Tracking High Velocity Metal Objects

Tracking Metal Projectiles in Replicated Extreme Testing Conditions

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Introduction

- Replicating the mechanical environment in which MEMS devices (microelectromechanical systems) are exposed requires extreme test strategies
- Acceleration levels in excess of 10,000 g's are normal conditions for today's MEMS applications. Reliable and repeatable experimental generation of high-g shock environments is a long-standing problem which faces significant difficulty.
- Typical pneumatic launchers in use today launch projectiles at velocities greater than 100 mph and capture velocity data utilizing LED "light screens" and break circuits
- Tracking and recording data from high velocity objects is a difficult task, especially when the object is out of view during part of its flight
- The methods proposed for high velocity projectile tracking utilize electromagnetic wave radar technology, and magnetic based induction sensors
- These sensors are not affected by gas flow, particle showers, etc. that often accompany a projectile downrange making them ideal for projectile detection/velocity measurements

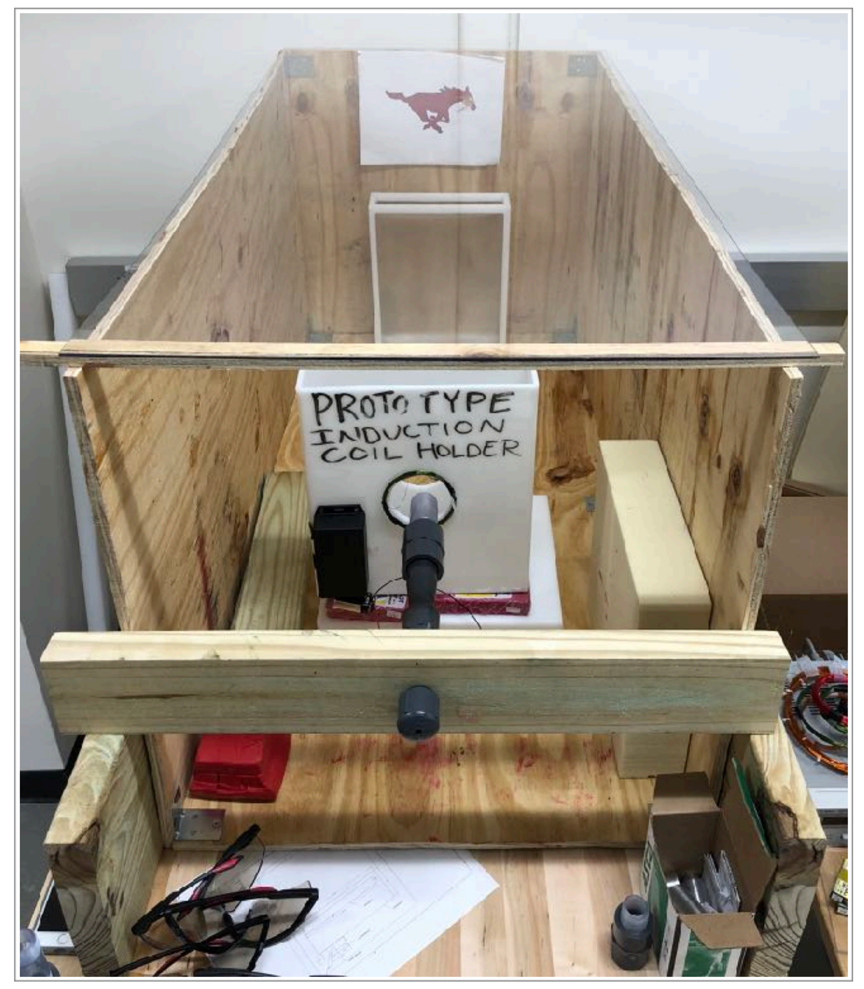

Image 1: Target Practice with a Custom Bench-top Testing Range

Methodology

Goal: Demonstrate proof of concept for electromagnetic wave radar technology and magnetic based induction coil sensors. Set up a small bench-top testing area, test technology, analyze the results, and make modifications to optimize the systems.

- The bench-top testing setup was created to simulate low velocity launches
- A clear PVC pipe and shop air located in the senior design room were used to launch the projectile
- This setup was used to determine if induction coils and radar could become viable options for tracking the projectile at higher velocities
- Faraday's Law was demonstrated during the low velocity launches
- When the projectile passes through the center of the coil, a distinctive shift in frequency is realized, monitoring this frequency shift in real time allows for accurate projectile tracking through the catchbox
- To determine the optimum coil parameters; number of turns, wire gage, & diameter, a testing matrix was developed to test several coils with various parameters
- Small magnets were added to the projectiles in an attempt to induce larger frequency shifts
- Resistor and capacitor values were varied in the induction coil sensor circuit to experiment with changing time constants
- Each of these coils were individually tested to determine which gave the largest shift in frequency when the projectile passed through it

Image 4: Enameled Copper Wire Induction Coils of Various Diameters

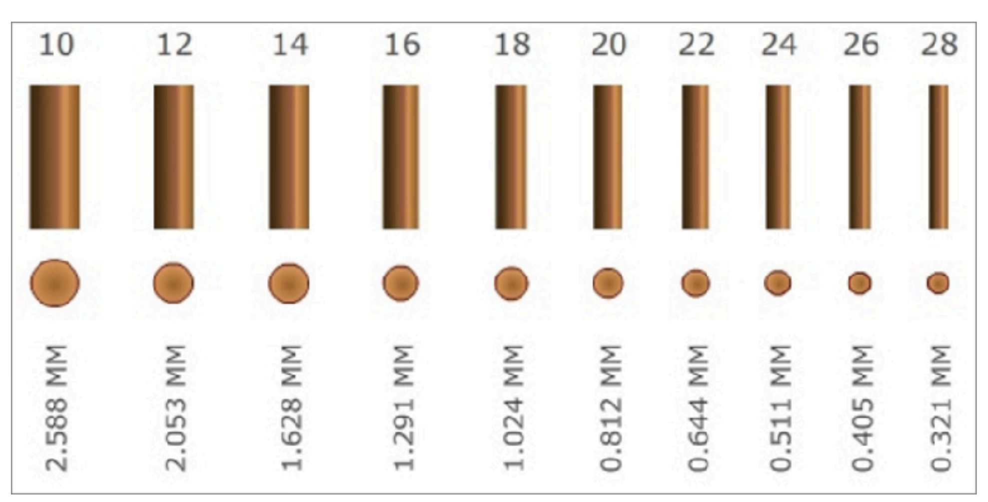

Image 5: Wire Thickness Relation to Gage (AWG) Number

Physical Theory

Induction Coils:
- Magnetic flux from the induction coil is radiated, hits the aluminum projectile and induces an eddy current
- Advantages of Aluminum
  - Aluminum is paramagnetic and has a small susceptibility
  - Aluminum is conductive
- Faraday's Law: ε **= dϕ/dt,** the change in flux will result in a change in current and frequency shift.This signifies the proximity of the projectile to the coil

Radar Technology:
- Millimeter Wave Radar is a class of radar that transmits millimeter wavelength electromagnetic waves
- After transmitting and hitting an object, reflected millimeter waves that are received allow radar to determine range, velocity, & angle
- TI mmWave radar uses a chirp signal which increases frequency from 77GHz to 81GHz each pulse and then repeats
- Chirp signal or frequency-modulated continuous wave (FMCW) allows for range, velocity, & angle to be determined through a number of calculations including Fast Fourier Transform (FFT)

References: (Image 2) http://www.learningaboutelectronics.com/Articles/555-timer-pinout.php; (Image 5) https://learn.sparkfun.com/tutorials/working-with-wire/wire-thickness; http://www.ti.com/lit/wp/spyy005/spyy005.pdf; http://www.ti.com/lit/wp/spyy005/spyy005.pdf

Concept Development

Induction Coils

Materials Used in Testing

- Mini Bread Boards
- Coaxial Cables with BNC male to alligator clip adaptor
- 9 Volt Batteries
- Circuit Components: resistors, capacitors, 555 IC Timer chips, mini circuit speakers, LEDs
- Different gauge enameled copper wires ranging from 16 - 28 gauge
- PicoScope 4000 Series and accompanying software
- Oscilloscope
- Coil enclosures and clamps

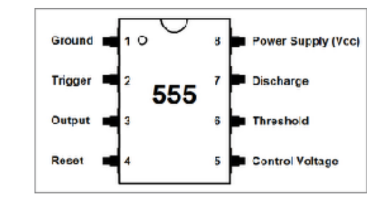

Image 2: 555 IC Chip

Image 3: Circuit Components

Testing Procedures

- Power Supply: 9 Volt Battery
- Apply circuit to oscillate our signal
- 8 ohm resisters are used in place of the 8 ohm speakers for user comfort
- Make Coils the smallest allowable diameter of 3.5"
- Vary the gauge of wires used to make the coils and the number of turns
- Coil Set down on and flush with Flat Surface
  - Projectile is made of aluminum placing nose down into the center of the coil
  - Scope probes are connected across the coil leads
  - Use PicoScope to Quantify Frequency Shift as a Result of Changed Parameters
- Record results and compare
- Strategically change values of resistors & capacitors in the circuit to see potential changes in sinusoidal voltage signal outputs
- Add magnets to the projectile to see if they aid in increasing frequency shift
- Simulate the Circuit using LTSpice Software

Radar Tracking

Technology Tested

- IWR1642Boost: an evaluation board for the IWR1642 mmWave sensor. This pack has everything required to communicate with TI's mmWave Demo Visualizer software.
- mmWave DevPack: Add-on board that can be used with the mmWave EVMs to enable next-level device performance.
- Data Capture/ Pattern Generator: Allows for evaluation of high speed ADC and DAC data and the module's full data rate.
- mmWave Software Development Kit (SDK): This software package allows for evaluation, data recording, programming, and running the mmWave Demo Visualizer.

Testing Procedures

- Test 1: The goal of this test was to detect an aluminum plate at various distances (between 1-5m) and compare the range measured by a tape measure and by the radar. The distances were then compared using percent error analysis.
- Test 2: Next, the radar was tested to see if it could pick up an aluminum projectile. Both hollow projectiles and solid projectiles were tested for range accuracy and evaluated using a percent error.
- Test 3: Foams of varying density were placed in front of the projectile to see if the radar could detect the projectile's range accurately. This range data was again compared with tape measurements using a percent error analysis.
- Test 4: For dynamic testing, the mmWave radar was tested using the velocity resolution setting and a projectile was swung in a pendulum type motion in front of the radar. The goal being that the projectile can be detected, plus measuring its range and velocity.

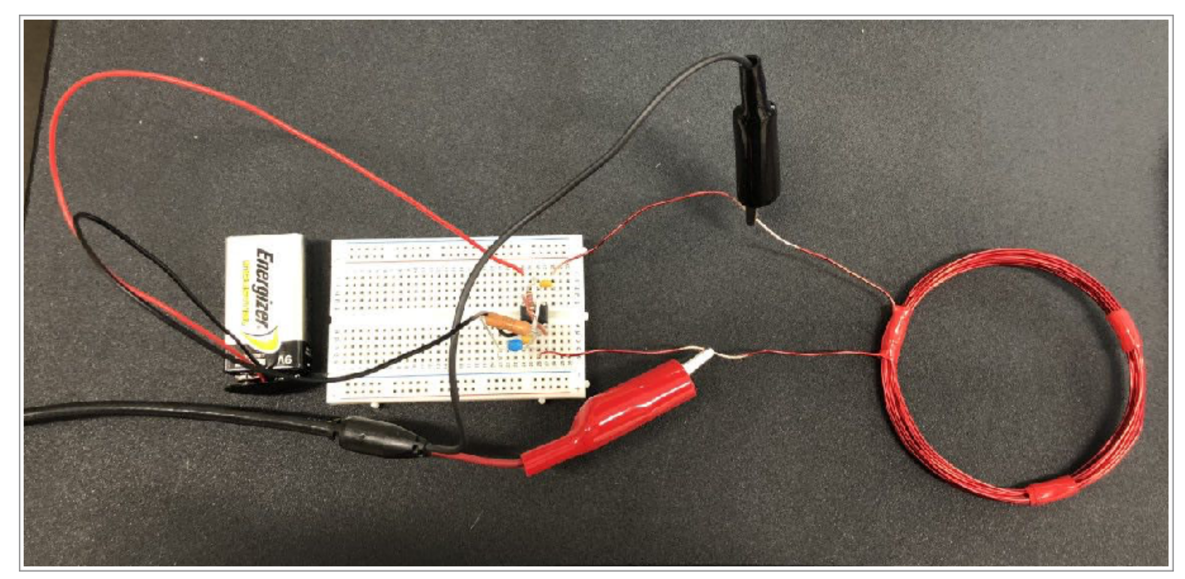

Image 6: Image of Induction Coil, Circuit, 9 V Battery, & Oscilloscope Leads

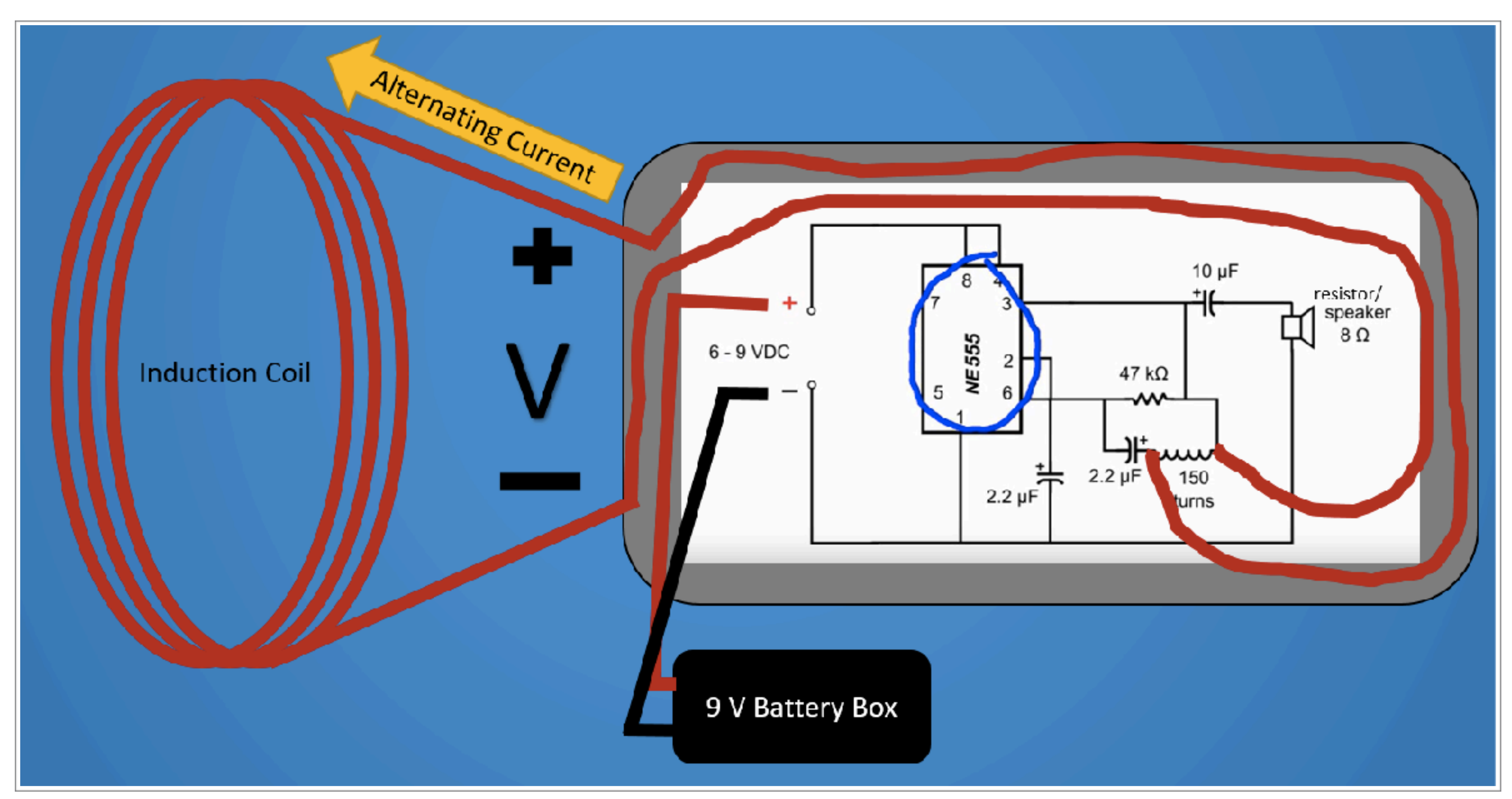

Image 7: Schematic & Configuration for Custom Induction Coil Design

Results

- **Induction Coils:**
- The induction coils successfully detect the projectile at high velocities
- Discovery of certain aspects have resulted in larger frequency shifts to make the projectile easier to detect:
  - The faster the projectile travels, the larger the frequency shift because of Faraday's law: ε = dϕ/dt
  - The more hollow the projectile, the larger the frequency shift due to the eddy currents being concentrated to the outer ring of the projectile
  - Smaller coil diameter, smaller gauge wire, smaller number of turns up to a certain threshold, and when projectile is placed closer to the edge of the coil
  - The smaller the self inductance of the coil, the larger the resonance frequency and sensitivity, $\omega = 1/\sqrt{L}$
- **Radar:**
- mmWave radar technology proved to be able to detect small aluminum objects
- The mmWave radar was able to provide excellent range resolution (In most cases +/- 2% error)
- Using the mmWave radar, projectiles were accurately detected behind foam blocks
- The mmWave radar was also able to track the range and velocity of the swinging projectile

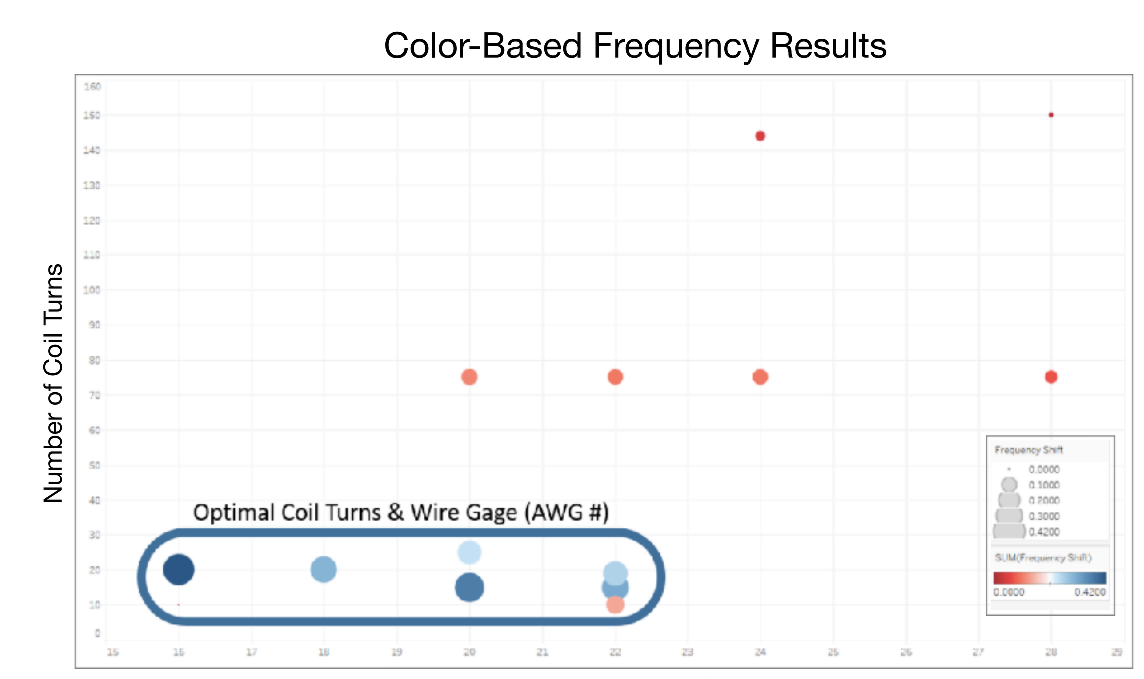

Image 8: Plot of Number of Turns versus Gage (AWG)