2019 NETL Multiphase Flow Science Workshop

NATIONAL ENERGY TECHNOLOGY LABORATORY

Microwave Doppler Sensing of Particulate Flow in a Chemical Looping Reactor

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Solutions for Today | Options for Tomorrow

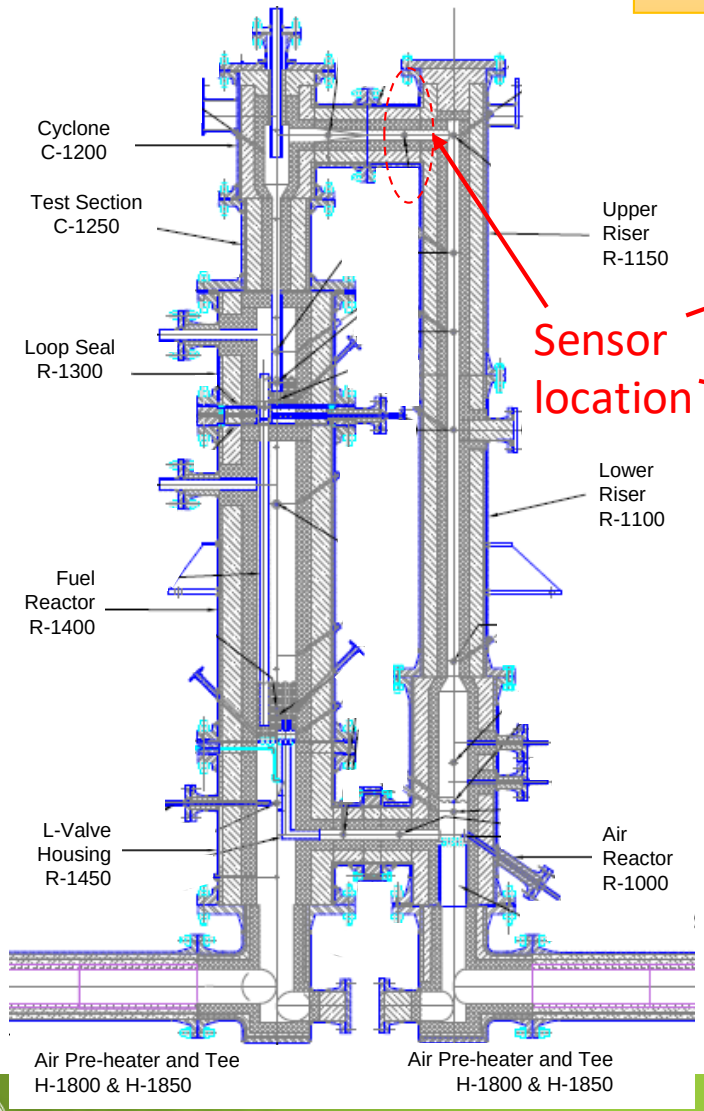
U.S. DEPARTMENT OF ENERGY

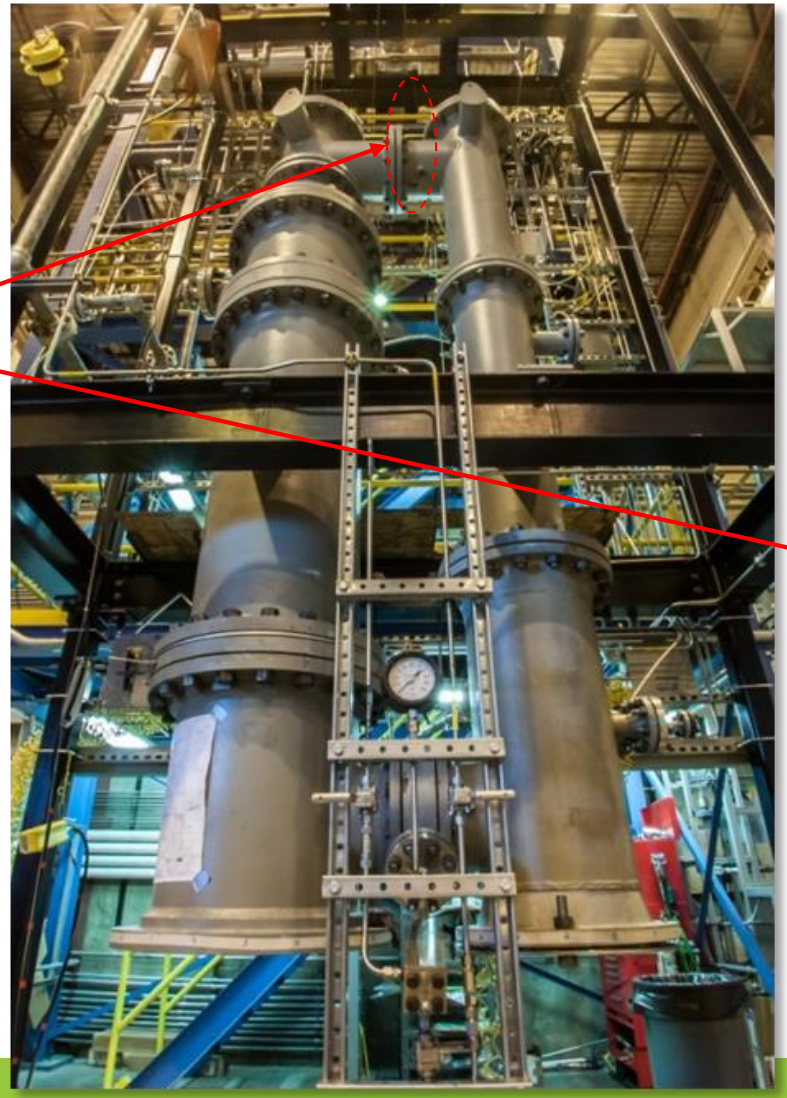
Transformational Technologies for New and Existing Plants
Task 14. Sensors and Controls

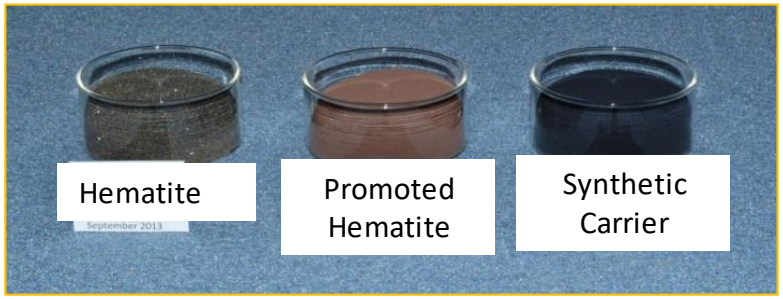
- **Objectives**
  - Develop innovative sensors to improve CLC system operations and reliability
  - Support CLC experimental research with advanced diagnostics

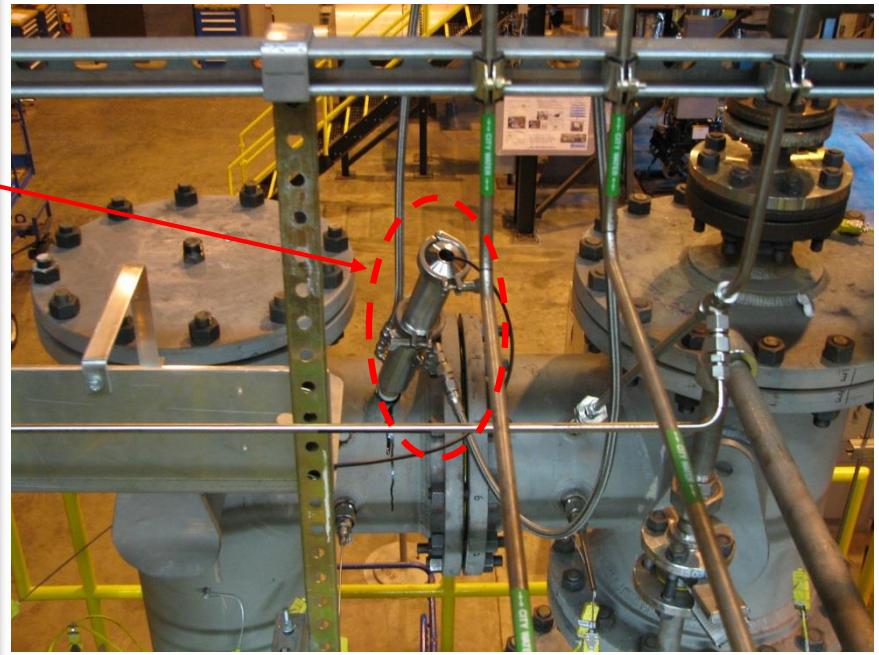
Application: NETL Chemical Looping Reactor

Sensor challenge: 1000°C, 12.5 atm (175 psig)



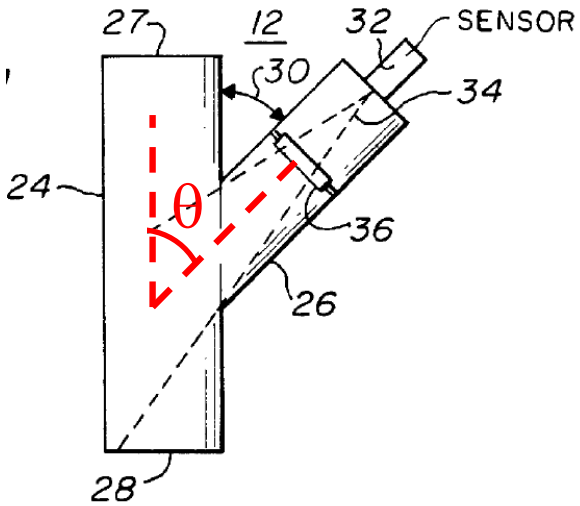


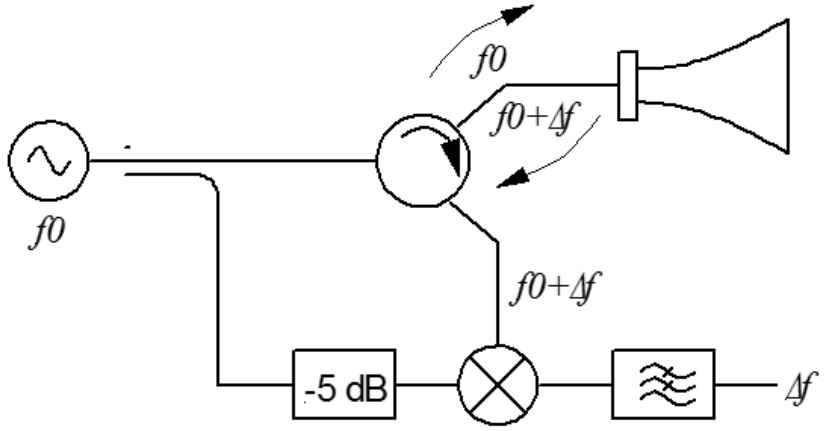




Microwave Doppler

- **Flow velocity determined from Doppler effect (frequency shift)**
- **Reflection magnitude related to density**





particle velocity

$$\Delta f = 2 f \frac{v}{c} \cos\theta$$

36.2 Hz per m/s
at 77° and 24.125 GHz

$$P_{reflected} = N\sigma_{total\ scattering} P(x)dx$$

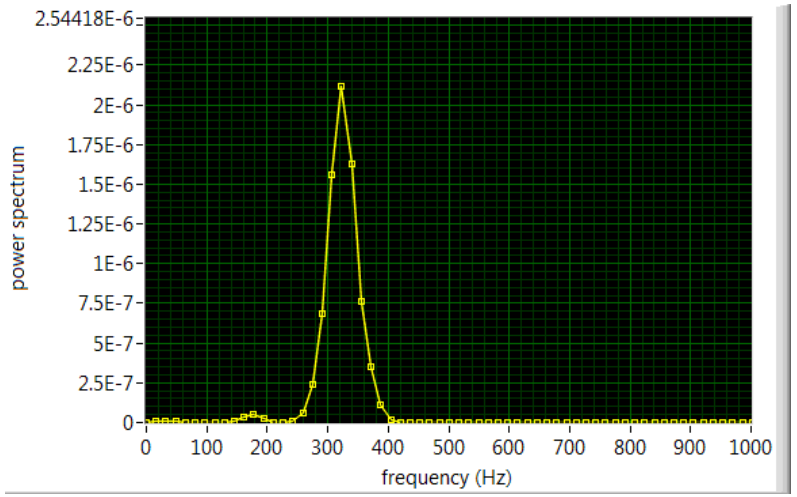
number density

scattering cross-section

Single particle vs. flow of many particles

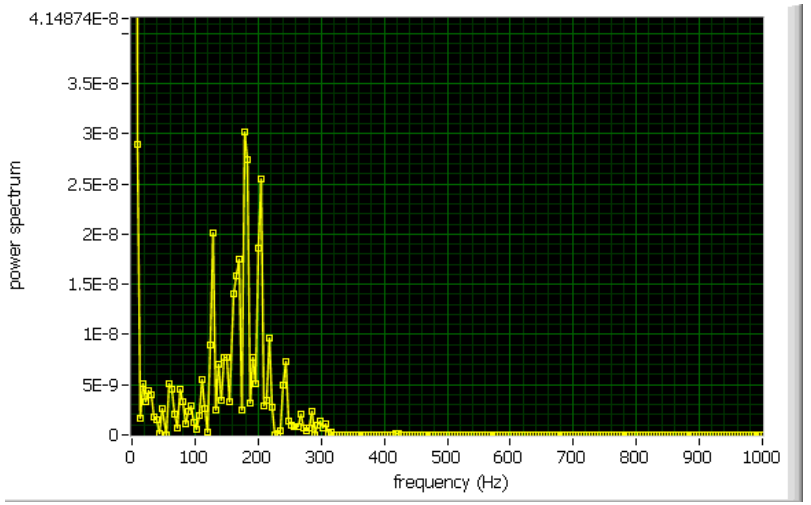
- Compute Fourier power spectrum of demodulated signal
- Get frequency shift of reflected signal

Single Particle



steel ball 0.157" diameter falling 1.8 m, horn angle 42 degrees; 10 GHz

Many Particles

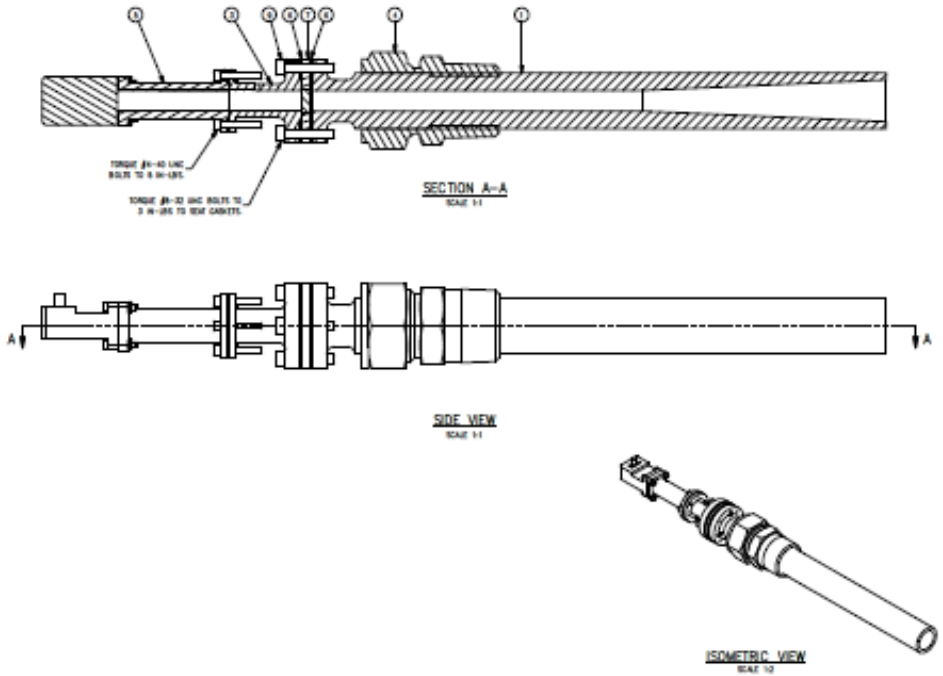


ilmenite falling 2.1 m, horn angle 52 degrees; 10 GHz

Many particles produce a frequency shift *distribution*

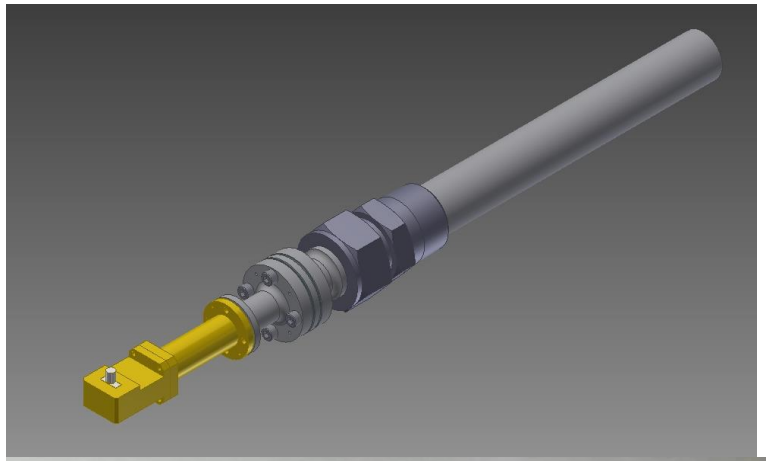
2nd Generation Design

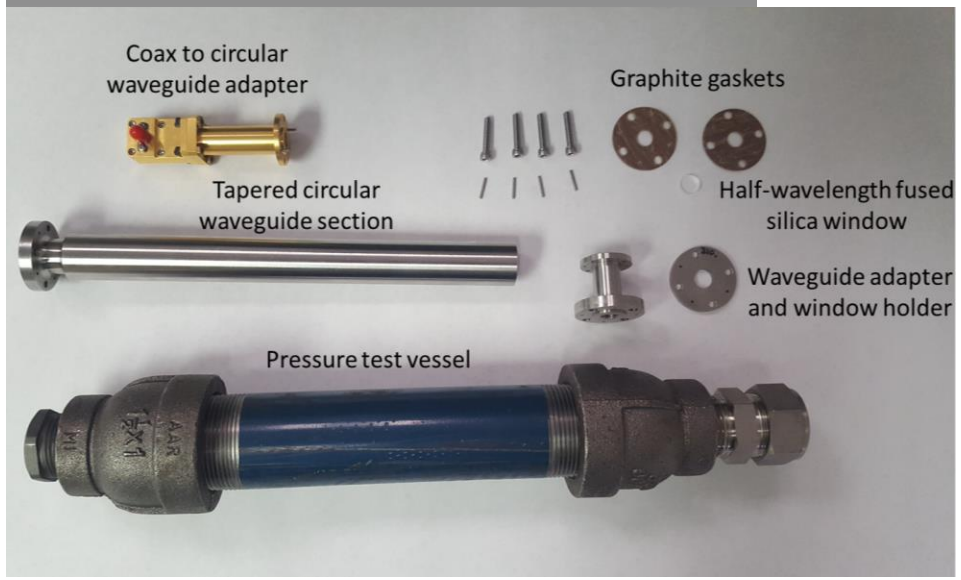
2nd generation design moves pressure boundary away from flow passage, uses hollow stainless steel waveguide



1st Generation design suffered from multiple internal reflections and plating under CLR operating conditions

Redesigned High Temperature Antenna





- Custom redesigned high temperature antenna
- Pressure tested
- Bench test of electromagnetic performance with VNA.
- Bench testing with CL carrier materials

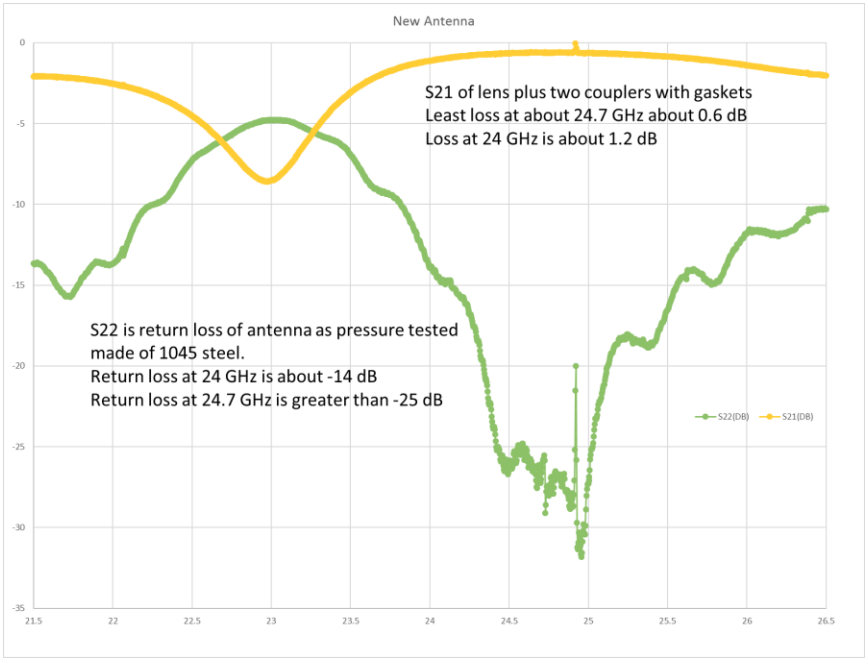


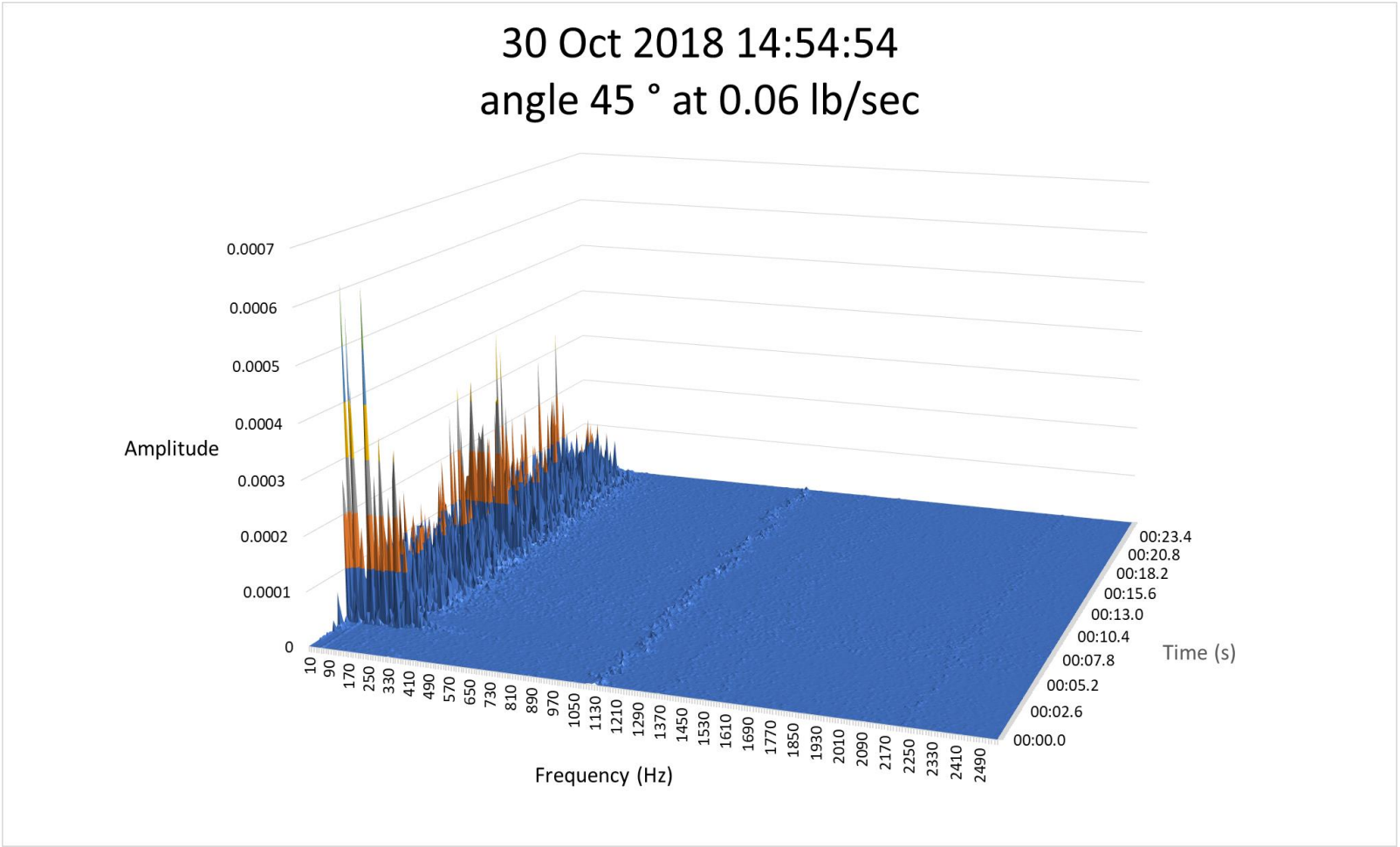
Table feeder results

Drop tube distance to antenna, d = 0.406m

Velocity at antenna from acceleration due to gravity, $V = (2*g*d)^{1/2} = 2.822$ m/s

Doppler frequency shift,
df = 2*f*V/c*cos (theta)
= 2*24.125E09*2.822/2.998E08*cos(45)
= 321.1Hz

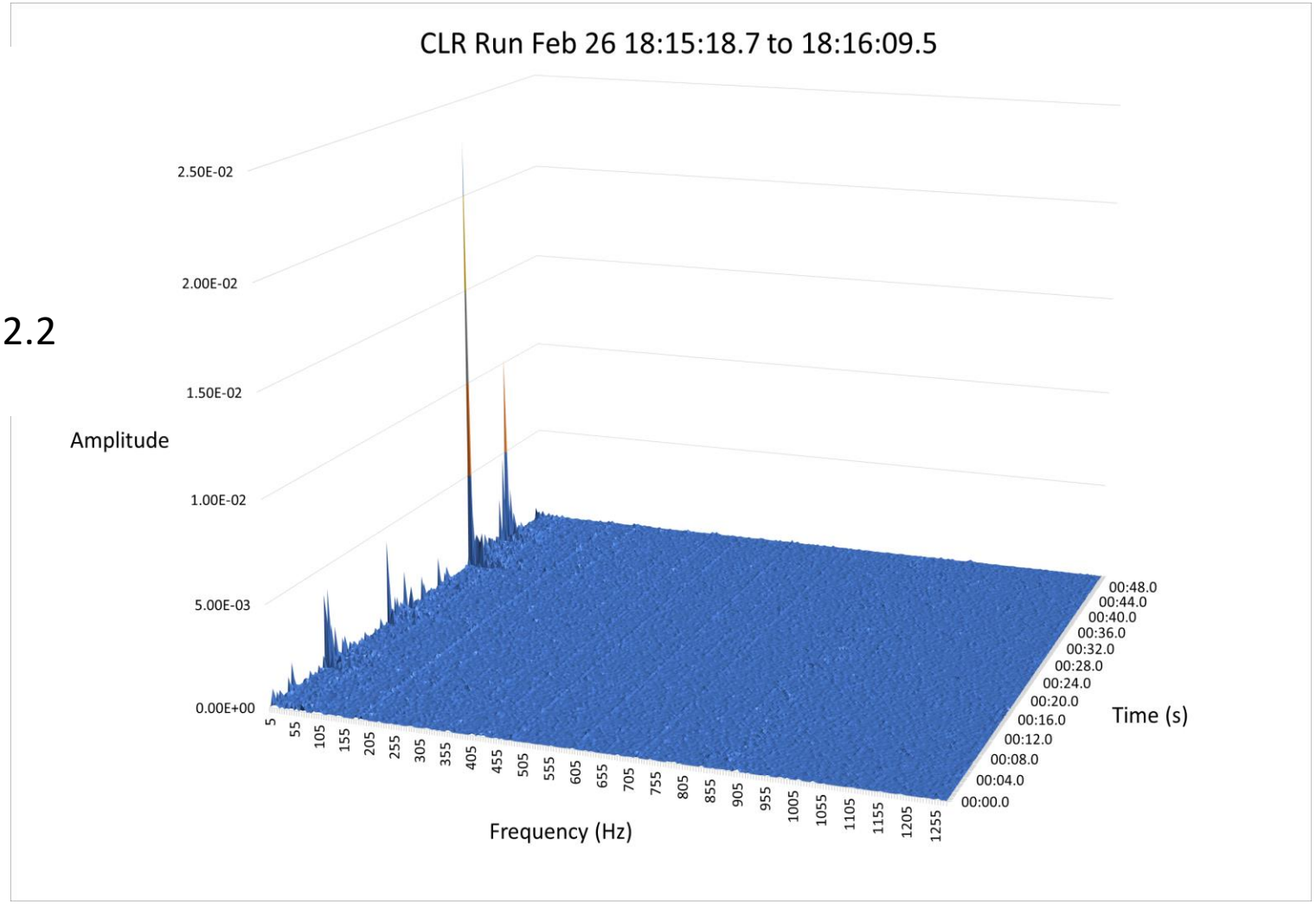
1 m/s = 113.8 Hz



CLR testing results

50 Sec. Microwave data sample during a period of oxygen carrier, $CuFe_{1.5}Al_{0.5}O_4$ 180-600 micron, circulation.

Temperature in the riser at the time was 816 °C and the gas velocity was around 12.2 m/s.

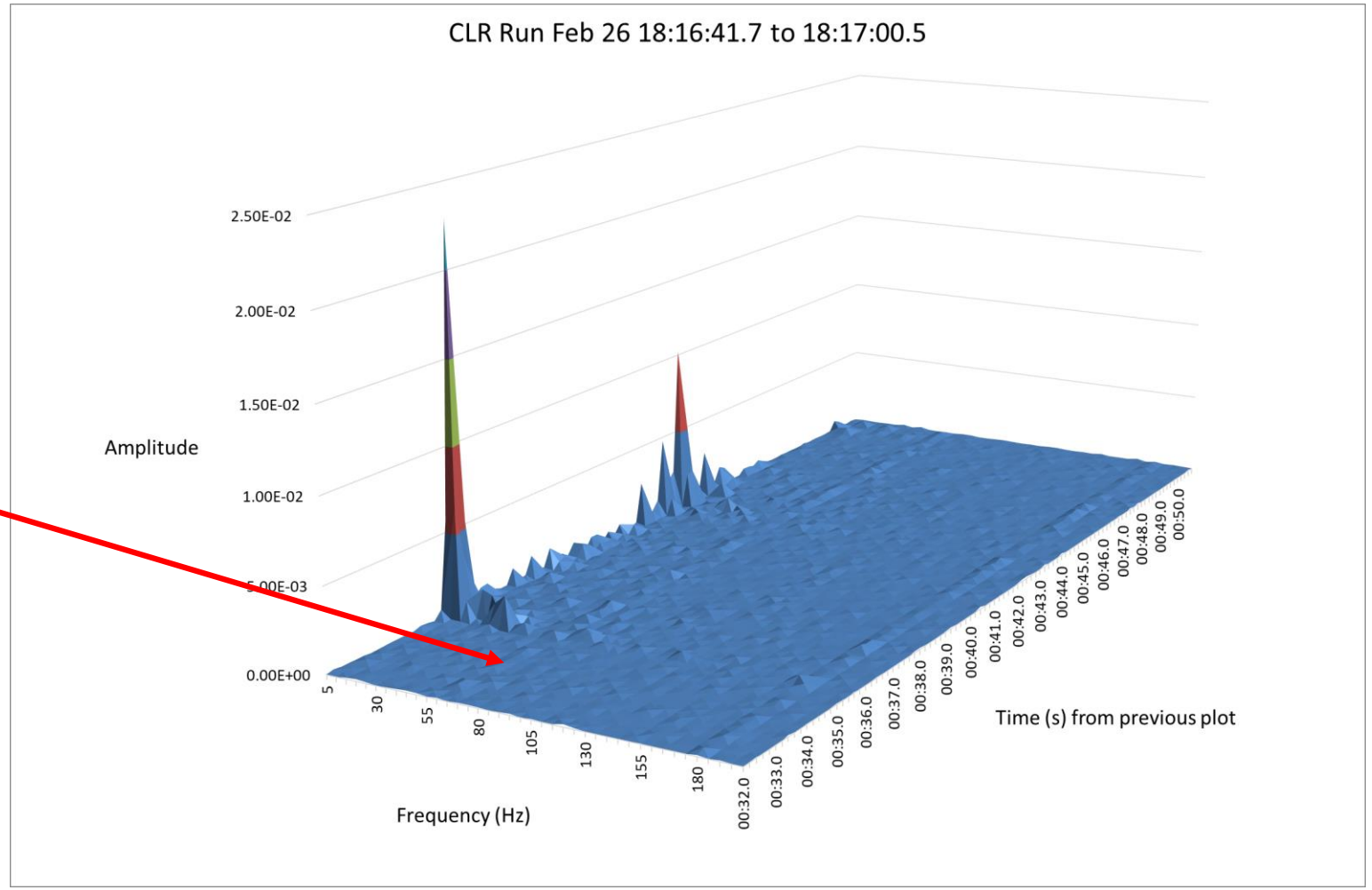


CLR testing results

Zoomed in 18 seconds of previous plot.

At an angle of 77°, 36.2 Hz = 1 m/s

60 Hz = 1.65 m/s



CLR testing results

New antenna after the CLR run

Conclusions and Future Work

- New antenna design survived the run and performed well.
- Mixer failed part way through run without having been able to calibrate but we did get some qualitative data.
- Future work includes exploring more complicated receiver architectures and mass flow extraction algorithms.

Acknowledgment

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