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Characterization of P-static for Antenna and Receiver Design Standards

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Robert Erikson, Federal Aviation Administration

FAA Cooperative Agreements 04-G-040, 06-G-001

October 28, 2008

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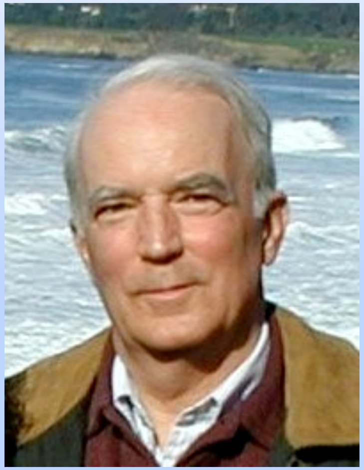
Who we are…



- Engineer, Consultant
- Aviation Management Associates, Inc., Virginia, USA
- Formerly Northrop Grumman, Illgen Simulation, Ohio University
- 22 years as commercial/instrument pilot
- **robert.lilley@avmgt.com**

- Engineer, FAA Loran Systems Test Director
- Research and Technology Development
- FAA, at the W.J. Hughes Technical Center, New Jersey, USA
- Engineering Development Services
- Navigation Team (AJP-652)
- **robert.erikson@faa.gov**

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P-static

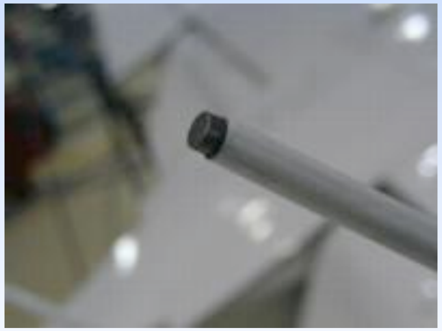
…the root cause

- **All aircraft charge in flight.**
  - Impact – snow, rain, dust
    - Frontal area, speed, weather
  - Engine ion production
    - Friction, against engine parts
- **Experience**
  - Snow impact glow
  - OAT spark

P-static

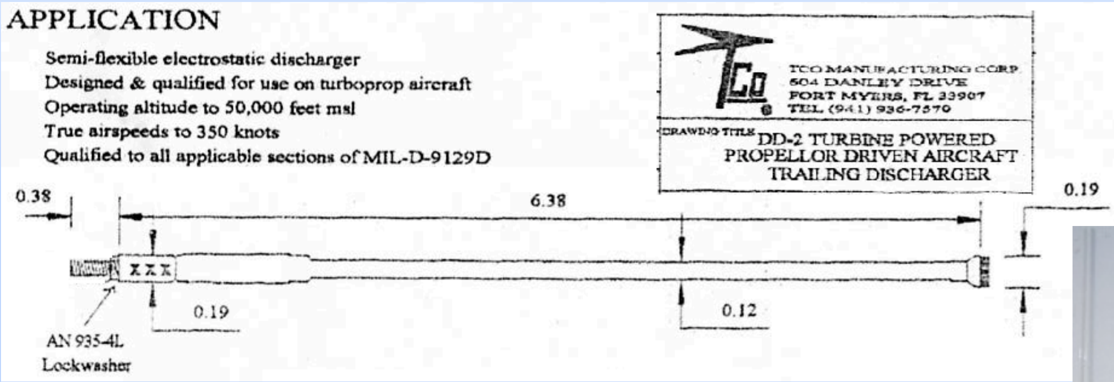
…the culprits

- **Discharge Mechanisms**
  - Arcs
    - Equalizing potential among airframe elements
      - Maintenance – bonding, loose rivets, bad antenna mount, corrosion
  - Streamers
    - Draining stored charge from dielectric surfaces
      - Maintenance – resistive coatings, windscreen glue bypass
  - Corona
    - Equalizing airframe and atmosphere
      - Maintenance – dischargers burnt, broken; antenna coatings pinholed, sharp points uncoated.



P-static

…stored charge reduction



ASA-3 discharger
-Same goal,
different design
-Resistive wicks

TCO DD-2 discharger

- -Low noise, efficient discharge at low corona threshold.
- -Resistive; forms filter with a/c capacitance
- -4µ wires

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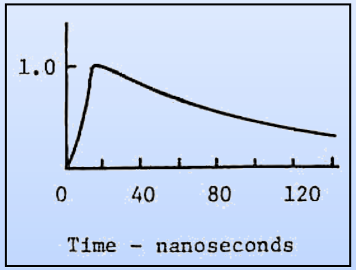
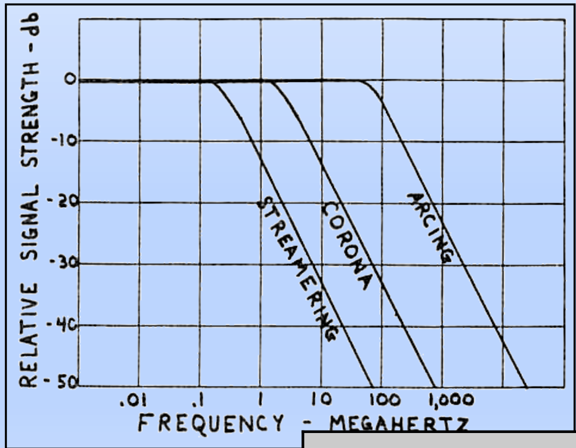
Corona – Since 1982…

…and a lot earlier



Each individual arc, streamer or corona pulse…



…produces a momentary wideband spectrum…

…which, when repeated at short intervals, reduces the signal-to-noise ratio in the loran band.

Noise @ 100 µA	DC-3	Saratoga	Aero Cmdr
Bare aircraft	33.9 dB	28.1 dB	24.0 dB
With dischargers	4.5 dB	2.6 dB	1.0 dB
Difference	**29.4dB**	**25.5 dB**	**23.0 dB**
Ground test corona p-static noise at Loran frequency: -100 µA current, e-field antenna.			

The p-static effects

…air and ground tests agree

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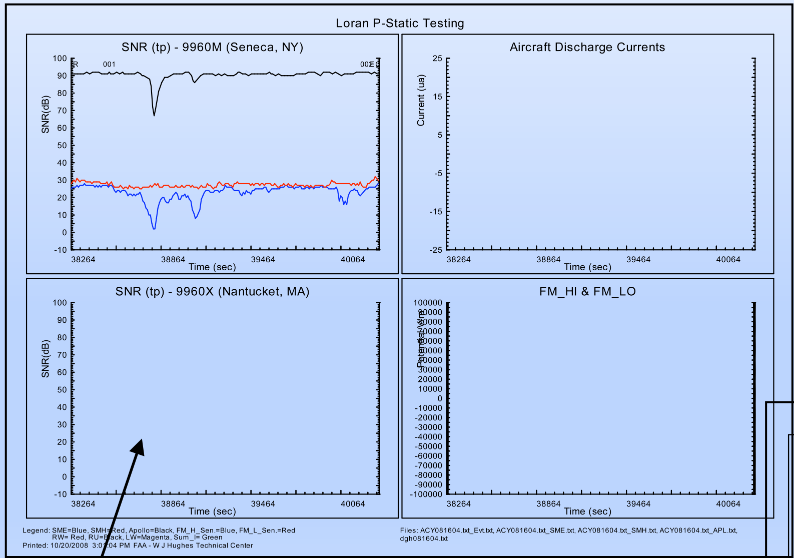
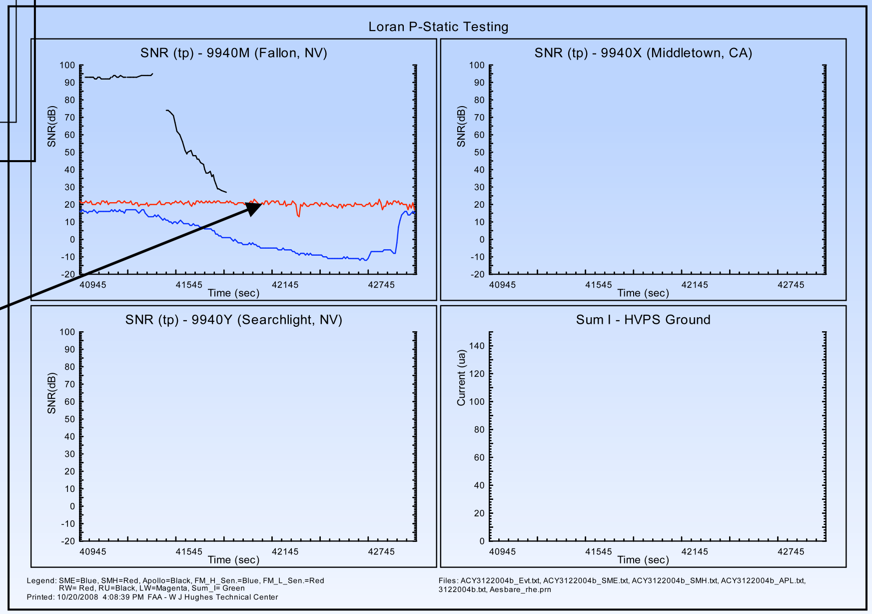


Three receivers, in flight and in the lab.

Black – legacy, hard-limited receiver
Red – linear averaging receiver, H-field antenna
Blue – linear averaging receiver, E-field antenna



H-field antennas do discriminate against p-static noise:

In flight – and in the lab

But why – and are there surprises in the details?

The FAA High Voltage Laboratory –

…up and running

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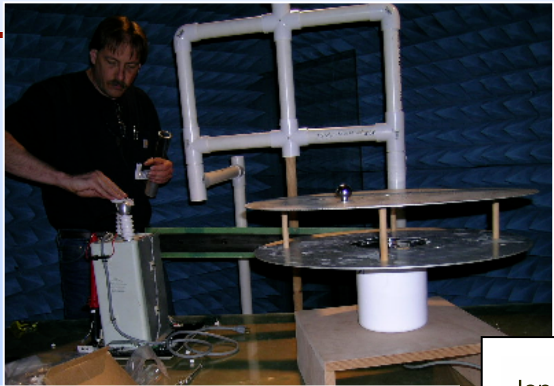

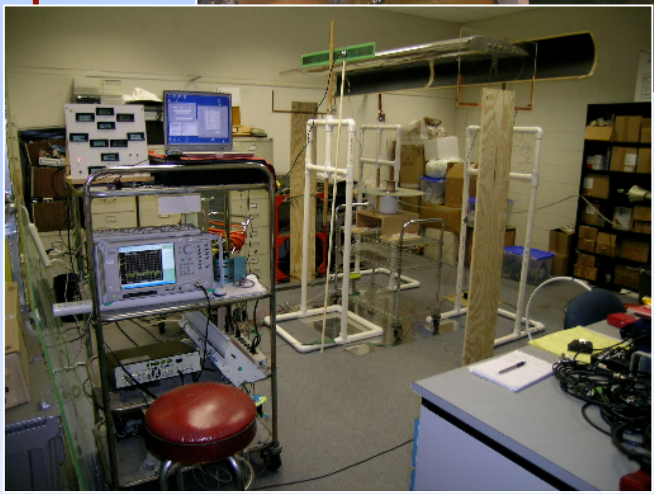

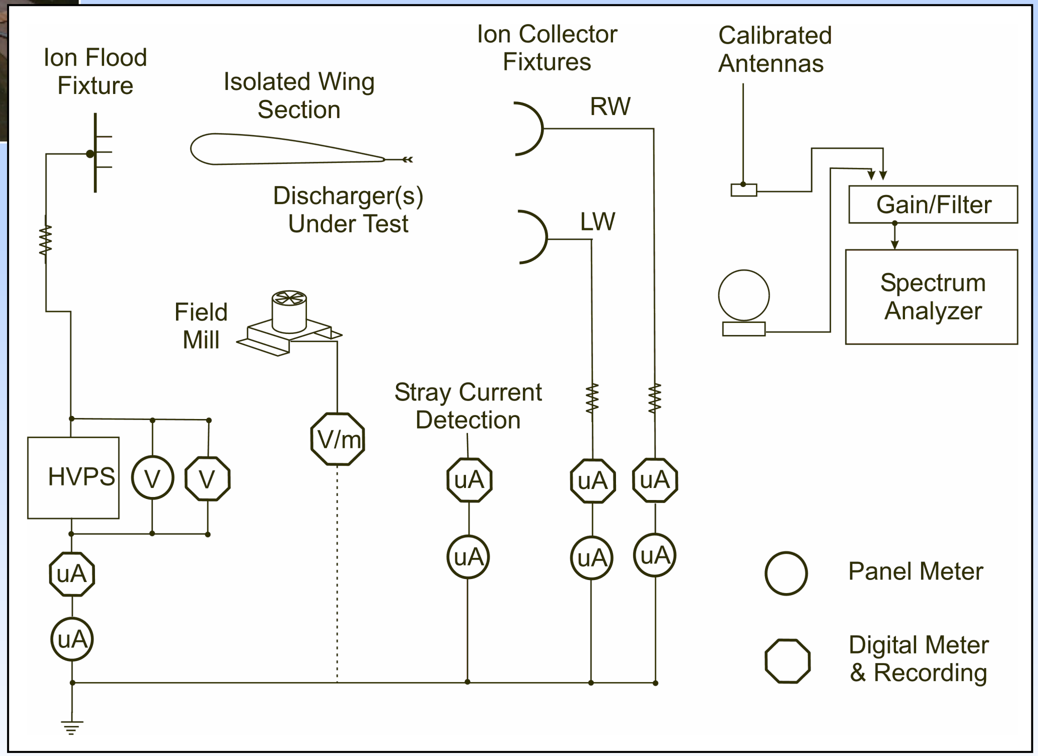

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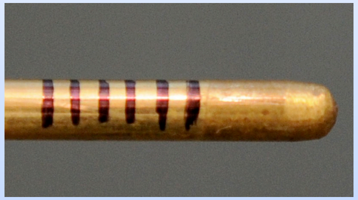
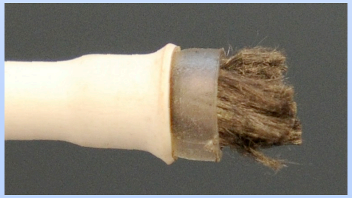
Dischargers

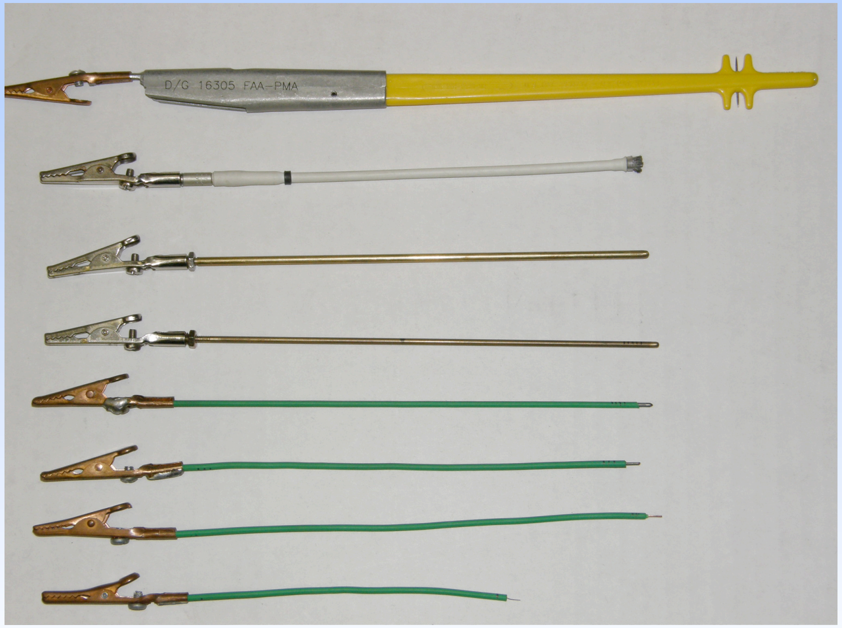
…yes, size matters



The "3-mm" discharge rod



-The DD-2 discharger
with a "brush" of 4-mil wires



-The full set of discharge devices:
- -Dayton-Granger
- -TCO DD-2
- -3.1 mm rod
- -2.0 mm rod
- -1.6 mm rod
- -1.0 mm wire
- -0.6 mm wire
- -30 AWG wire

What we observe

…drilling down to corona details

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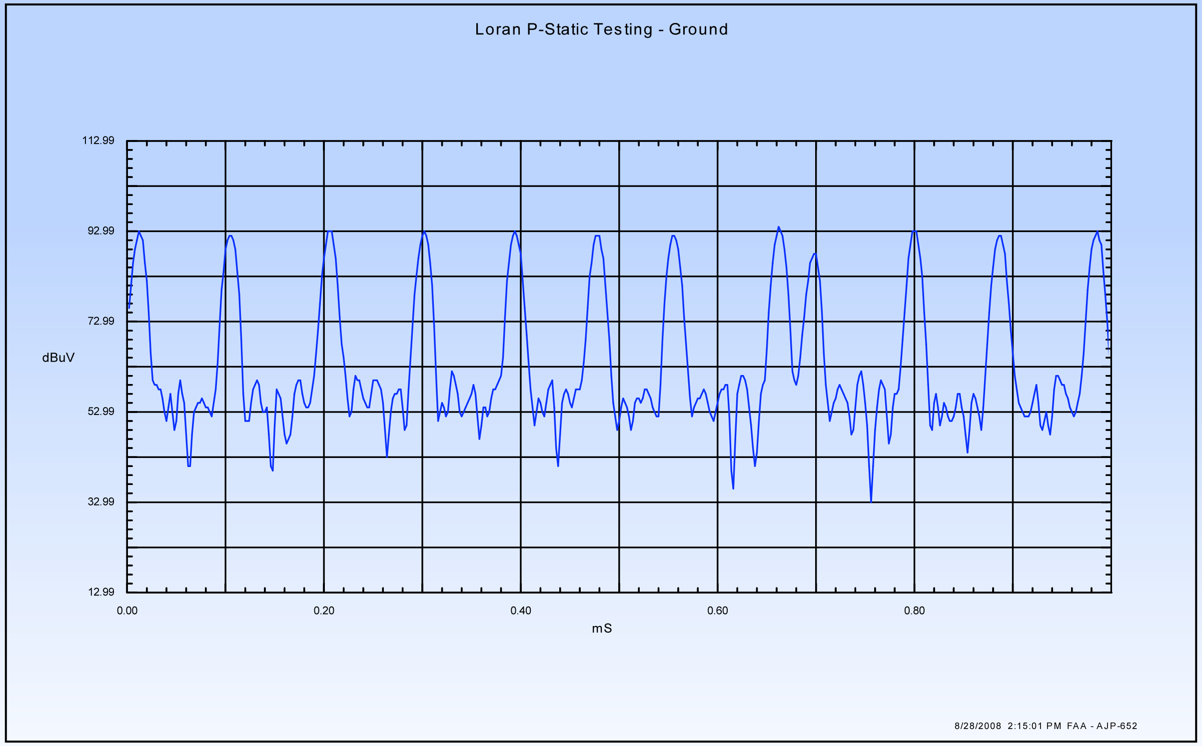
- Things that might be important to a signal generator or model, for use in approval of avionics.
  - Corona discharge – e-field / h-field
  - Discharger effect on airframe potential
  - Corona discharge rate – pulse rep-rate
  - Pulse amplitude, width
  - Pulse rep-rate coherence
  - Field strength with distance

Corona

…It's not just noise anymore

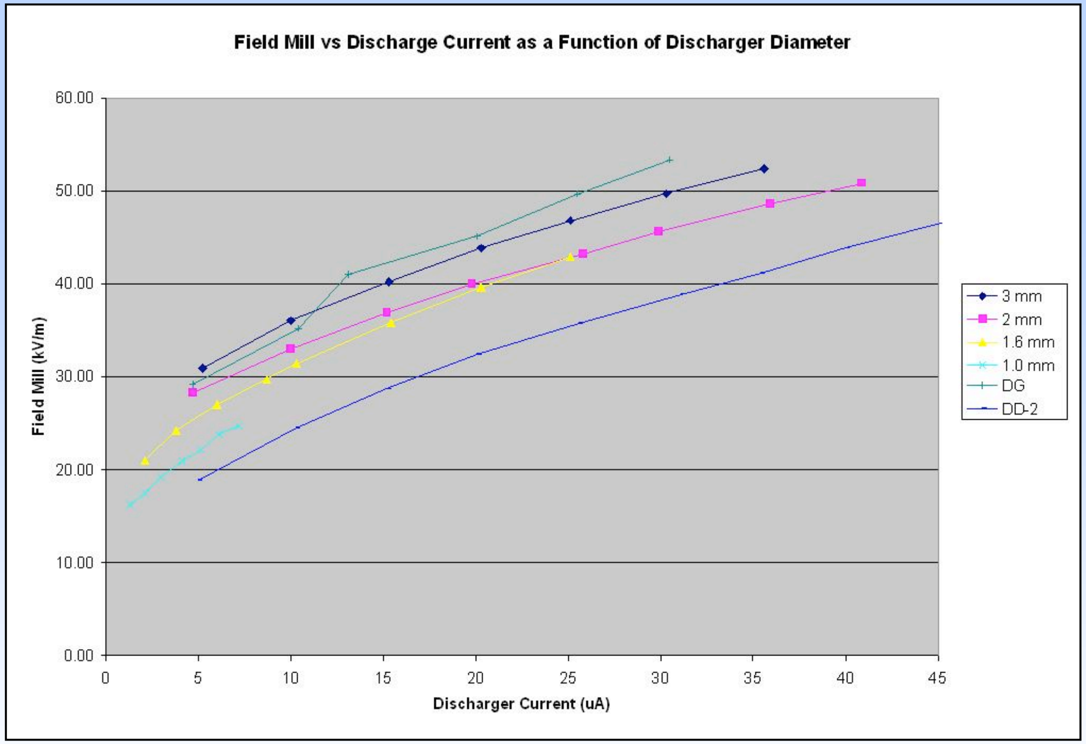
- This is not "just more noise".
  - Detected pulses in 75-125 kHz bandwidth
  - Each is a separate corona discharge
    - – an ion avalanche at a single sharp-ish point.



Airframe Potential

…the discharger rules

- For a given charge rate (discharge current)
  - Smaller-radius corona points hold the airframe to lower voltage
- Corona threshold field strength at a tip remains ~constant
  - Air, not aircraft, conditions set the corona threshold field strength.



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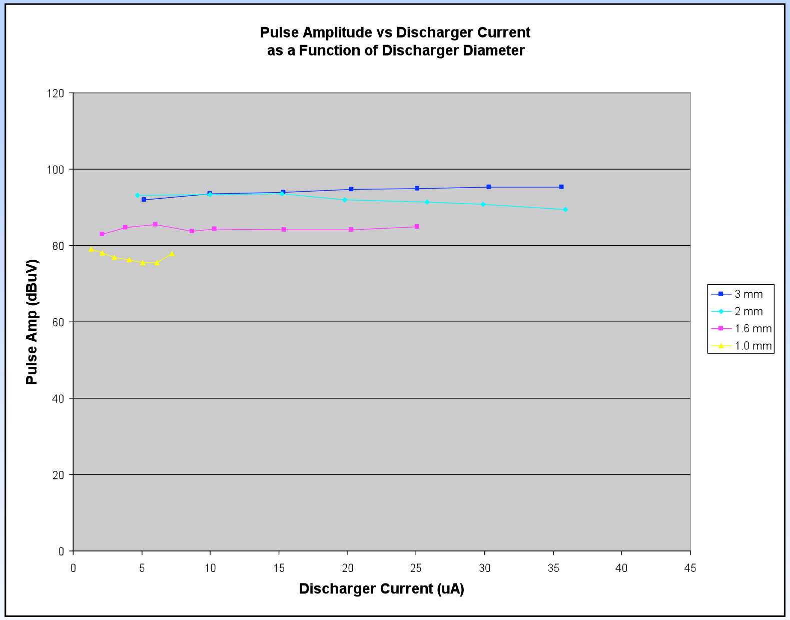
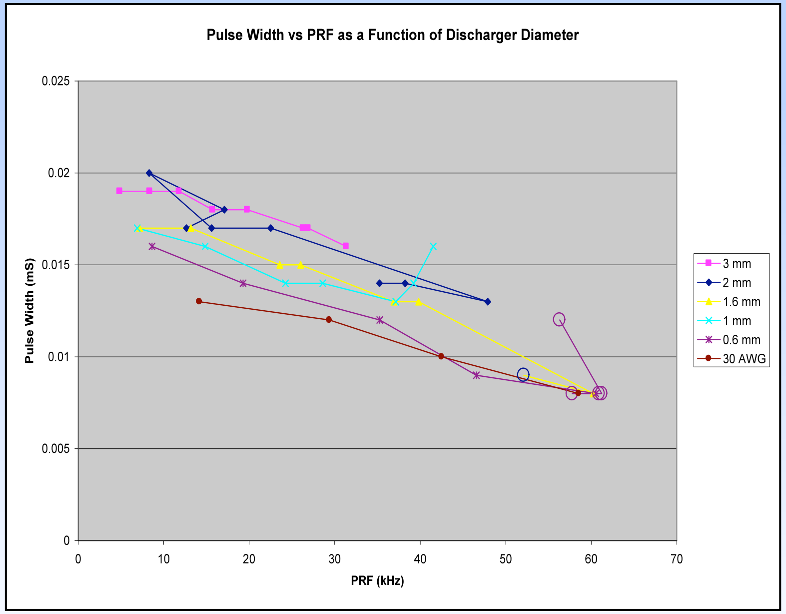
Pulse Amplitude and Width

…small changes – significant changes?

- For a given tip size, amplitude stays ~constant with current increase.
  - Apparent amplitude decrease with decreasing tip size is under study.
- Pulses in 50-kHz bandwidth tend to narrow as current increases, and to be narrower with smaller radius.
  - May be an instrumentation effect. Under study

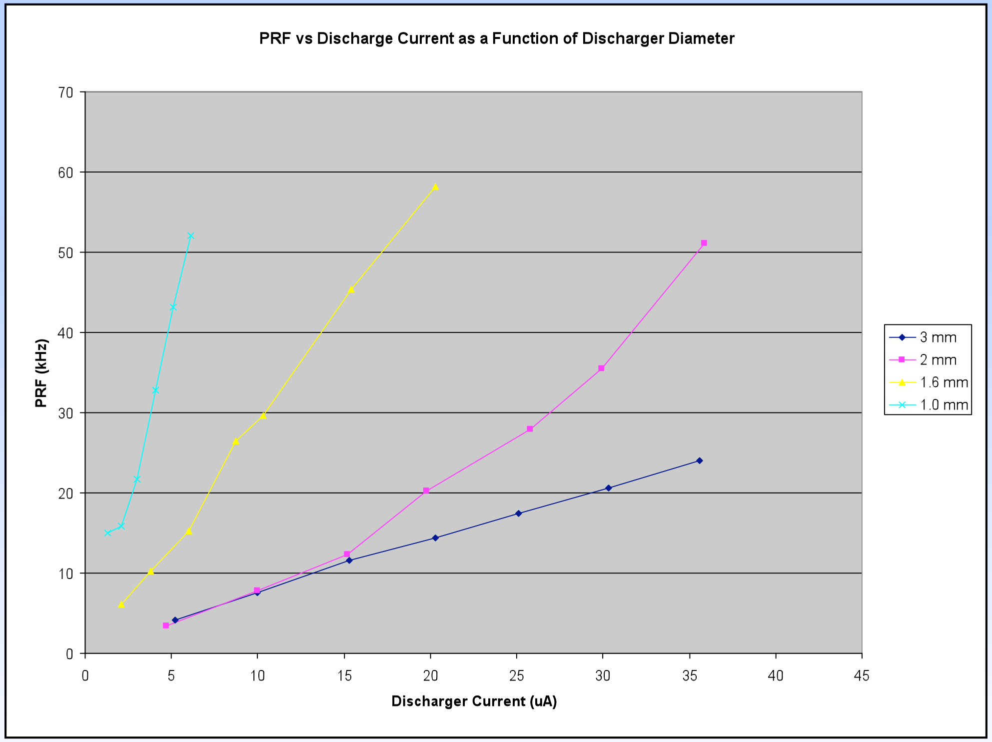




Pulses – Corona Rep Rate

…let's take another look at that

- **Pulse repetition rate increases with current – and vice versa.**
  - Current *is* pulse rate per unit time
- **Smaller corona points discharge more often for a given current**
  - This unexpected effect under study – could affect total noise



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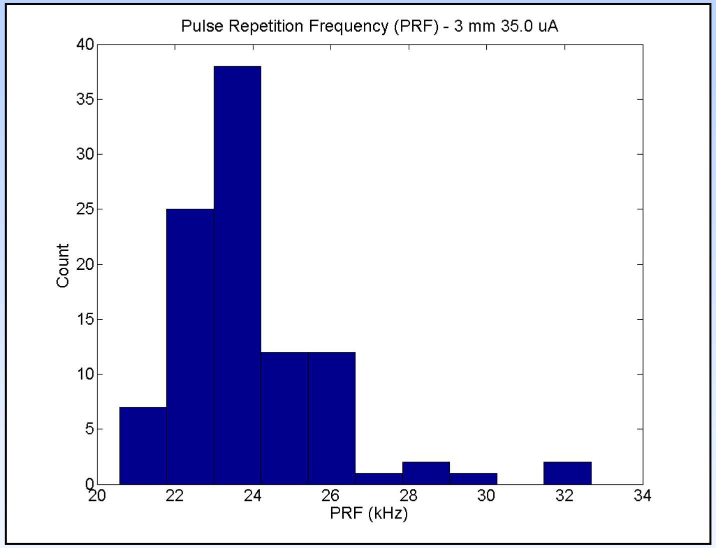
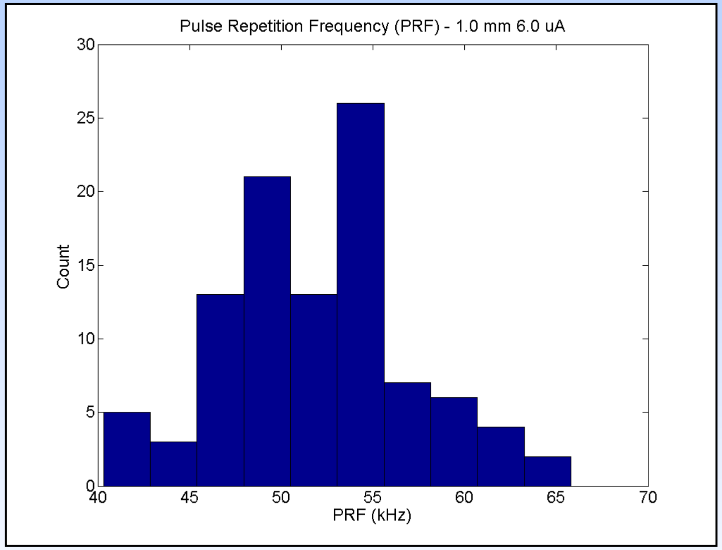
Corona Pulse Rep-Rate Coherence

…standard deviation?

- Shape of pulse interval probability distribution changes with current
- Standard deviation (STD) rises with increasing discharge current
  - STD may not be the best descriptor; distributions may not be ~Gaussian
  - Small irregularities in tip geometry may cause multimodal distributions
- Accurate description of p-static PRF coherence is important predictor of receiver effects





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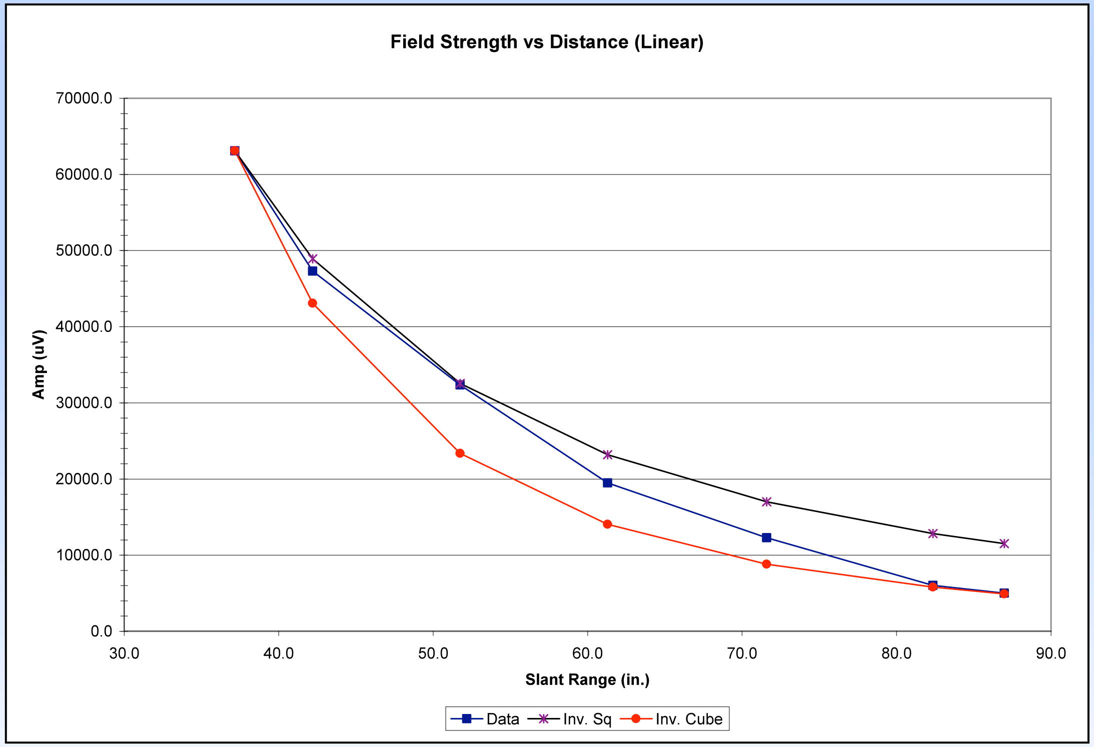
P-static Intensity vs. Distance

…we will add absolute numbers

- **The e-field is between $1/r^2$ and $1/r^3$ –near-field**
- **H-field not yet observed directly with standardized antennas**
  - By superposition, inferred to be some 65dB below the e-field intensity



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What were we *thinking*? (1)

…status of previous predictions and preliminary conclusions

- ***From 2006:***
  - **Is the screen room useful / required? (mixed)**
  - **A/C as capacitor – charge storage (yes)**
    - Effect on lab test results **(emulates actual aircraft)**
    - Wing section **(voltage can exceed HVPS voltage)**
  - Bench-top test configuration?
    - Direct-drive discharger or cluster as noise generator? **(future)**
    - LDaC to measure spectrum and capture noise data **(works)**
  - Emulate corona streamer, arc sources **(corona emphasis)**
    - Is it "just noise" based on current and distance to antenna? **(no)**

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What were we *thinking*? (2)

…status of previous predictions and preliminary conclusions

- ***eLoran* user equipment anticipated** (yes…)
  - Need to design tests for proponent receivers (RTCA)
  - Certification path must be sufficient, and affordable
- **Is p-static a threat to other systems? (literature-yes)**
- **Single and Multiple dischargers**
  - Does a single discharger with closely-spaced ion collector emulate an aircraft in flight generating corona? **(soon)**
  - Is the noise from multiple dischargers additive? **(soon – yes?)**
- **Ground test emulates flight conditions?** (yes)
  - Must we test every installation? **(under study)**
  - Define test sequence **(future work)**

Thanks to…

…you know who you are

- **Scott Shollenberger**
  - **W. J. Hughes Technical Center**
  - **Air Transportation System Evaluation Group**
  - **Navigation System Peformance Team (AJP-7B3)**
    - **Scott.Shollenberger@faa.gov**
- **Andre Ramjattan**
  - **W.J. Hughes Technical Center**
- **Mitch Narins**
  - **FAA Headquarters**