Design of a Compact Pressure Sensor for Multi-Layer Insulation in a Vacuum

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Presentation Overview

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- Project Constraints
- Designs
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Presenter: Jason Carvalho

Project Scope

- The goal of this project is to design and implement a compact pressure sensor that is easily embedded between layers of Multi-Layer Insulation (MLI).
  - Rapid Response Time
  - The ability to measure a large pressure range
  - Noninvasive to the MLI

- This interstitial pressure is measured to quantify the heat transfer through the system

- Heat transfer is critical to cryogenic storage and applications in space

Project Objectives

- Develop a pressure sensor with minimal parts
- Minimize the wiring and power consumption of the device
- Minimize the heat produced by the sensor

Project Constraints

- Pressure Sensor
  - Be able to measure a pressure as low as 10^{-2} Pa
  - Have a minimum response rate of 1 sample per second

- Multi-Layer Insulation
  - Sensor dimensions shouldn't exceed interlayer spacing
    - 12 layers is roughly 5 mm

- Working environment
  - Temperature conditions range from 293 K to 77 K
  - Out gassing
  - Vacuum

Capacitor Design

1. Palladium-gold sputtered capacitance tracts

2. Silicone diaphragm
   - 125 μm diameter
   - 0.25 μm thickness
3. Capacitor base shell
   - Germanium doped Silica base with cavity hollowed by acidic etching

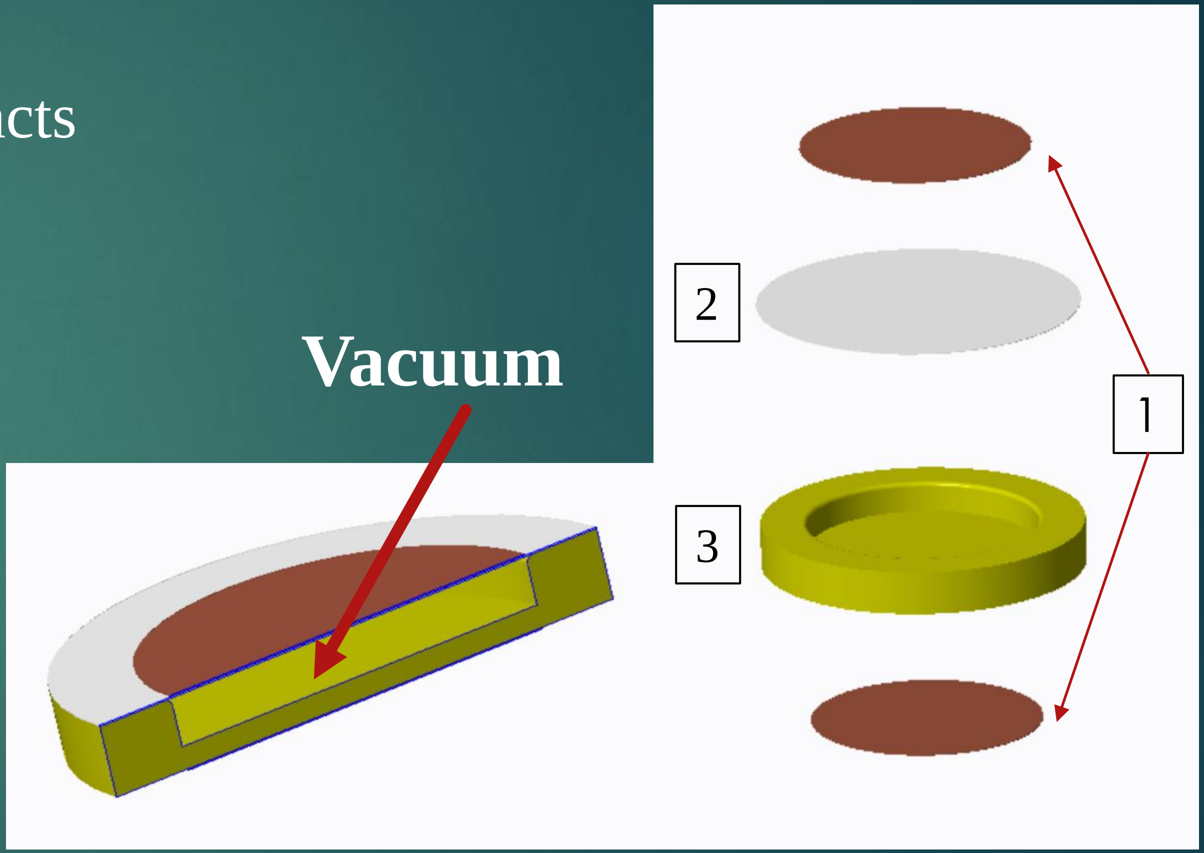

Figure 1: Cross section view of capacitor (left), and exploded view (right)

Multi-Stage Capacitor Design

1: Capacitor top diaphragm:

-High sensitivity – reads low pressures

-165 μm OD, 125 μm ID diaphragm

- 20 nm thickness, 27 μm deflection at 10 Pa

-Nano-metallic coating to create capacitor plate (sputtering)

2: Silica spacer

3: Intermediate diaphragm:

-Medium to low sensitivity – reads medium to high pressure ranges.

- 50 nm thickness, 28 μm deflection at 150 kPa

4: Silica Base plate

5: Capacitor bottom plate:

-Rigid metallic plate

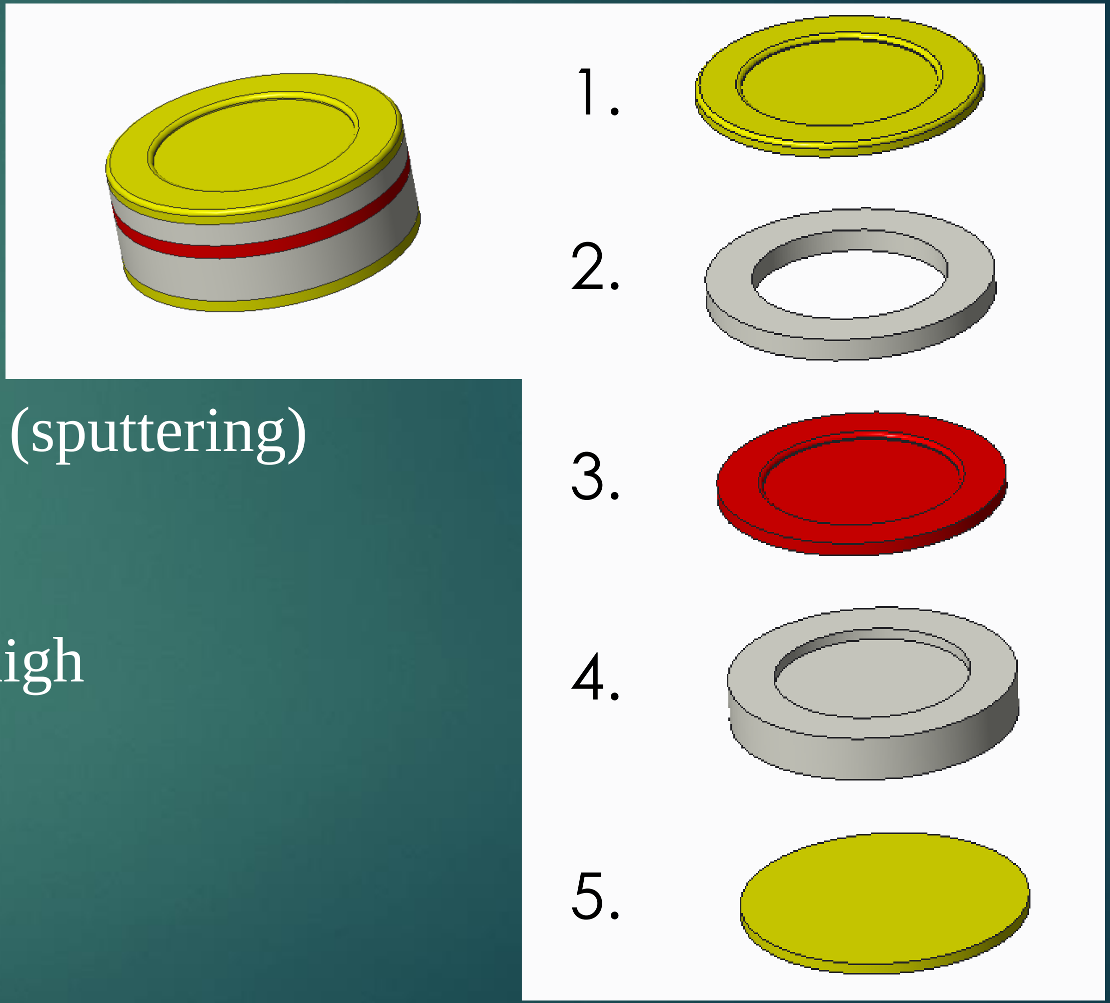

Figure 2: Displays the exploded view of the multi stage capacitor

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Multi-Stage Capacitor Design

- Cavities formed in the silica base by parabolic germanium doped etching
- Capacitor assembled in a vacuum
- Parts either fused together, or set with a UV-reactive polymer

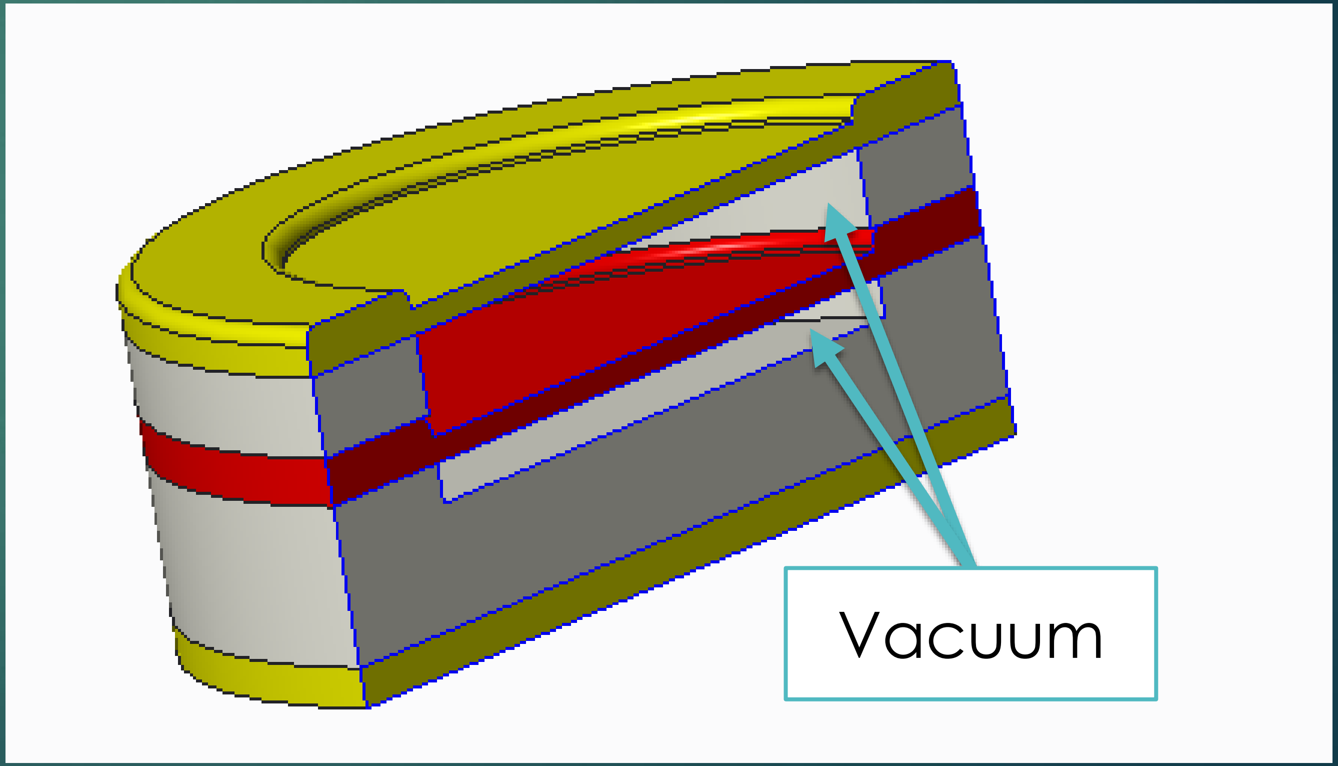

Figure 3: Multi stage capacitor cross sectional view

naNO

- Creating the nano-capacitance prototype falls outside of the time restraint and budget
- To progress with a prototype and testing, scaling must occur
- Wish to scale from 125 μm diameter diaphragm to a more pragmatic 25 mm (200x)
  - Enables the experimentation of capacitance pressure sensors in the previously shown design
  - Easier implementation with ongoing sensor research directed at temperature detection

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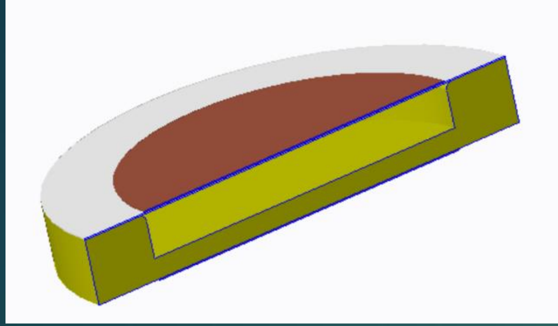

Design Calculations

Critical minimum thickness of diaphragm at given pressure (P):

$$h = \sqrt{\frac{3\pi r^2 * P}{4\pi\sigma_y}}$$

$\sigma_y = yield\ stress$

Maximum deflection at given Pressure (P) and thickness(h):

$$w_{max} = -\frac{3\pi r^2 P\left(\left(^1/_\mu\right)^2 - 1\right) r^2}{16\pi E h \left(^1/_\mu\right)^2}$$

Critical maximum body pressure at given shell thickness:

$$p = \frac{0.855}{(1-\mu^2)^{\frac{3}{4}}} * \frac{E\sqrt{\gamma}}{\left(\frac{r}{t}\right)^{\frac{5}{2}} * \frac{l}{r}}$$

$$\gamma = 1 - 0.901(1 - e^{-\phi})$$

$$\phi = \frac{1}{16}\sqrt{\frac{r}{t}}$$

$\mu = Poisson's\ Ratio$

$E = Young's\ Modulus$

$r = diaphragm\ radius$

$l = sensor\ length$

$t = shell\ thickness$

Max Pressure during liftoff ≈ 150 kPa

	Diaphragm Diameter	Min. Thickness (@150 kPa)	Design Thickness	Safety Factor	Critical Diaphragm Pressure	Maximum Deflection (@150kPa)	Shell Thickness	Critical Body Pressure
Prototype	25 mm	0.05 mm	0.10 mm	2.00	600 kPa	5.60 mm	5 mm	20 MPa
Actual Sensor	125 µm	0.25 µm	0.50 µm	2.00	600 kPa	28.0 µm	20 µm	400 MPa

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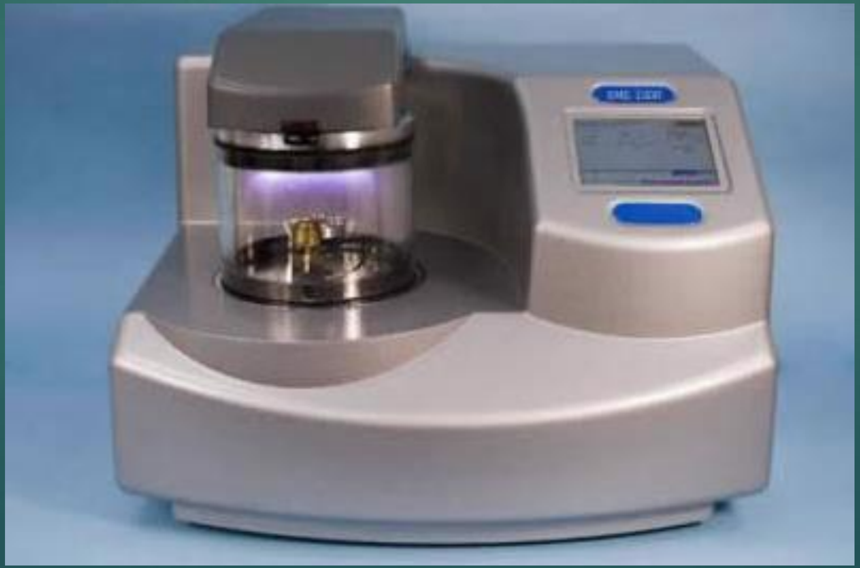
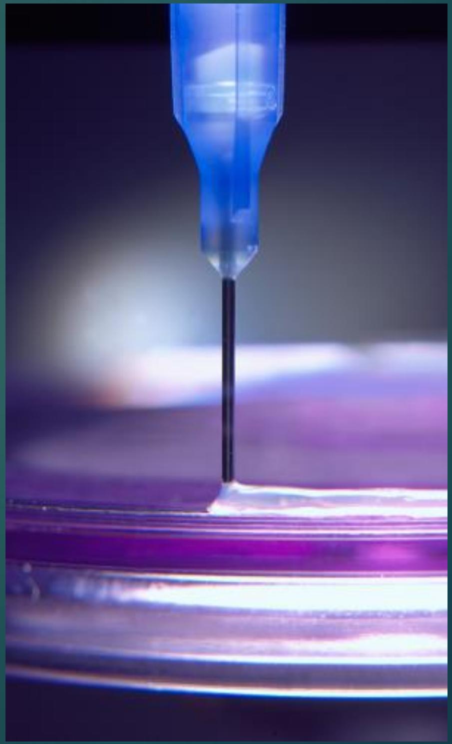
Current Production Standpoint

- Silicone diaphragm acquired (0.1mm and 0.2 mm)
- Epoxy capacitor base finished using HIPS dissolvable filament

Current Production Standpoint

- Waiting on access to SEM lab to begin sputtering tracts onto silicone
- Waiting on ordered UV polymer to adhere the diaphragm



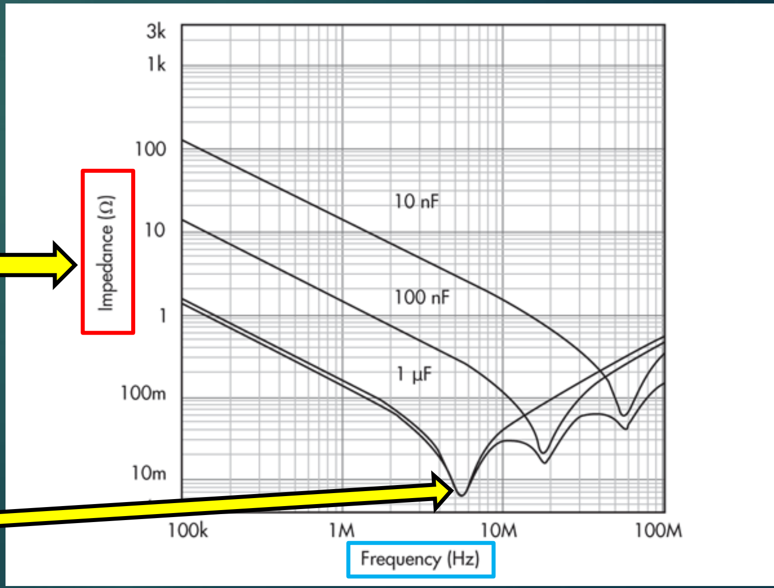


Experimental Testing

- Capacitance is a function of geometry (area and distance apart)
- Each capacitor has a resonant frequency that can be determined using a network analyzer and oscilloscope
- Network analyzer creates electromagnetic fields, which will cause voltage to oscillate in the capacitor
- Voltage read at the capacitor positive will decrease when resonance has been achieved at the dictated frequency
- Resonance becomes a function of deflection, thus a function of pressure

$$V = I * R$$

$$Voltage = f(frequency)$$
$$Frequency_R = f(deflection)$$
$$Pressure = f(deflection)$$
$$Pressure = f(frequency_R)$$



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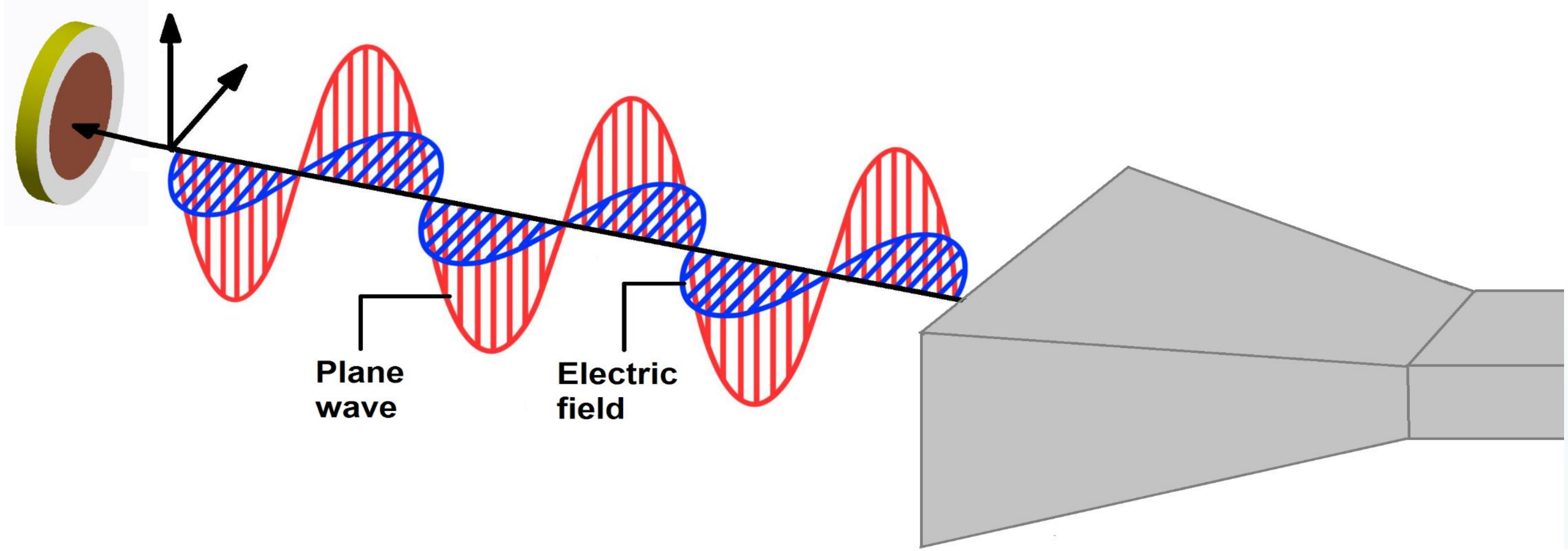
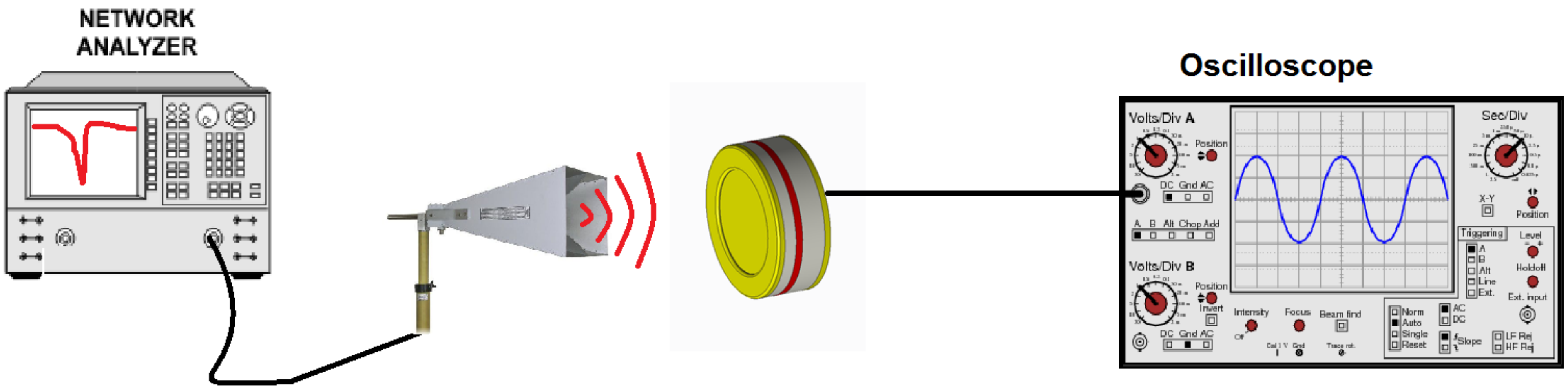
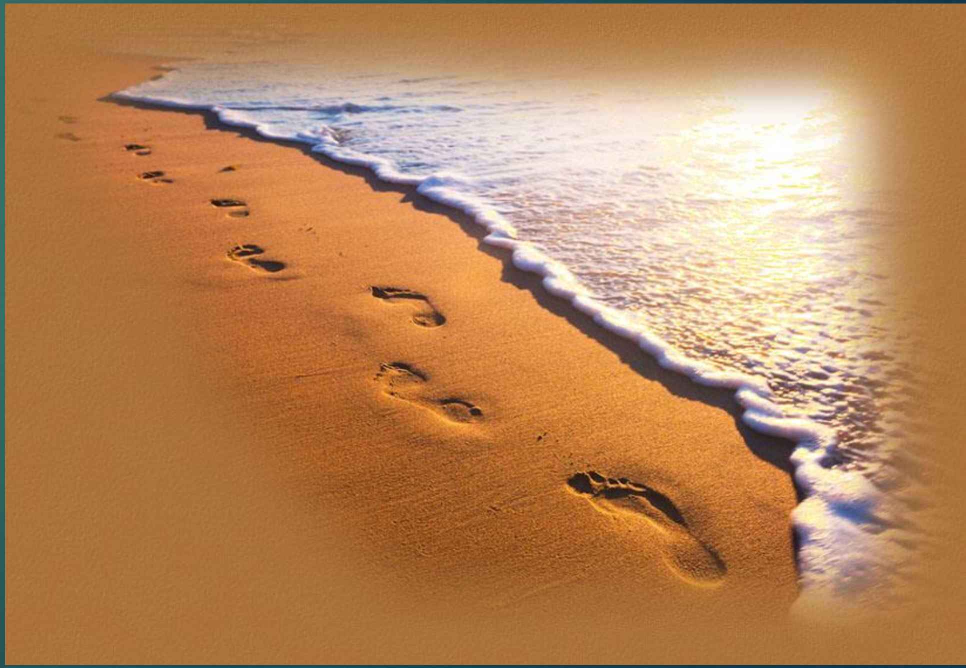

Plane
wave
Electric
field

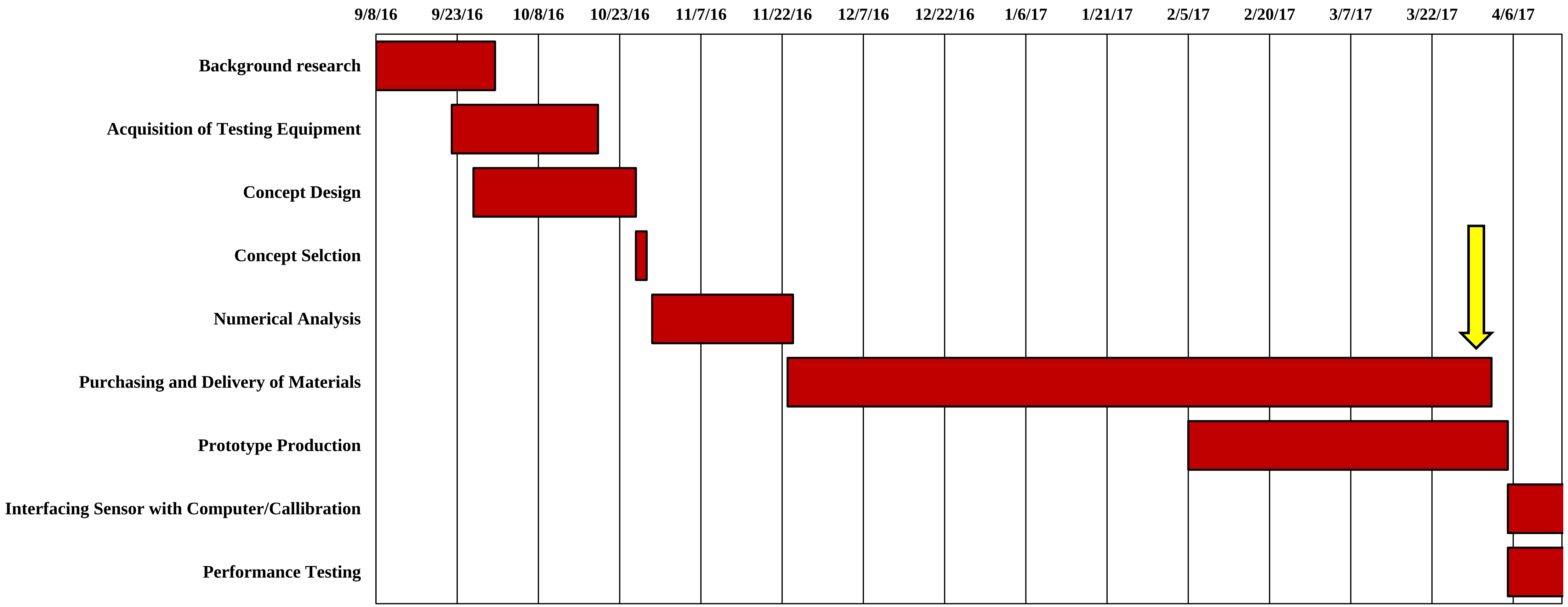

NETWORK
ANALYZER
Oscilloscope
Volts/Div A
Position
DC Gnd AC
A B Alt Chop Add
Volts/Div B
Position
Invert
DC Gnd AC
Intensity
Focus
Beam find
Sec/Div
X-Y
Position
Triggering
Level
Holdoff
Ext. input
A
B
Alt
Line
Ext.
Norm
Auto
Single
Reset
AC
DC
Slope
LF Rej
HF Rej

Future Steps

- Prototype production finalization
- Interfacing sensors with system and computer
- Calibration
- Performance testing



Updated Gantt Chart



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Questions?