Frequency Division Multiplexed Strain Sensor System

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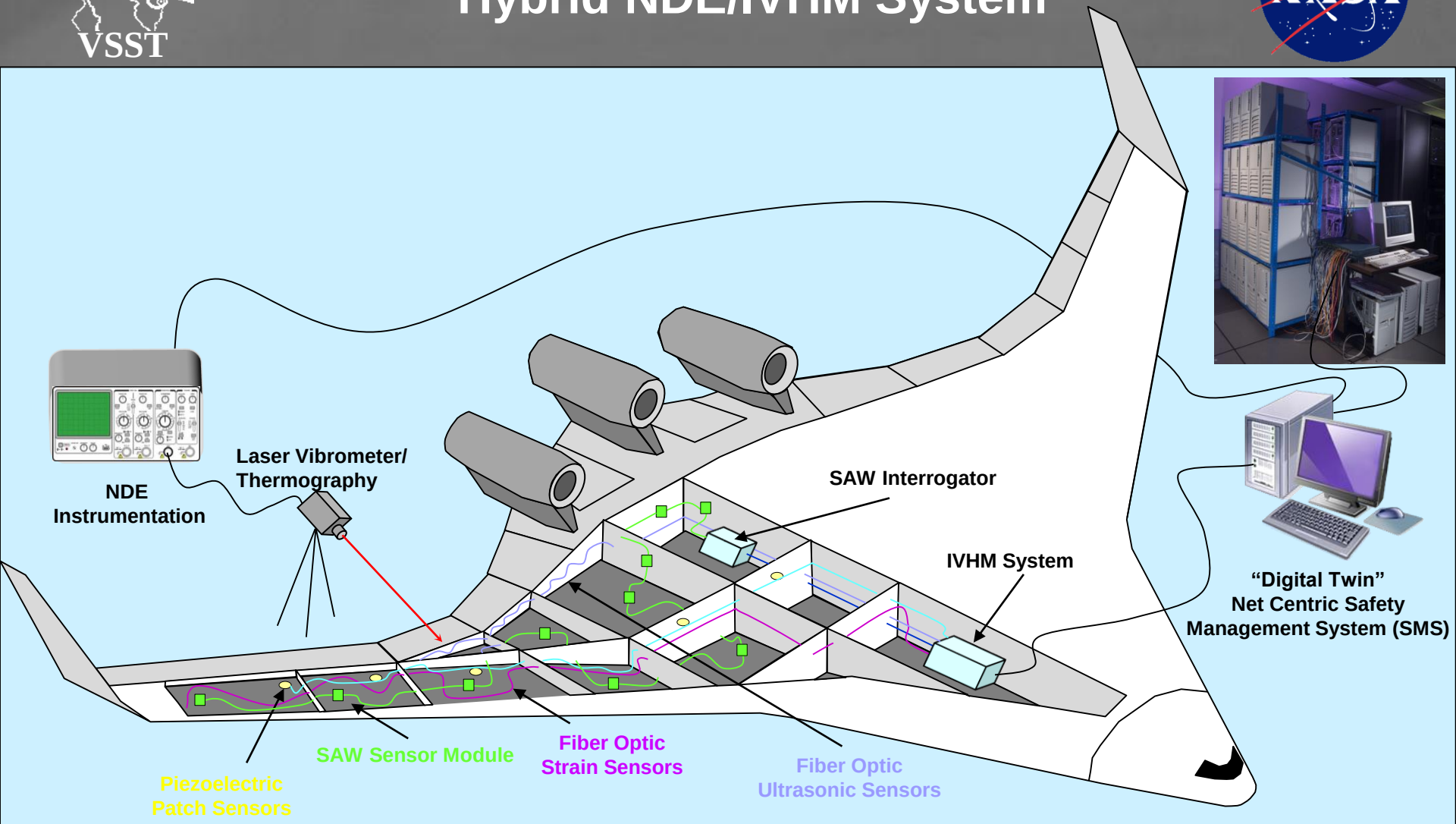
Outline

- Project Goals
- FDM SAW Modules
- SAW Sensor Details
- FDM Strain Sensor System
- Results
- Conclusions
- Funding/Partnership Opportunities

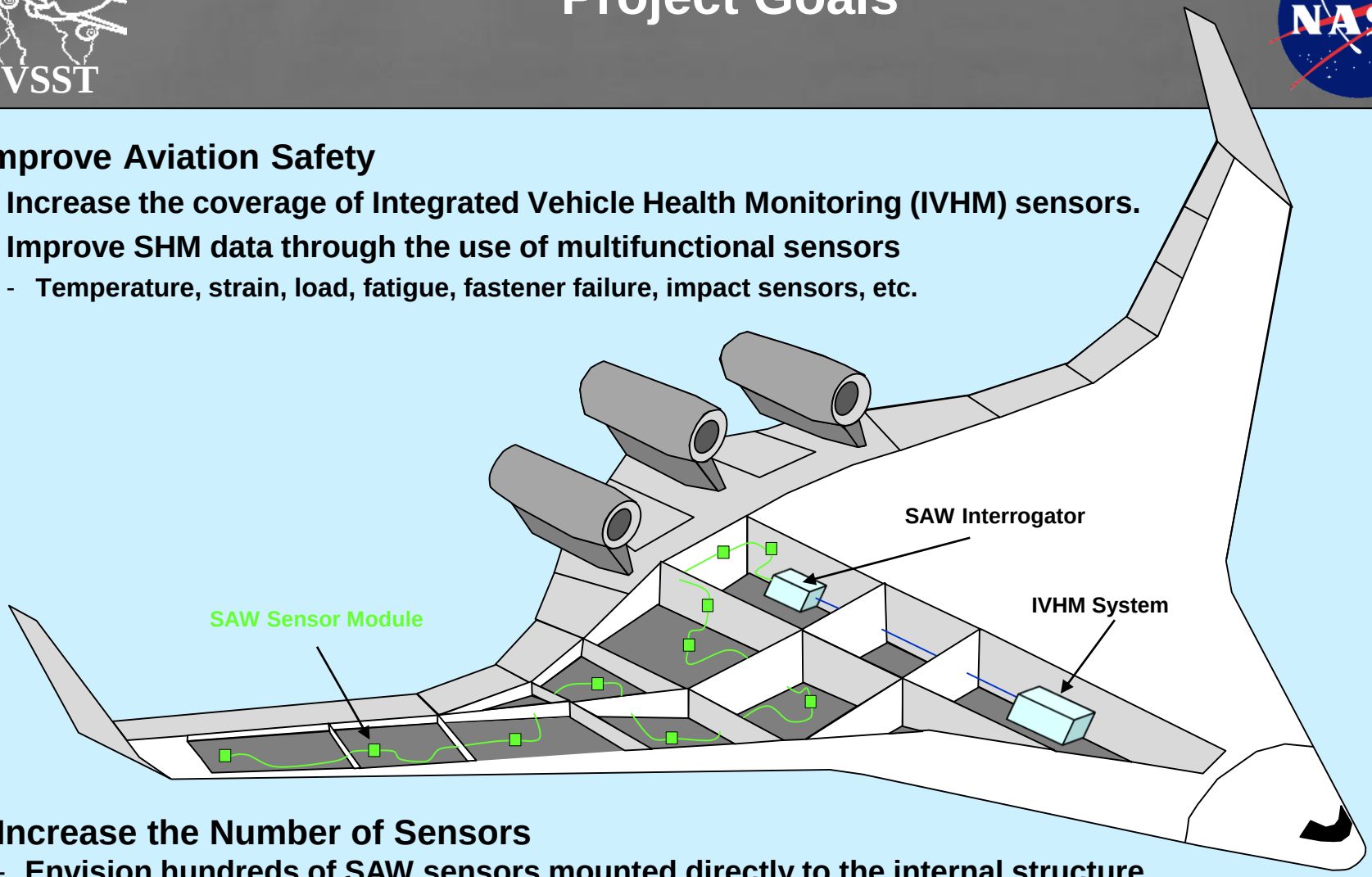
The Big Picture
Hybrid NDE/IVHM System



Hybrid NDE/IVHM - Combines traditional ground NonDestructive Evaluation (NDE) methods with Integrated Vehicle Health Management Systems (IVHM) through the use of external loads and/or excitation methods combined with fixed sensors and onboard IVHM systems.

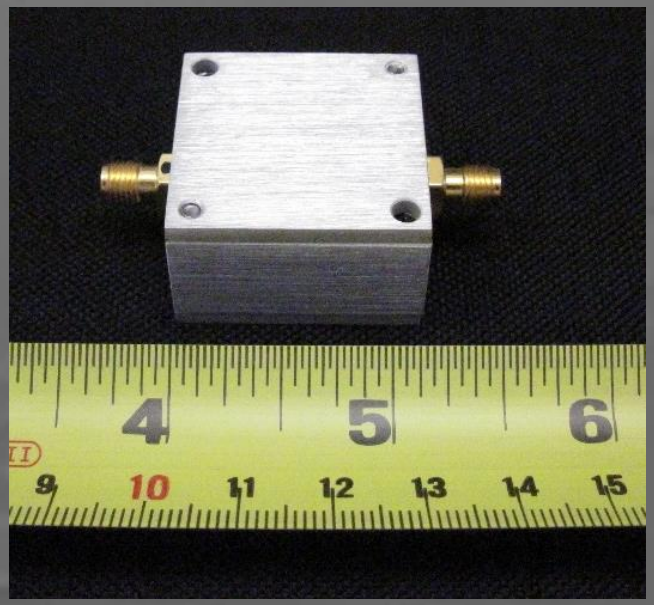
Project Goals

- **Improve Aviation Safety**
  - **Increase the coverage of Integrated Vehicle Health Monitoring (IVHM) sensors.**
  - **Improve SHM data through the use of multifunctional sensors**
    - **Temperature, strain, load, fatigue, fastener failure, impact sensors, etc.**

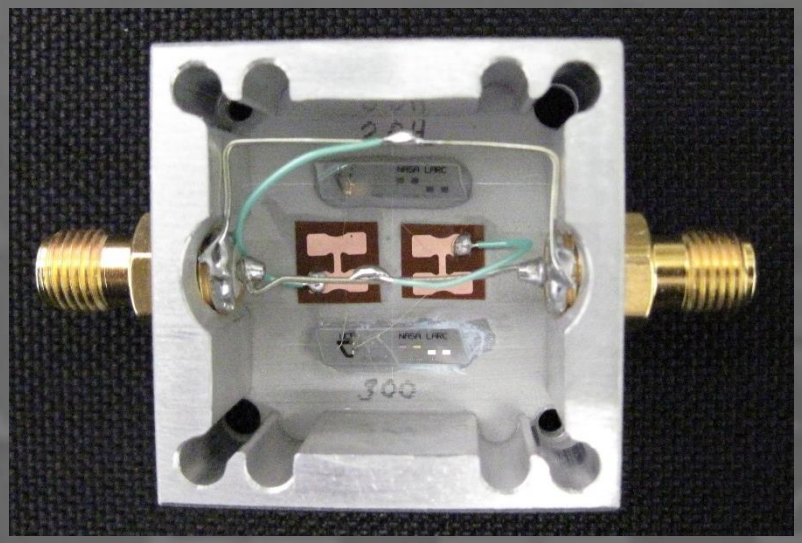


- **Increase the Number of Sensors**
  - **Envision hundreds of SAW sensors mounted directly to the internal structure.**
  - **Reduce sensor power to enable more sensors onboard aircraft.**
- **Reduce Wiring**
  - **FDM allows for all sensors to be individually interrogated on a single coaxial cable.**
  - **Power and signals use the same coaxial cable.**

SAW Frequency Division Multiplexed (FDM) Sensor Modules



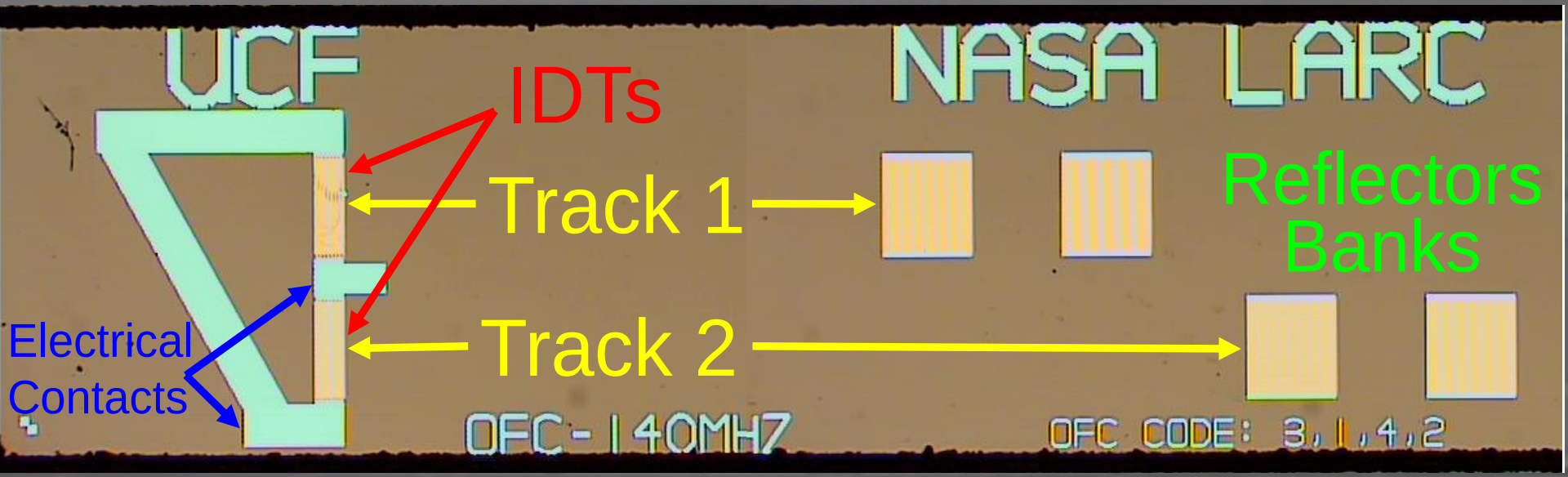
SAW sensor module
3.81cm x 3.81cm x 1.9cm
(1.5” x 1.5” x 0.75”)



Two SAW die bonded inside, and two SMA connections.

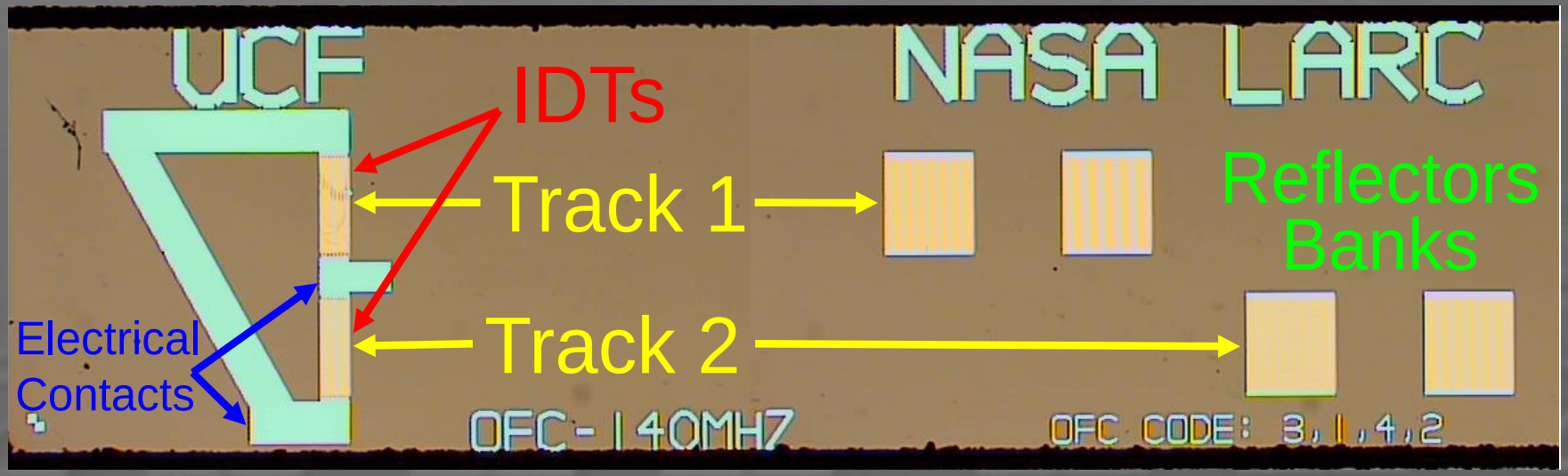
- The prototype FDM system has six SAW sensors (140, 172, 204, 236, 268, 300 MHz) in three modules. 140/236, 172/268, 204/300.
- One SAW sensor is bonded rigidly to the bottom of the package and is used for measuring strain (236, 268, 300)
- The other SAW sensor is bonded with a flexible bonding agent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

Surface Acoustic Wave Sensor

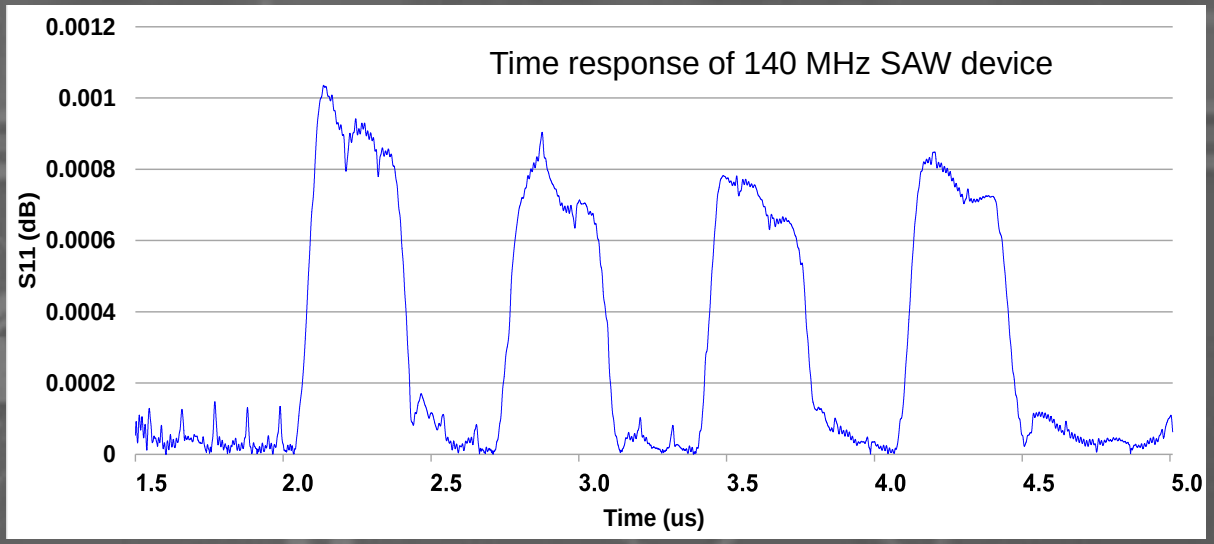


- The sensor has four orthogonal frequency coded (OFC) reflector banks in two tracks,
- The IDTs have a wider bandwidth of 15 MHz, while each reflector has a bandwidth of 6MHz.
- The gratings in each track reflect a different frequency with an arrangement of f3, f1, f4, f2.
- The reflector center frequencies are f1=135.5, f2=138.5, f3=141.5, f4=144.5 MHz

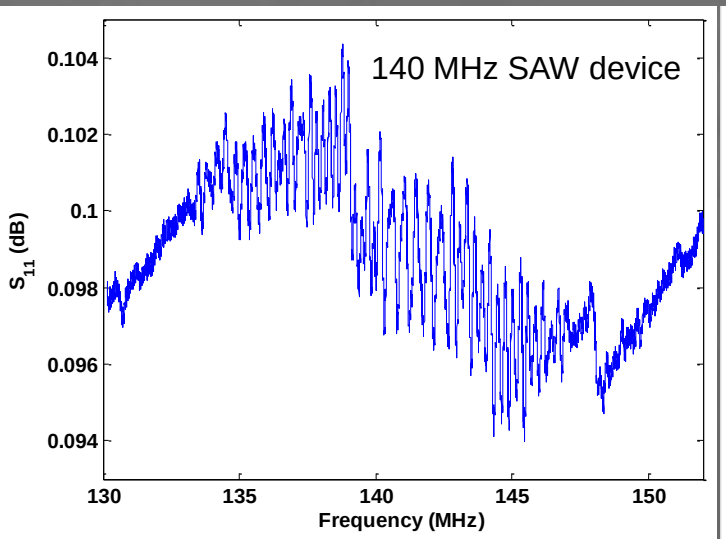
Surface Acoustic Wave Sensor

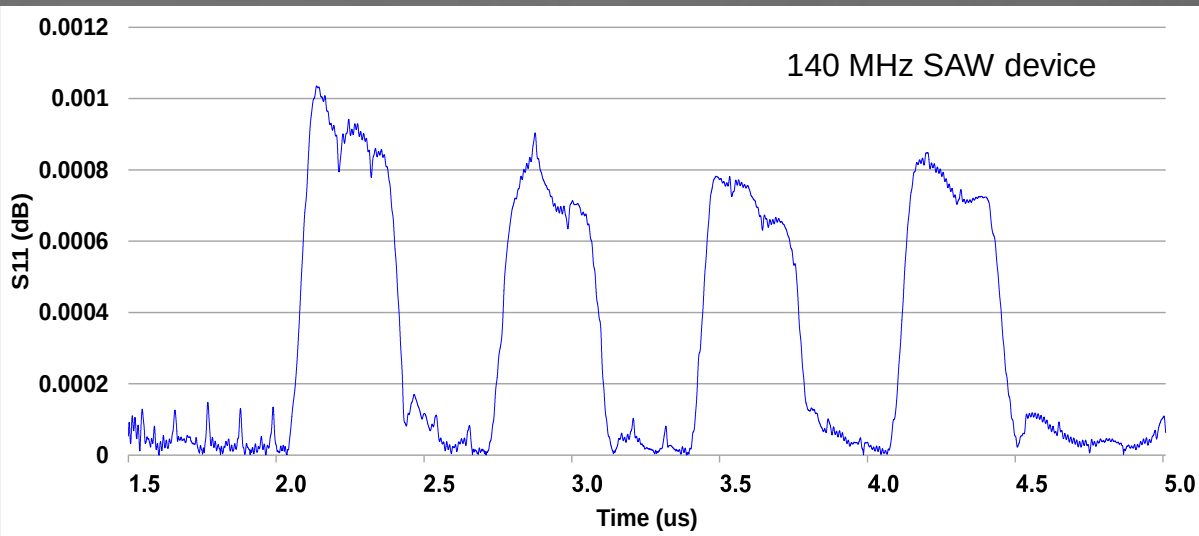


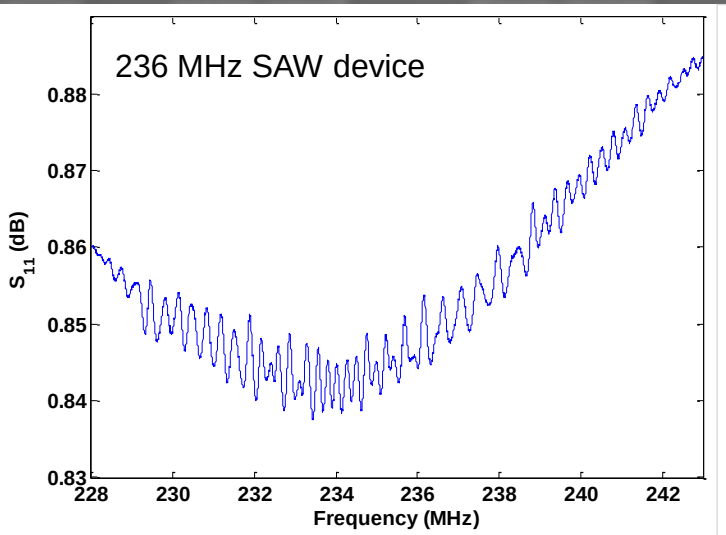
- Time Response for the four gratings.

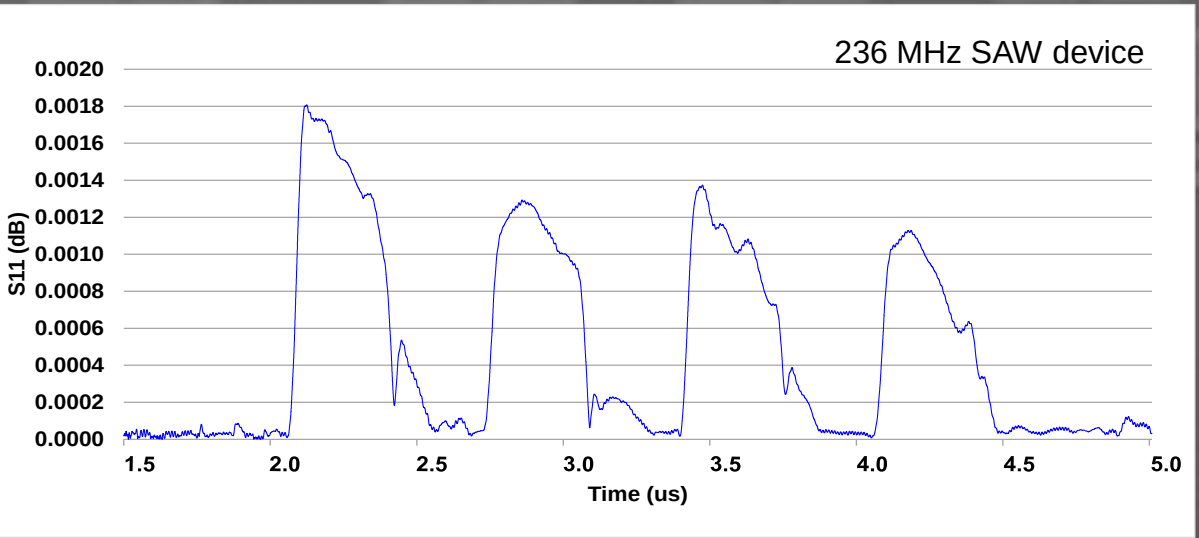


S_{11} Frequency and Time Reponse

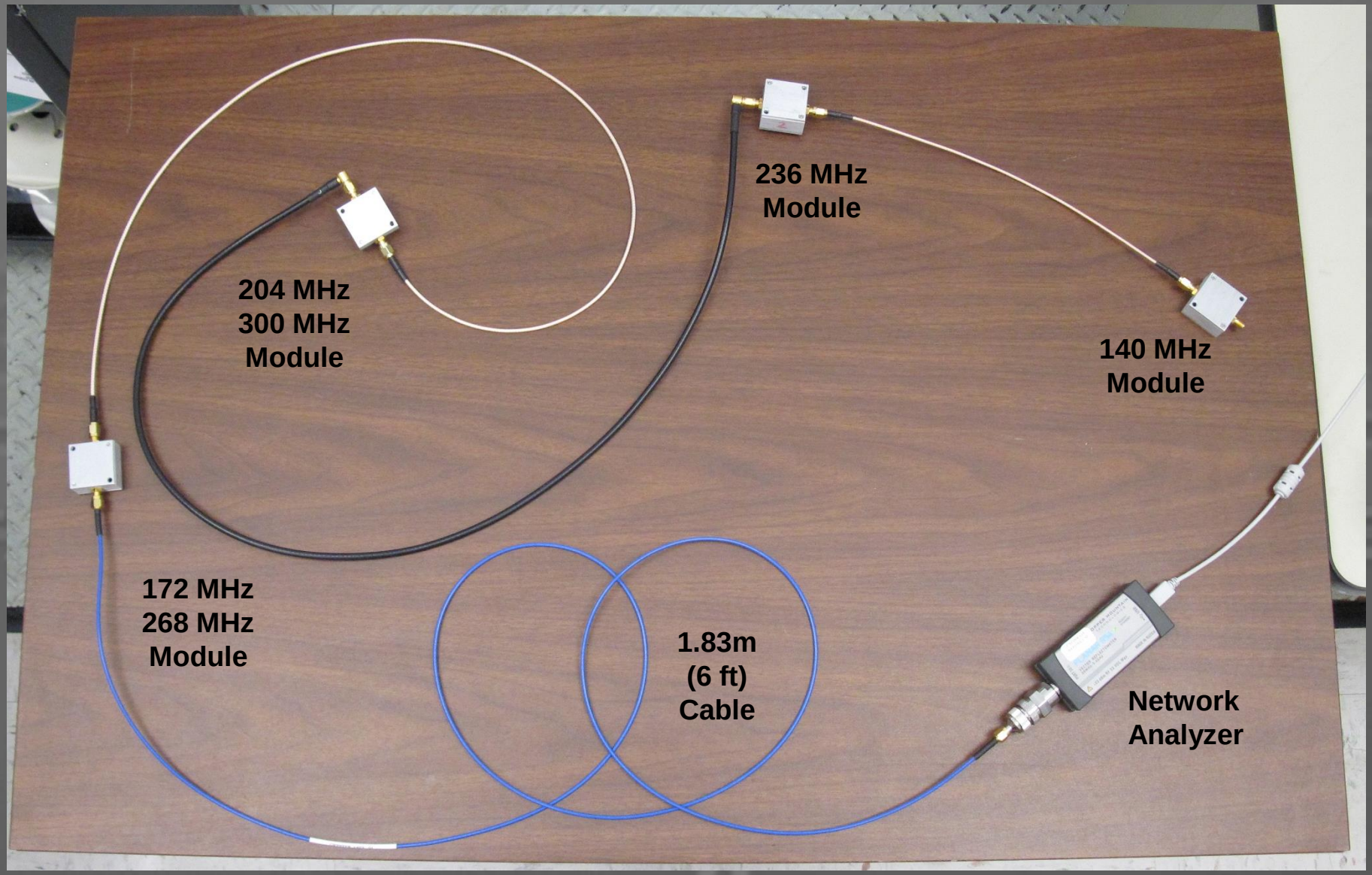




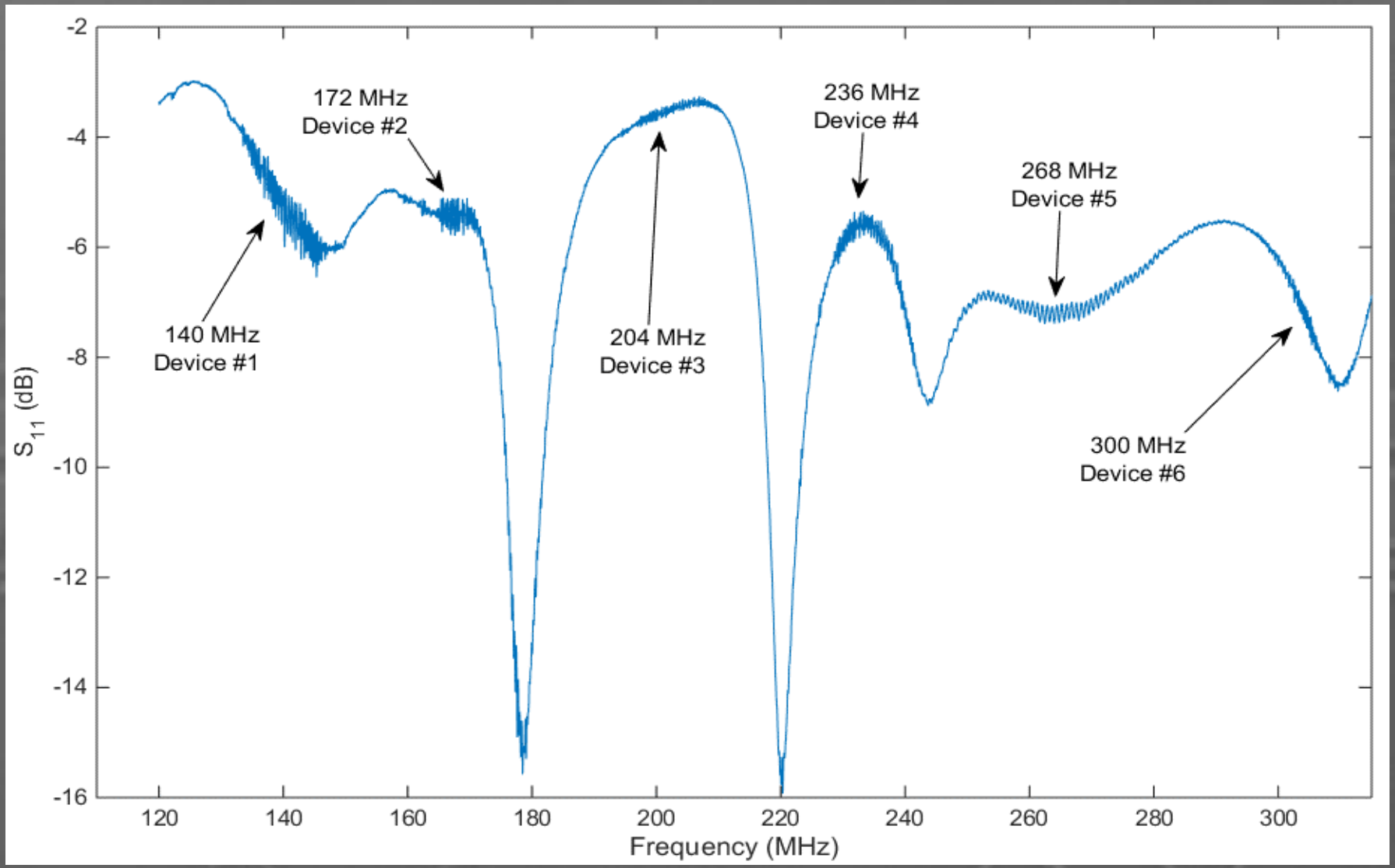




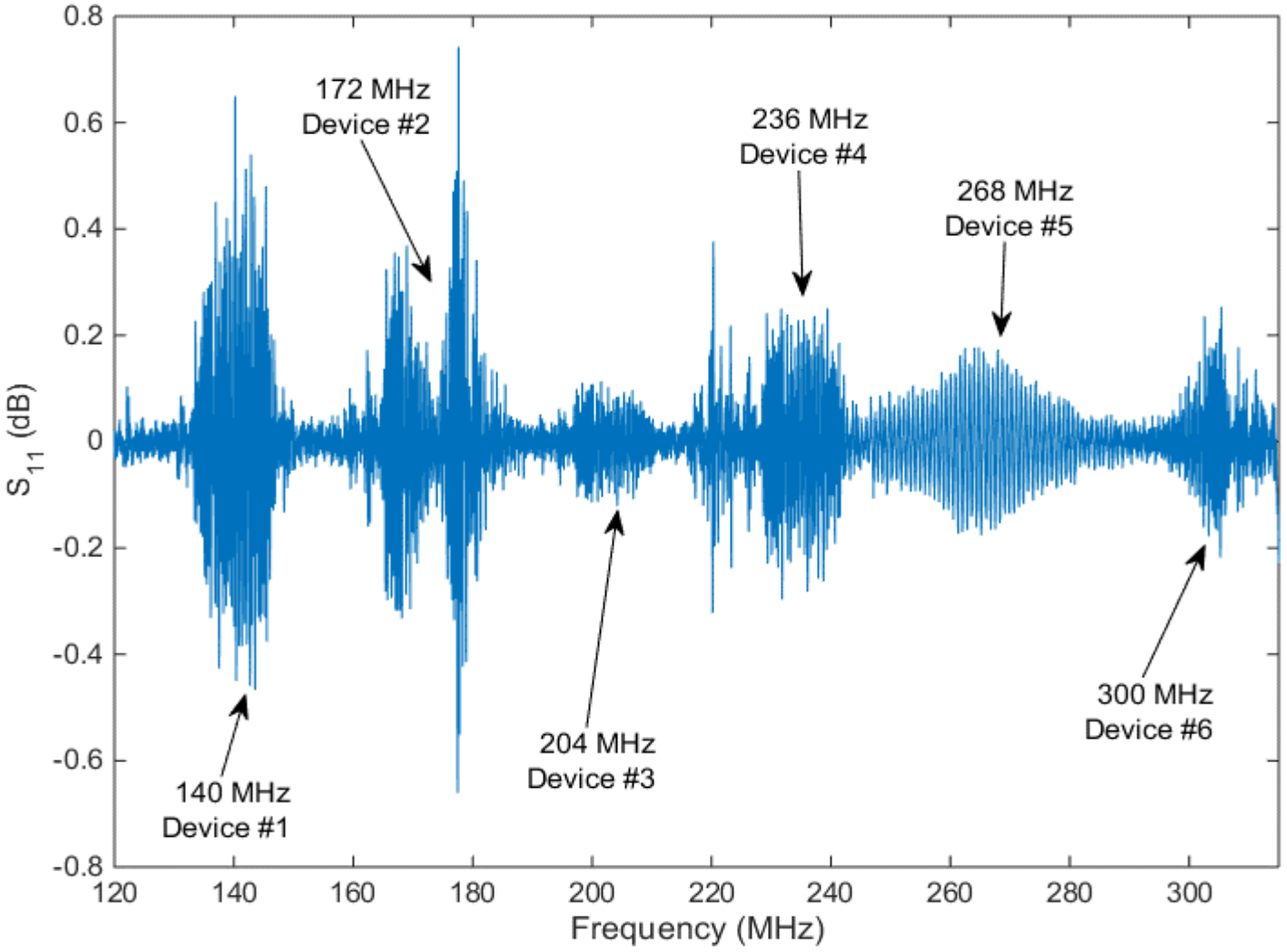
FDM SAW Sensor System



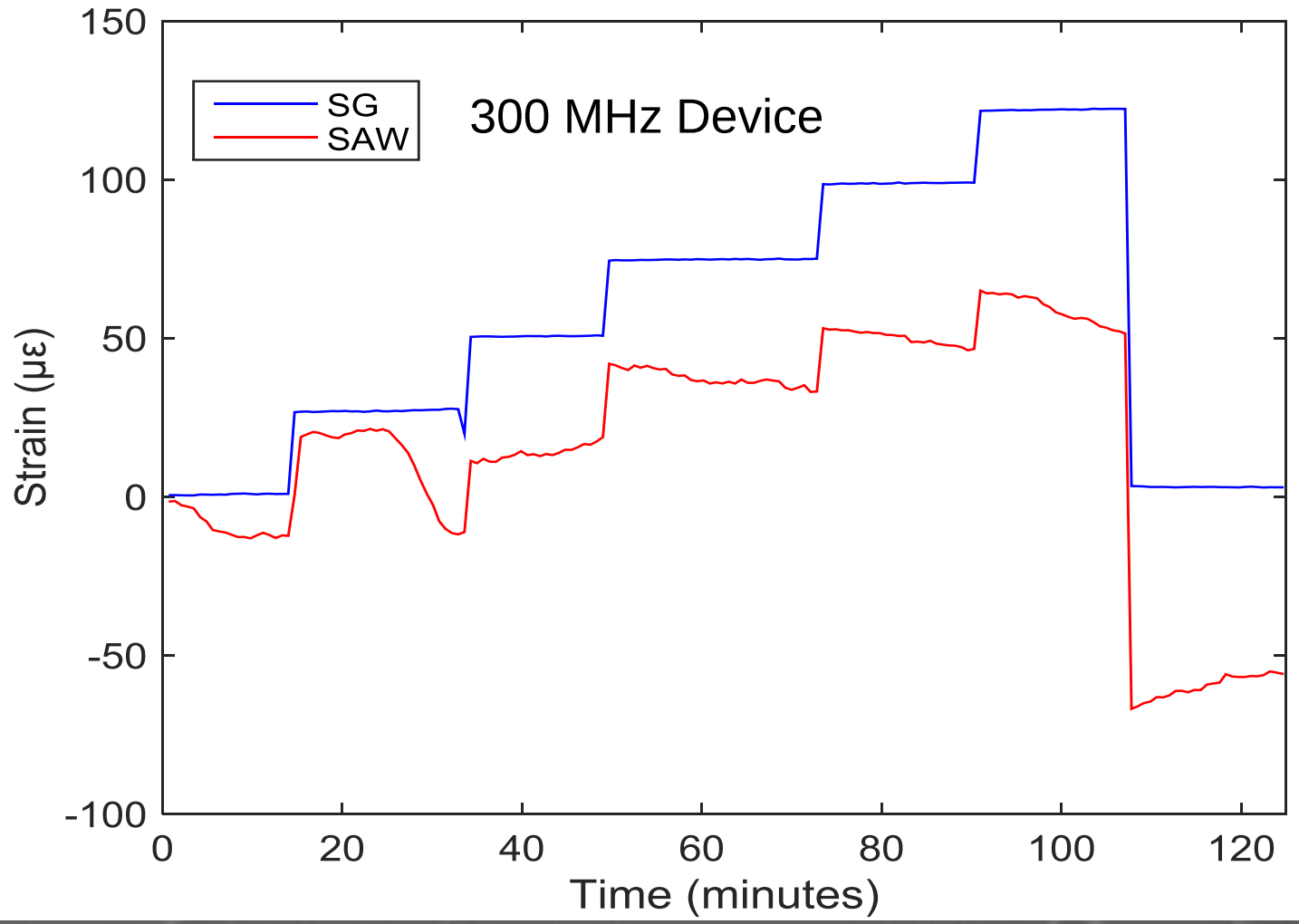
Frequency Division Multiplexed S_{11} Response



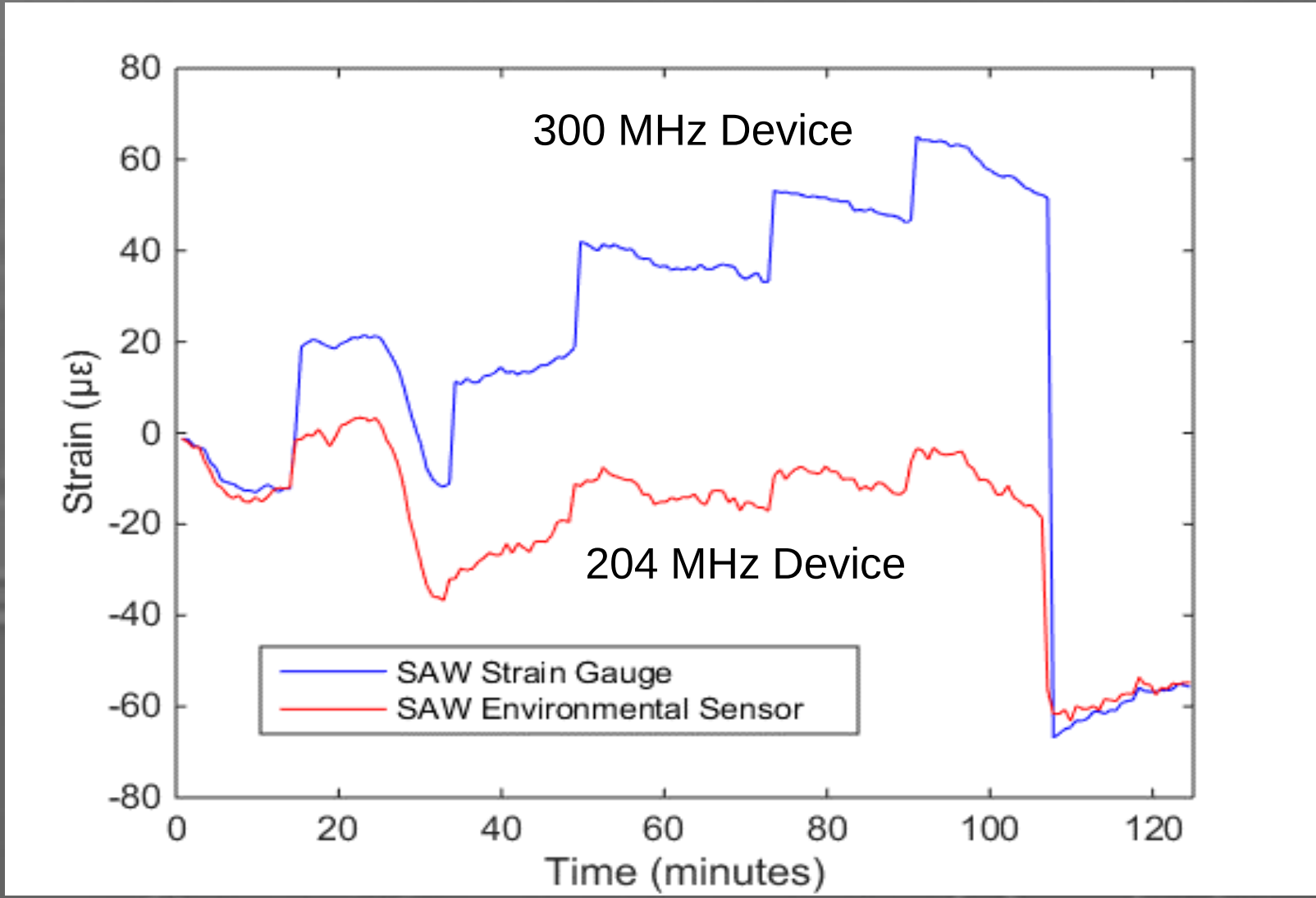
Frequency Division Multiplexed Filtered S11 Response



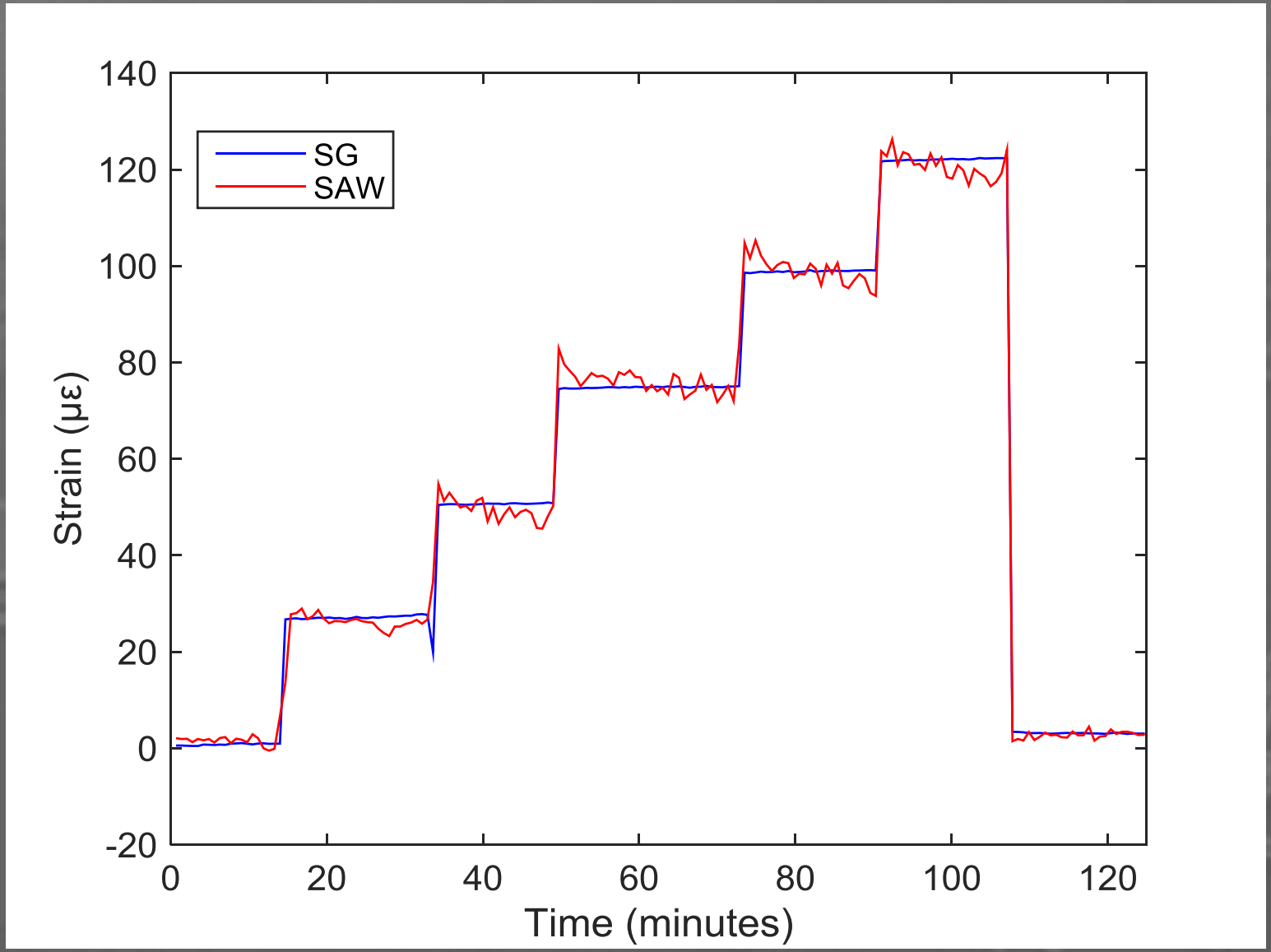
Uncompensated Strain Results
SAW vs Strain Gauge



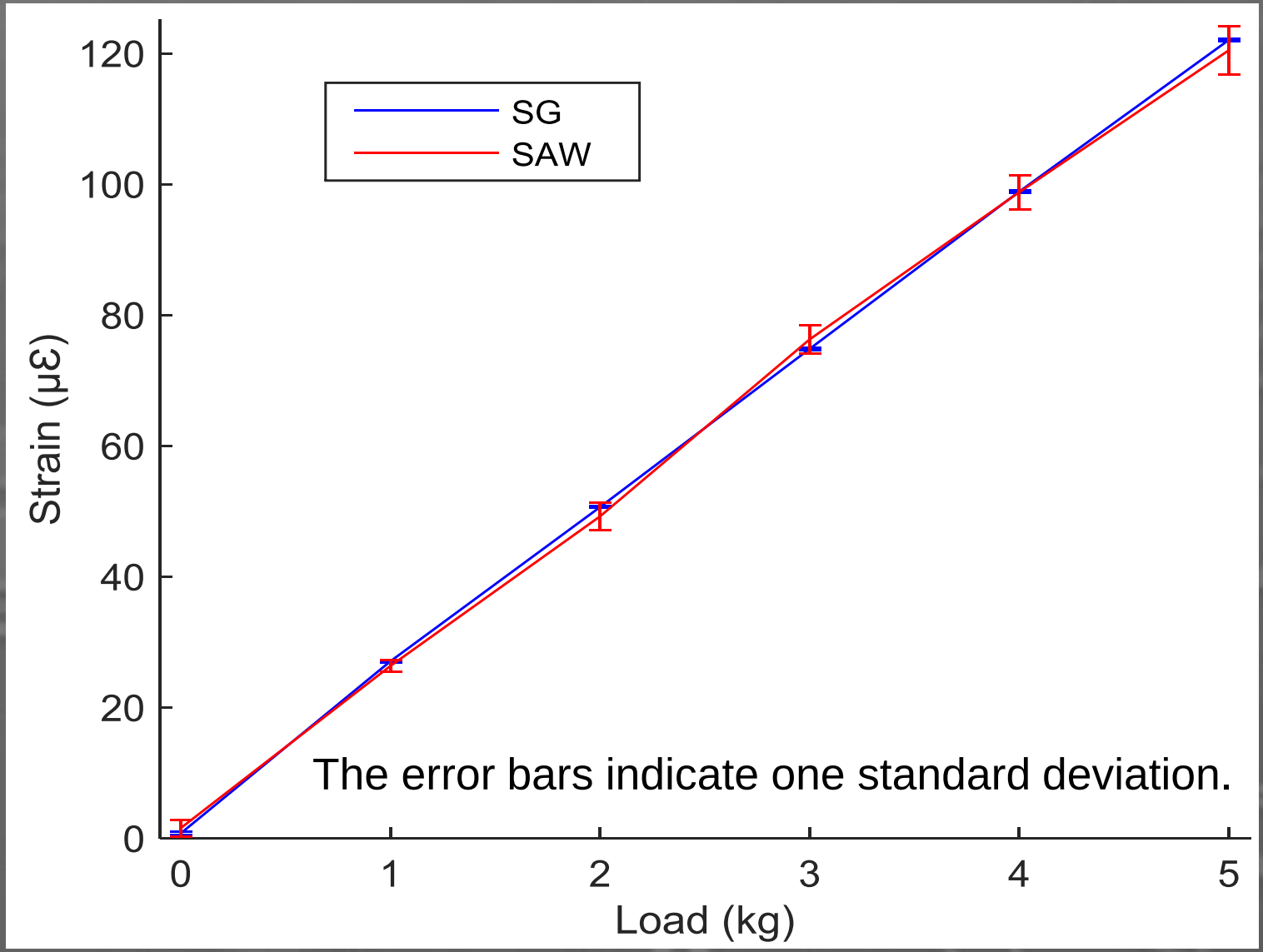
Environmental Response
SAW Sensor vs SAW Environmental



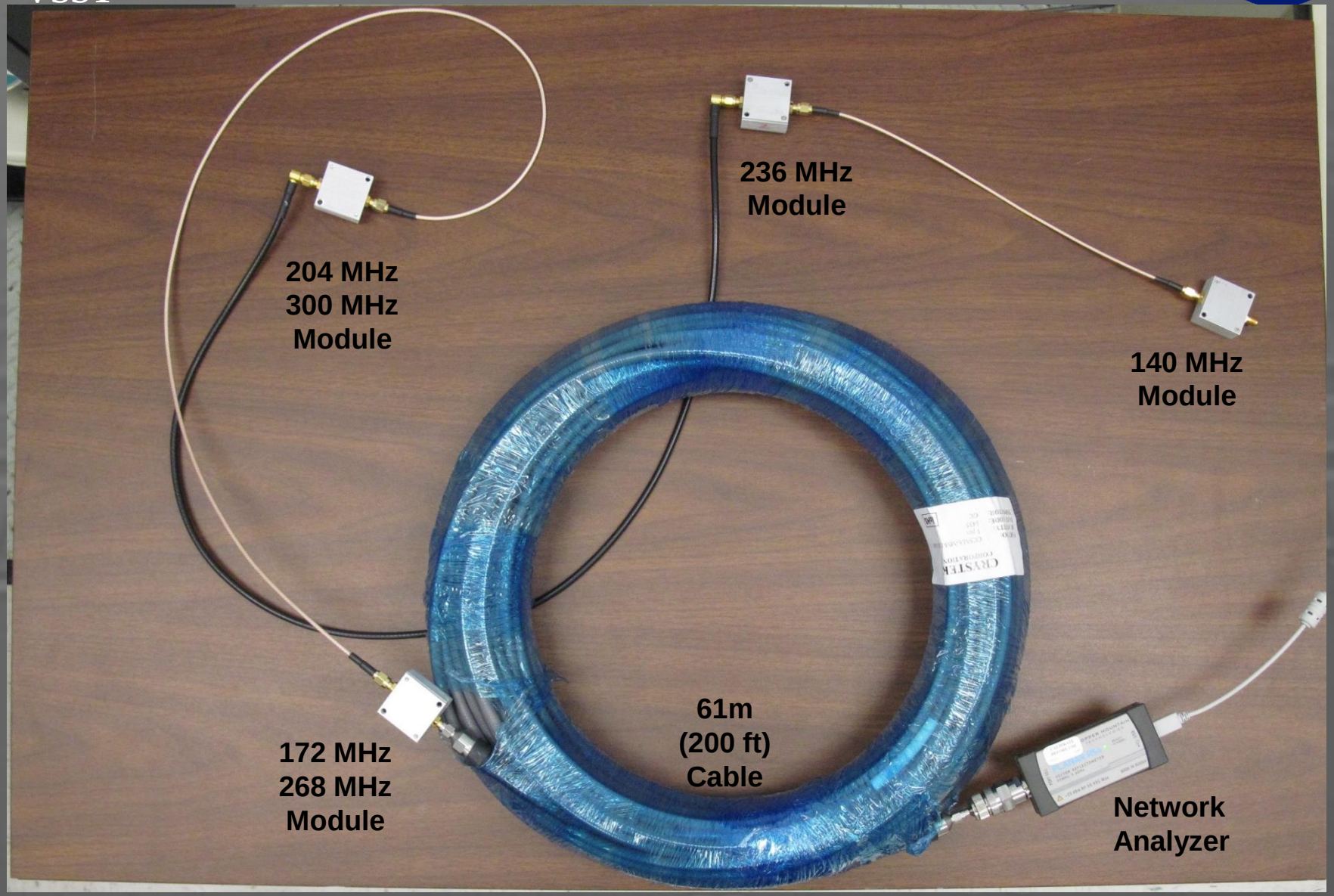
Compensated Strain Results
SAW vs Strain Gauge



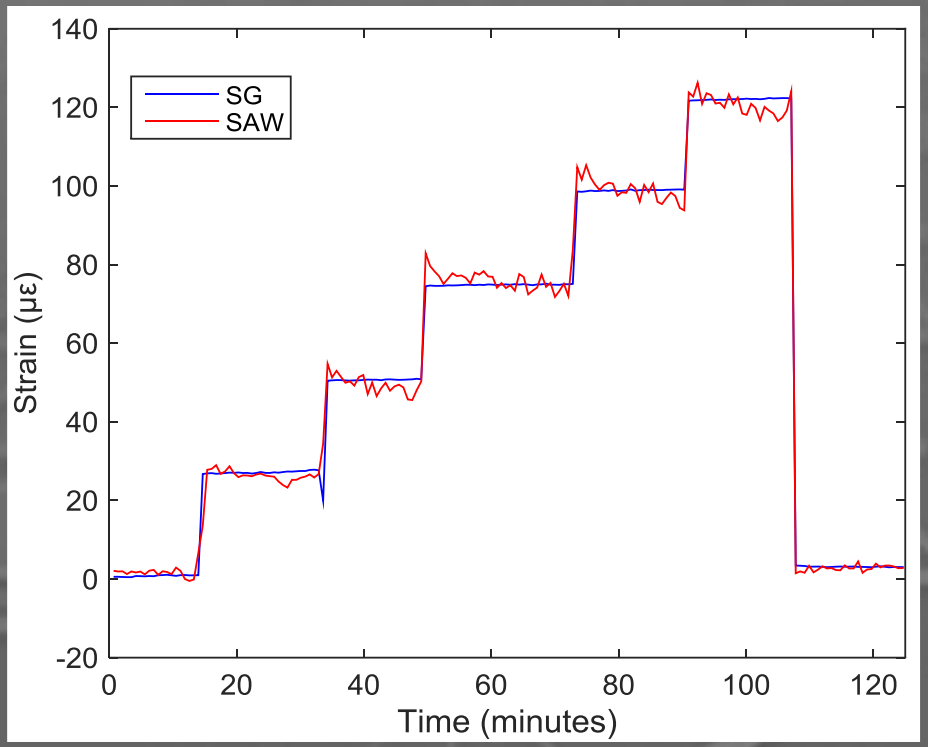
Average Compensated Response SAW vs SG

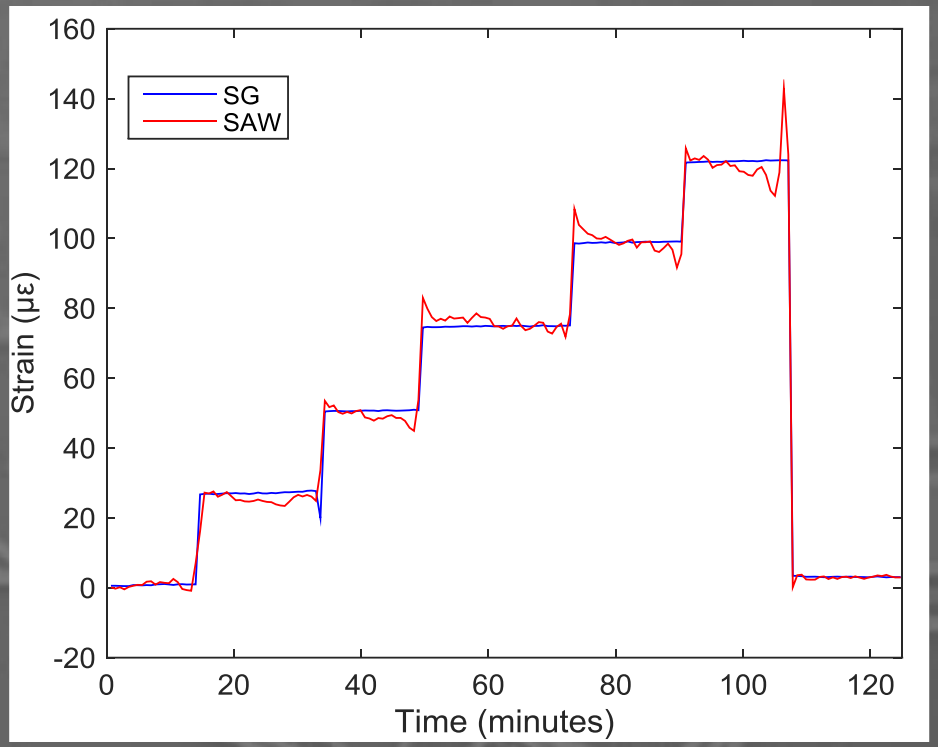


FDM SAW Sensor System



Compensated Strain Results
SAW vs Strain Gauge





Short Cable Response
1.83m (6 foot)

Long Cable Response
61m (200 foot)

Future Work

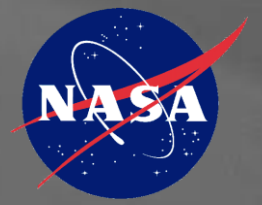
- Need optimized wire bonding techniques that will not crack the crystal and make stronger connections.
- Need impedance matching (50 Ω) of the modules for more consistent behavior.
- Need to investigate ways to increase the signal to noise response of the SAW device.
- New testbed with multiple sensors (SG, TC , SAW).

Conclusions

- Demonstrated operation of 6 FDM SAW sensors, in four modules.
- Demonstrated wiring reduction by using a single coaxial cable for all power and signals on the four modules.
- Demonstrated compensated strain measurements
  - –Using short 1.83m (6ft) cable.
  - –Using long 61m (200ft) cable.

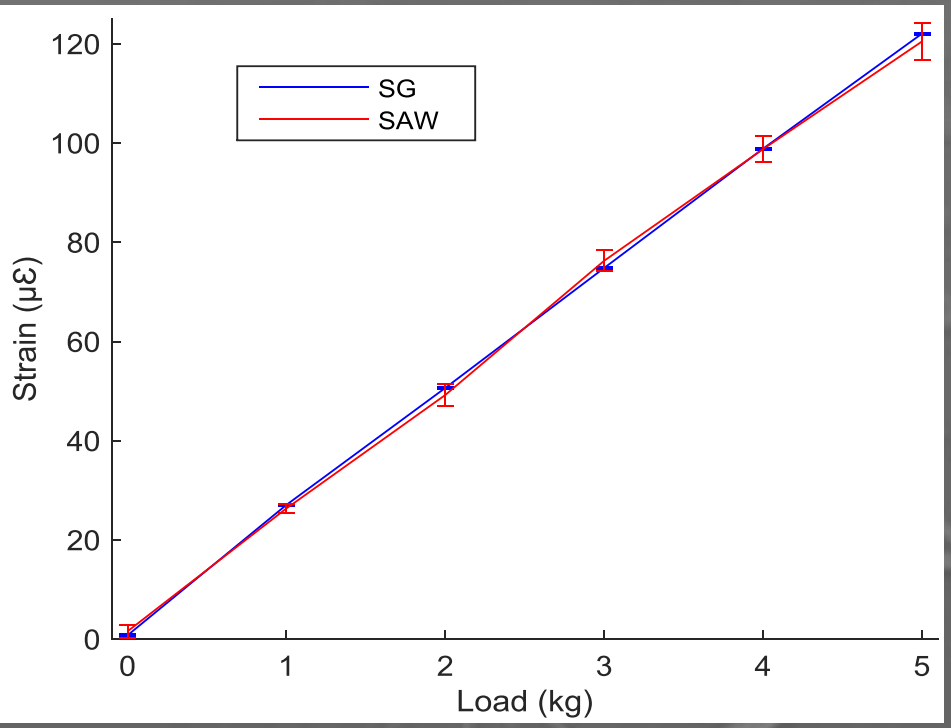
Funding/Partnership Opportunities

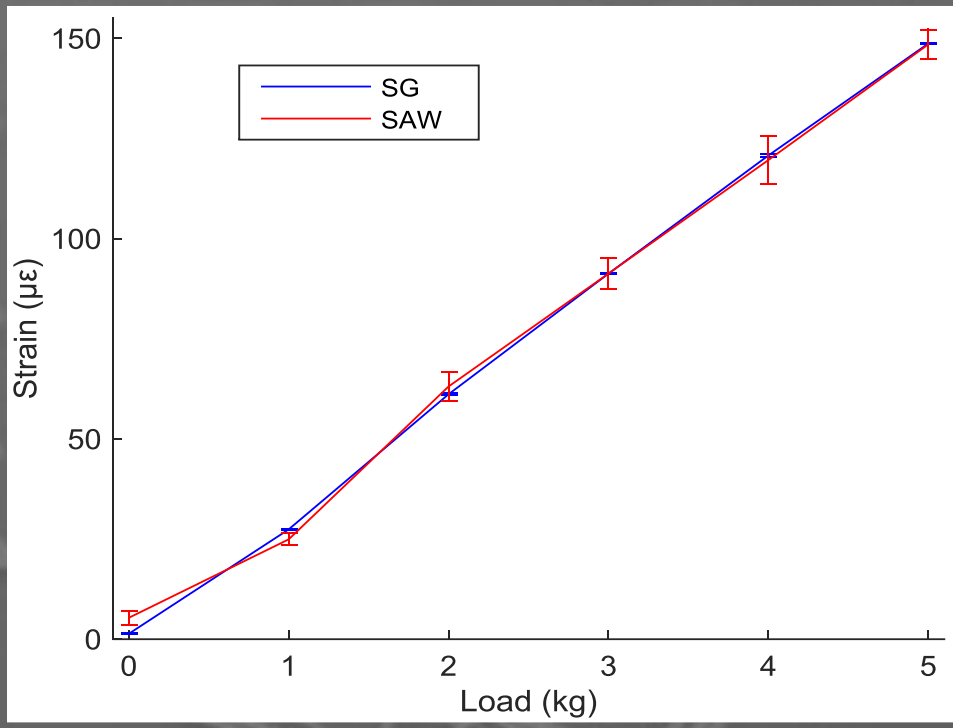
- NASA does not have the resources to develop all of the sensors it needs for its applications, therefore, we are looking for partners!
- Small Business Innovation Research (SBIR) Small Business Technology Transfer (STTR)
  - http://sbir.gsfc.nasa.gov/
  - SBIR H13 Non-Destructive Evaluation
    - H13.02 NDE Sensors
  - STTR T12 Materials, Structures, Mechanical Sys. and Man.
    - T12.01 Advanced Structural Health Monitoring
- NASA Research Opportunities (NRAs) Grants & Contracts
  - http://nspires.nasaprs.com/
- Space Act Agreements (SAA)
  - Partnerships with and without exchange of funds



Auxiliary Slides

Distance Response
SAW vs SG





Short Cable Response
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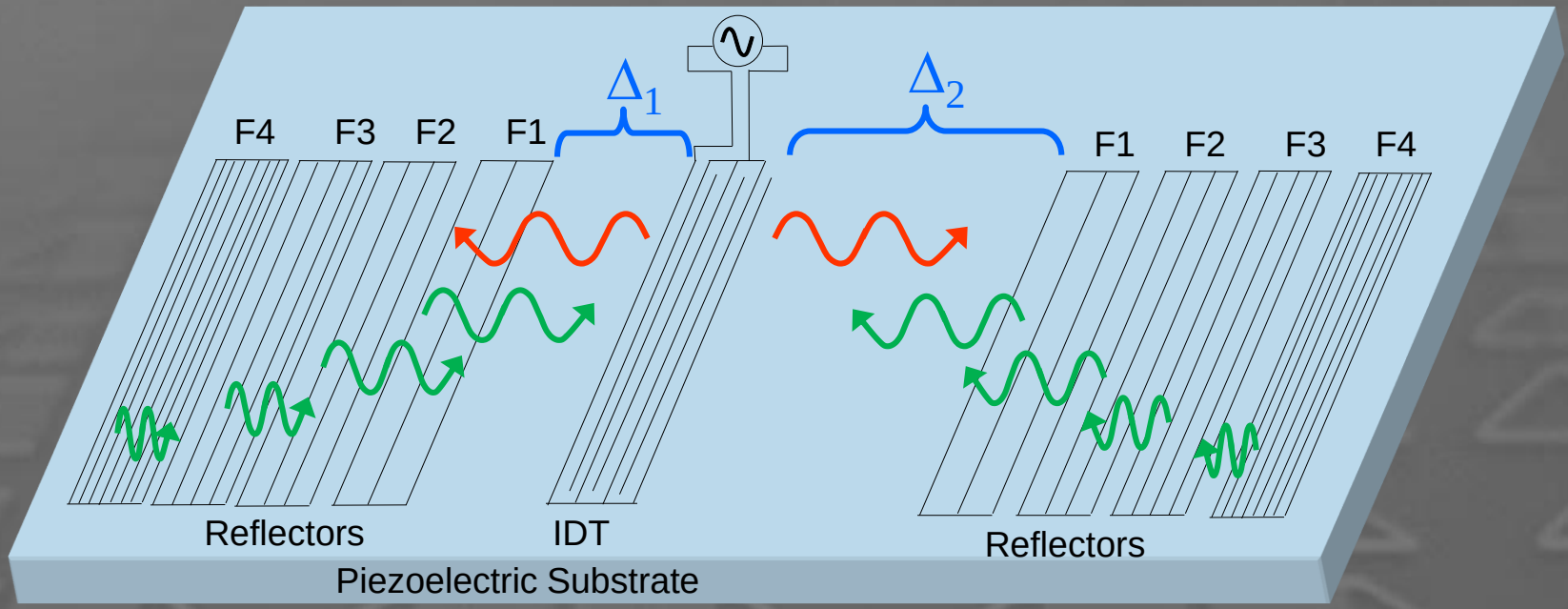
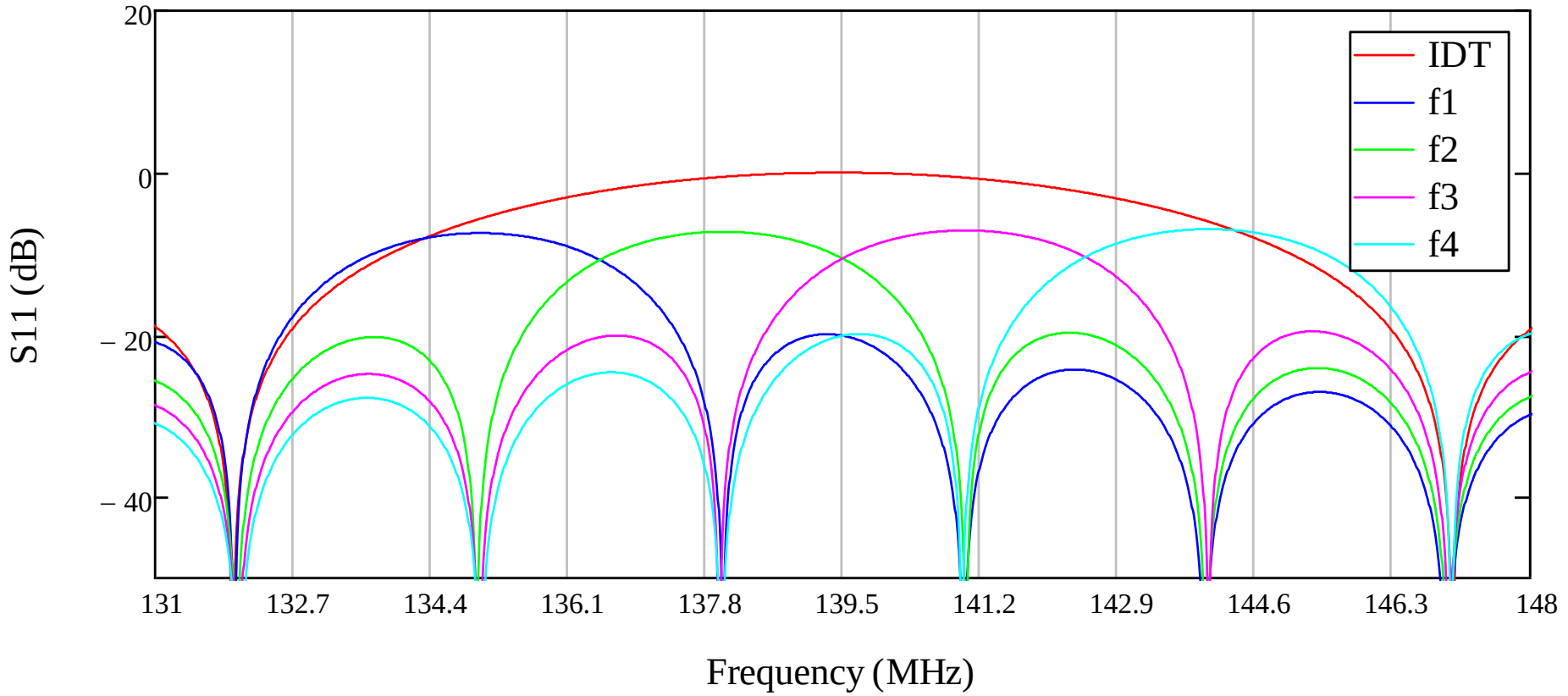
Single IDT OFC SAW Sensor



- SAW sensor that employs four orthogonal frequency coded (OFC) reflectors in two banks.
- Broadband signal generates SAW waves from the IDT (red arrows).
- Each reflector grating reflects a single frequency back (green arrows).
- Δ_1 and Δ_2 are the spacings between the reflector banks and the IDT.
- $\Delta_2 > 2\Delta_1$ so ensure the reflector banks responses do not overlap in time.
- The reflected signals change frequency in response to physical changes.
- OCF uniquely codes each sensor and is Spread Spectrum (multiple frequencies).

140 MHz OFC Device



The peak of each reflector occurs at the nulls of the others. The IDT bandwidth must cover all of the reflectors.

Module Wiring