Source: www.mwftr.com/charlesk.html

Arcing Fault Detection with Experimental Verification using Antenna for Signal Capture of Radiated Electromagnetic Energy

Charles Kim and Robert Sowah
Department of Electrical and Computer Engineering
Howard University
Washington, DC

Outline

- Arcing Faults
- Arcing Fault Models
- Experiments with Staged Arcs/Sparks
- Experimental Results
- Conclusions
- Q & A

Arcing Faults

- Main Electrical Distribution Panels and Wires
  - Fire 3/year in submarine fleet.
  - Mission abortion 271 Air Force Aircraft Mishaps (10 year period)
  - Loss of Life
    - Swiss Air 111
    - Fires and possibly explosion by arc and spark ← TWA 800
  - Quick start and fast spread into big damage

Turbine Gen. Switchboard.

1975.

Arc Damage sustained on USS Parche (SSN 683)

Some of the copper bus, cables, insulators, and board are missing

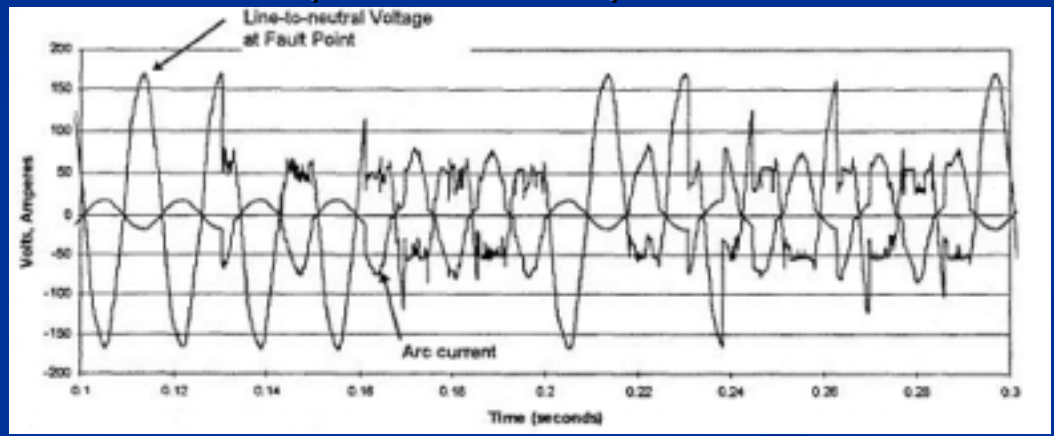
Arcing Faults

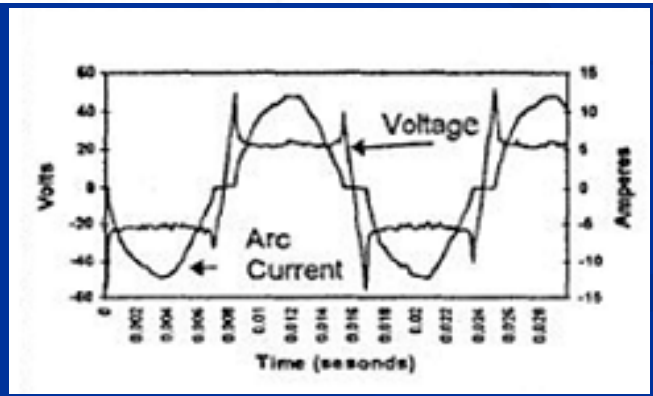
- Arc current is determined by the arc resistance and the impedance of the return path --- usually low
- Low arc current is not sufficient to trip circuit breaker
- Faulty connections due to corrosion etc cause most of arcs.

Arcing from wiring of the in-flight entertainment network did not trip the circuit breakers but ignited flammable covering on insulation blankets and quickly spread across other flammable materials. The crew did not recognize that a fire had

Arcing Fault Current and Voltage

- Characteristics of arc current
  - discontinuous, nonlinear, and non-sinusoidal

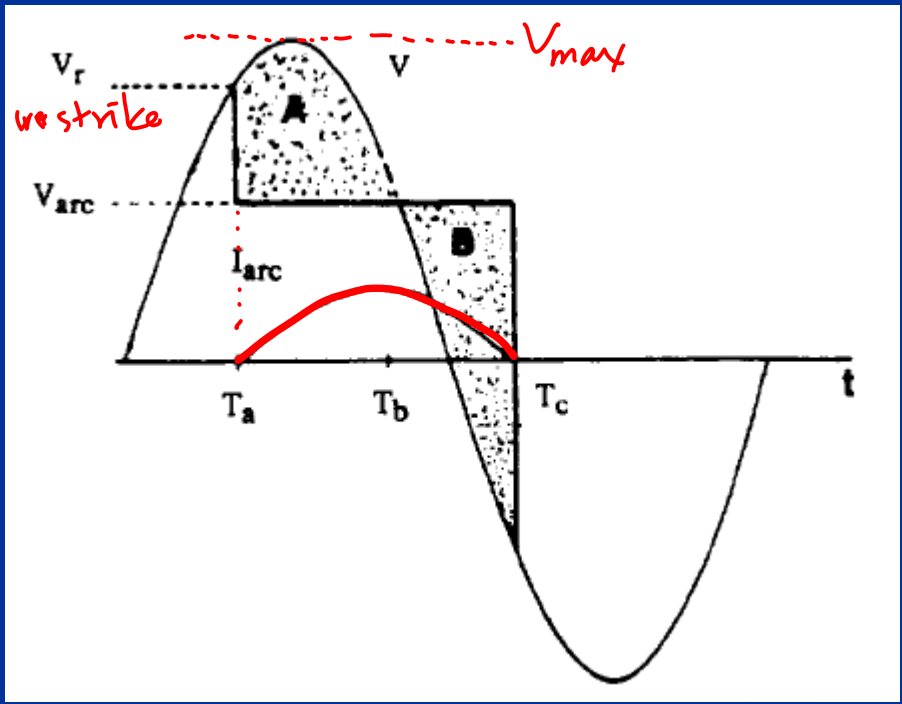




Arcing Fault Models

- Instantaneous arc current model
  - Relying on inductive circuit
  - Energy balance
  - Flat-topped voltage

$$i_{arc} = \int_{t=t_a}^{t} (V_{\max} \cos wt - V_{arc})dt \quad \text{where} \quad t_a = \frac{1}{w}\arcsin\left(\frac{V_{restrike}}{V_{\max}}\right)$$



$$V_{\max}\sin\omega t = i_{arc}R + L\frac{di_{arc}}{dt} + (20+534g)i_{arc}^{k}$$

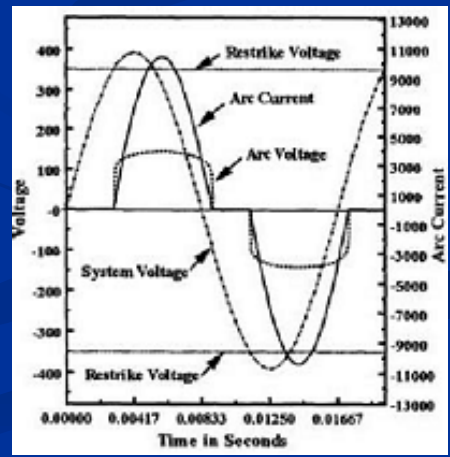
k

∝ Luminance of arc

g: arc conductance

∝

{ voltage, current, arc medium }



Arcing Fault Models

- Arc Conductance Model
  - Relation of Arc Conductance with Arc Voltage and Arc Time
  - Developed for Arc Circuit Breaker Interruption
  - Based on common property that Arc Current depends on Line Impedance (X/R ratio) and Arc Gap

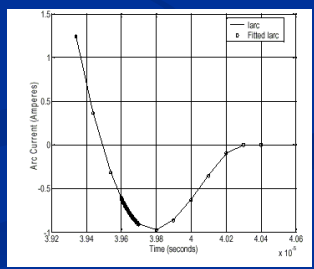
Mayr arc model :

$$\frac{1}{g}\frac{dg}{dt} = \frac{d\ln g}{dt} = \frac{1}{\tau}\left(\frac{ui}{P} - 1\right)$$

Cassie arc model:

$$\frac{1}{g}\frac{dg}{dt} = \frac{d\ln g}{dt} = \frac{1}{\tau}\left(\frac{u^2}{U_c^2} - 1\right)$$

g: arc conductance
u: arc voltage
i: arc current
P: cooling power of arc (arc loss constant)
τ: arc time constant
U_c: constant arc voltage



Arcing Fault Models

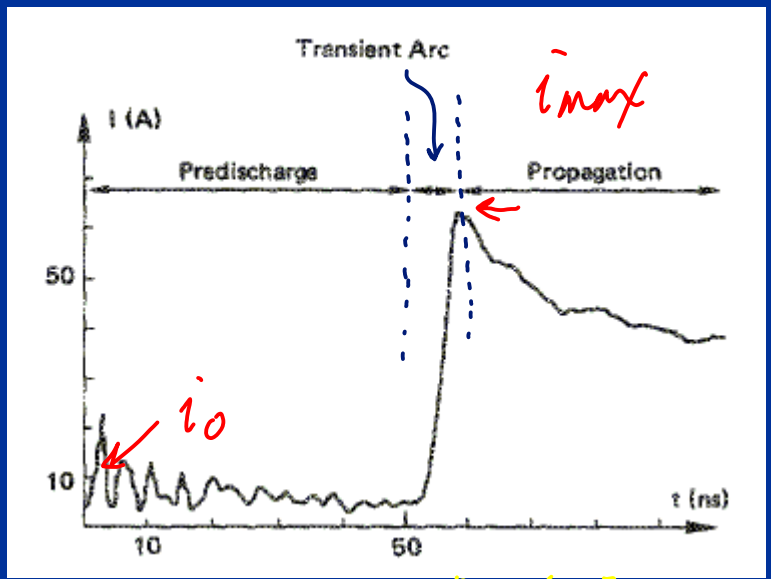
- Electromagnetic Energy Radiation Model
  - Rompe and Weisel's Conductivity Law
  - Heat, Sound, and EM Wave from Arcing
  - Radiated EM energy from arcing source
  - The transient current determines the intensity and spectral content of the radiation
  - Three Phases
    - Breakdown Phase ---Pre-Discharge
    - Strong Ionization -- Transient Arc Phase
    - Conductive channel development

$$E_{rad}(R,t) = \frac{\sin\theta}{4\pi\varepsilon_o Rc^2} v\Delta i$$

EM Energy Radiation Model –and surface discharge case with DC source

$$E_{rad}(R,t) = \frac{\sin\theta}{4\pi\varepsilon_o Rc^2} v\Delta i$$

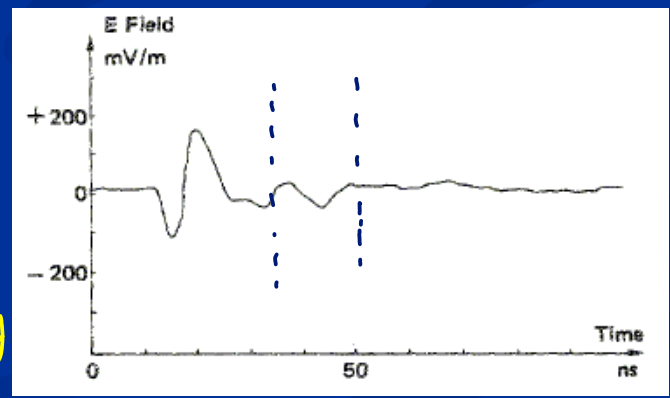
R : distance
θ : angle between current direction and R vector
c : velocity of light
i_{max} : peak current at the beginning of propagation
i_o : current associated with primary breakdown



Ref. [10]

$\Delta i = i_{max} - i_o$

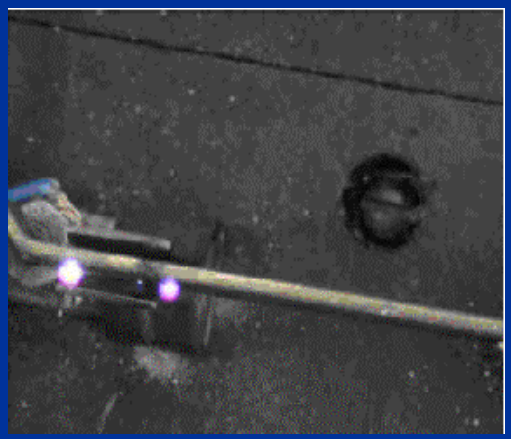
ε_o : permittivity

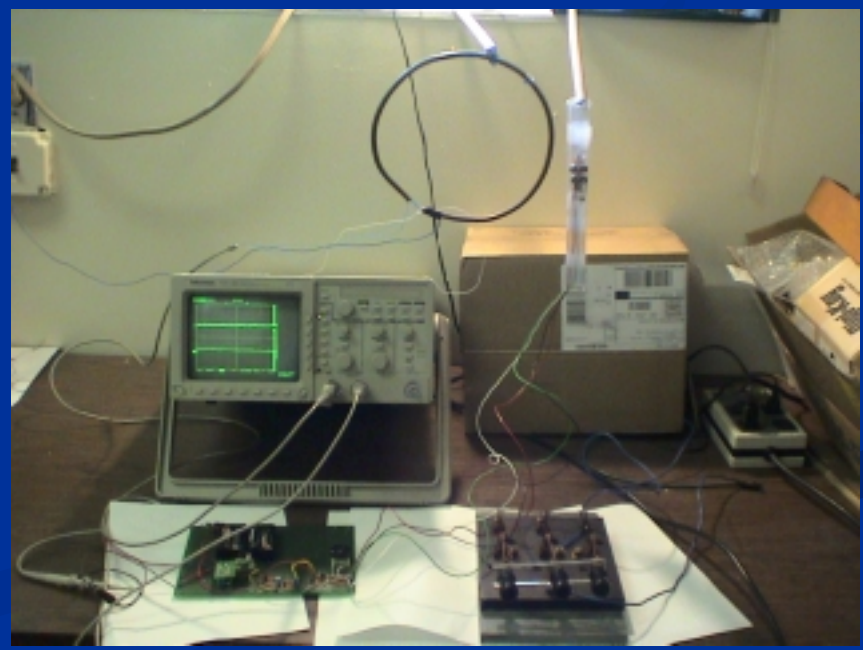


Ref. [10]

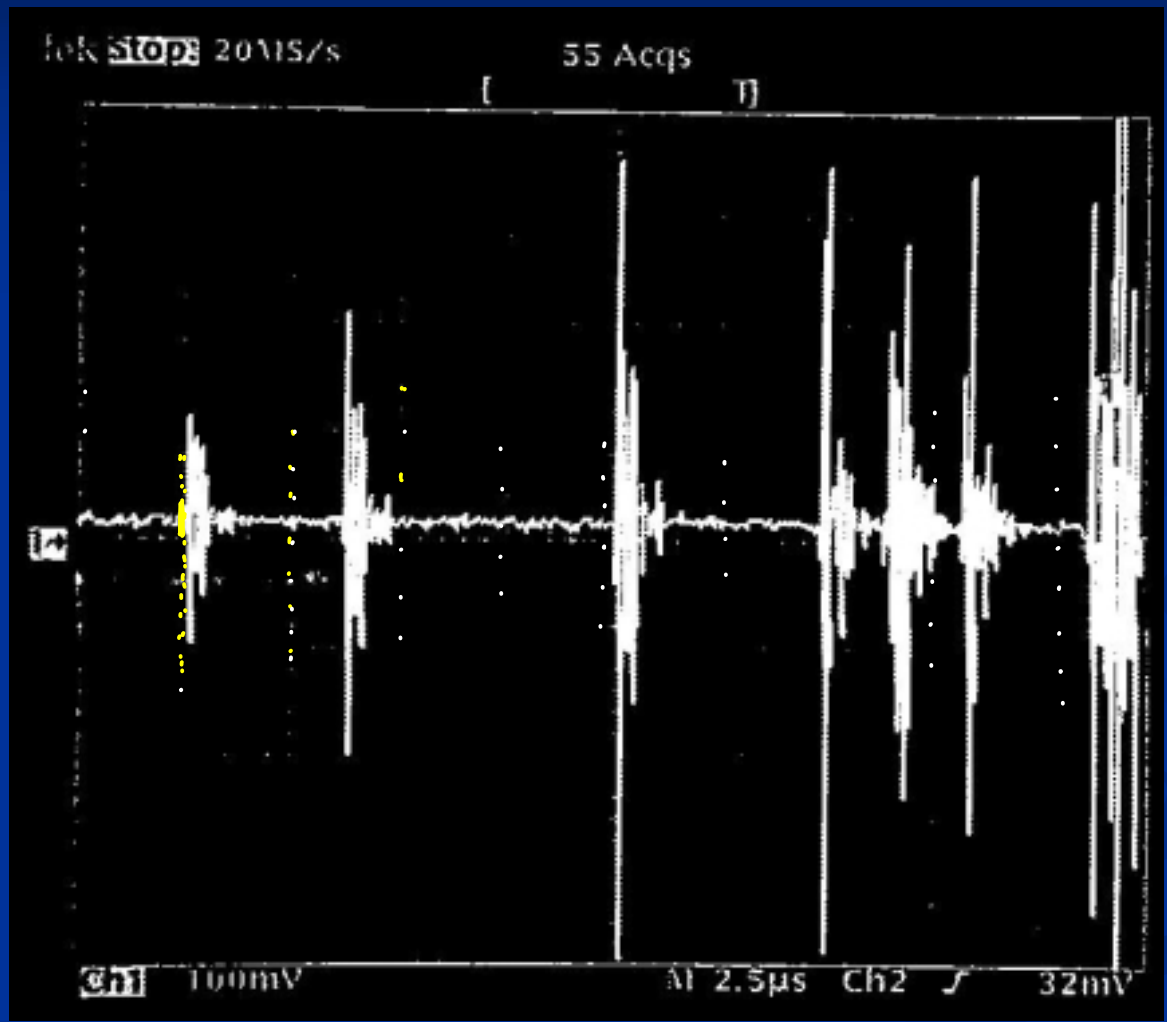
Experimental Setup

- Experiment Focus
  - Detection of two types of spectrum -- for first 2 phases of the radiation
- Antennas (in-house)
  - Loop Antenna - Air Core ~MHz band
  - Stick Antenna - AM/FM Band
- Arc/Spark Generator
  - Knife Switch

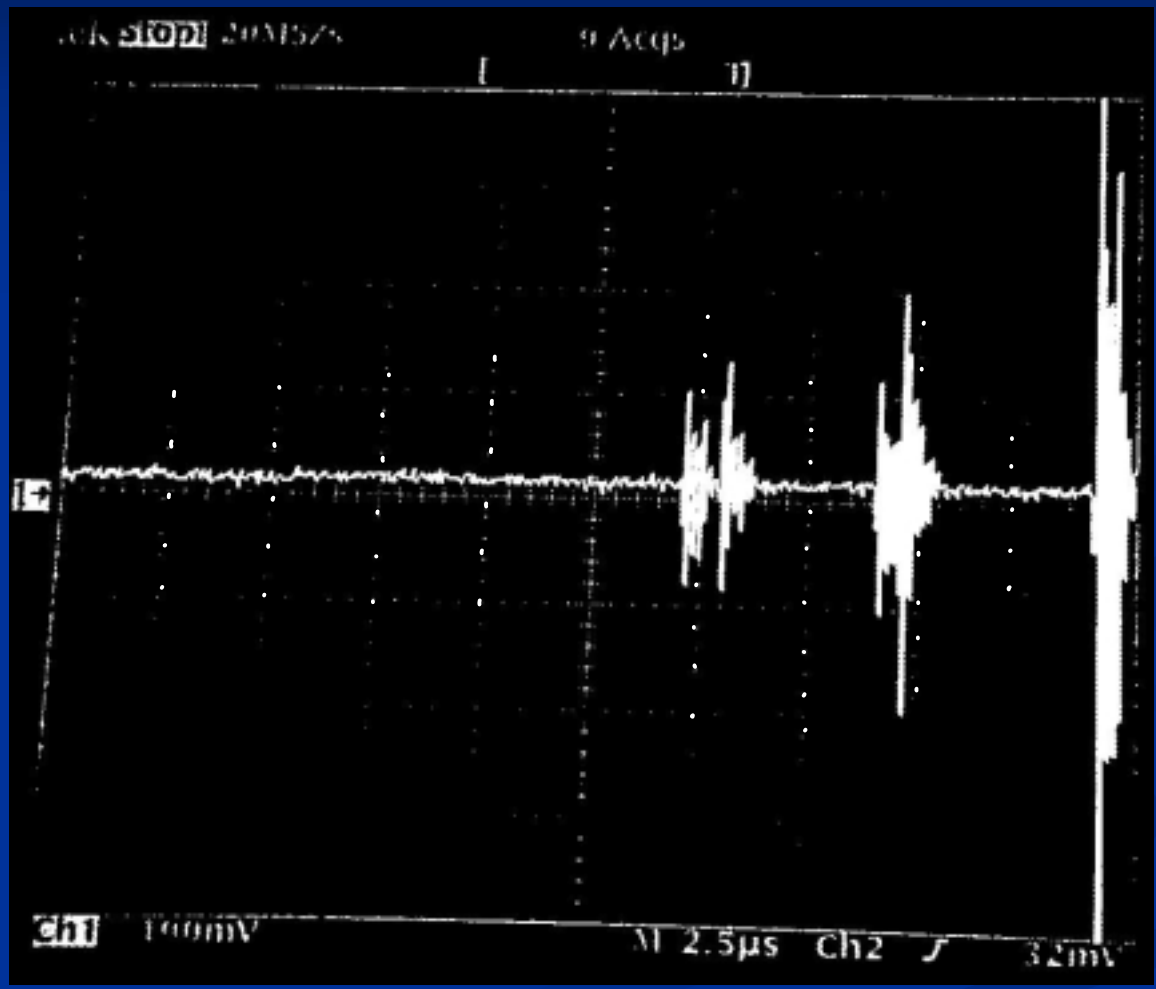




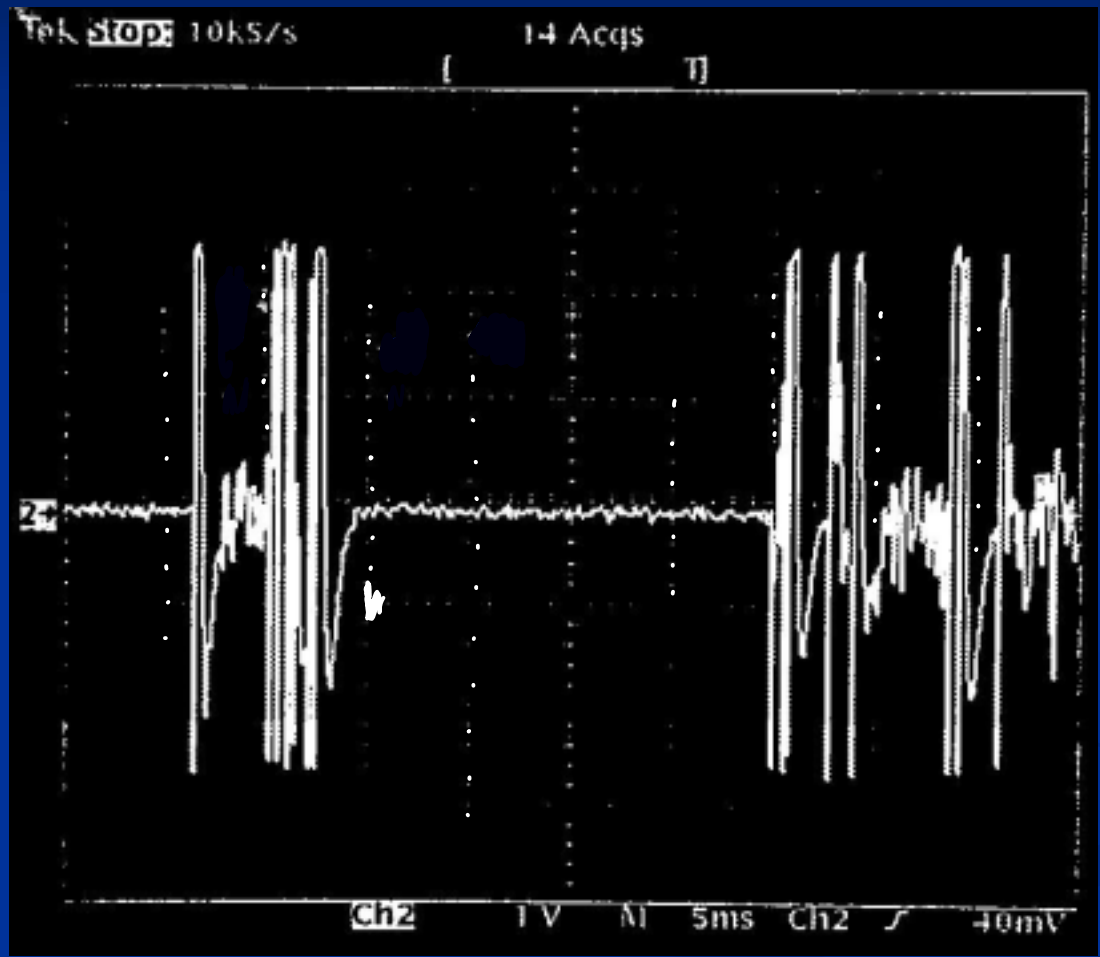
Captured Signals - Loop Antenna



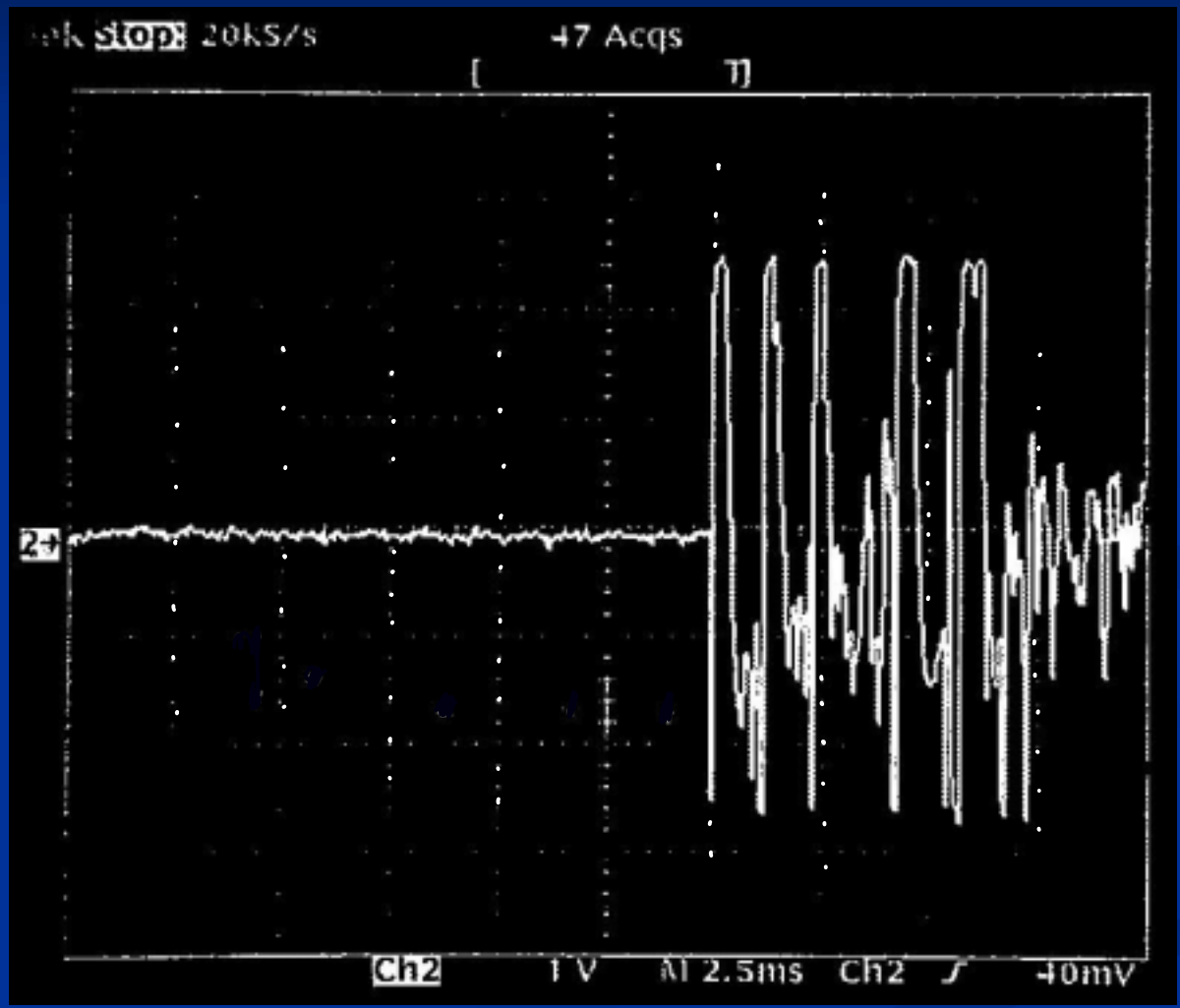
Captured Signals - Loop Antenna



Captured Signals - Stick Antenna

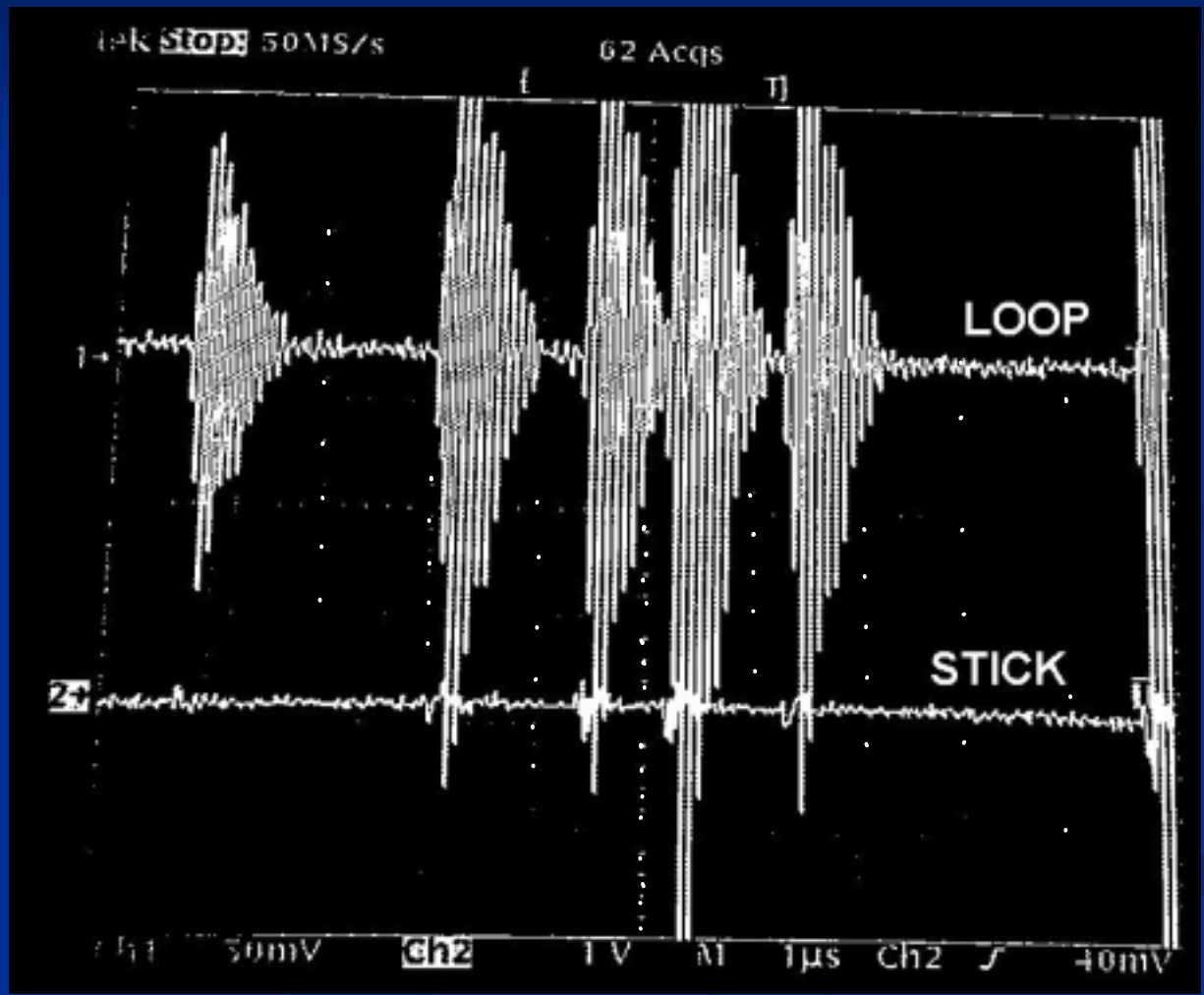


Captured Signals - Stick Antenna



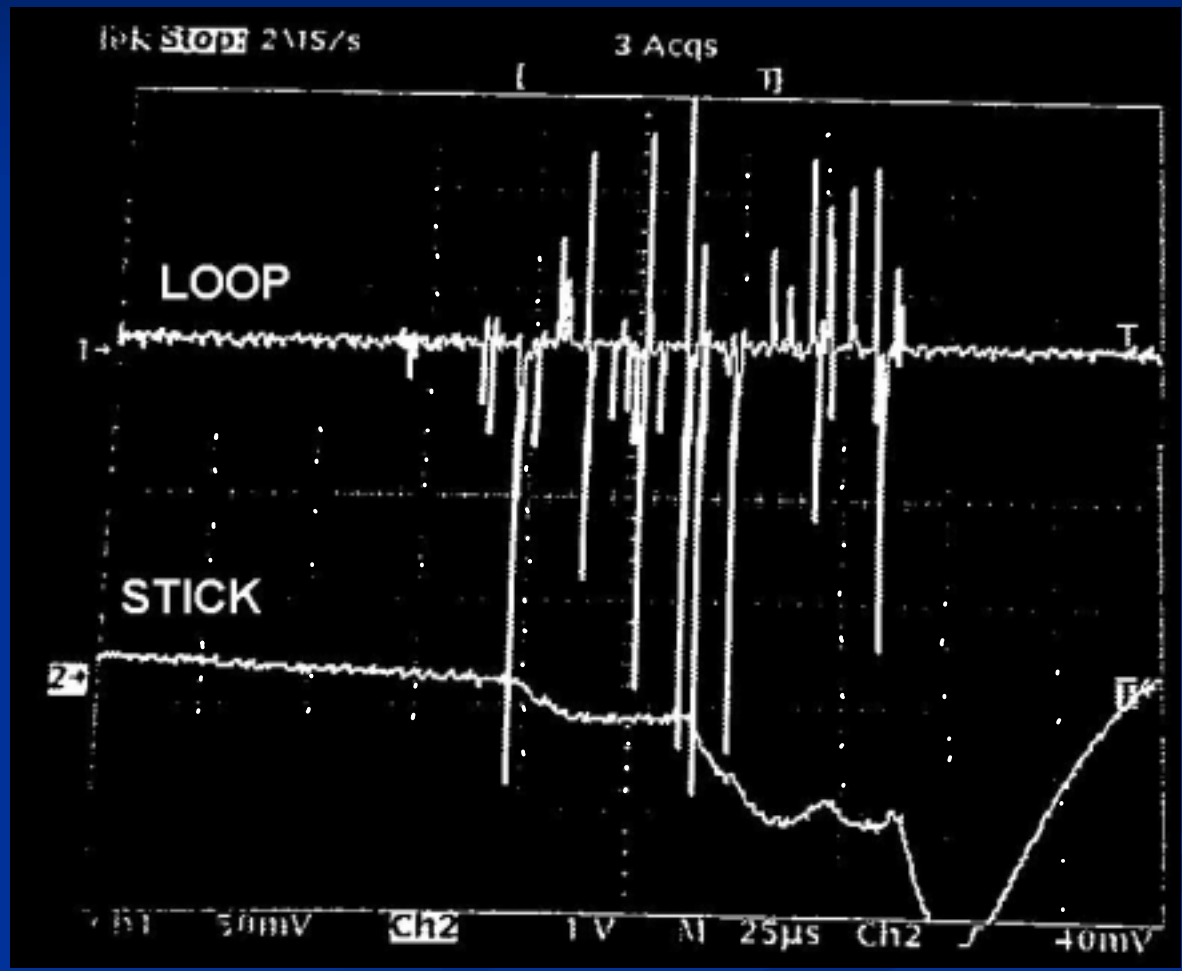
Captured Signals - Comparison

- Frequency



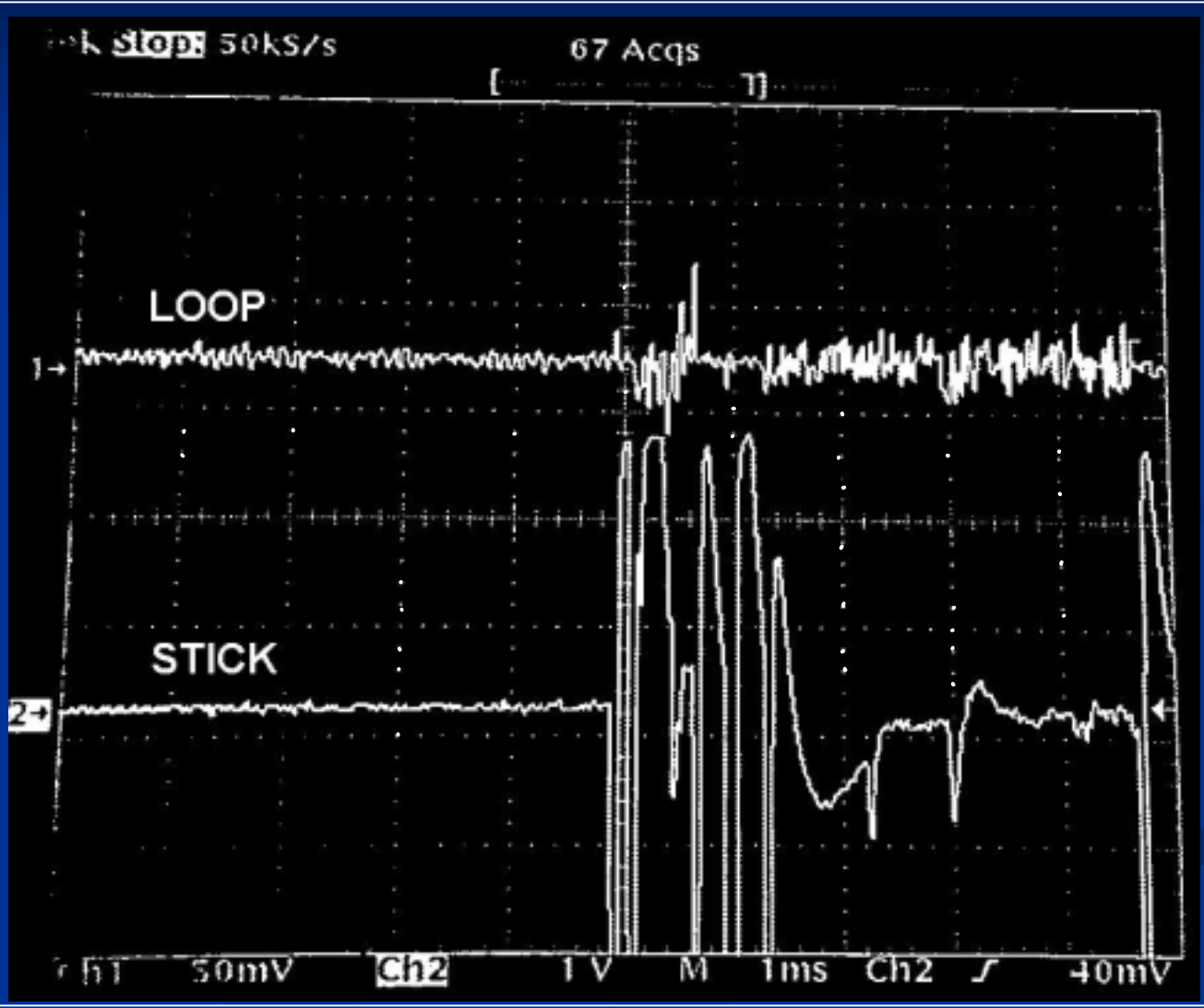
Captured Signals - Comparison

- Frequency



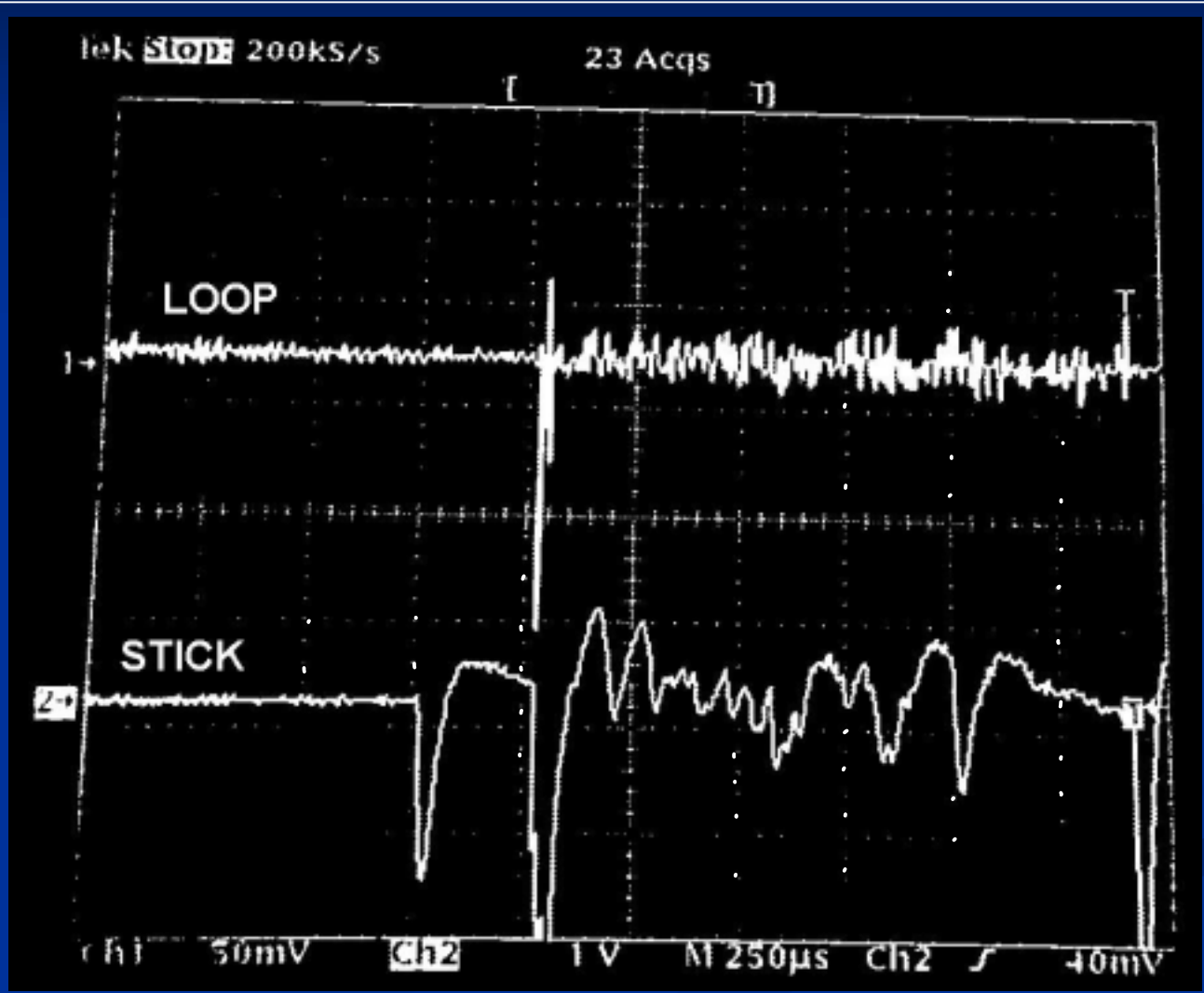
Captured Signals - Comparison

- Arrival



Captured Signals - Comparison

- Arrival



Discussions

- Different Frequency Sensitivity of Antennas
- Different behavior of Two Frequency Bands
- Slight Different Arrivals of the Bands
- Antennas in tandem capture the distinctive frequency feature of arc (model)

Conclusions

- EM Energy Radiation Model is adopted for the study on detection of arcs
- Experiments are performed with Loop and Stick antennas for different spectral features of two phases of arc development
- Differences are observed and captured
- Only preliminary testing
  - Further experimental investigation is needed
  - Refinement of hardware and tools are needed
  - Discriminative investigation is needed using devices, if any, with similar radiation energy during normal operation

Q&A

Questions?

- Contact:
  - Charles Kim, Ph.D.
  - ckim@howard.edu