1. *Kenneth Swartz*, This Day in Aviation, 1980.

Transportation Safety Board of Canada
Bureau de la sécurité des transports du Canada

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Aviation Investigation Report A01P0282

Input freewheel unit failure

Dwayne Air 2000, Ltd.

Eurocopter SA315B Lama C-GXYM

Sawtooth Mountain, British Columbia

08 November 2001

2. Transportation Safety Board of Canada, *Aviation Investigation Report A01P0282*. November 2001

Measuring Oil Contamination with a Microwave Cavity Resonator

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Alex Studer - Electrical Engineering & Computer Science
Fischer Moseley - Electrical Engineering & Physics

6.013 Spring 2021

Cavity Resonator

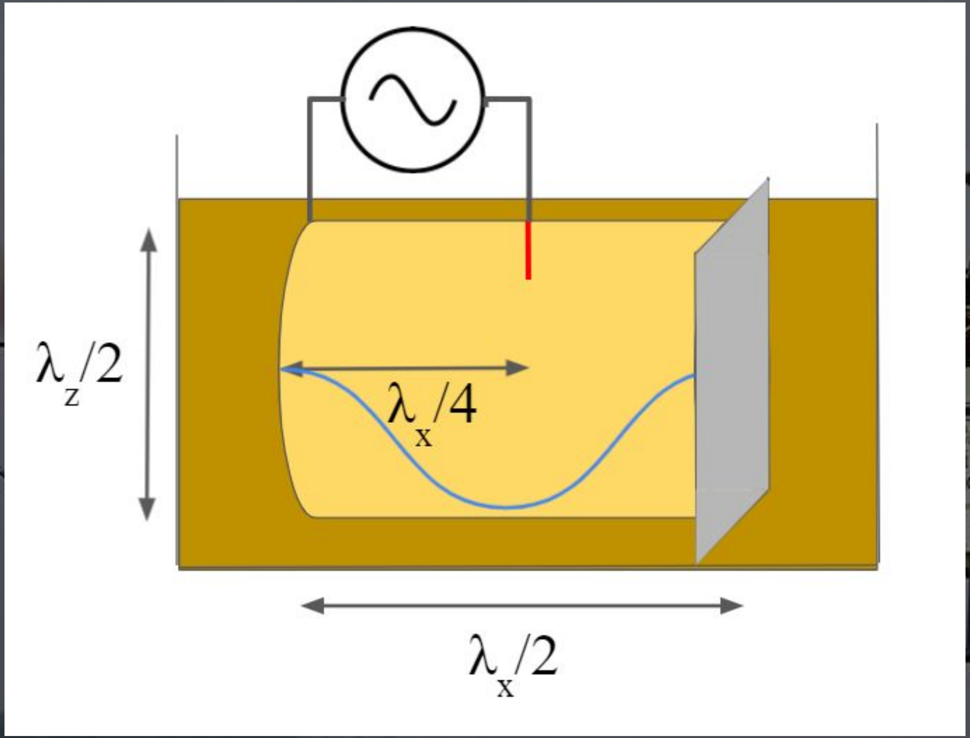


Figure 1: Diagram of resonator modes and setup

Figure 2: H125 Helicopter Main Gearbox Cutaway.[2]

3. Forum 73, Vertical Flight Society. "Airbus Helicopters H125 main gearbox cut-away". 2017.

Cavity Resonator

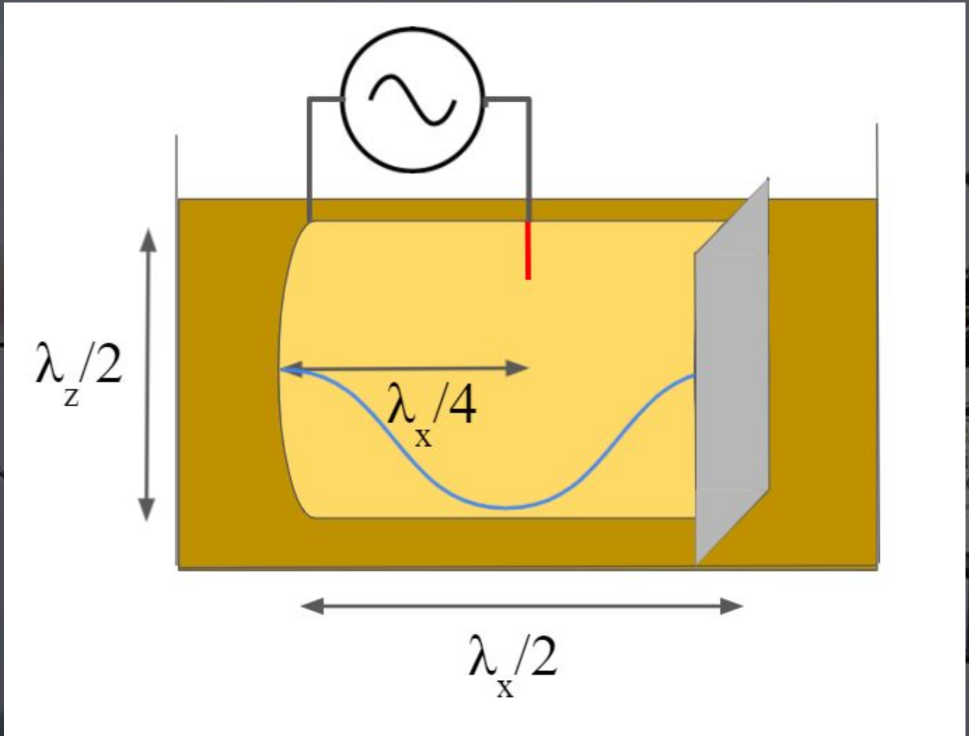


Figure 1: Diagram of resonator modes and setup

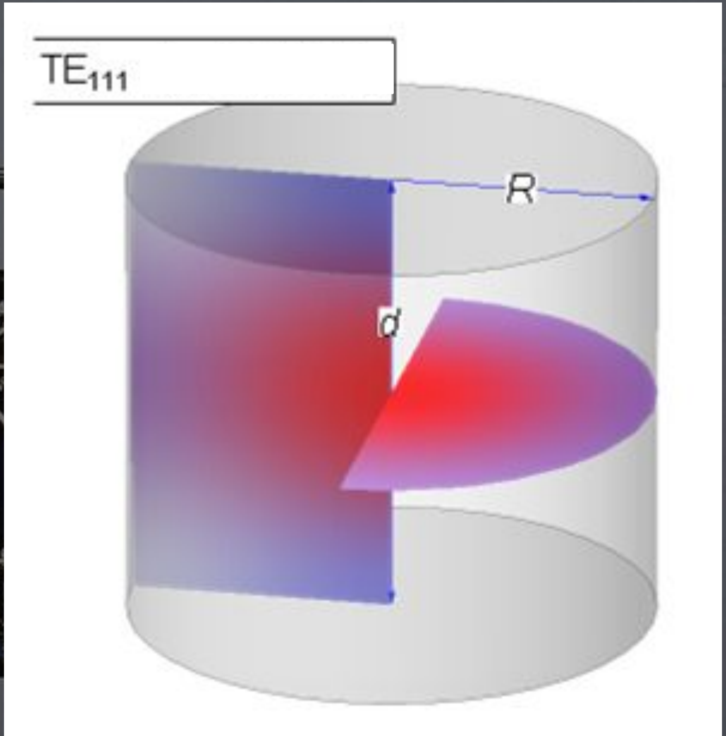
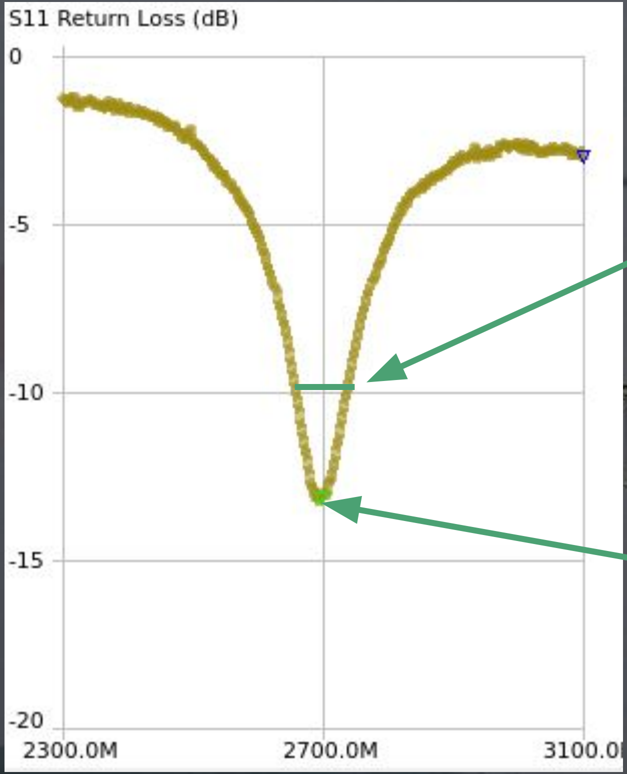


Figure 3: Electric Field in Resonant Mode Display[3]

4. Y. Shibuya, Wolfram Demonstrations Project, 2015

S11 results for resonator



Half-power bandwidth
This is Q loaded (Q total) -- we want Q unloaded

Dip at resonant frequency
Frequency changes based on material properties

Figure 4: S_{11} Bode Plot, representative resonator

Water Setup + Demo

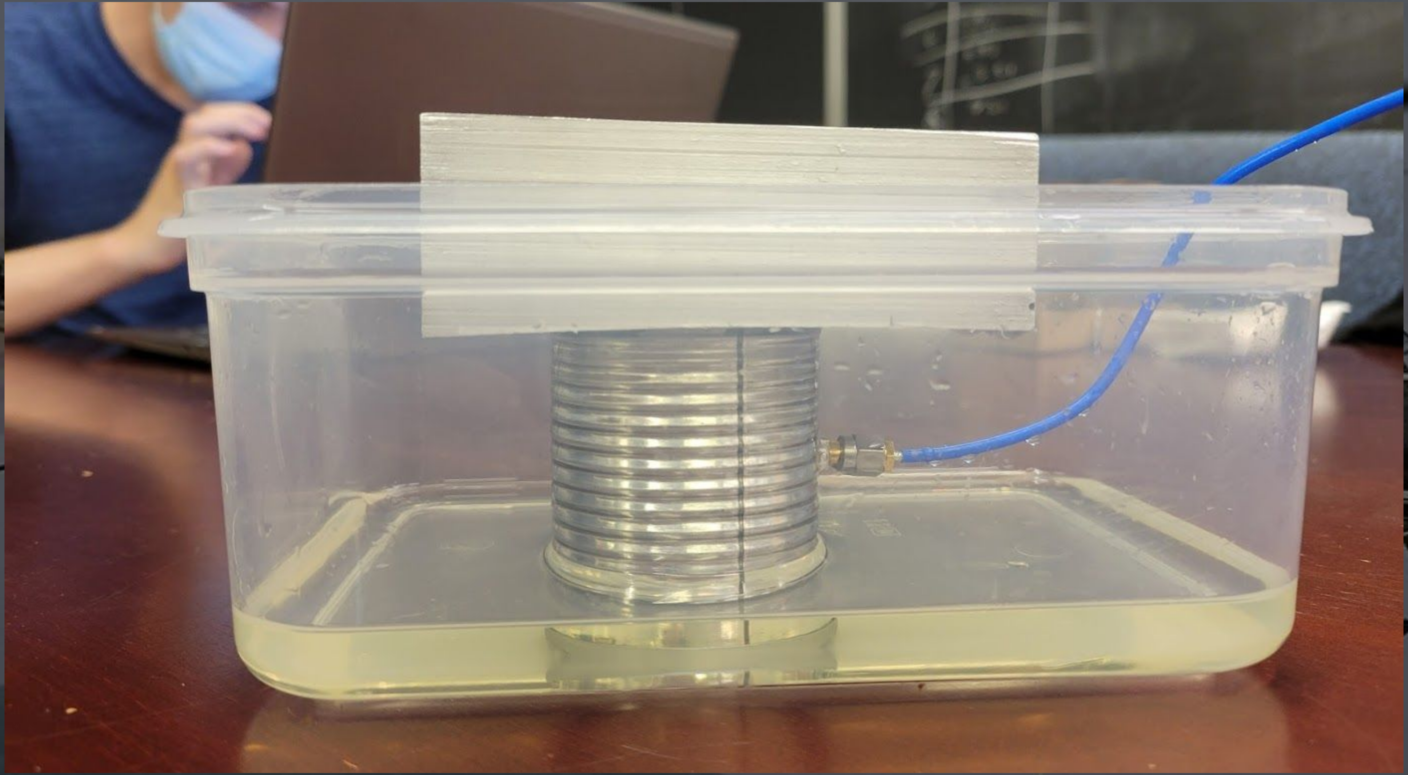
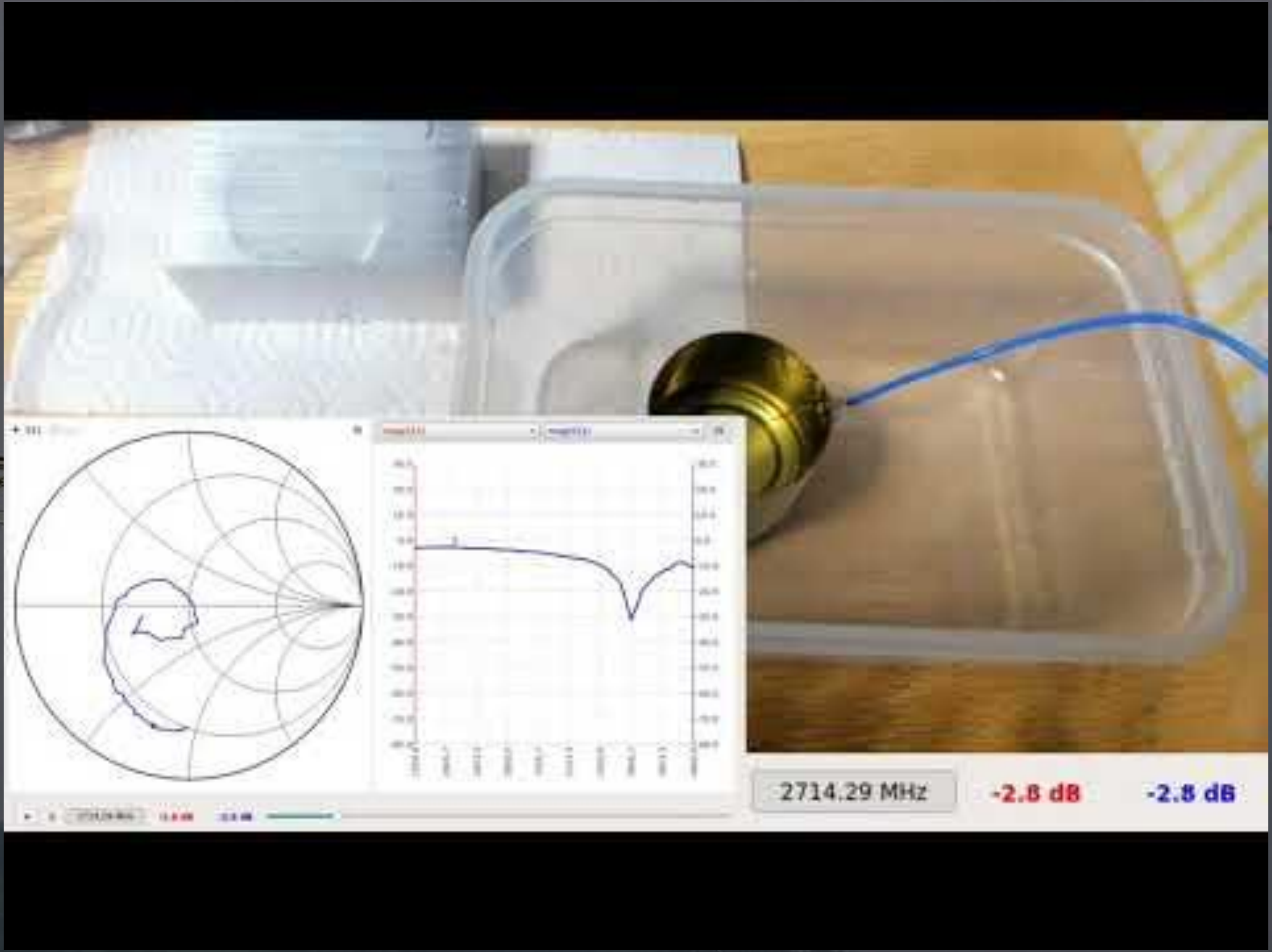


Figure 5: Water cavity setup

Water Demo Recording



Finding unloaded Q factor

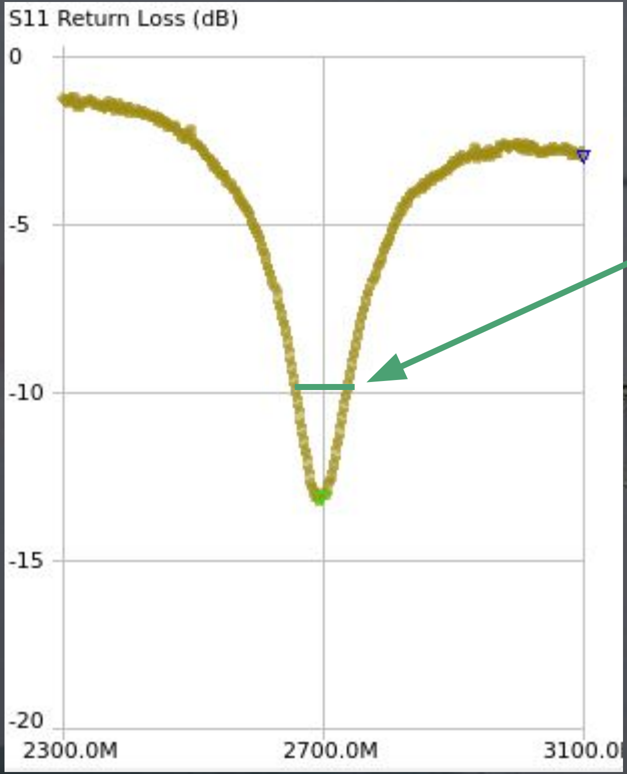


Figure 4: S_{11} Bode Plot, representative resonator

Half-power bandwidth

This is Q loaded (Q total) -- we want Q unloaded

$$\frac{1}{Q_{unloaded}} + \frac{1}{Q_{external}} = \frac{1}{Q_{total}}$$

Finding unloaded Q factor

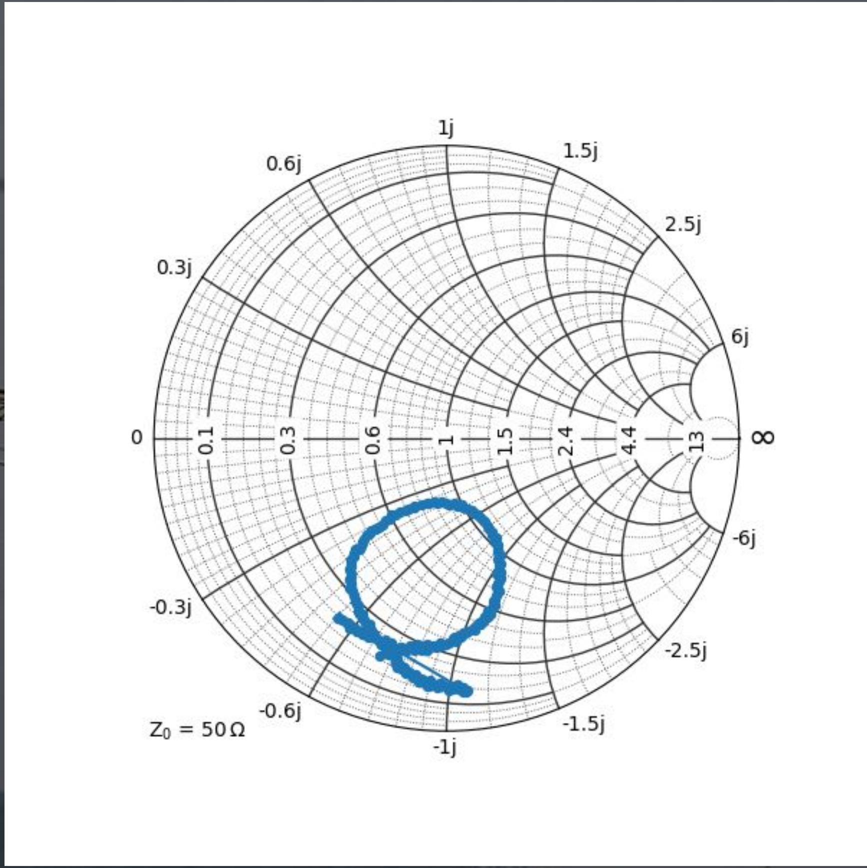


Figure 6a: Smith chart of resonator response

5. Shahid et al, *Reflection type Q-factor measurement using standard least squares methods.* IET proceedings. Microwaves, antennas and propagation. 2010.

Finding unloaded Q factor

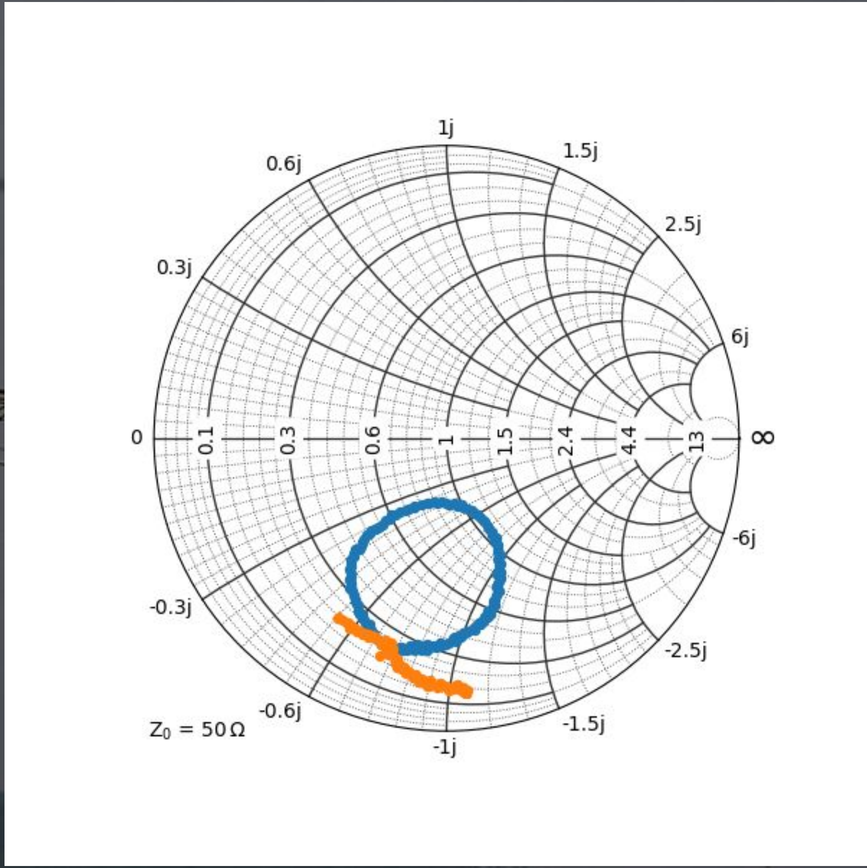


Figure 6b: Smith chart of resonator response, TE_{11} mode

5. Shahid et al, *Reflection type Q-factor measurement using standard least squares methods.* IET proceedings. Microwaves, antennas and propagation. 2010.

Finding unloaded Q factor

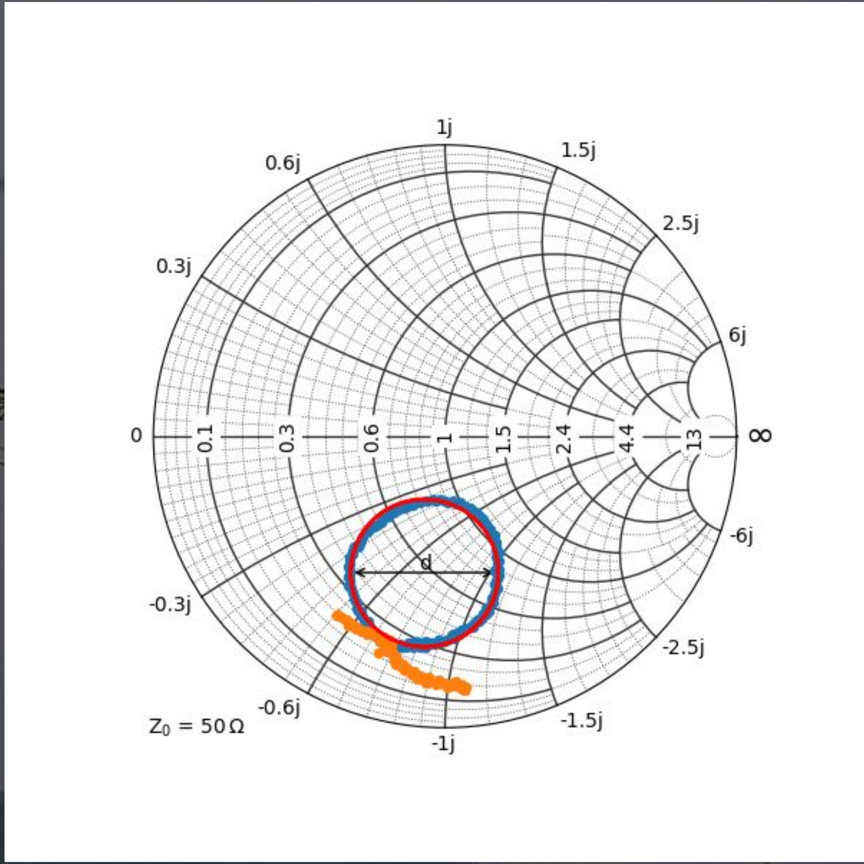


Figure 6c: Smith chart of resonator response, fitted

$$\kappa = \frac{d}{2-d}$$

$$Q_0 = Q_L(1+\kappa)$$

5. Shahid et al, *Reflection type Q-factor measurement using standard least squares methods.* IET proceedings. Microwaves, antennas and propagation. 2010.

Results for Water Contamination

Figure 4: Internal quality and resonant frequency for varying water concentrations.

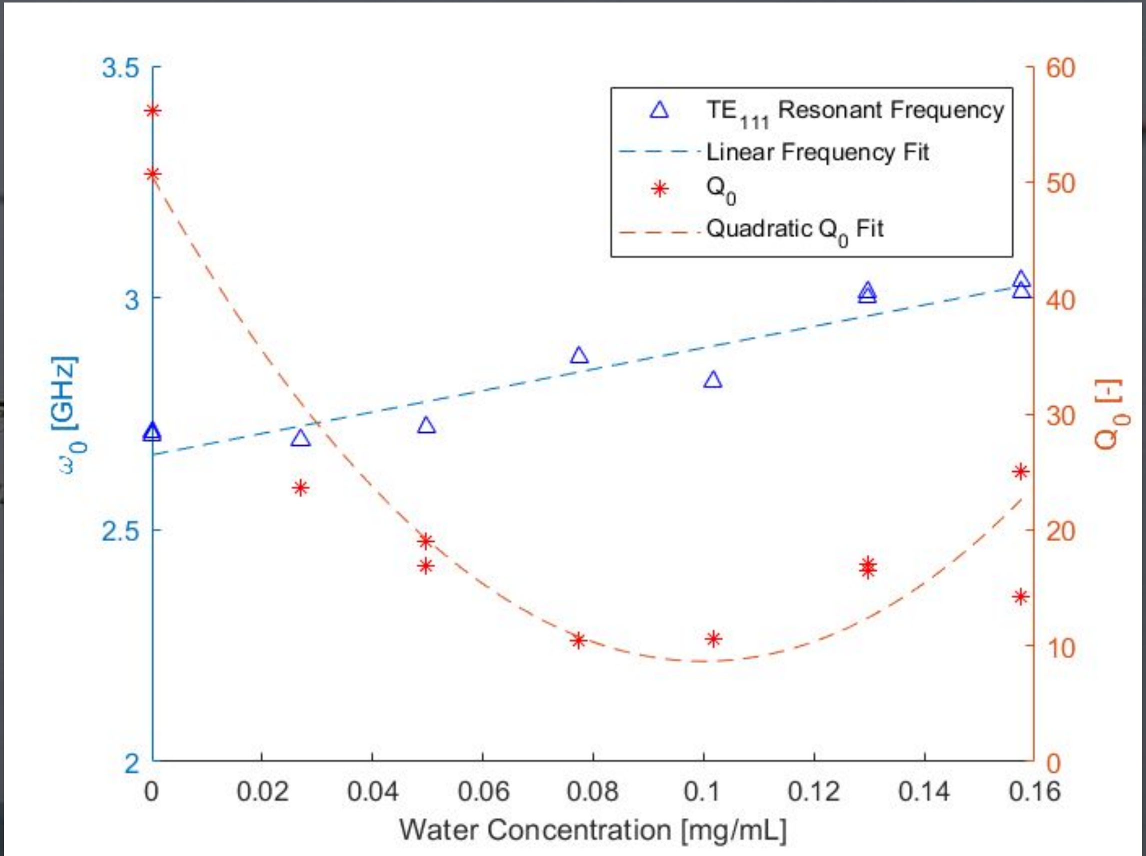


Figure 7: Water results

Steel Fillings Setup

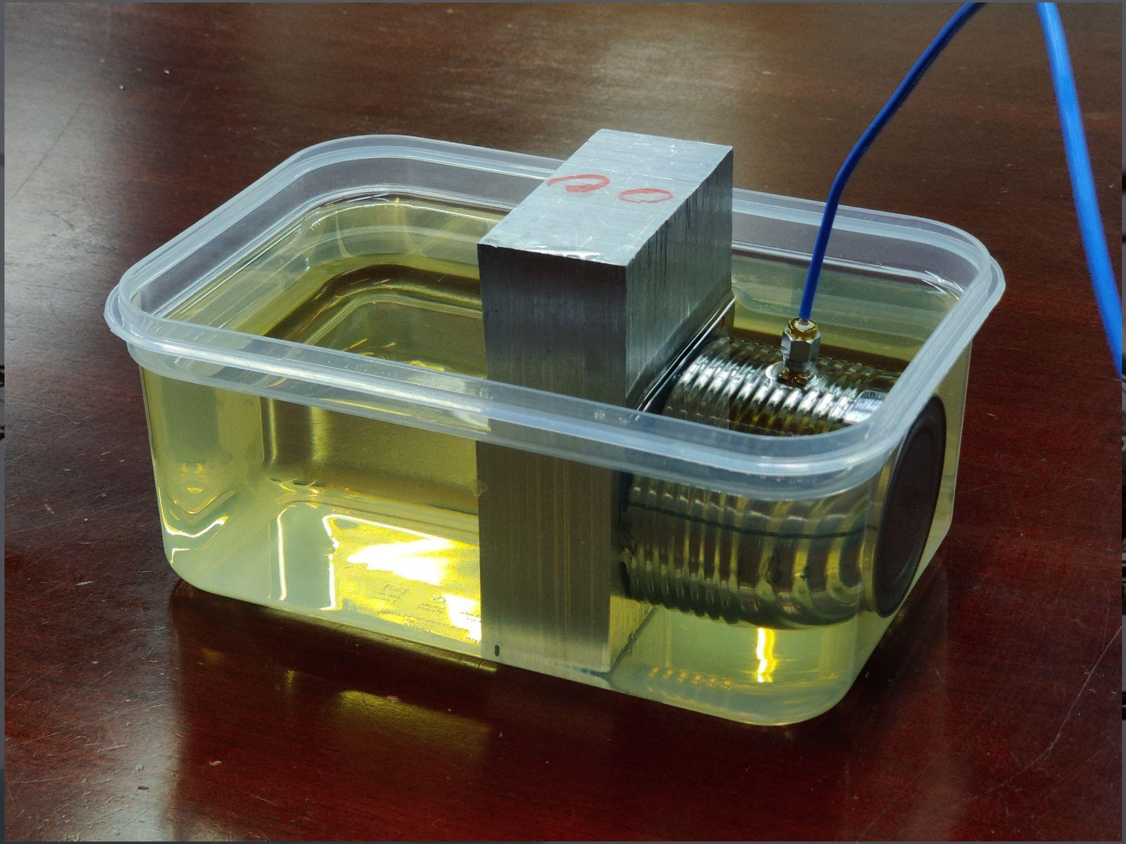


Figure 8: Steel setup, fully submerged

Results for Steel Filings

Figure 4: Internal quality and resonant frequency for varying steel contamination levels.

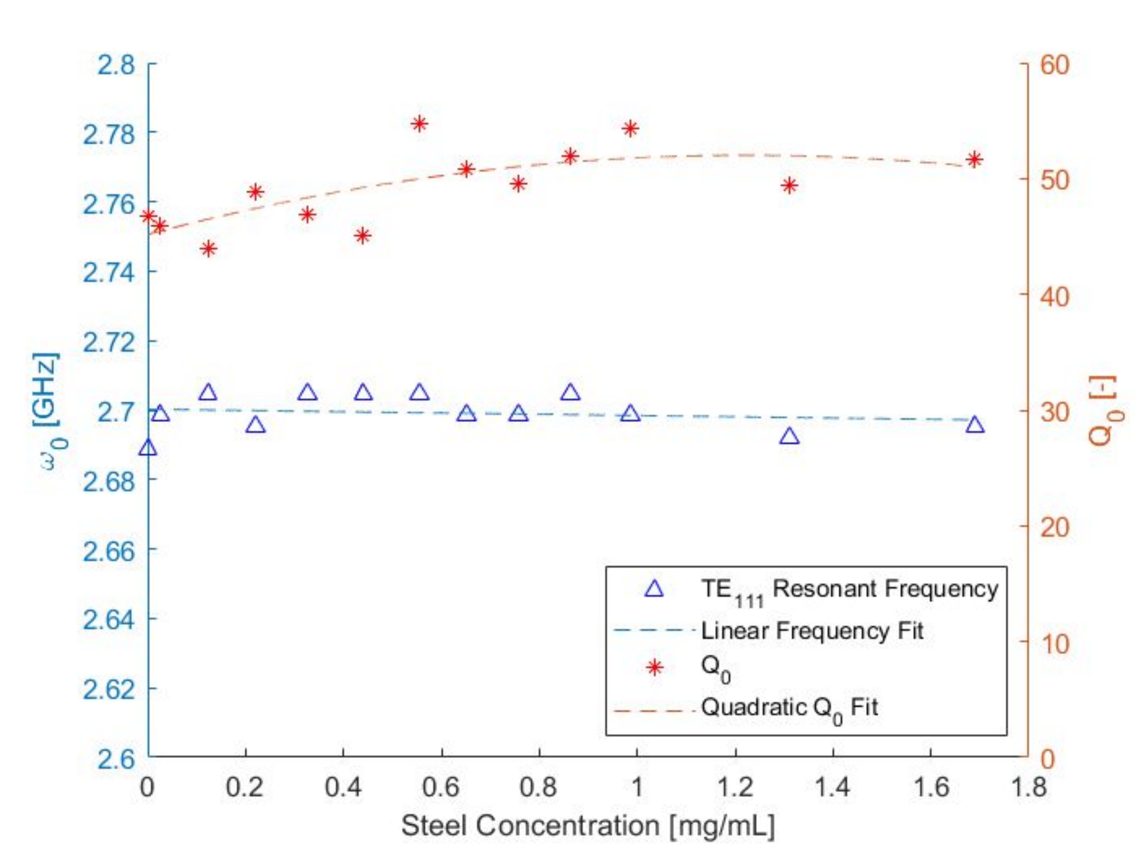


Figure 9: Steel results

Material Property Sensitivities

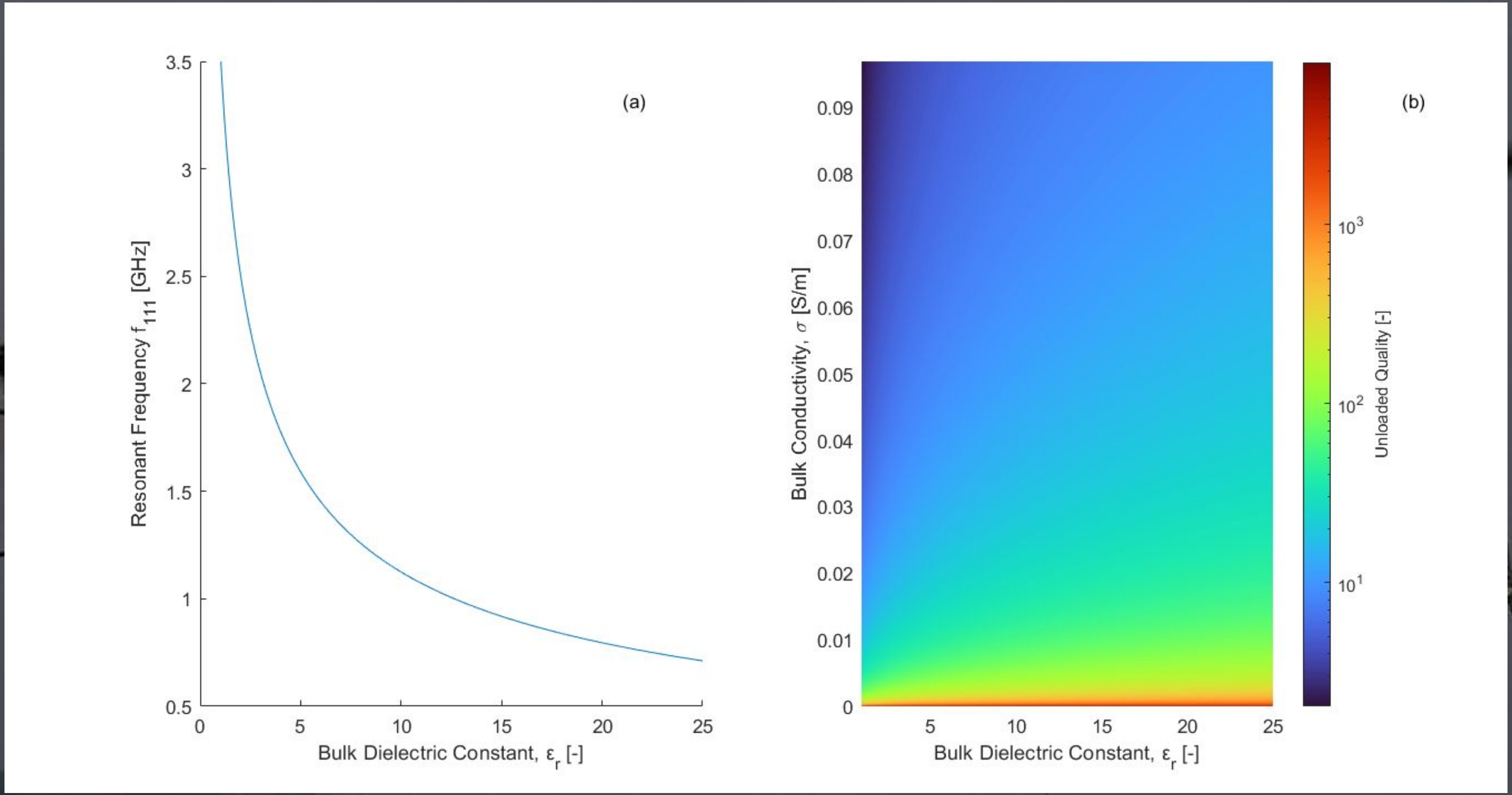


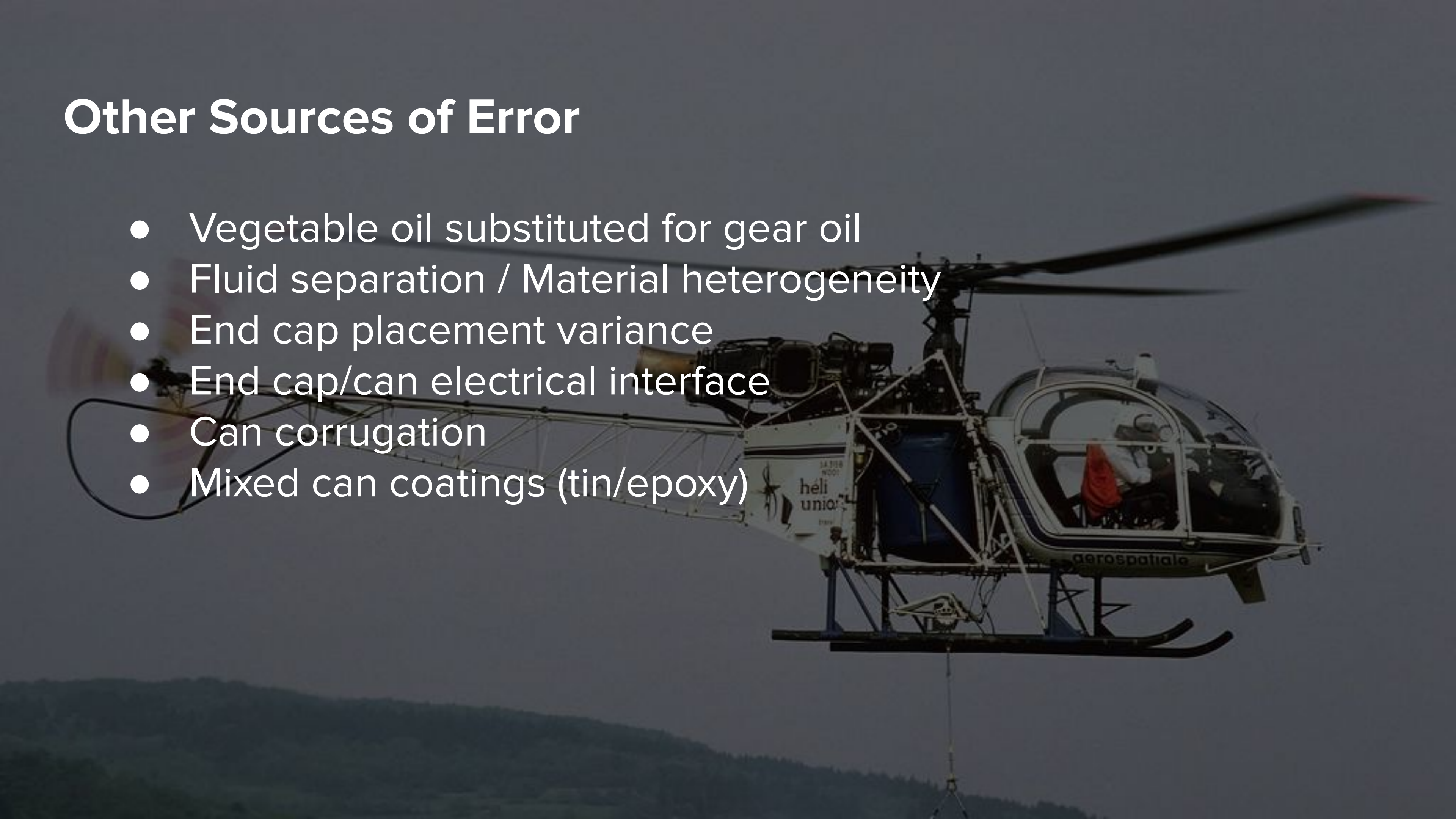
Figure 10: (a) Resonant frequency vs bulk dielectric constant for homogeneous fluid. (b) Heatmap of internal quality factor versus material properties.[3]

6. Pozar, David M. *Microwave Engineering, 4th Edition.* Hamilton Printing, 2012.

Conclusion

- Sensitive to water
- Insensitive to metal contaminants
- In-situ measurement possible
- Inexpensive

Questions?



Other Sources of Error

- Vegetable oil substituted for gear oil
- Fluid separation / Material heterogeneity
- End cap placement variance
- End cap/can electrical interface
- Can corrugation
- Mixed can coatings (tin/epoxy)