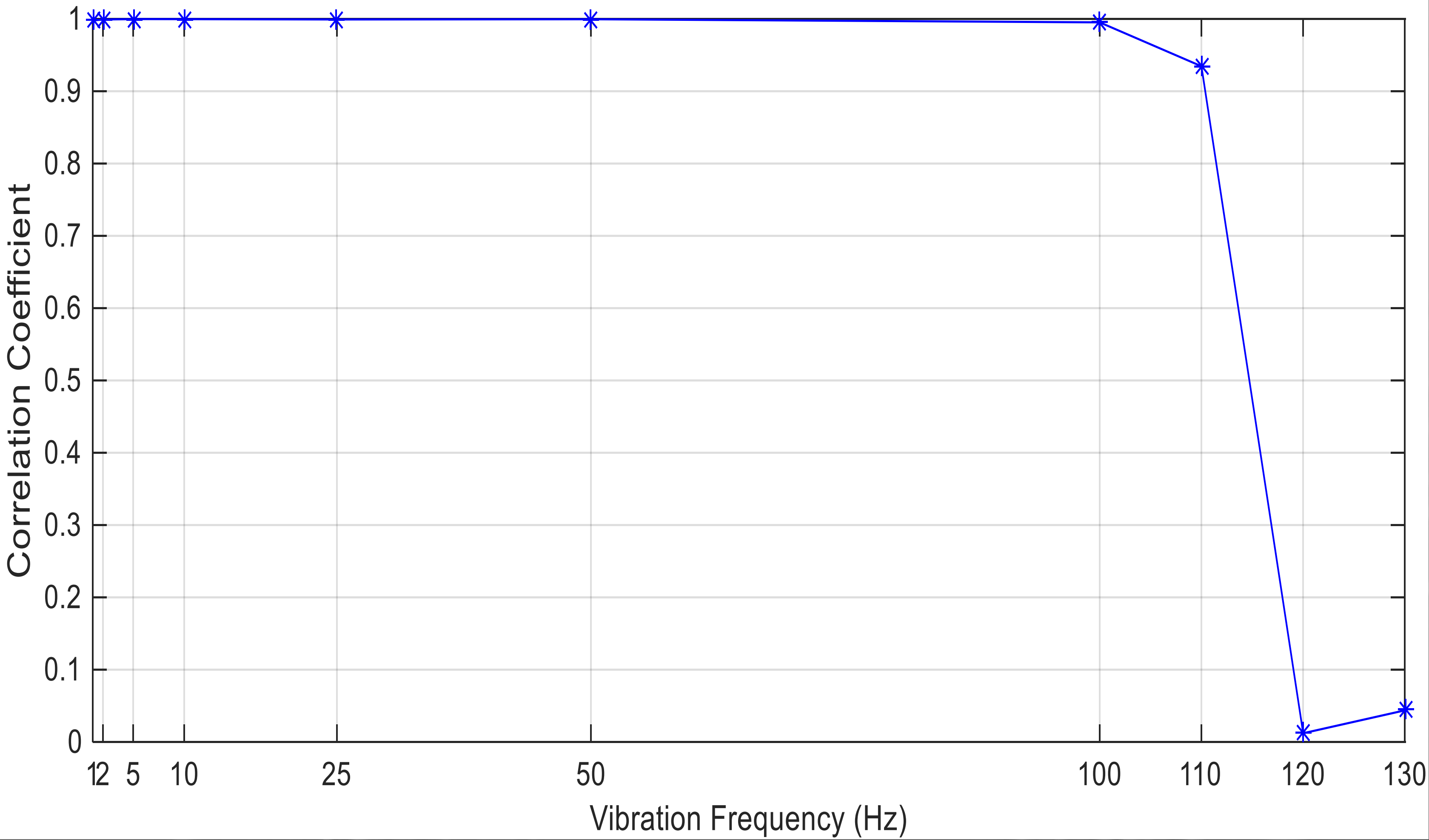


120 Hz & 130 HZ Data
Acceleration (g)
Time (s)
0.08
0.06
0.04
0.02
0
-0.02
-0.04
-0.06
-0.08
0
0.005
0.01
0.015
0.02
0.025
0.03
0.035
0.04
RF Sensor 120Hz
Accel 120Hz
RF Sensor130Hz
Accel 130Hz

FFT Results of RF Data



Error



Correlation coefficient of the vibration data.

Conclusions

- A new method of employing microwaves to detect aeroelastic structural flutter phenomena has been presented.
- The RF sensor data was compared to accelerometer data taken from a cantilevered panel vibrating at 1Hz, 2Hz, 5 Hz, 10 Hz, 25 Hz, 50 Hz, 100 Hz, 110 Hz, 120 Hz, and 130 Hz.
- Up to 100 Hz, the processed RF sensor phase data yielded a vibrational behavior that qualitatively closely matches the accelerometer-measured vibrational input.
- The spectrum of the data is also closely matches the expected frequency response up to 100 Hz.

Funding/Partnership Opportunities

- **NASA does not have the resources to develop all of the sensors it needs for its applications, therefore, we are looking for partners!**
- **Small Business Innovation Research (SBIR) Small Business Technology Transfer (STTR) sbir.nasa.gov**
  - **Focus Area 3 Autonomous Systems for Space Exploration**
  - **T12.01 Advanced Structural Health Monitoring**
  - Wireless low power, small, sensors for structural health monitoring
  - **Focus Area 15 Lightweight Materials Structures and Assembly / Construction**
  - **Z11.01 NDE Sensors**
  - Wireless sensors for nondestructive testing
- **NASA Research Opportunities (NRAs) Grants & Contracts**
  - **nspires.nasaprs.com**
- **Space Act Agreements (SAA)**
  - **Partnerships with and without exchange of funds**

Auxiliary Slides

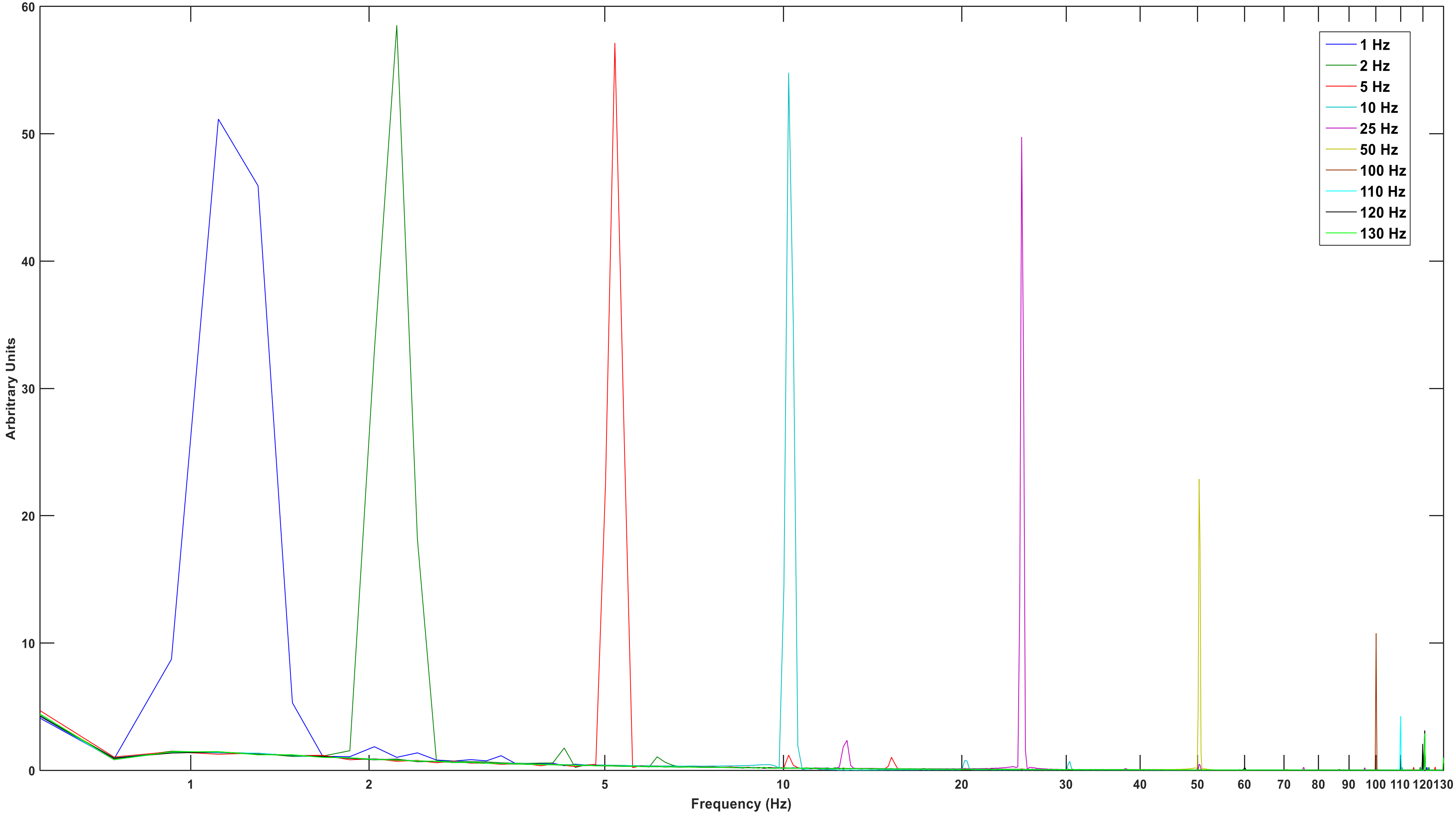
Correlation Coefficient

$$r = \frac{\sum_{i=1}^{n}\left(x_i - \bar{x}\right)\left(y_i - \bar{y}\right)}{\sqrt{\sum_{i=1}^{n}\left(x_i - \bar{x}\right)^2}\sqrt{\sum_{i=1}^{n}\left(y_i - \bar{y}\right)^2}}$$

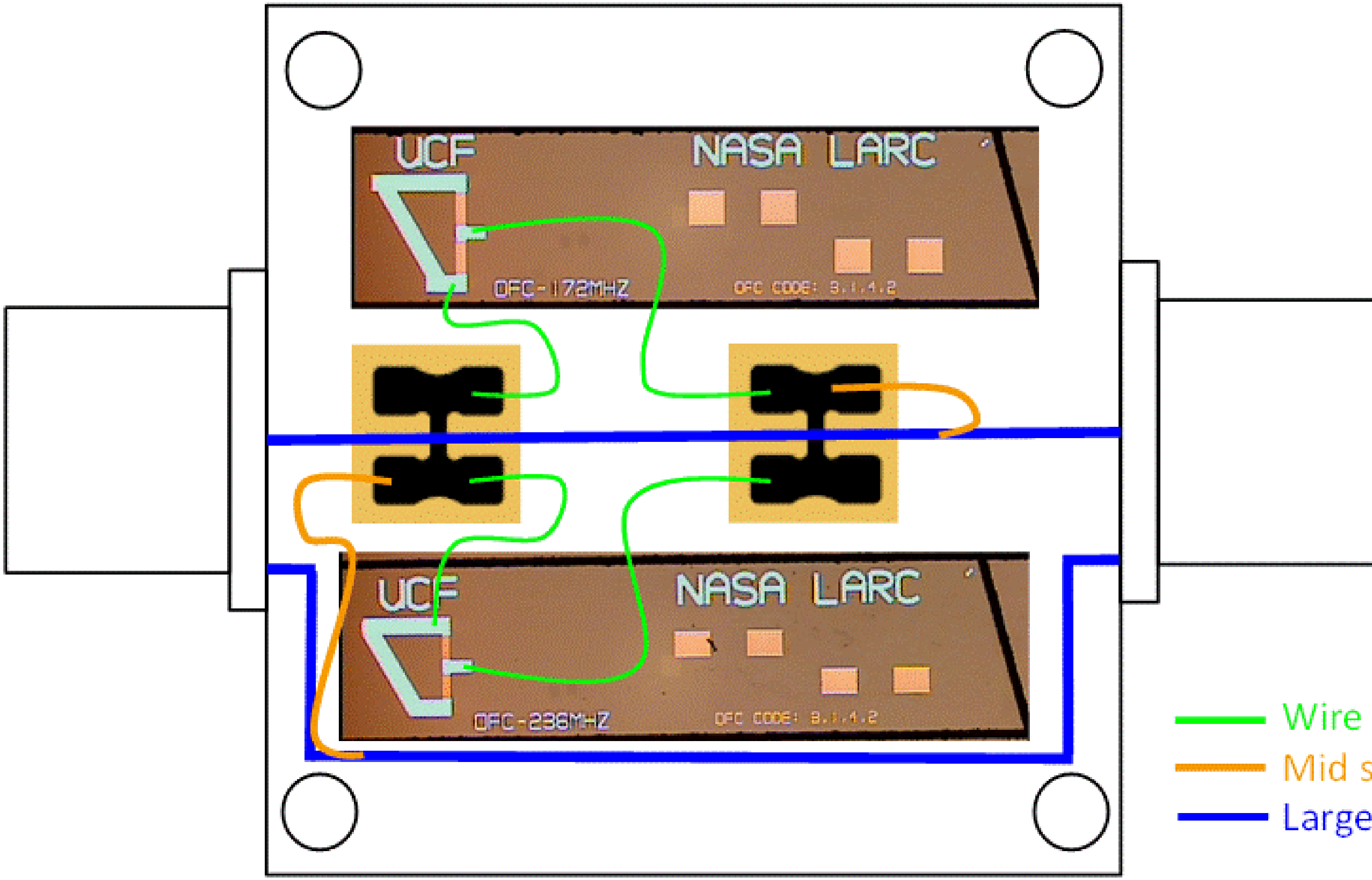
Frequency (Hz)	Correlation Coefficient
1	9.9788e-01
2	9.9920e-01
5	9.9979e-01
10	9.9971e-01
25	9.9922e-01
50	9.9959e-01
100	9.9523e-01
110	9.3451e-01
120	1.2193e-02
130	4.3864e-02

Pearson correlation coefficient was computed for each data set

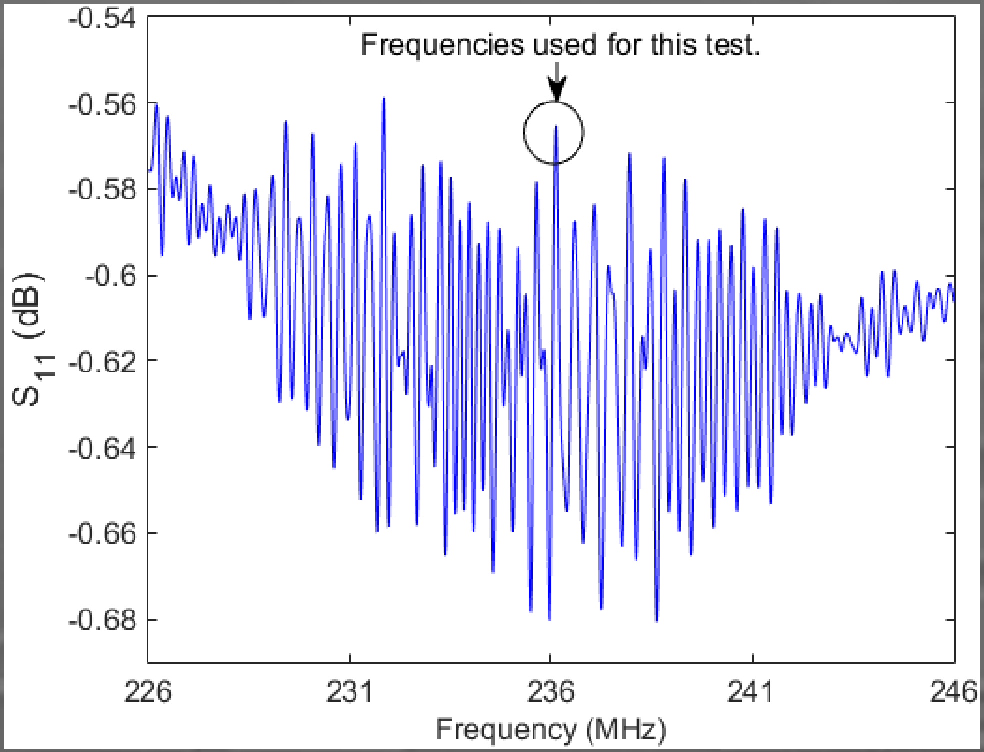
FFT of Raw Phase Data



Module Wiring



SAW S_{11} Response



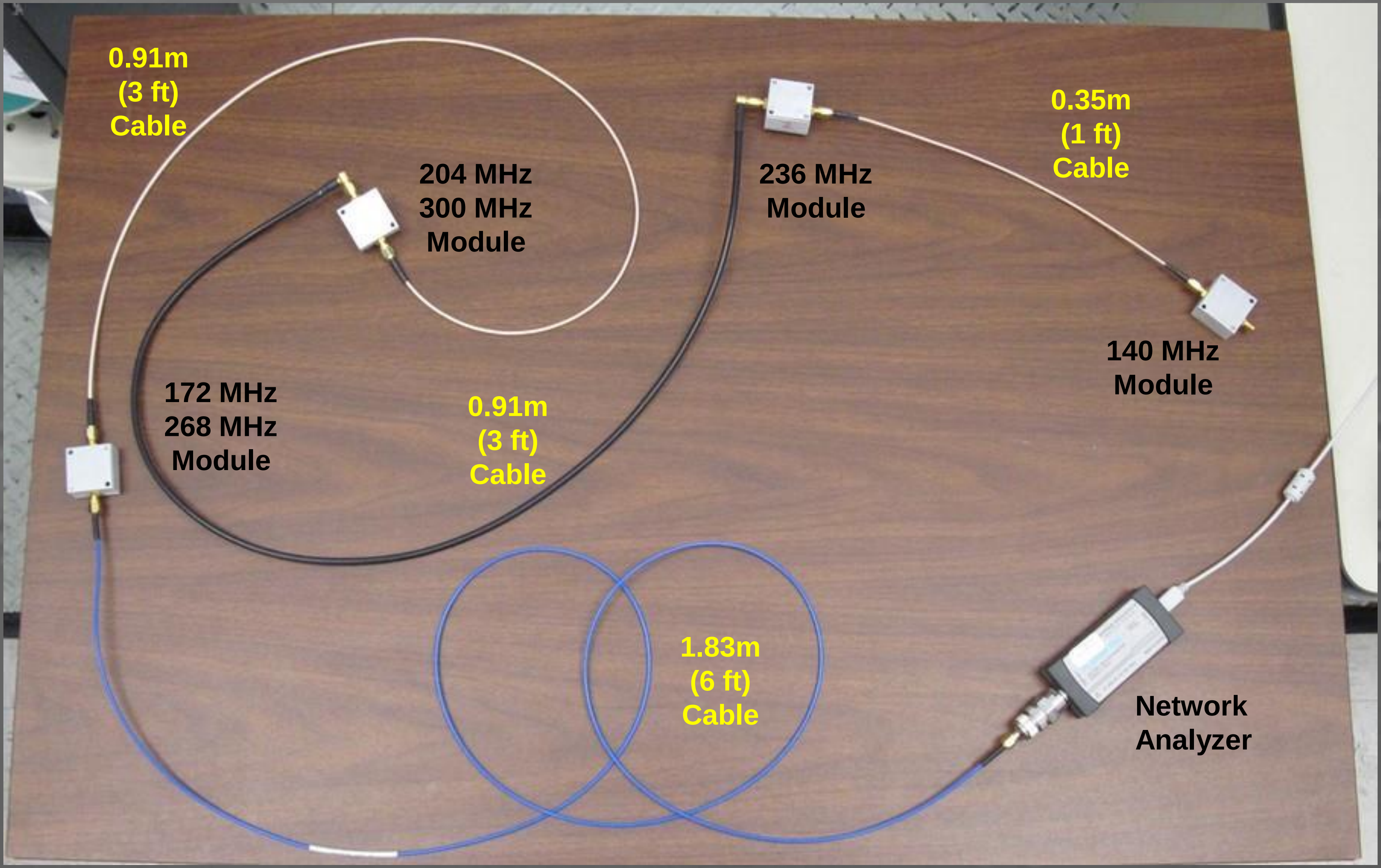
SAW S_{11} response.

The circle indicates the frequencies used for this work.

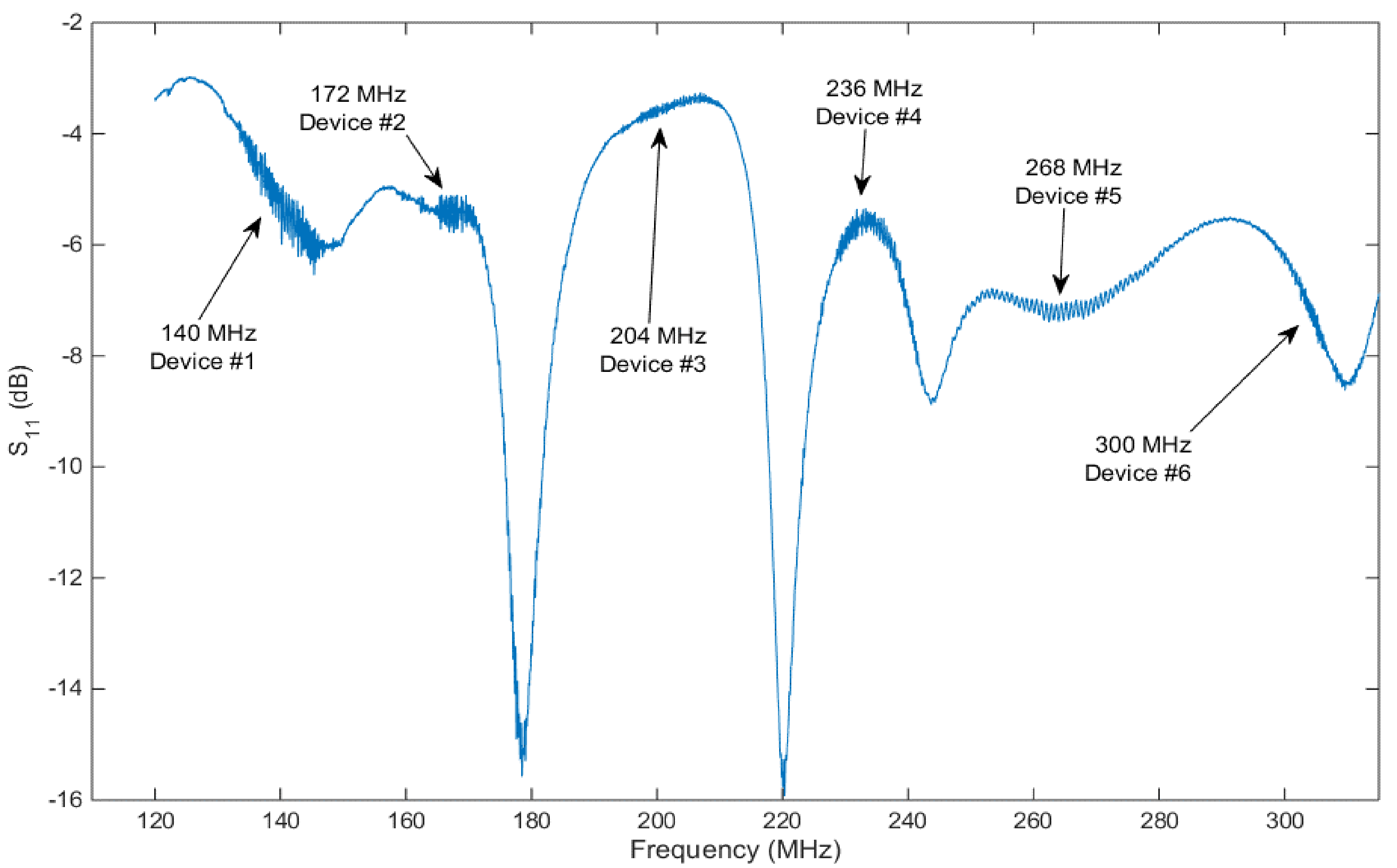
The subset of frequencies is a100 kHz frequency window.

(236.055 MHz to 236.155 MHz)

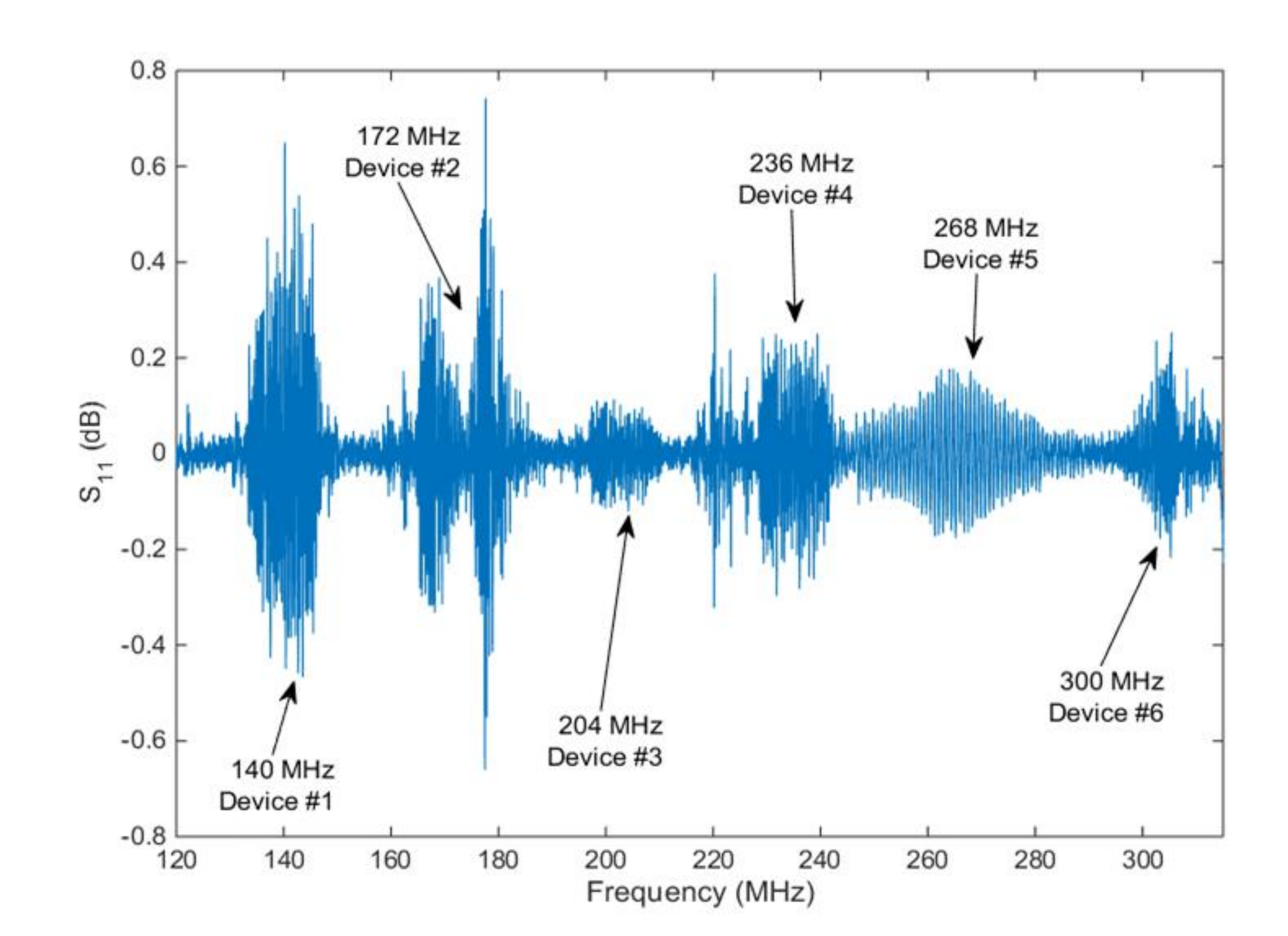
FDM SAW Sensor System



Frequency Division Multiplexed S_{11} Response



Frequency Division Multiplexed Filtered S11 Response



FDM SAW Sensor System