Exponent®

New Frontiers in Stray Voltage: "Discovering" Lightning 100 Years Too Late

MREC Presentation

February 12, 2026

About Exponent

Exponent is the only premium engineering and scientific consulting firm with the depth and breadth of expertise to solve our clients' most profoundly unique and urgent challenges.

1967
50+ Years of Scientific Excellence

950+
Consulting Staff

90+
Technical Disciplines

30+
Offices Across North America, Europe & Asia

Speakers

- With you today

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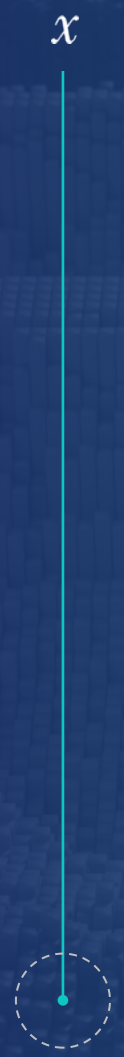
Outline



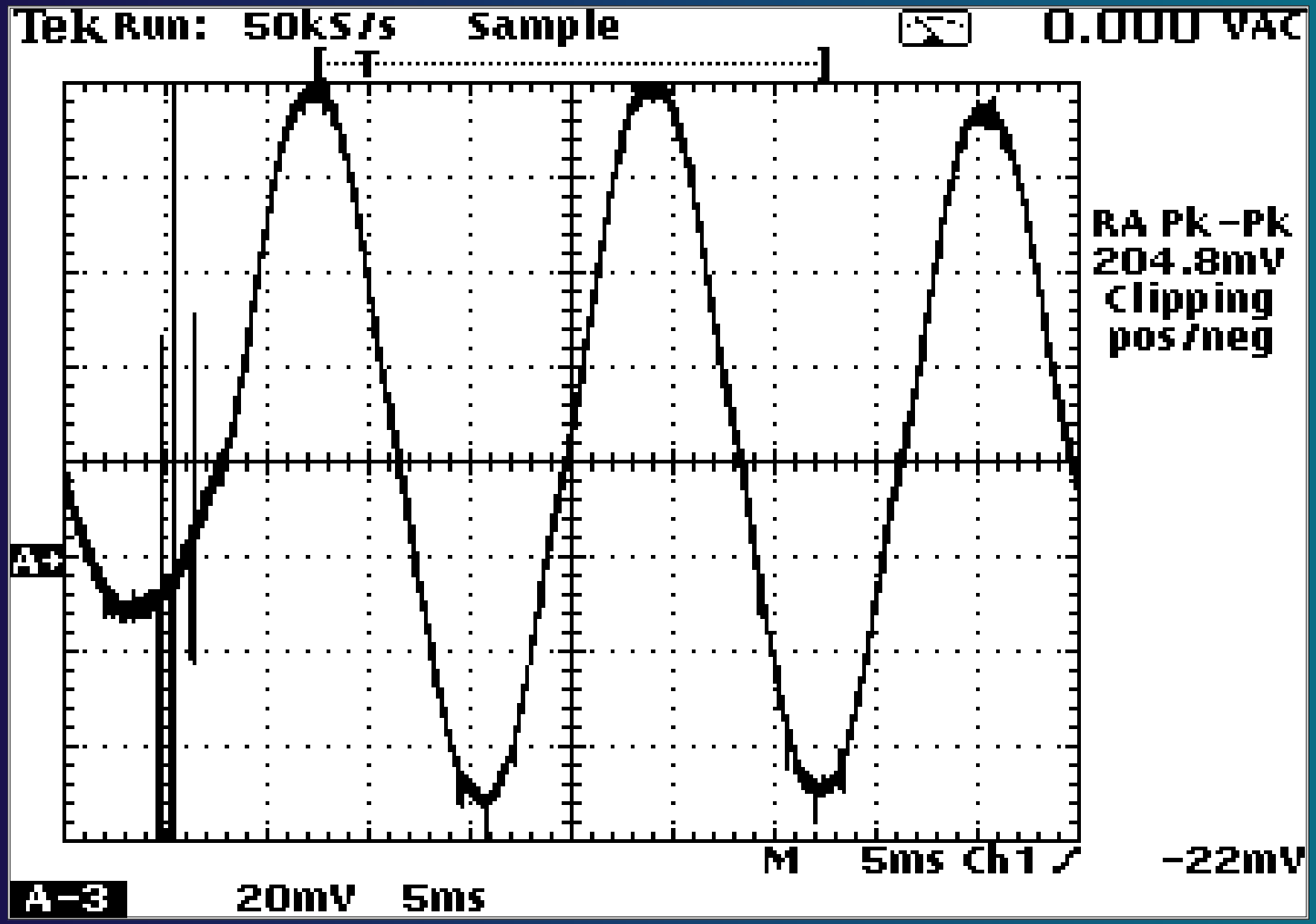
- History
- Claimed Sources of VLF
- Lightning
- Telling the Technical Story
- Harm to Cows
- Conclusions

History of Exponent's Involvement in Stray Voltage

Exponent: Stray Voltage Investigations

- Started ~ 1996 (30 years ago)
- Investigated a series of claims that the milking equipment was electrically shocking the cows
  - Measured the voltages/currents in the cows' environment
  - Milking equipment ruled out after numerous investigations
- 1999 Investigation – no SV contribution from the milking equipment
- Began investigating allegations of distribution-system-caused stray voltage
  - Spoke at MREC in 2003 – Benefits of the Oscilloscope
- October 2006 jury verdict adverse to utility (No Exponent Involvement)
  - Began rebuilding distribution line per the instructions of plaintiffs' "expert"

1999: Cow contact voltage measurement: Multiple VLF Transients in addition to 60 Hz Signal



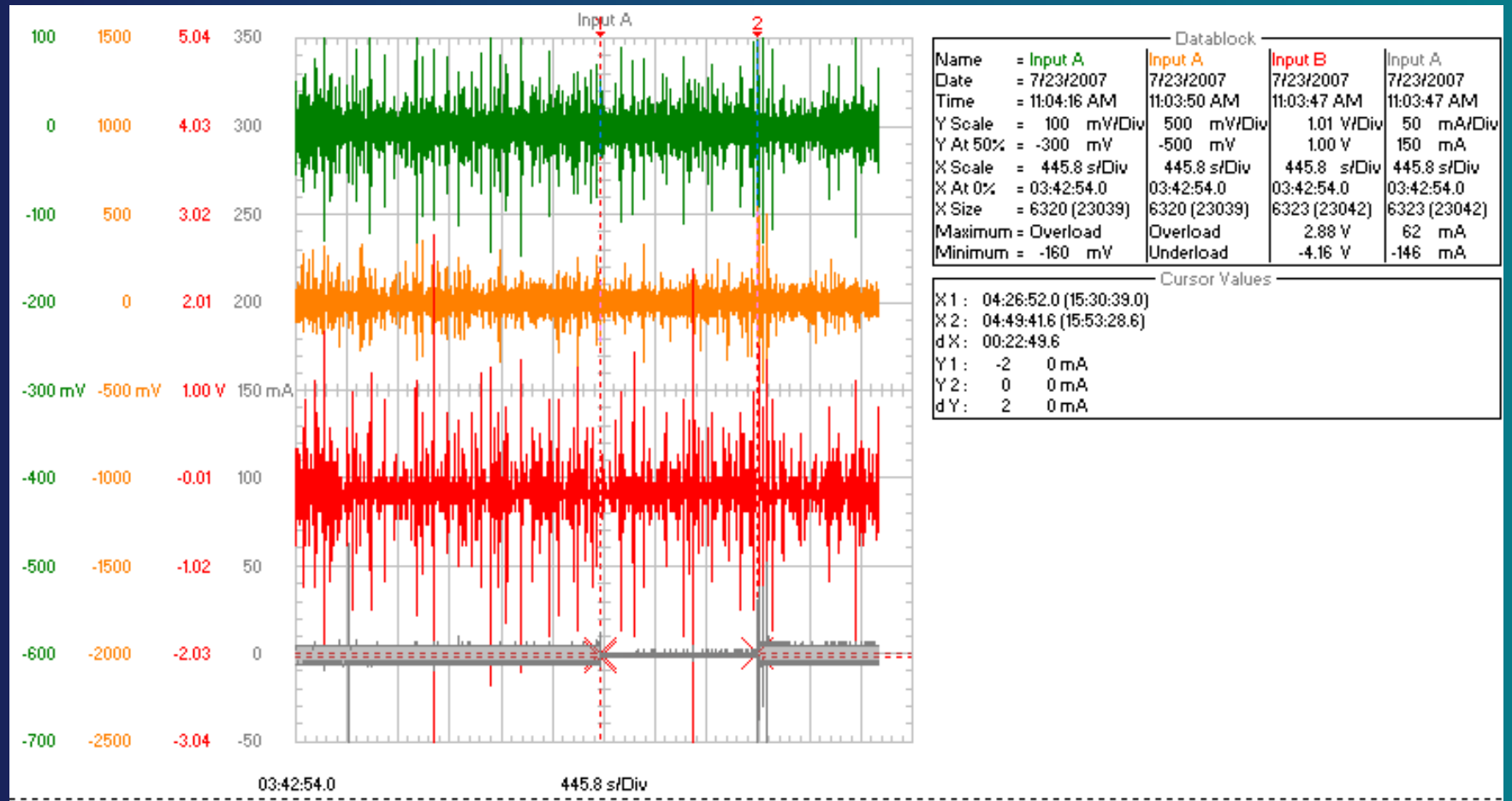
2007

Farm Measurements

- Green: Cow contact
- Orange: barn steel to remote rod
- Red: Telco cable shield to remote rod
- Gray: current on barn steel

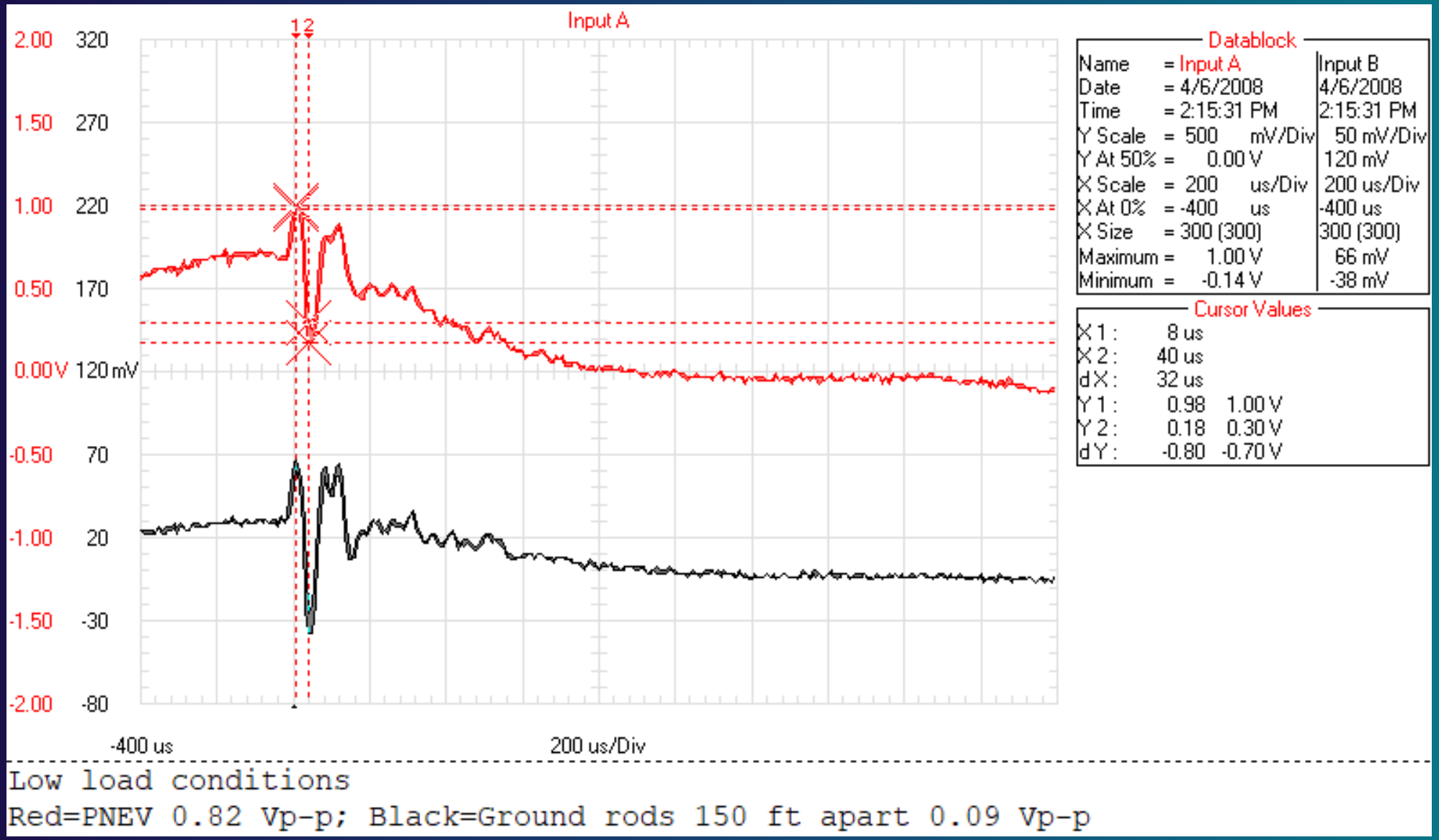
Observations

- Transients present at cow contact
- Transients present to remote rod from barn steel and telco shield
- Current present on farm steel when farm on

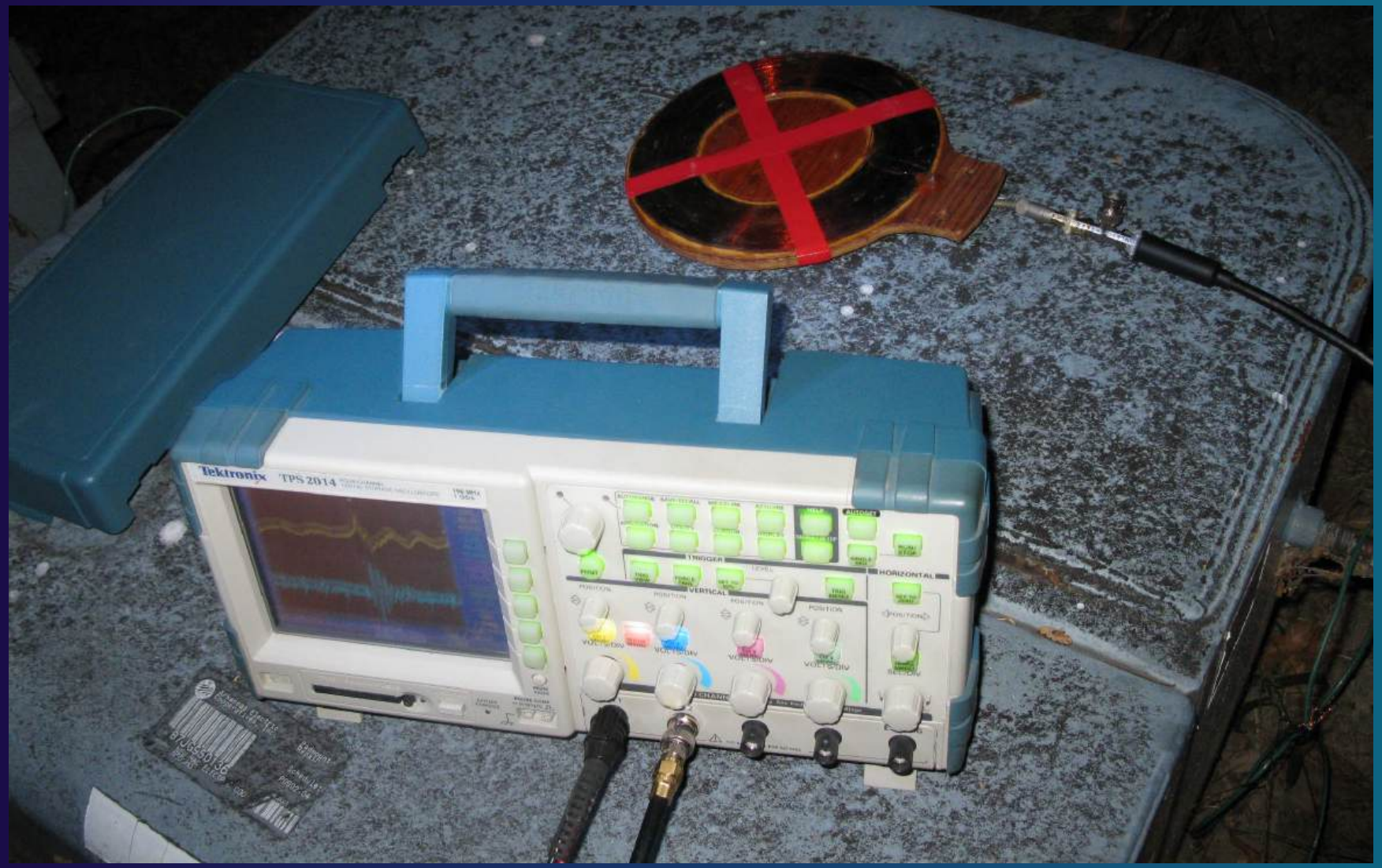


Green=CCV; Orange=Barn steel to reference; Red=Tel cable shield to ref;
Gray=(Current on barn steel)
Gray shows narrowing during farm power off.
Note little or no difference in transient activity during power off.

2008: VLF Measurements

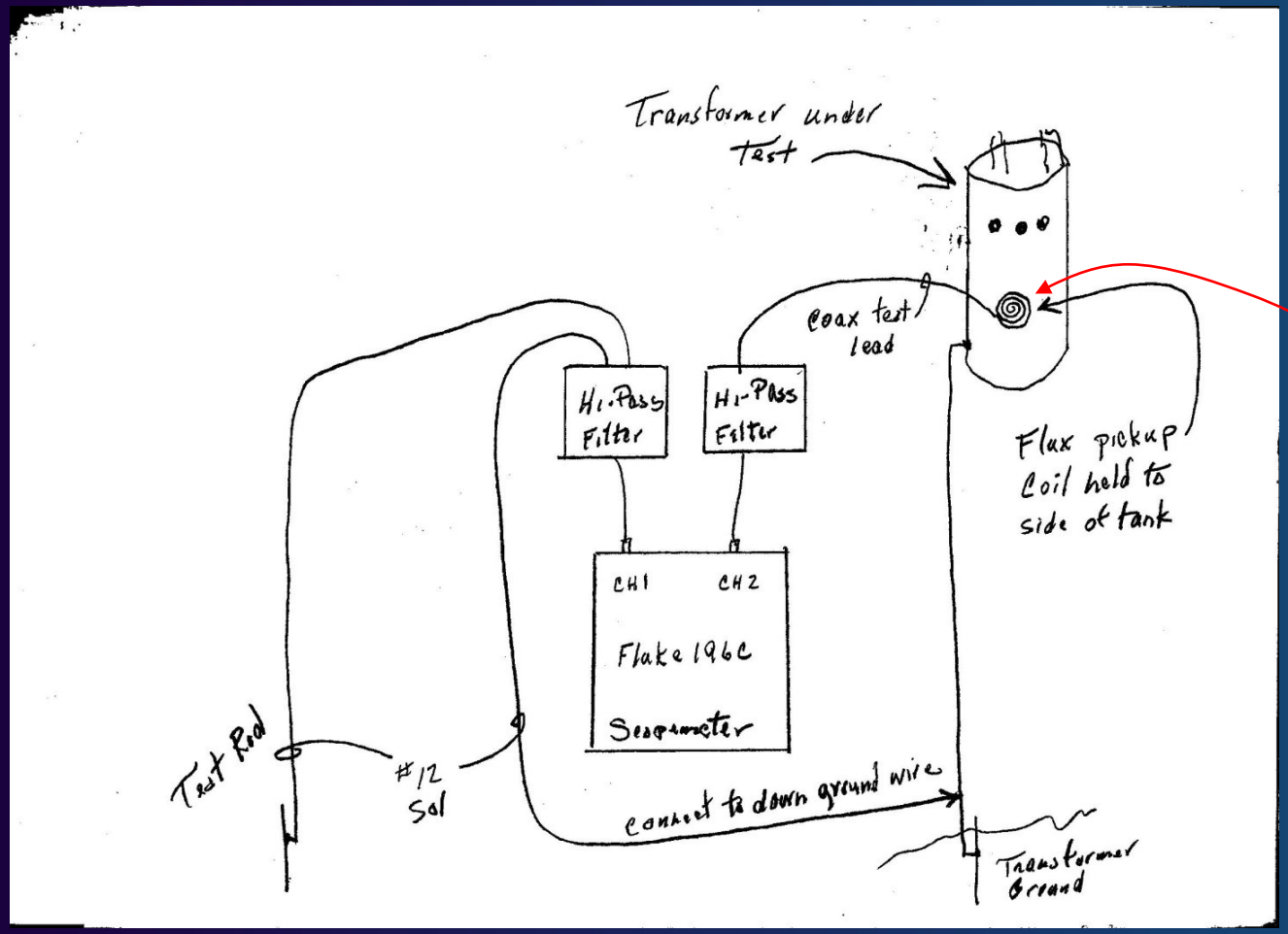


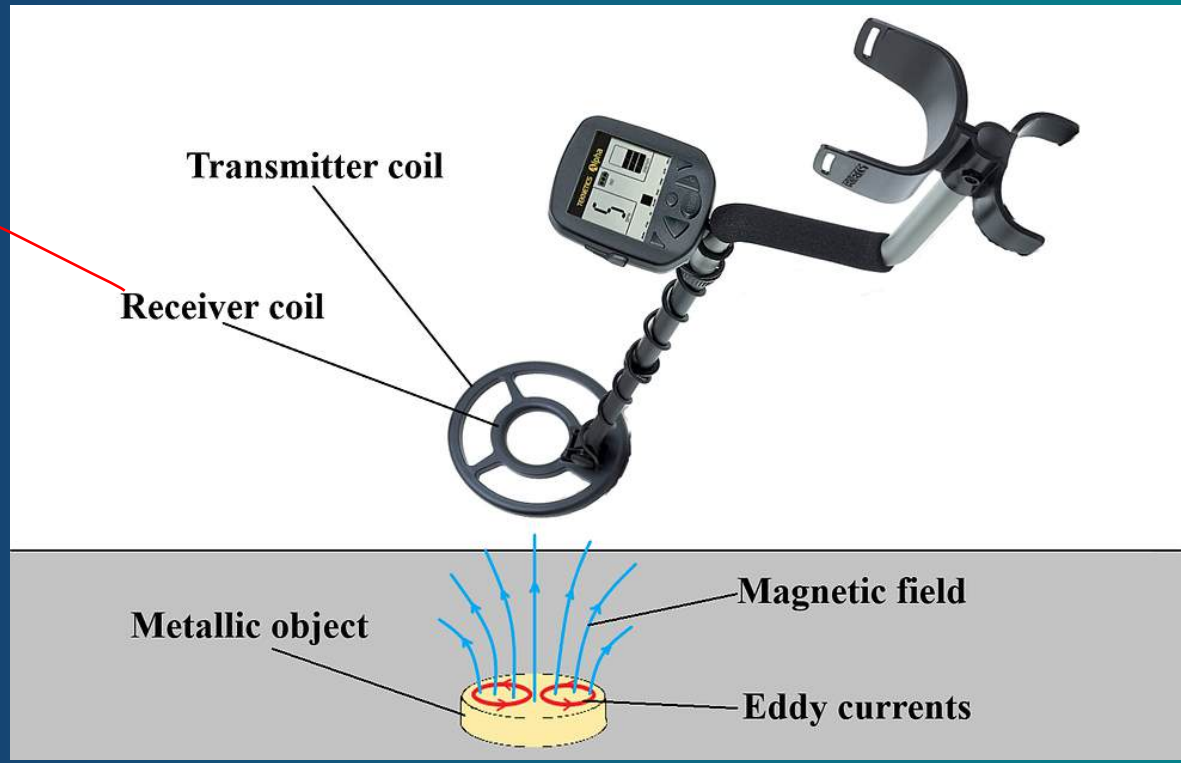
“Flux Pick-Up Coil:” Transformer Diagnostic



Not to be confused with the Flux Capacitor (Back to the Future - 1985)

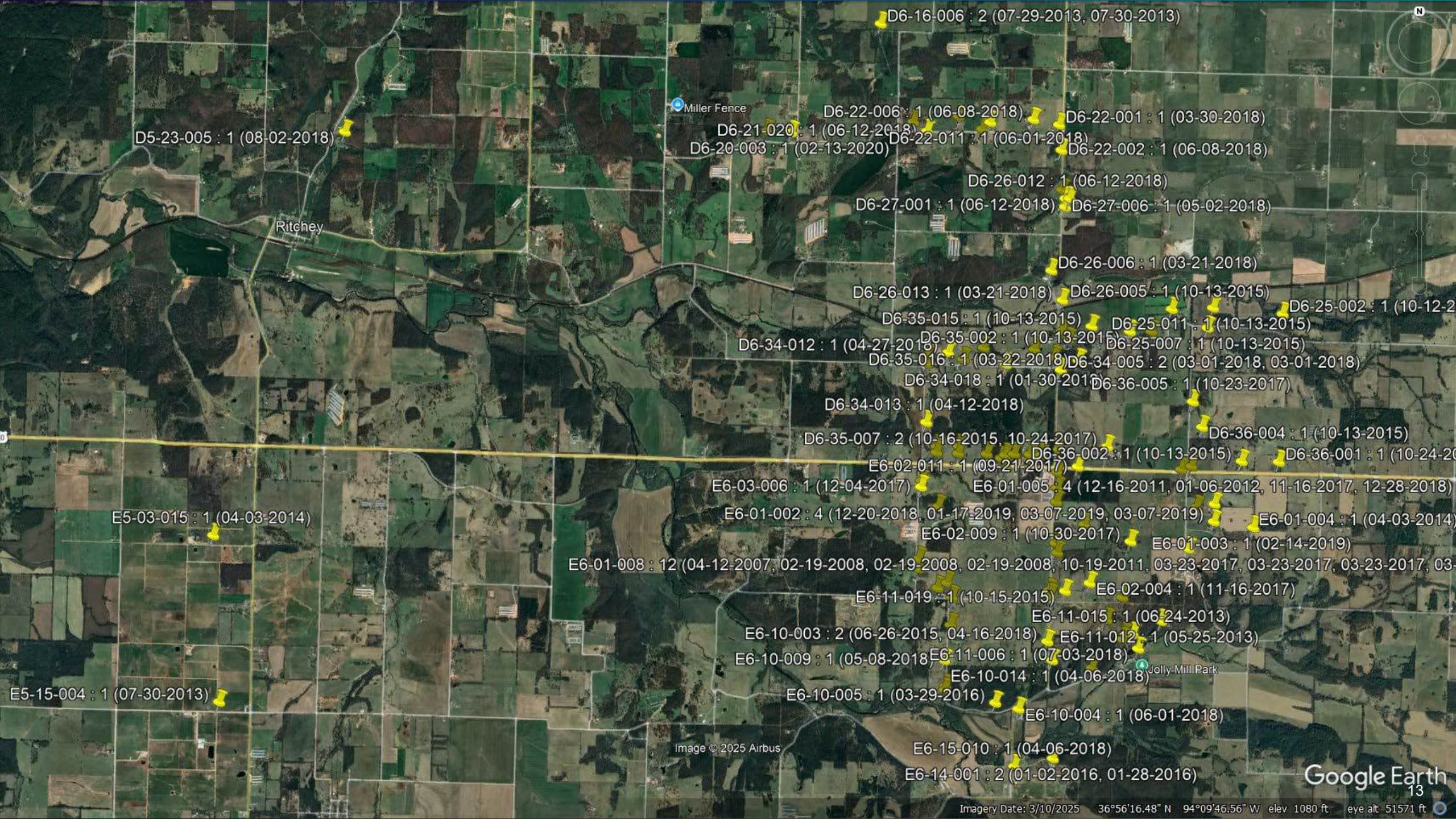
Evaluation Test Setup





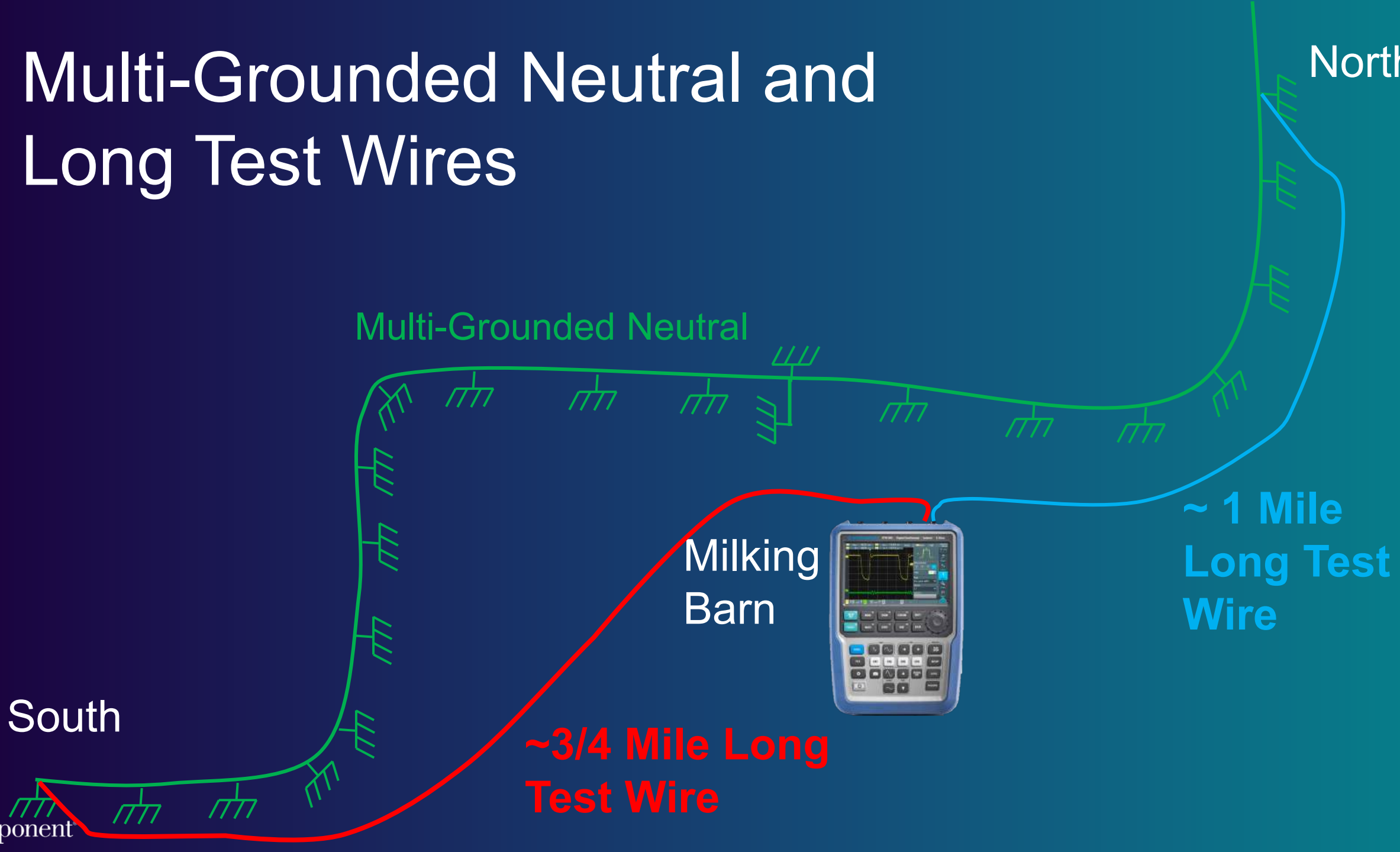
The “Technical Explanation”

- Each testing endeavor succeeded in locating the same 6 kHz transient disturbances at many locations and within many miles from the Dairy.
- All attempts to narrow the search area by triangulation and other methods, ended with confusing vectors and led to no conclusive source.
- The nature of the disturbances was suspected to be some type of unintended oscillation or “Parasitic Oscillation” caused by an unintentional resonance of a distribution transformer and the primary circuit from the substation. This can happen when the reactance of the circuit components combine to become electrically resonant. The circuit thus becomes “tuned” to a particular frequency, in this instance about 6 kHz.
- It appears that [utility] may have purchased quite a number of low quality distribution transformers. These may possibly be rebuilt units that are often stripped of the old cores at the remanufacturer, and fitted with a new low quality core assembly.


D6-16-006 : 2 (07-29-2013, 07-30-2013)
Miller Fence
D6-22-006 : 1 (06-08-2018)
D6-22-001 : 1 (03-30-2018)
D6-21-020 : 1 (06-12-2018)
D6-22-011 : 1 (06-01-2018)
D6-20-003 : 1 (02-13-2020)
D6-22-002 : 1 (06-08-2018)
D5-23-005 : 1 (08-02-2018)
D6-26-012 : 1 (06-12-2018)
D6-27-001 : 1 (06-12-2018)
D6-27-006 : 1 (05-02-2018)
Ritchey
D6-26-006 : 1 (03-21-2018)
D6-26-013 : 1 (03-21-2018)
D6-26-005 : 1 (10-13-2015)
D6-25-002 : 1 (10-12-2
D6-35-015 : 1 (10-13-2015)
D6-25-011 : 1 (10-13-2015)
D6-35-002 : 1 (10-13-2015)
D6-34-012 : 1 (04-27-2018)
D6-25-007 : 1 (10-13-2015)
D6-35-016 : 1 (03-22-2018)
D6-34-005 : 2 (03-01-2018, 03-01-2018)
D6-34-018 : 1 (01-30-2018)
D6-36-005 : 1 (10-23-2017)
D6-34-013 : 1 (04-12-2018)
D6-36-004 : 1 (10-13-2015)
D6-35-007 : 2 (10-16-2015, 10-24-2017)
D6-36-002 : 1 (10-13-2015)
D6-36-001 : 1 (10-24-20
E6-02-011 : 1 (09-21-2017)
E6-03-006 : 1 (12-04-2017)
E6-01-005 : 4 (12-16-2011, 01-06-2012, 11-16-2017, 12-28-2018)
E5-03-015 : 1 (04-03-2014)
E6-01-002 : 4 (12-20-2018, 01-17-2019, 03-07-2019, 03-07-2019)
E6-01-004 : 1 (04-03-2014)
E6-02-009 : 1 (10-30-2017)
E6-01-003 : 1 (02-14-2019)
E6-01-008 : 12 (04-12-2007, 02-19-2008, 02-19-2008, 02-19-2008, 10-19-2011, 03-23-2017, 03-23-2017, 03-23-2017, 03-
E6-02-004 : 1 (11-16-2017)
E6-11-019 : 1 (10-15-2015)
E6-11-015 : 1 (06-24-2013)
E6-10-003 : 2 (06-26-2015, 04-16-2018)
E6-11-012 : 1 (05-25-2013)
E6-10-009 : 1 (05-08-2018)
E6-11-006 : 1 (07-03-2018)
Jolly Mill Park
E6-10-014 : 1 (04-06-2018)
E5-15-004 : 1 (07-30-2013)
E6-10-005 : 1 (03-29-2016)
E6-10-004 : 1 (06-01-2018)
Image © 2025 Airbus
E6-15-010 : 1 (04-06-2018)
E6-14-001 : 2 (01-02-2016, 01-28-2016)
Google Earth
Imagery Date: 3/10/2025 36°56'16.48" N 94°09'46.56" W elev 1080 ft eye alt 51571 ft

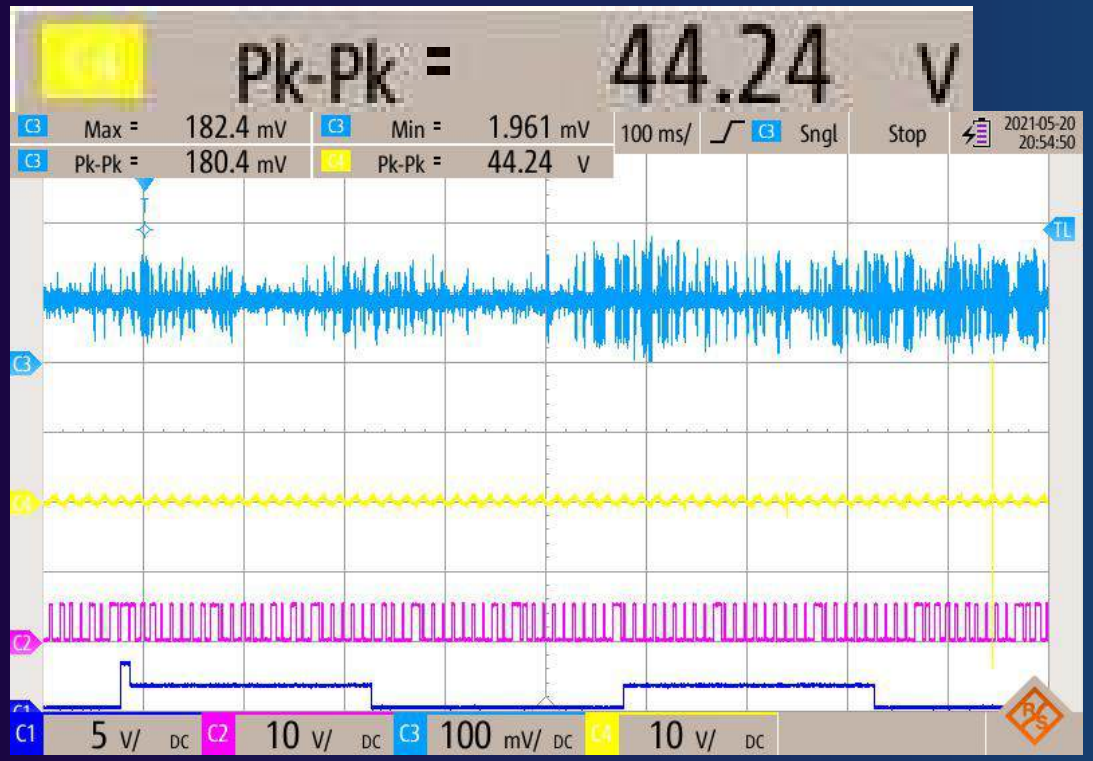
2019 Lawsuit - Testing at the Milking Barn for VLFs on the Long Wires to Other facilities

Multi-Grounded Neutral and Long Test Wires

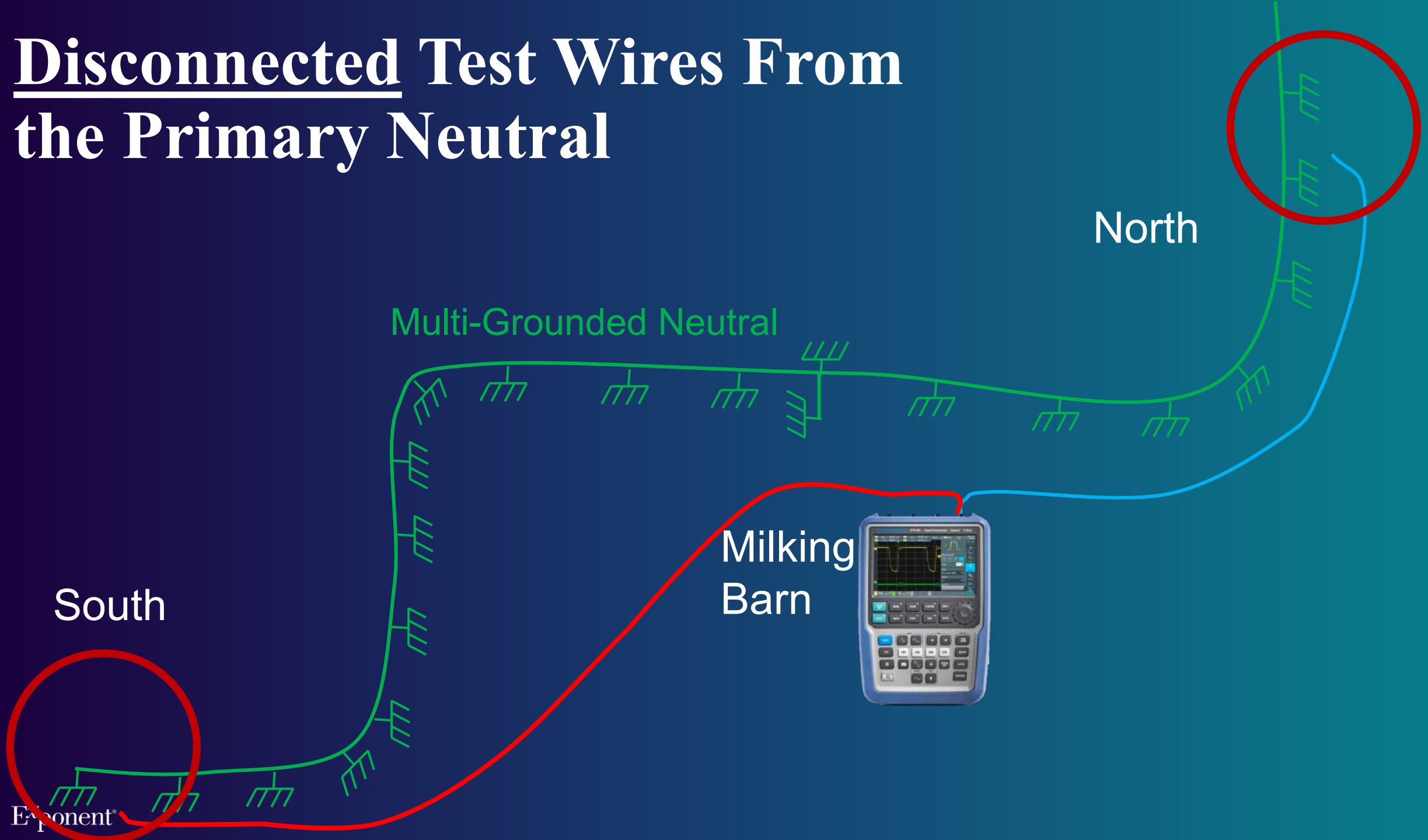


Replicating Measurement of VLFs on North and South While Connected to Primary Neutral at Each

Yellow: PN_{North} to PN_{South}
Blue: Dry Cow Waterer



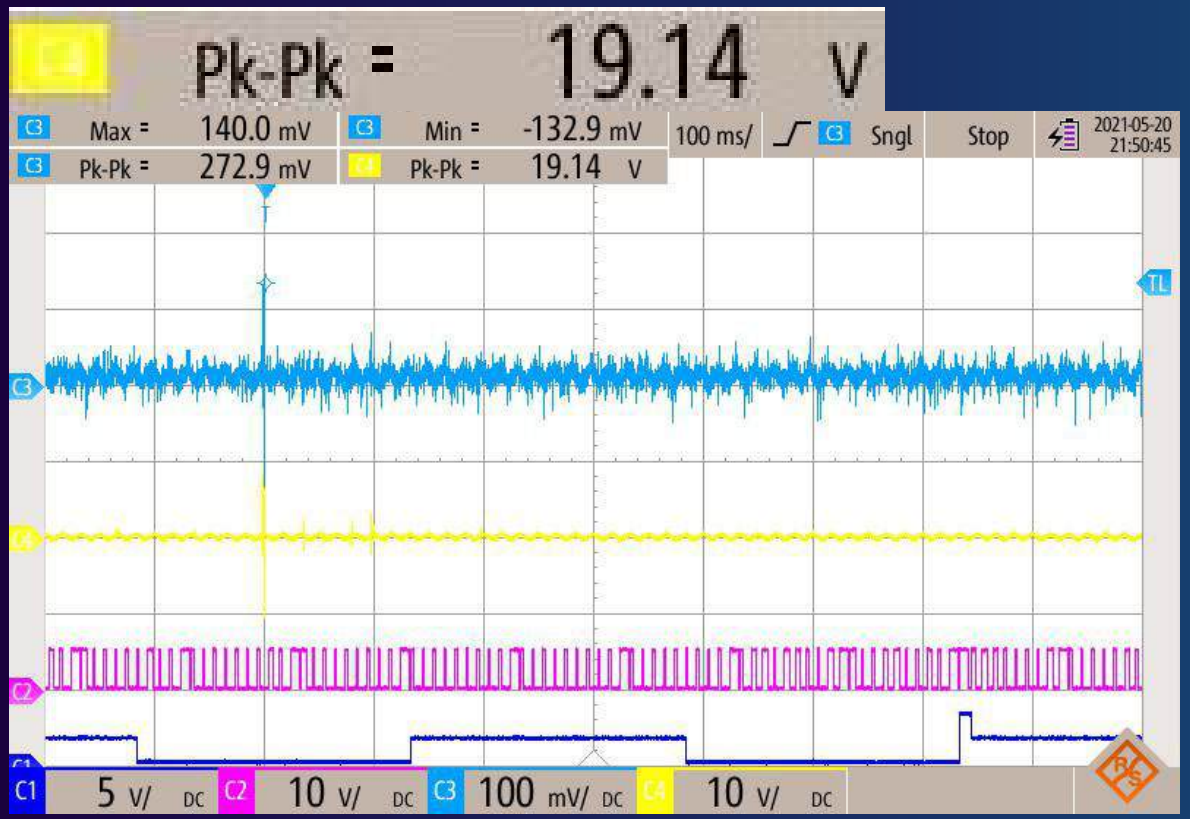
Disconnected Test Wires From the Primary Neutral

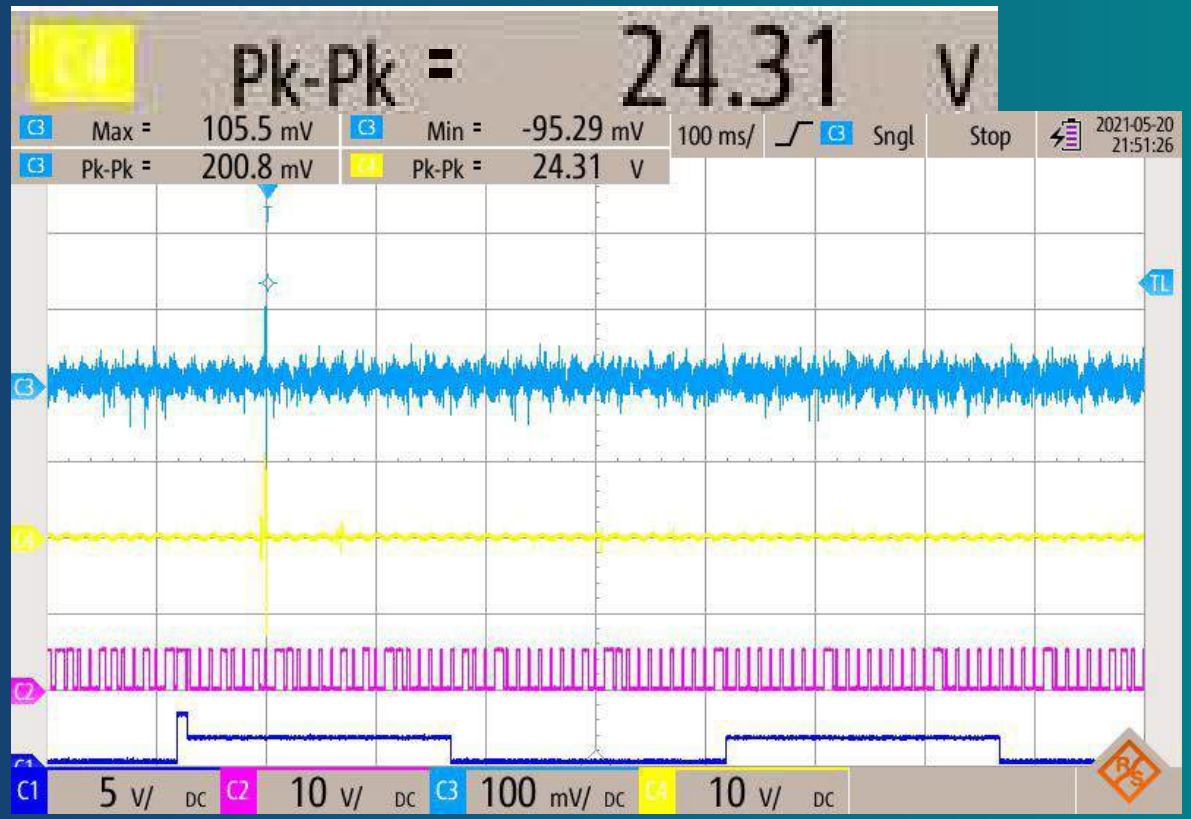


Disconnected Test Wires From the Primary Neutral at North and South Facilities

Floating Wires Produced the Same Signals

Yellow: Floating Wires
Blue: Dry Cow Waterer







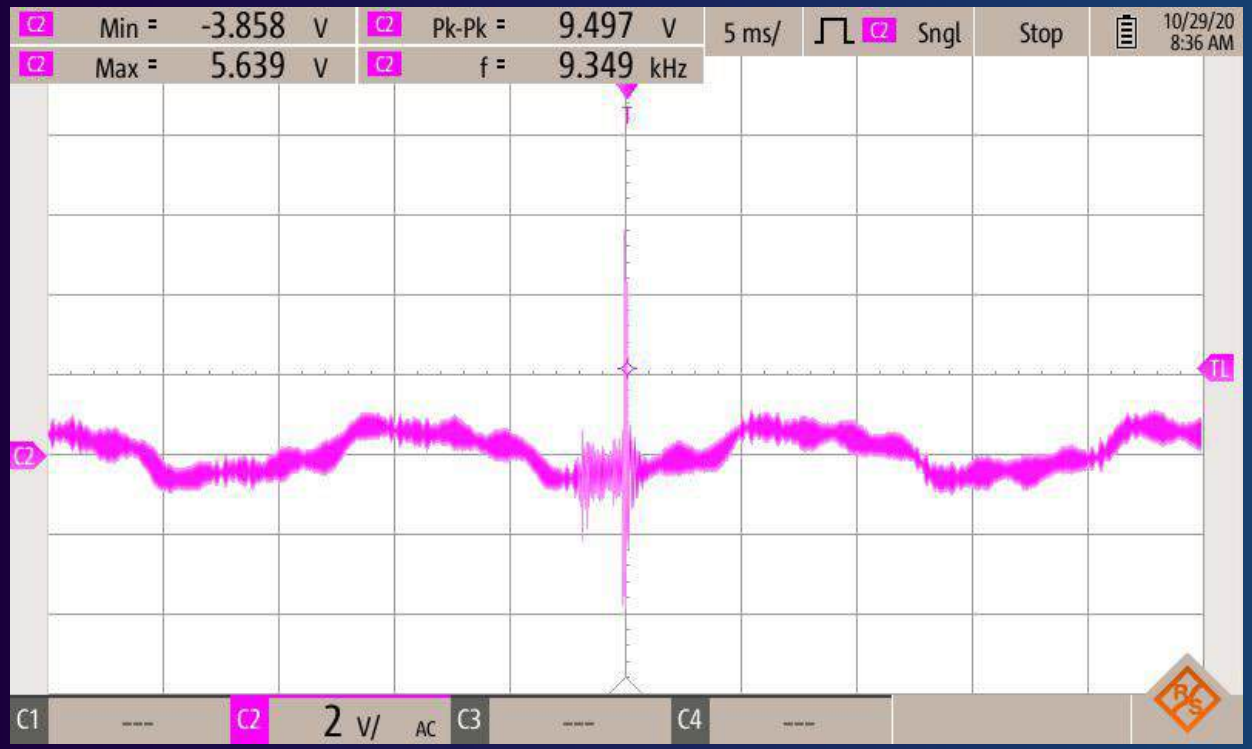
Testing at a State Natural Area Remote from Utility Power


Antenna Location Shown in Red (0.4+0.3=0.7mi)
M: Marks where midpoint testing was performed
E: Marks where the end point testing was performed
M
E
560th St
564th St
565th St
566th St
Jeremiah's Bullfrog Fish Farm - Eat My Fish
Upper Dunnville Bottoms
Google

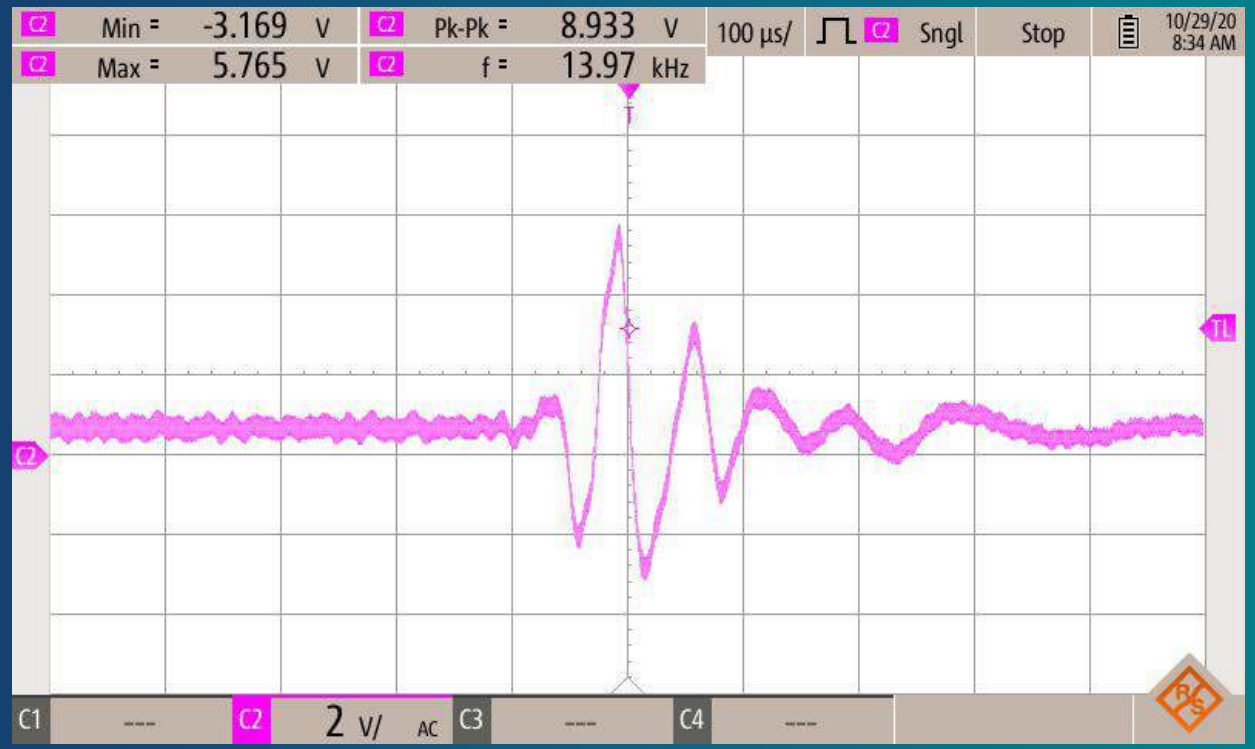
Midpoint Antenna Test

- 0.4 miles of antenna to the north
- 0.3 miles of antenna to the south

0.4mi/0.3mi Midpoint Testing

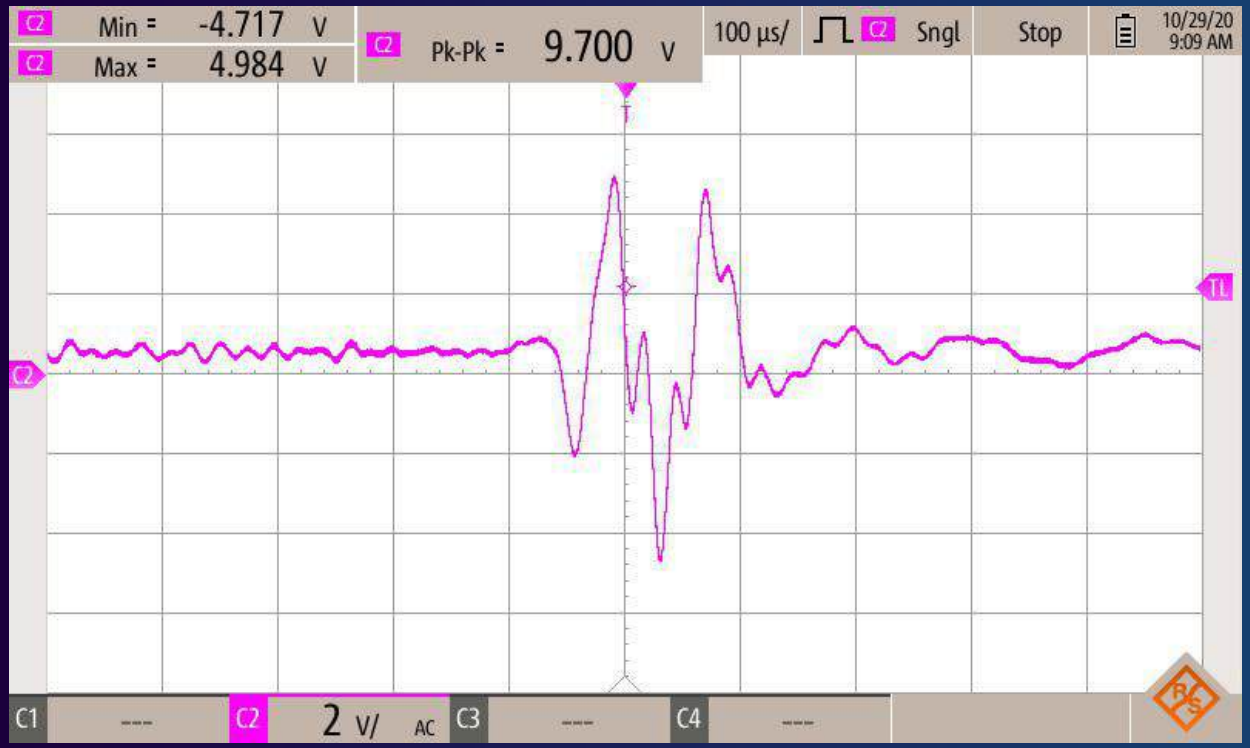


Example of a transient on the noisy 60Hz signal

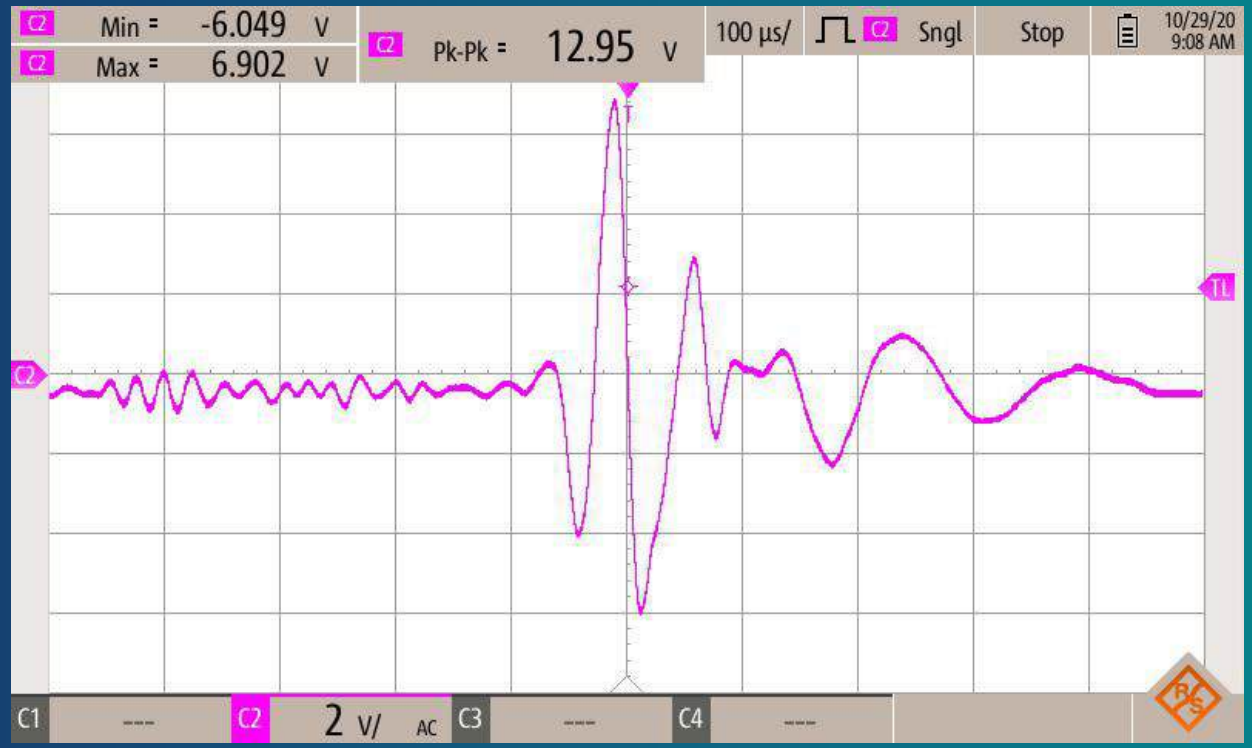


Largest ringing transient

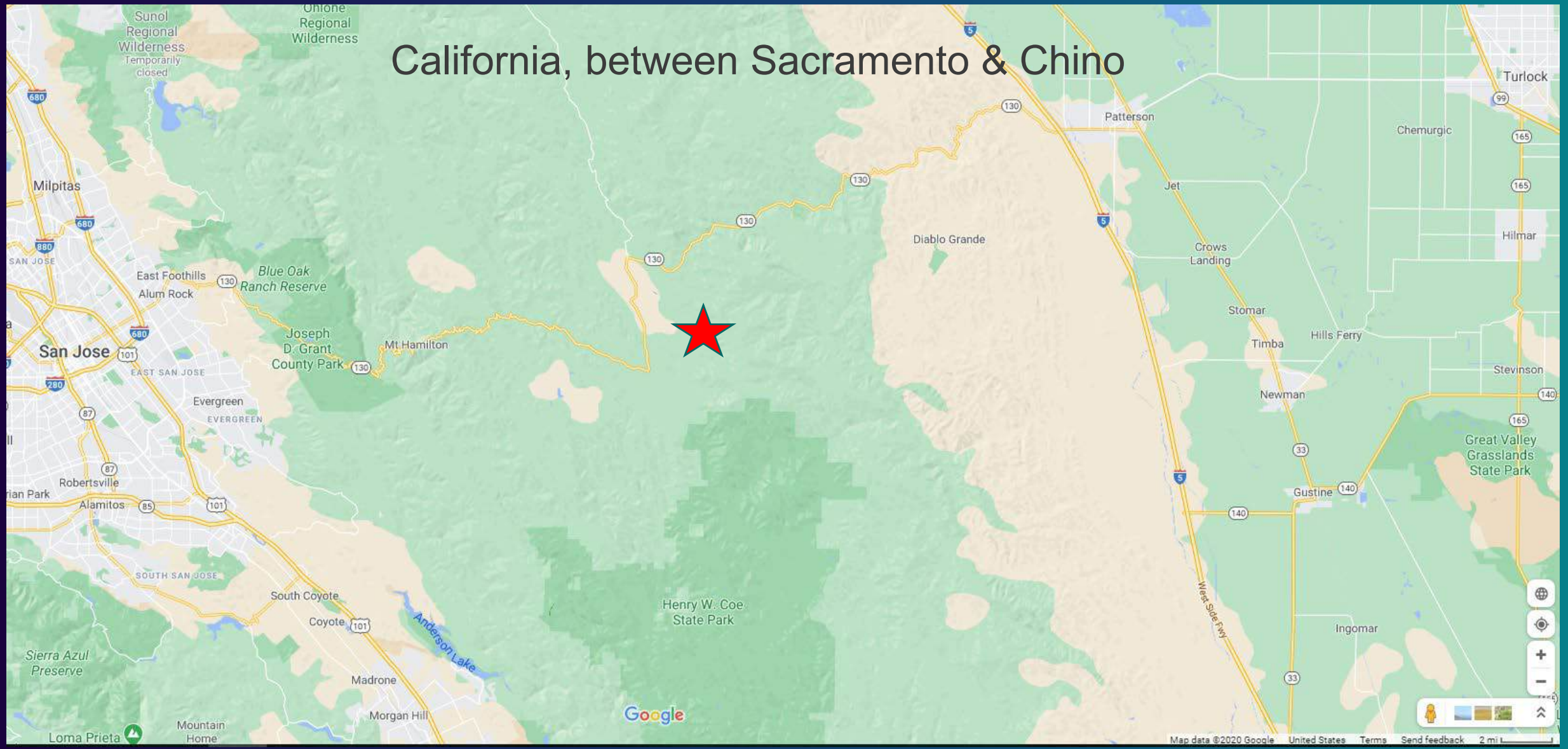
South End (0.7mi) to Ground Rod



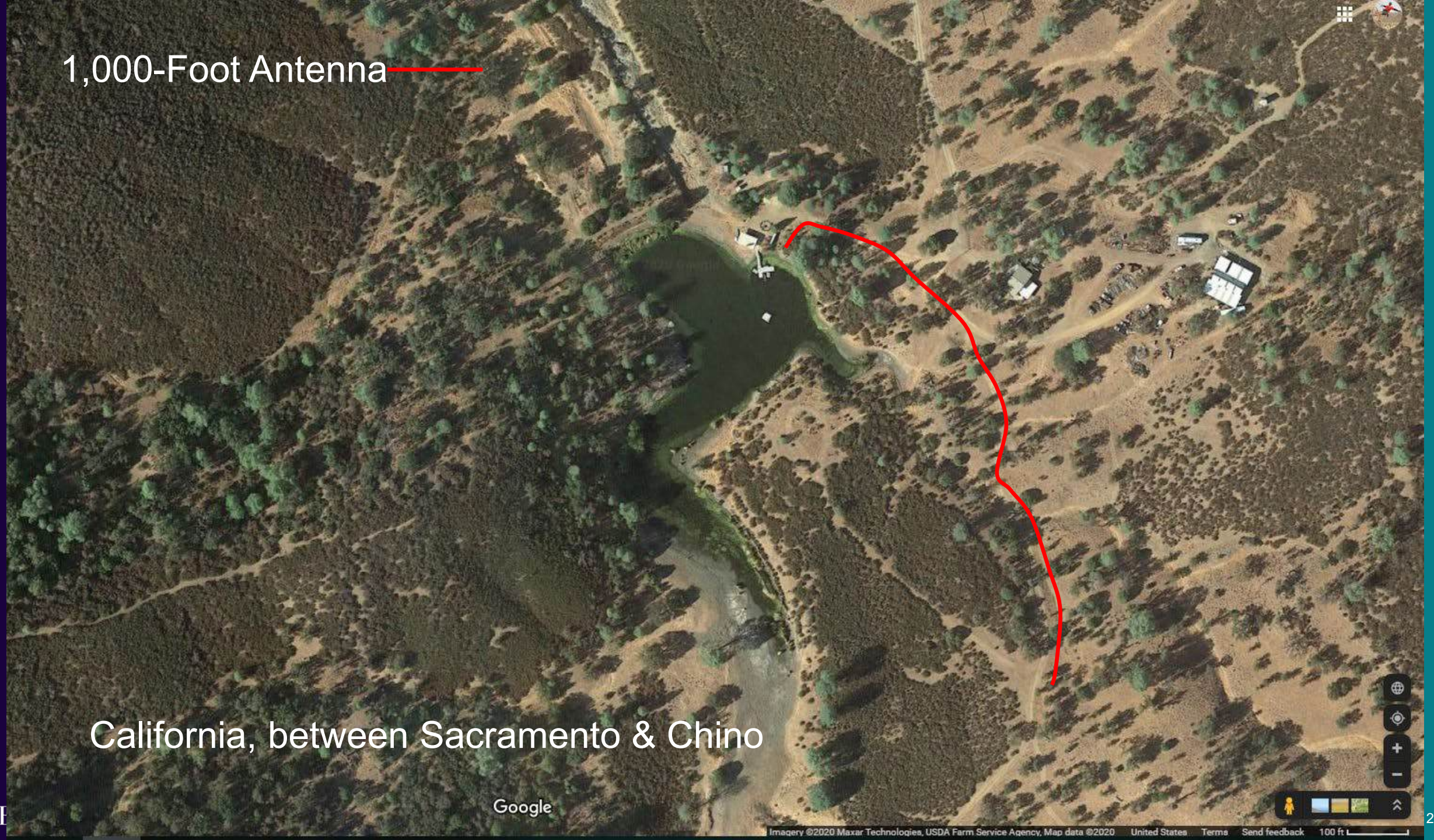
Ringing transient at 9.7Vpp



Ringing transient at 12.95Vpp



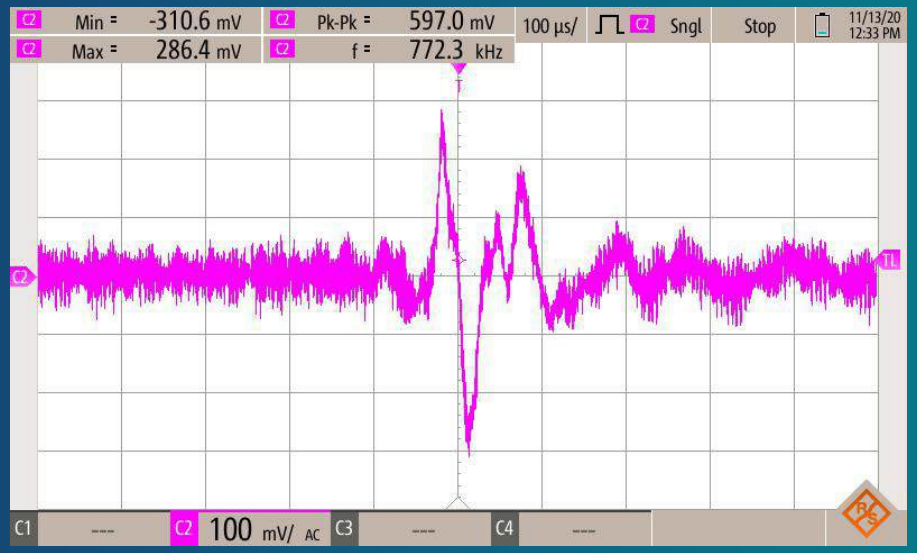
Off-Grid Testing


1,000-Foot Antenna
California, between Sacramento & Chino
Google
Imagery ©2020 Maxar Technologies, USDA Farm Service Agency, Map data ©2020
United States
Terms
Send feedback
100 ft

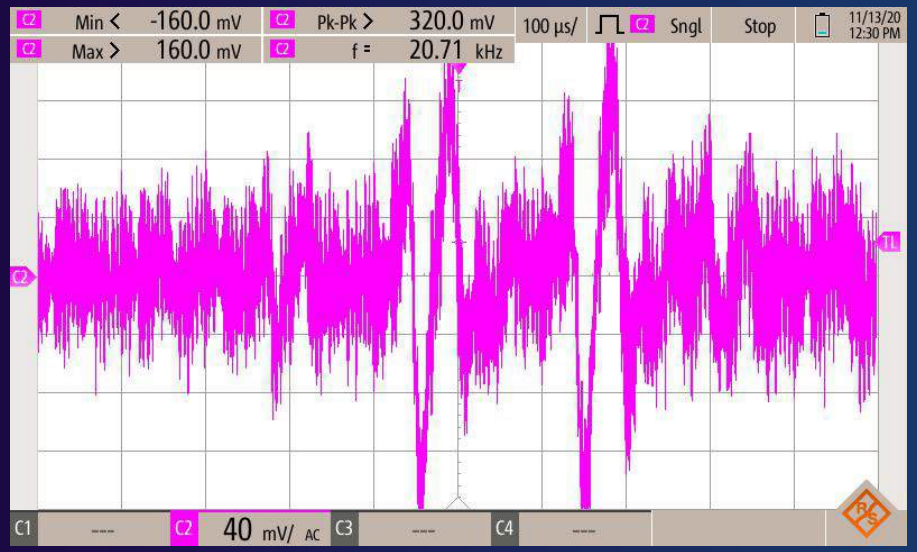
1,000-Foot Antenna with respect to pipe driven into the ground

Location: 37°20'16.2"N 121°26'55.0"W

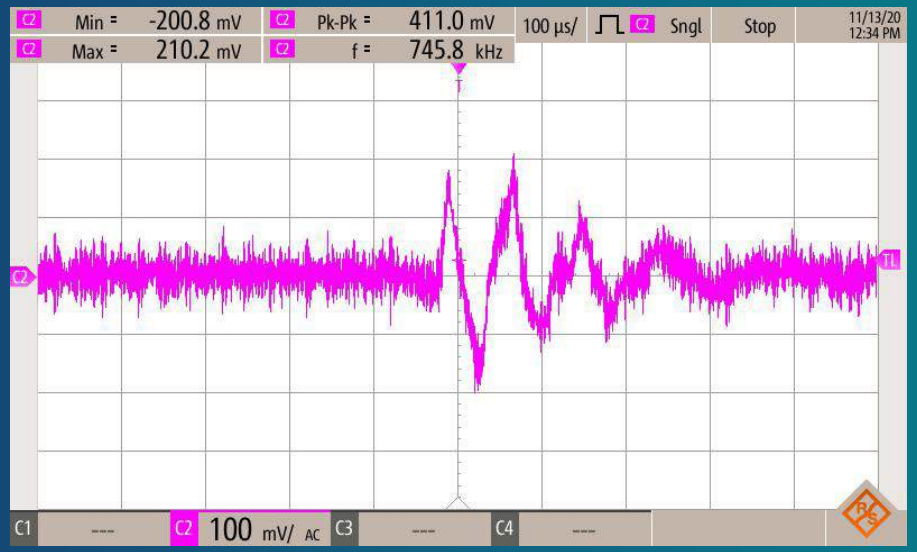
“100µs Transient”



“100µs Transient”

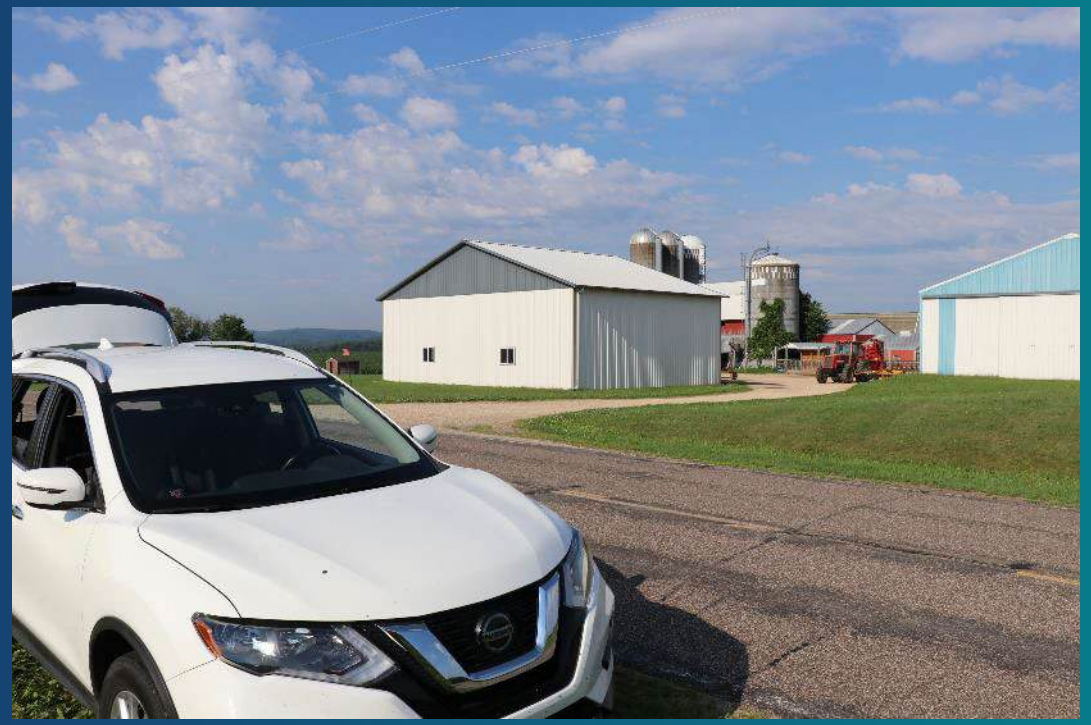


“100µs Transient”



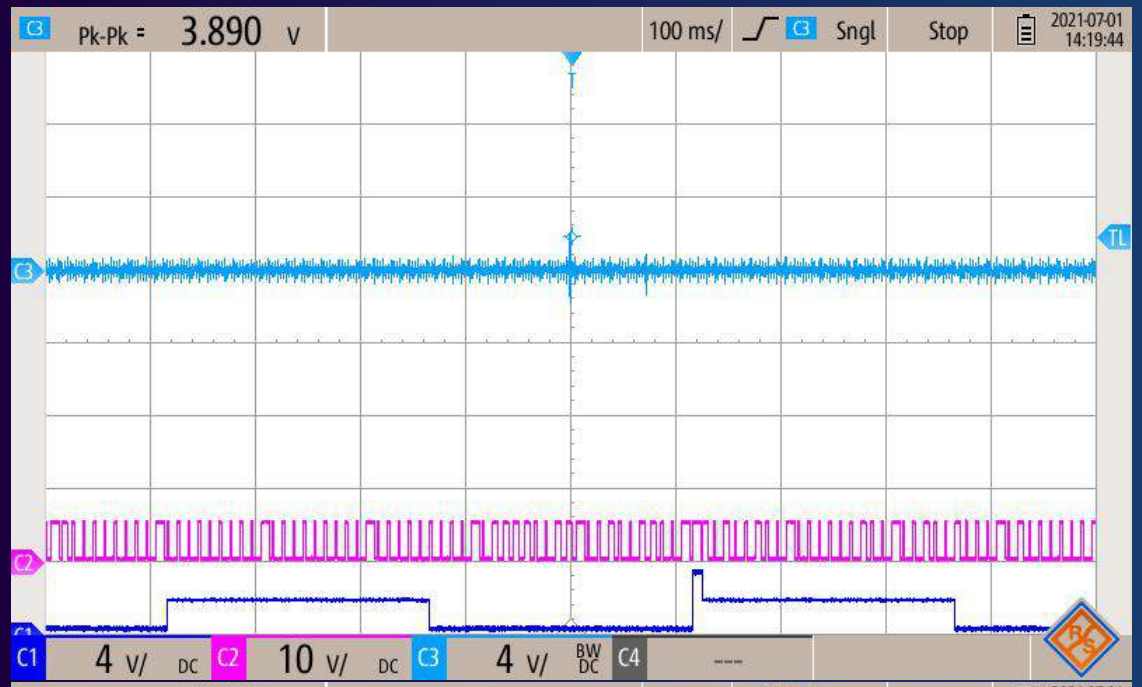
“100µs Transient”

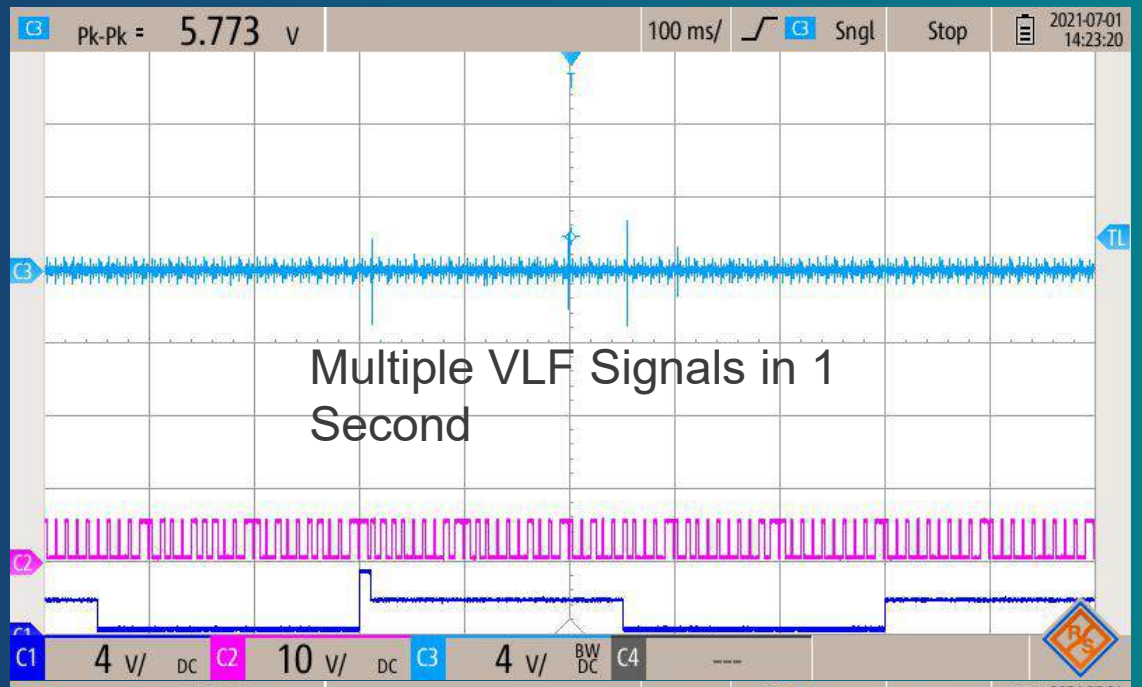
Testing the Claim of “No VLFs” at Another Location

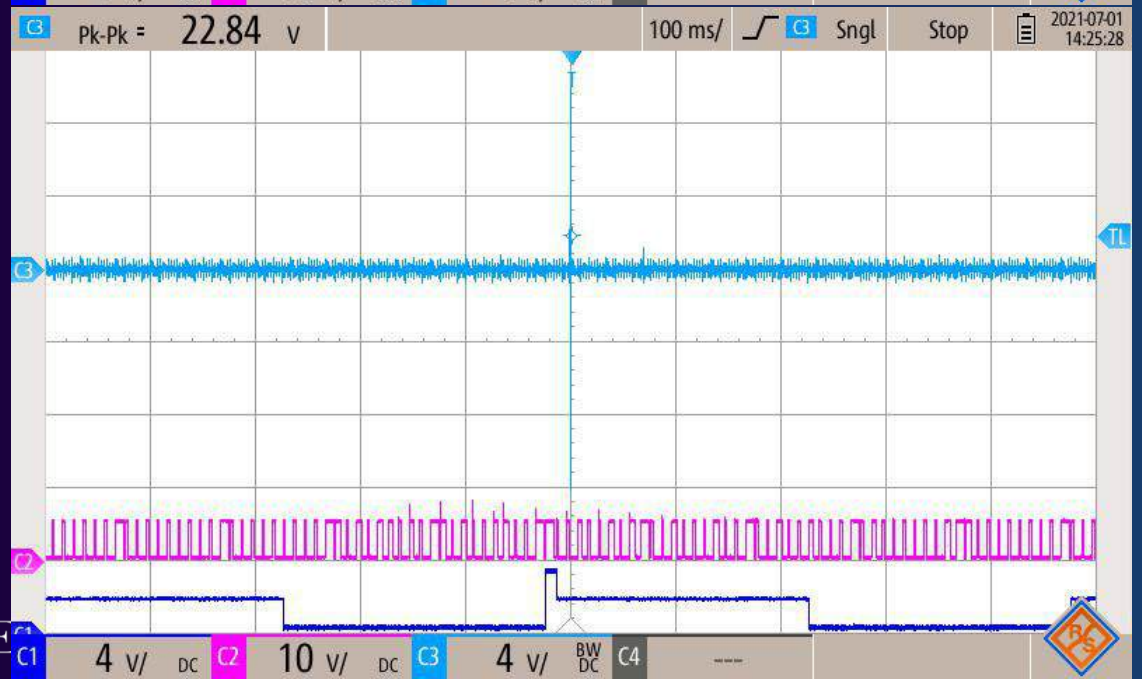


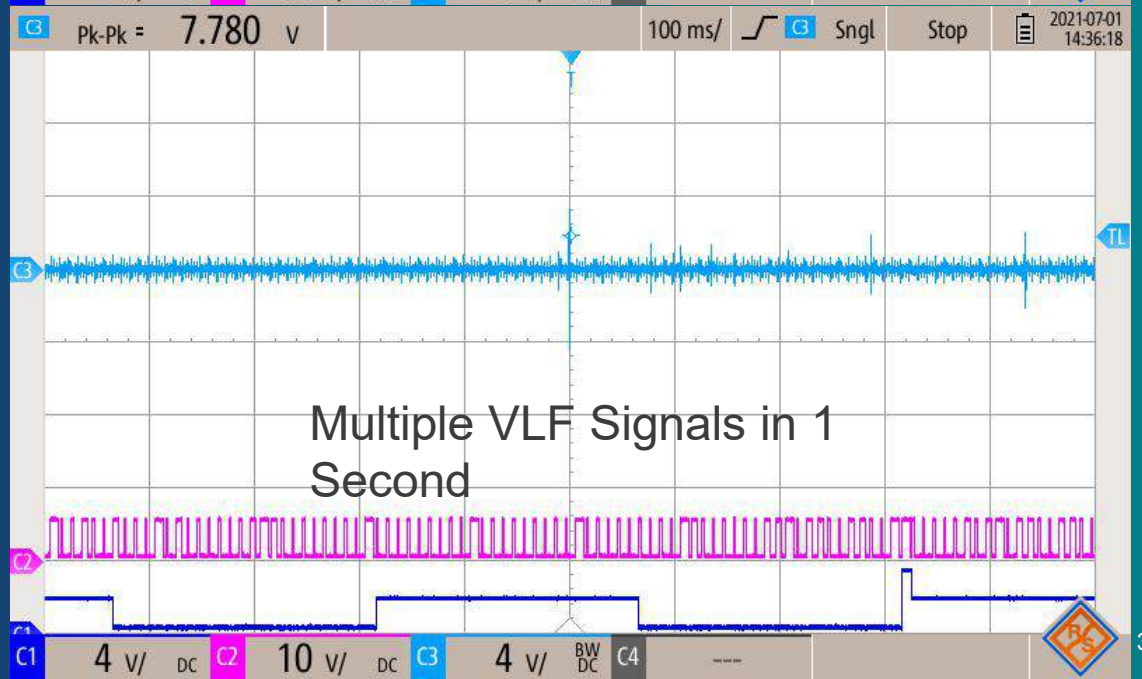

North Wire: 1.45 miles
South Wire: 0.9 miles
Chippewa River
Chippewa River
Chippewa River
State Rd 85
State Rd 85
Komro Sales & Services
Marshland
Sign in
Layers
Google
Imagery ©2021 Landsat / Copernicus, Maxar Technologies, USDA Farm Service Agency, Map data ©2021
United States
Terms
Privacy
Send feedback
2000 ft

500Ω, 10kHz Filter

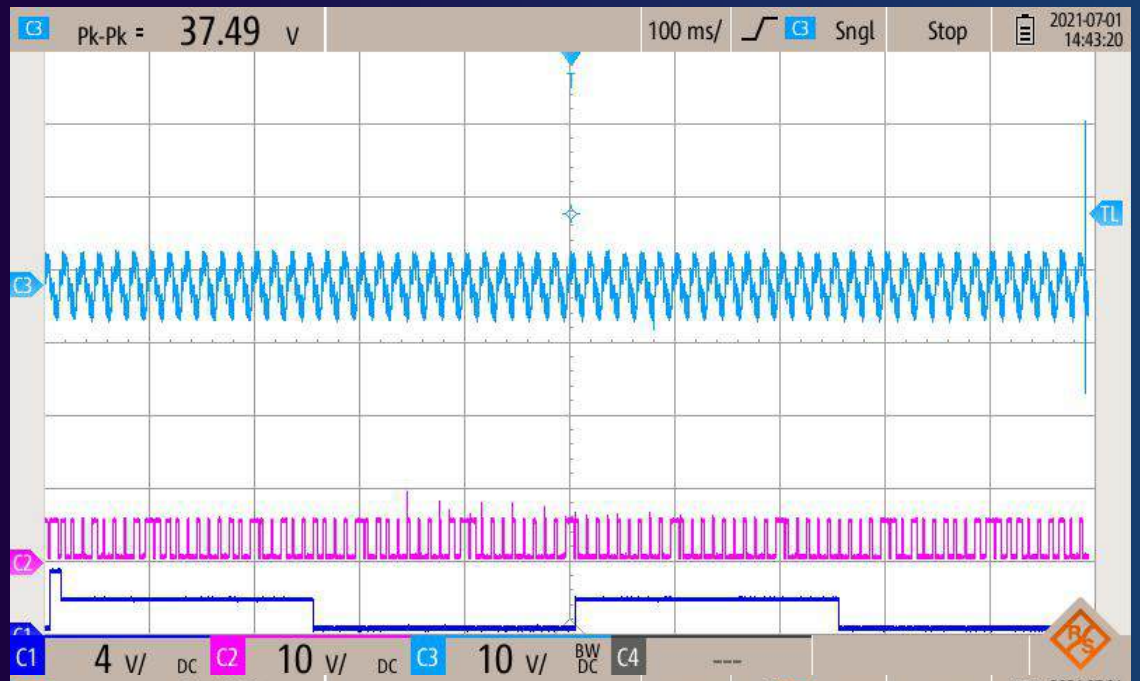


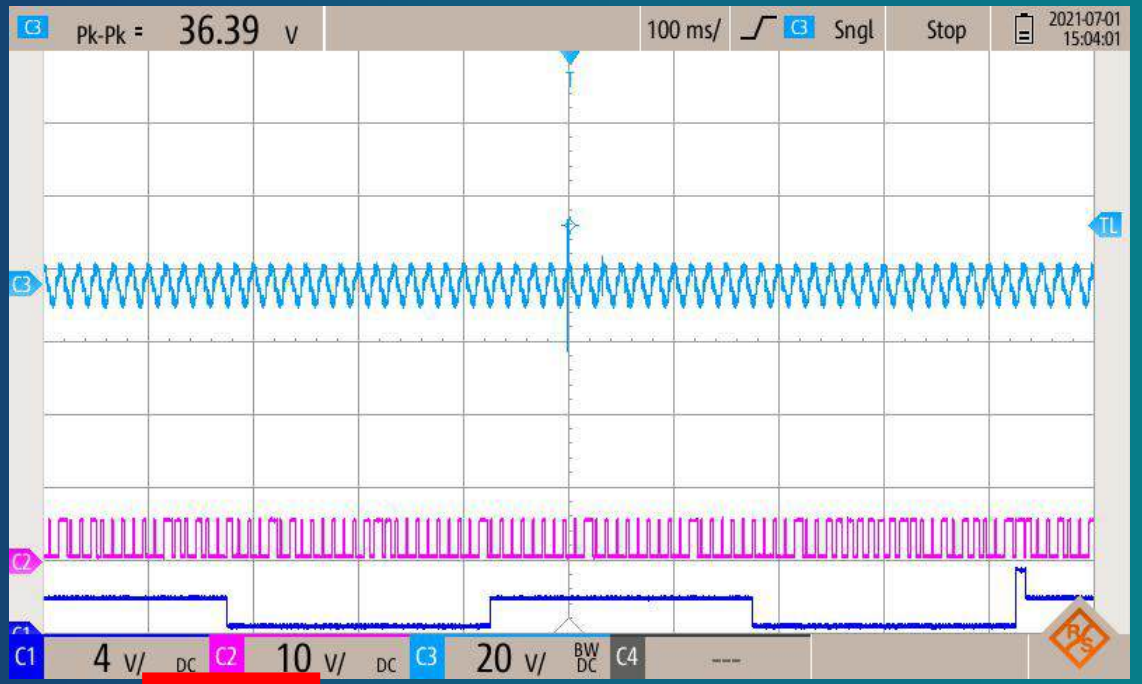


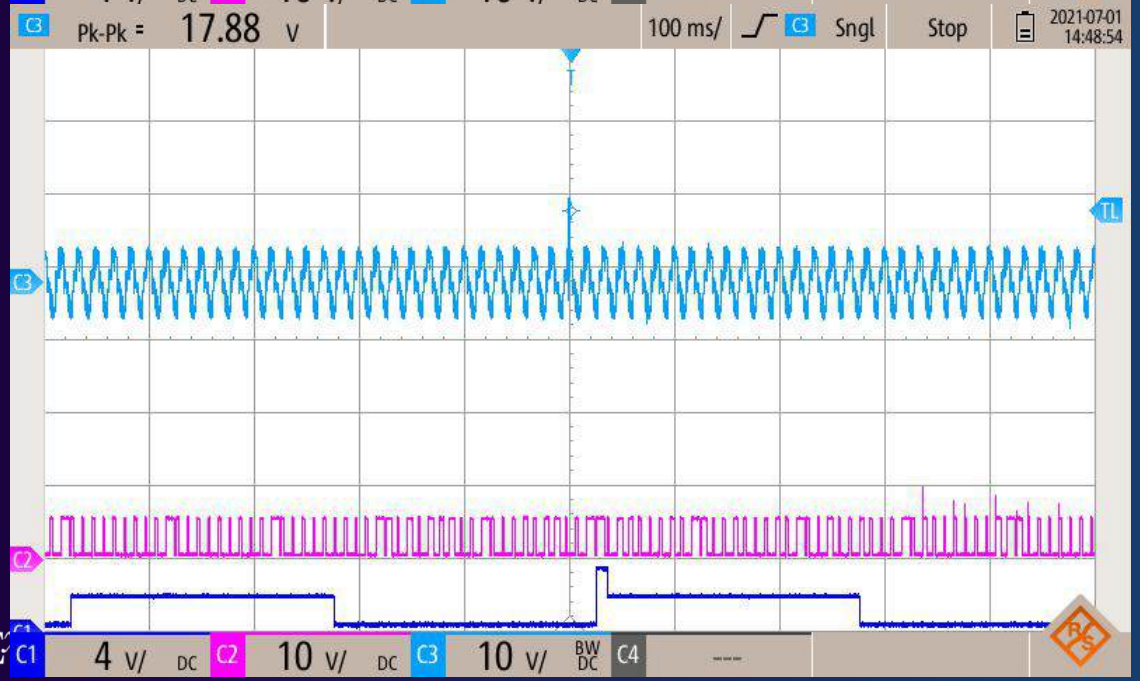


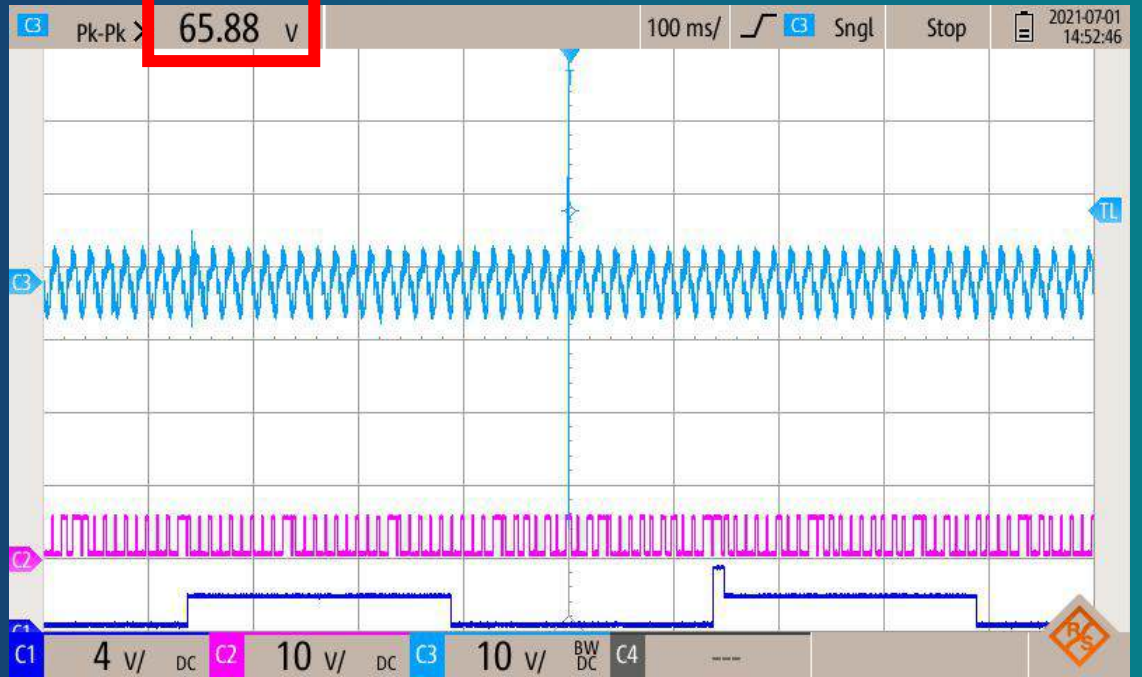


No Resistor, 50kHz Filter







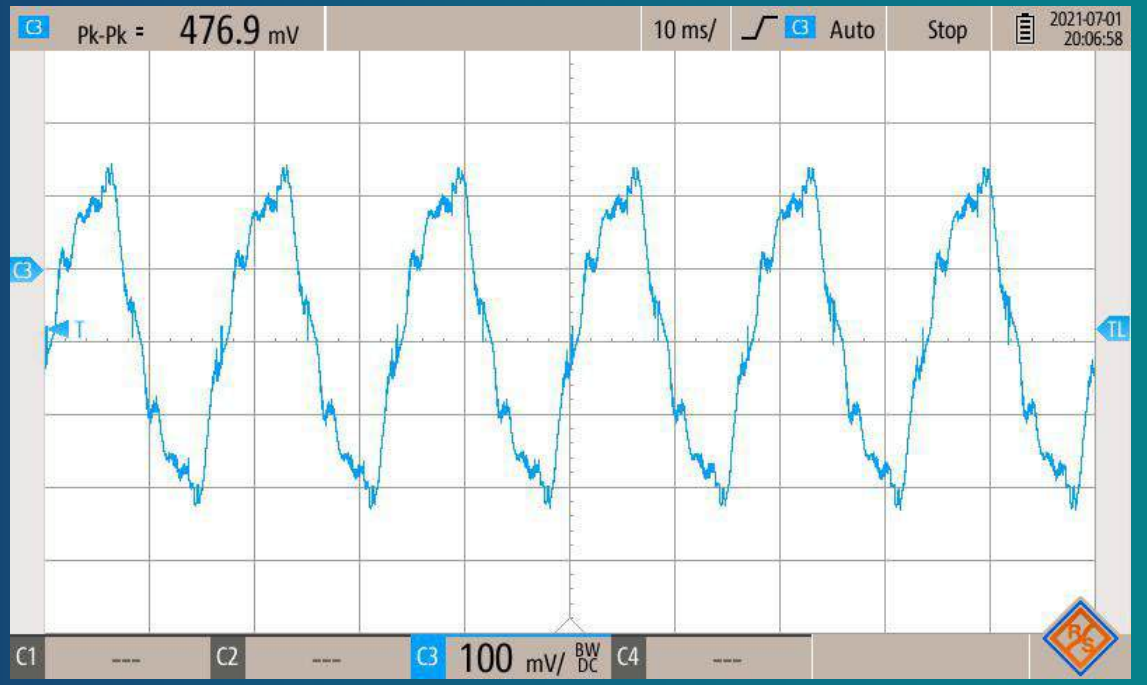


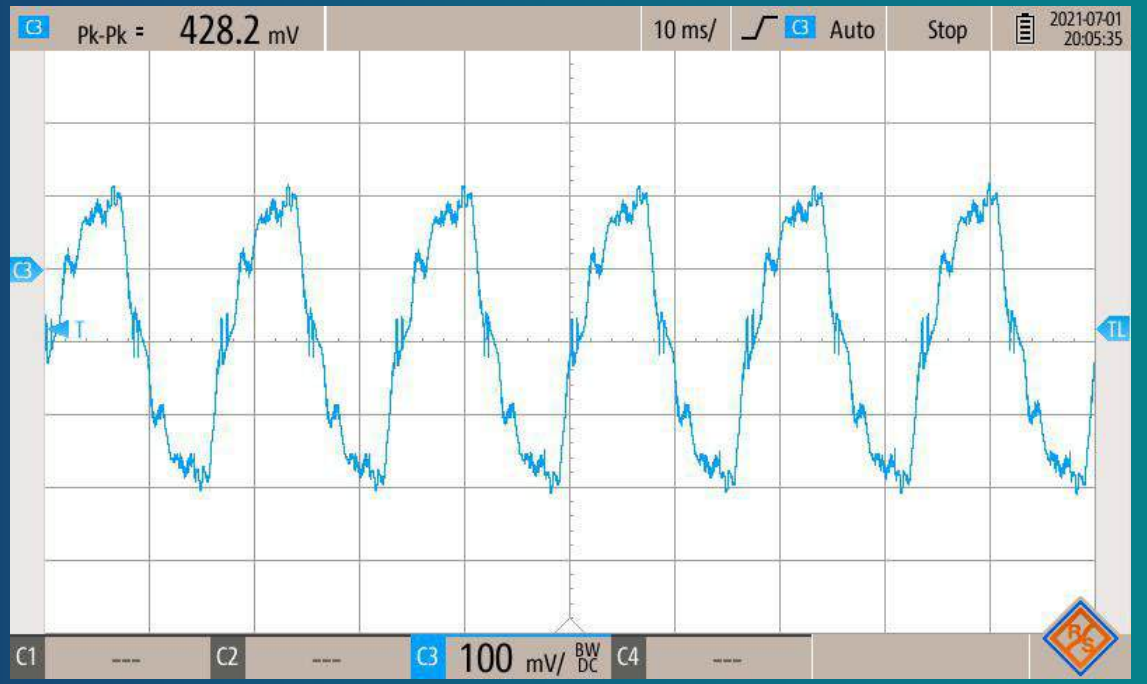
Testing at a High-Producing Dairy

One floating wire run 2.4 miles south

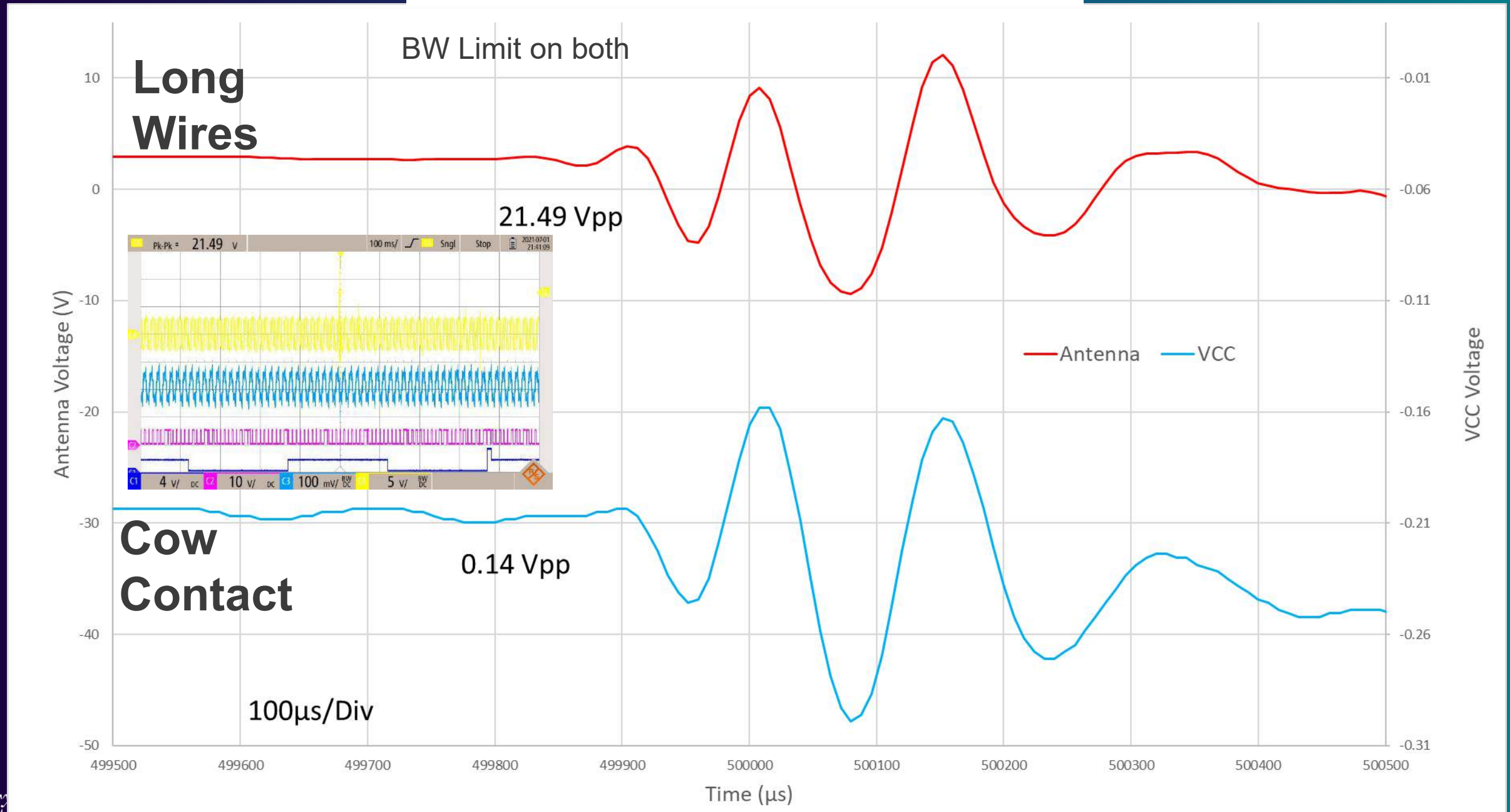

7956

0.17V_{RMS} present with 500Ω in calf waterers (0.47 Vpp)

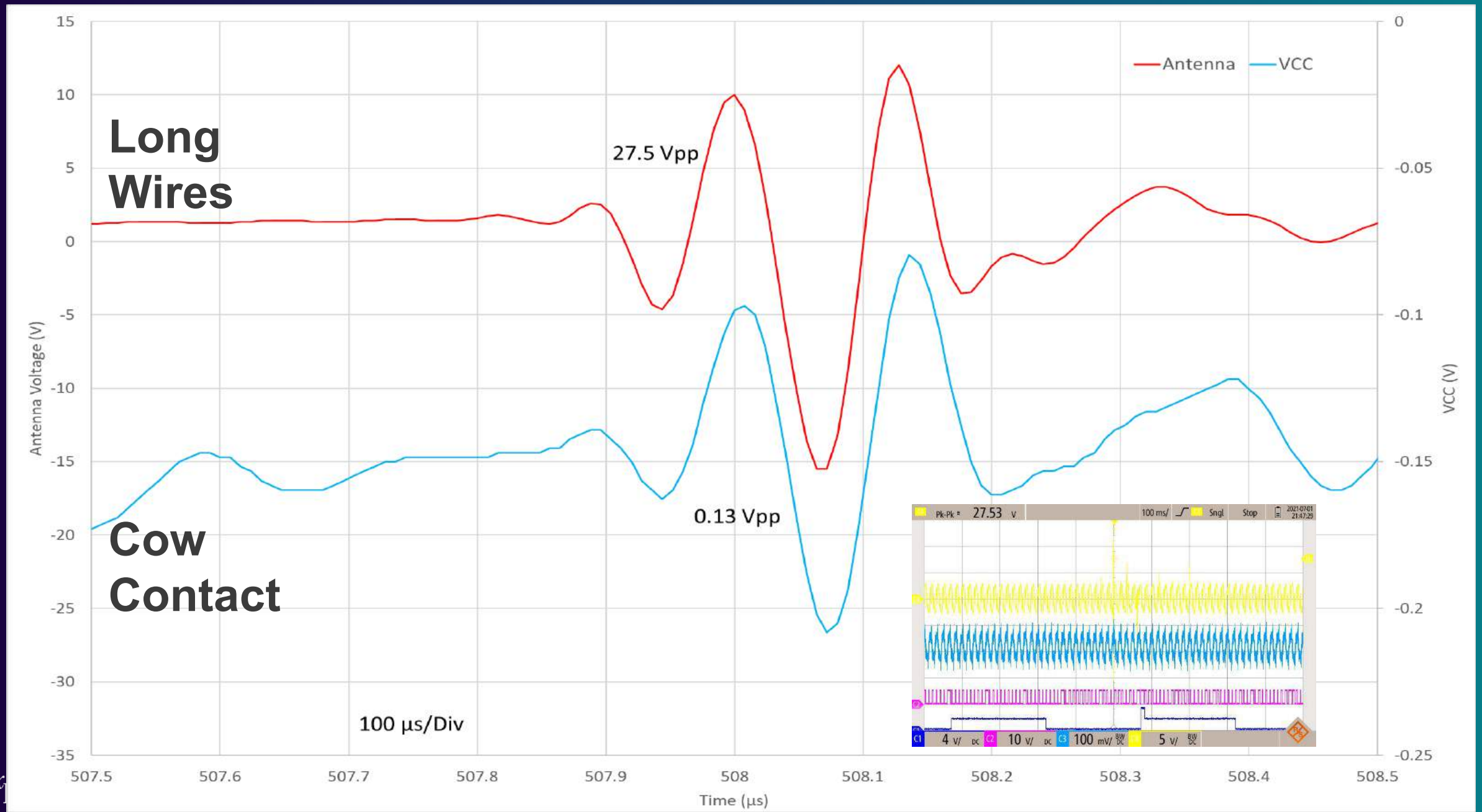




VLF Signal at Cow Contact



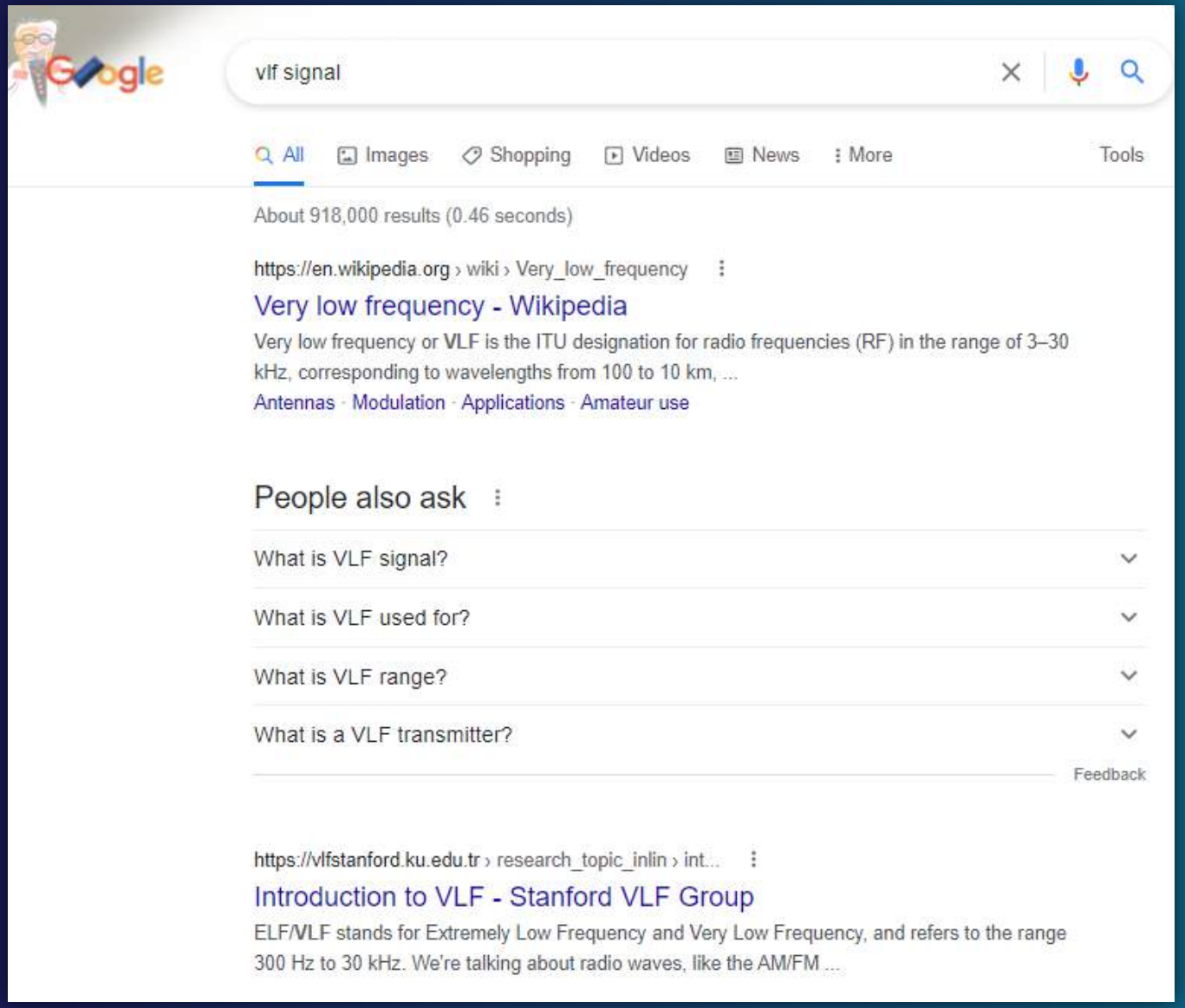
VLF Signal at Cow Contact



Summary of Findings: VLF Signals

- Found everywhere on conductive surfaces
- Have no apparent distribution system source
- Are radiated and conducted
- Come and go seemingly at random
- Similar to the electromagnetic signature of a fencer except:
  - They are not periodic
  - They vary greatly in amplitude
  - They vary in frequency content (within the VLF range)
- Loud reached out for help to identify the source …

Potential Sources of Non-Periodic VLF Signals



Potential Sources of Non-Periodic VLF Signals

Stanford VLF Group

Home › Research Topic (inline) › Introduction to VLF

What is ELF/VLF Research?

ELF/VLF stands for Extremely Low Frequency and Very Low Frequency, and refers to the range 300 Hz to 30 kHz. We're talking about radio waves, like the AM/FM signals you get, just at an even lower frequency. On our planet, the most potent source of ELF/VLF waves is lightning, so a lot of what we do comes down to studying lightning and its various impacts on our Earth's environment, detectable even in Antarctica.

Why are ELF/VLF Waves Useful for Engineers and Scientists?

ELF/VLF waves are useful scientifically because they largely reflect at the D region of the Earth's ionosphere (60–90 km altitude), and are thus efficiently guided in the Earth–ionosphere waveguide to global distances. For instance, if you set up a radio receiver just about anywhere on Earth, you can pick up short bits of radiation from lightning strikes literally halfway around the world. These are called radio atmospherics, or sferics. ELF/VLF waves also penetrate into seawater, which has led to their use over the past several decades for communication with submerged submarines at long distances.

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From a scientific perspective, though, the reflectivity of the D region at these frequencies make ELF/VLF a unique tool for remote sensing of the D region, which responds to a variety of inputs like solar activity, lightning energy, electron precipitation from the radiation belts, cosmic gamma-rays, and earthquakes. Measurements of properties of the D region are extremely difficult, since those altitudes are too high for balloons, yet too low for satellites, so this is a useful ability. Complicating these studies, however, is the fact that the propagation of radio waves in complex media such as the plasma in the Earth's lower ionosphere is one of the most fundamentally difficult ones in electromagnetism, violating nearly every convenient simplifying assumption like homogeneity, linearity, symmetry, and anisotropy. Numerically modeling these waves is requires the most advanced techniques available.

Lightning:

Bottom Line Up Front

Characteristics of the VLF Signals

Physics of Induction

Radio Atmospherics (Sferics)

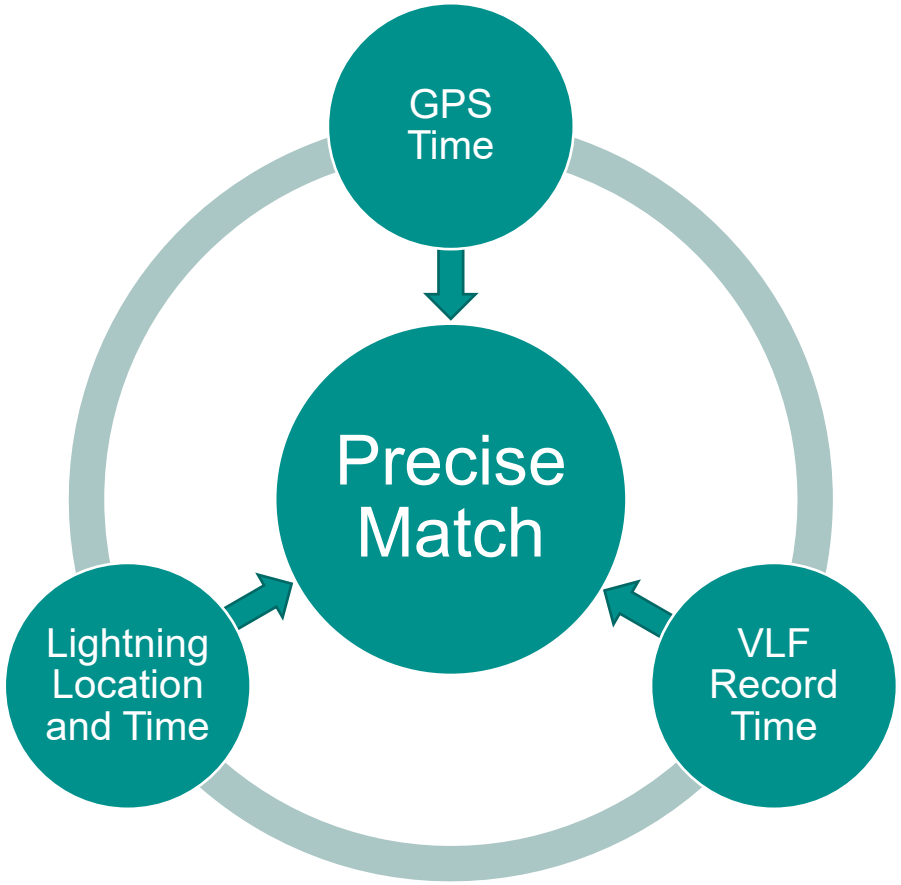
- Known Variability
- Source Identification

Matching Each VLF Recording to an Individual Lightning Stroke

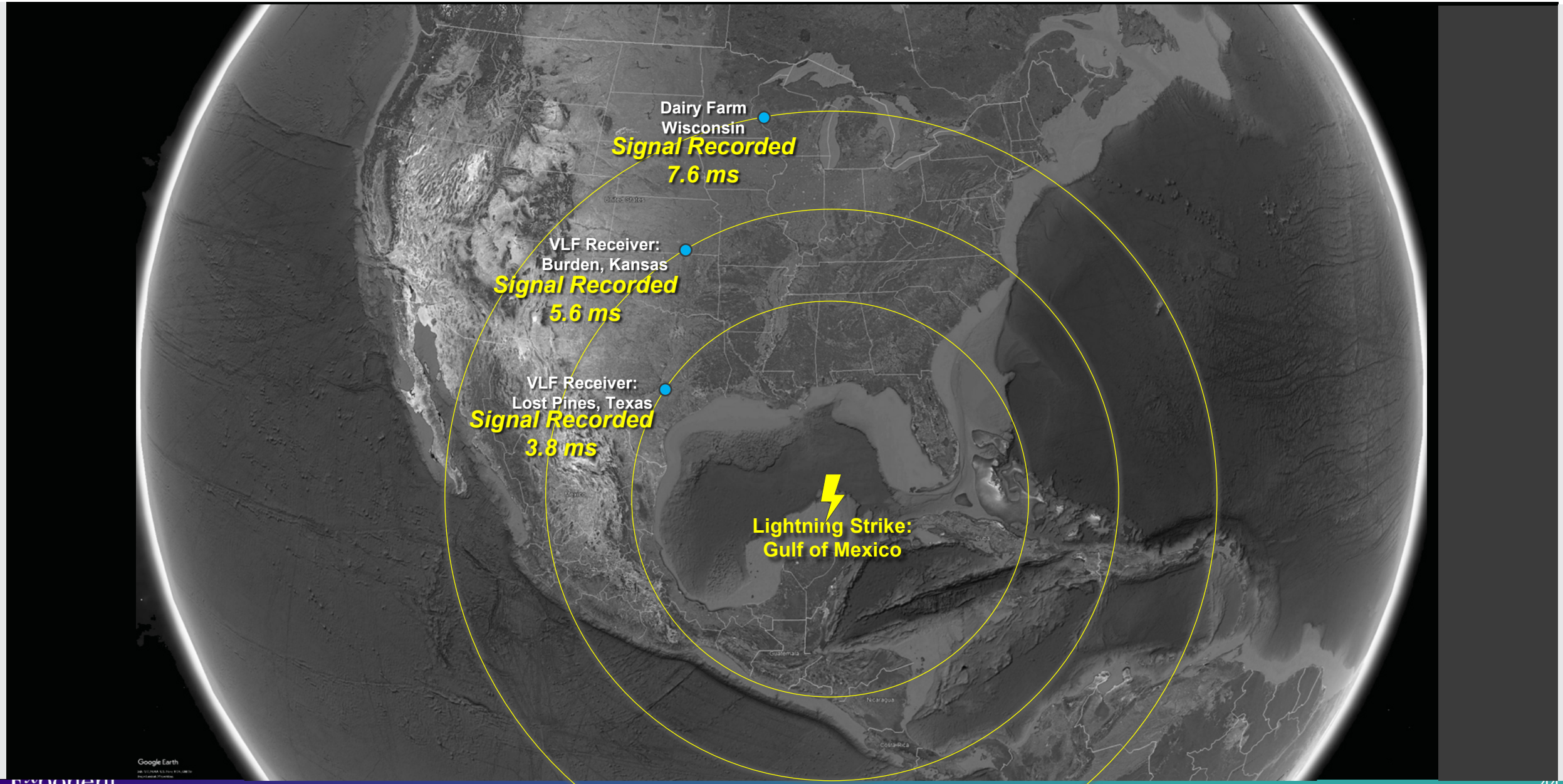
Known Lightning Strokes – National Lightning Detection Network

- Precise GPS time
- Precise time of VLF
- Lightning info
  - Precise time
  - Precise location

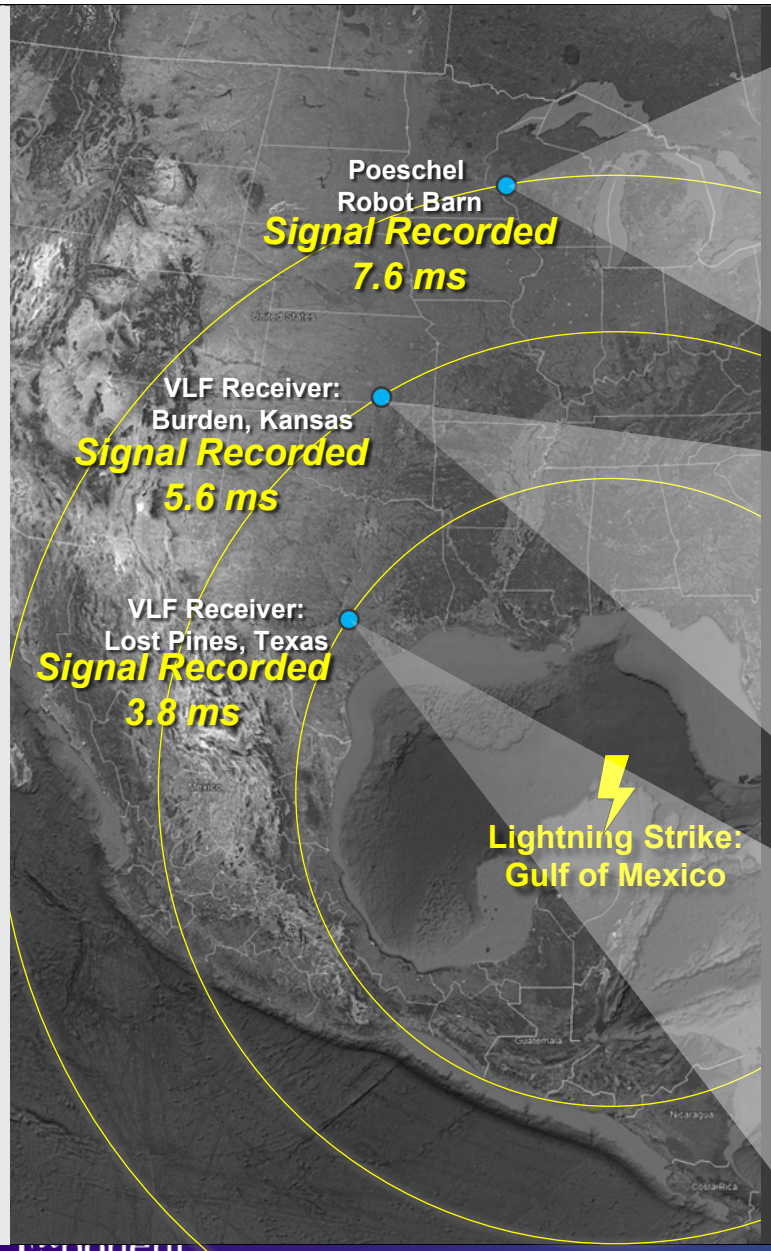
- Match within 1/1000th of a second

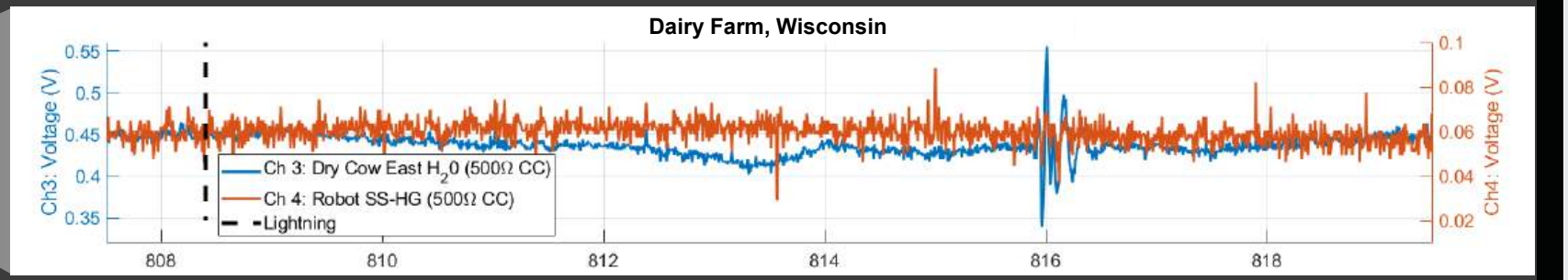


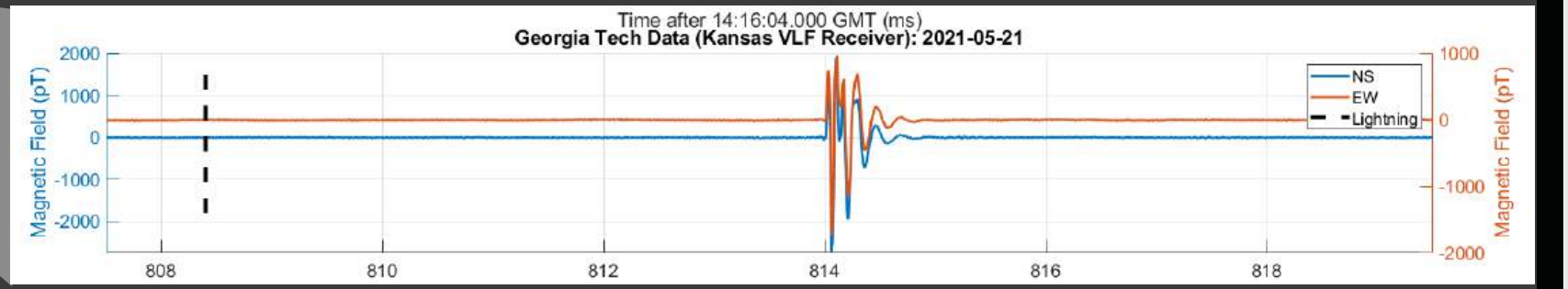
Lightning Strike in Gulf of Mexico

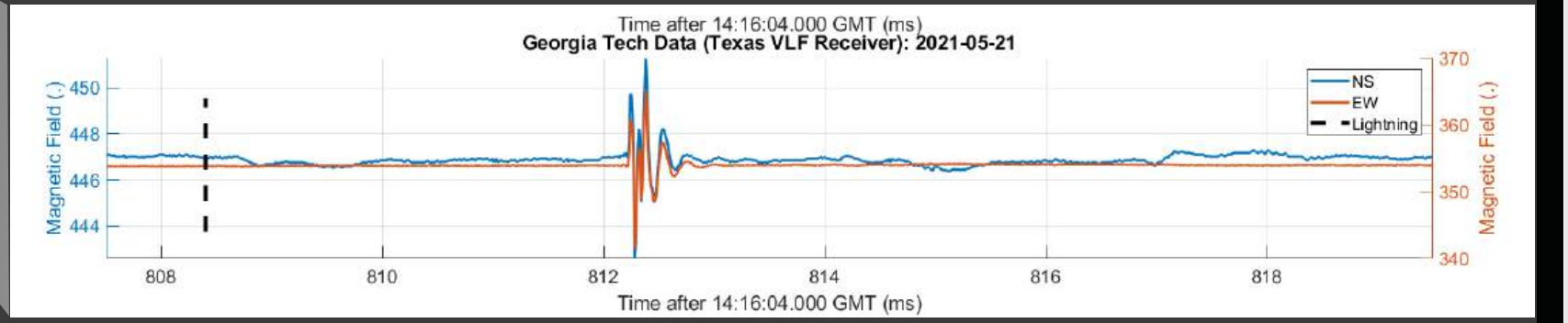


Lightning Strike in Gulf of Mexico

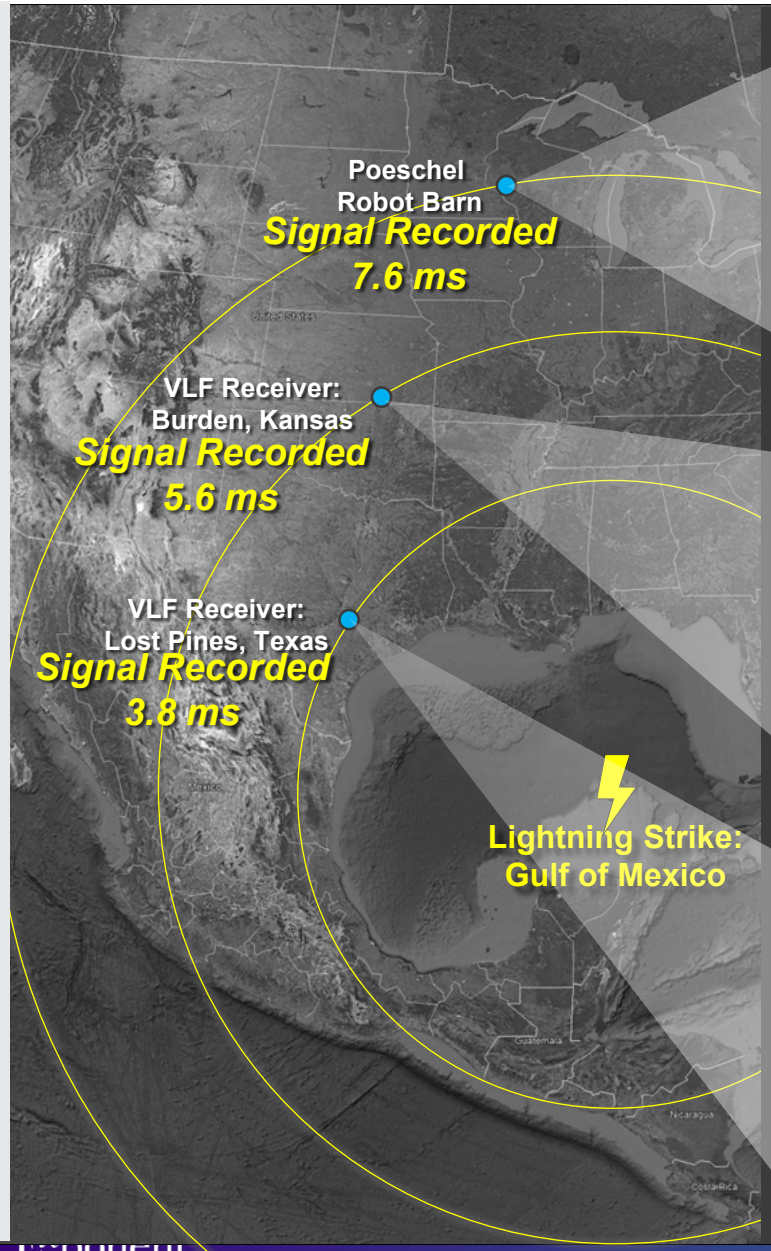


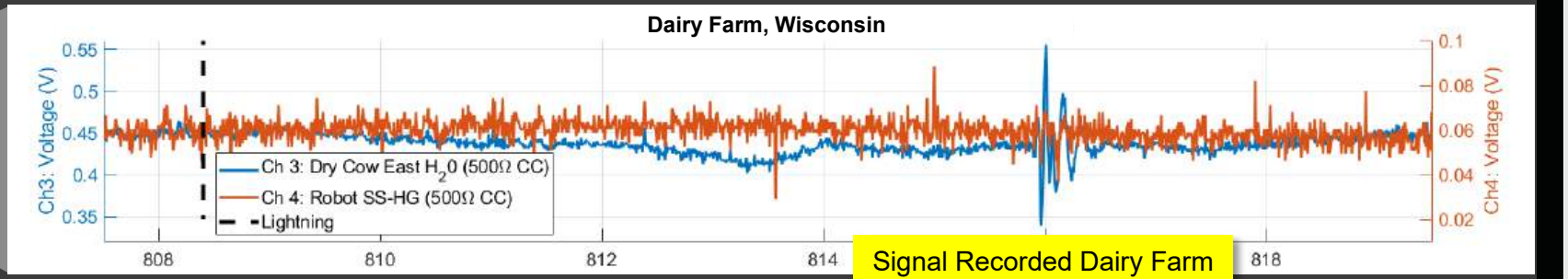


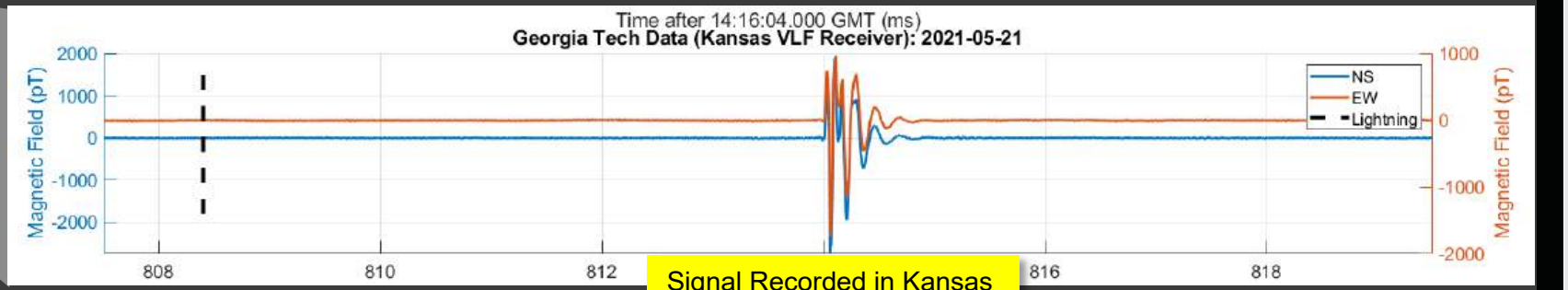


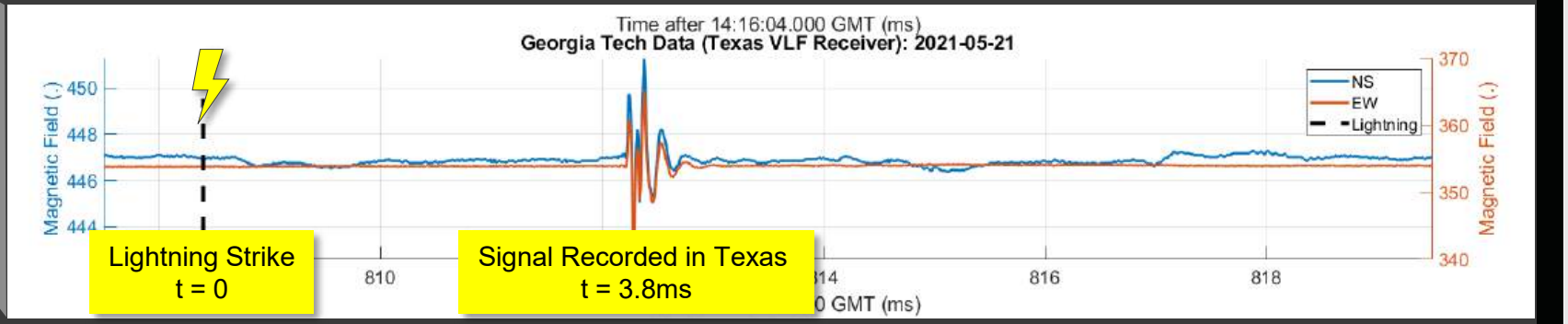


Lightning Strike in Gulf of Mexico









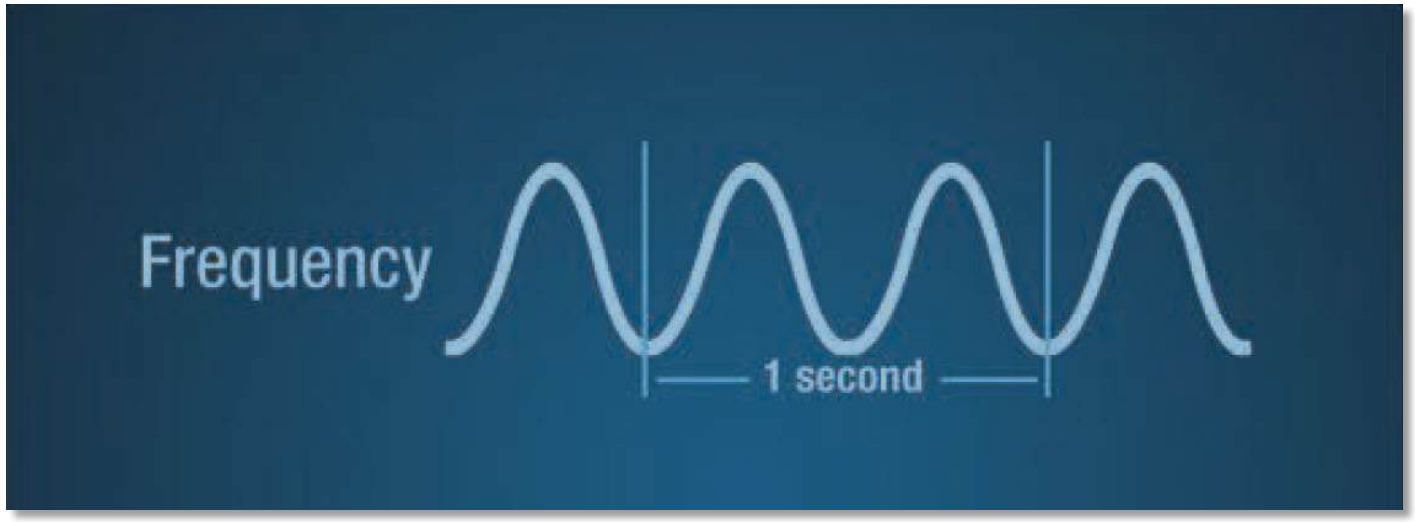
Bottom Line Summary

- VLF Events from lightning are measured everywhere
  - Litigious Dairies
  - High-producing dairies
  - Off-grid
  - Anywhere there is a conductor (e.g., metal)
- Matched exactly to known individual lightning strokes
- In addition to the physics, statistics proves the source

Powerball _ California State Lottery.pdf, Mega Millions _ California State Lottery.pdf

Characteristics of VLF Signals

Frequency



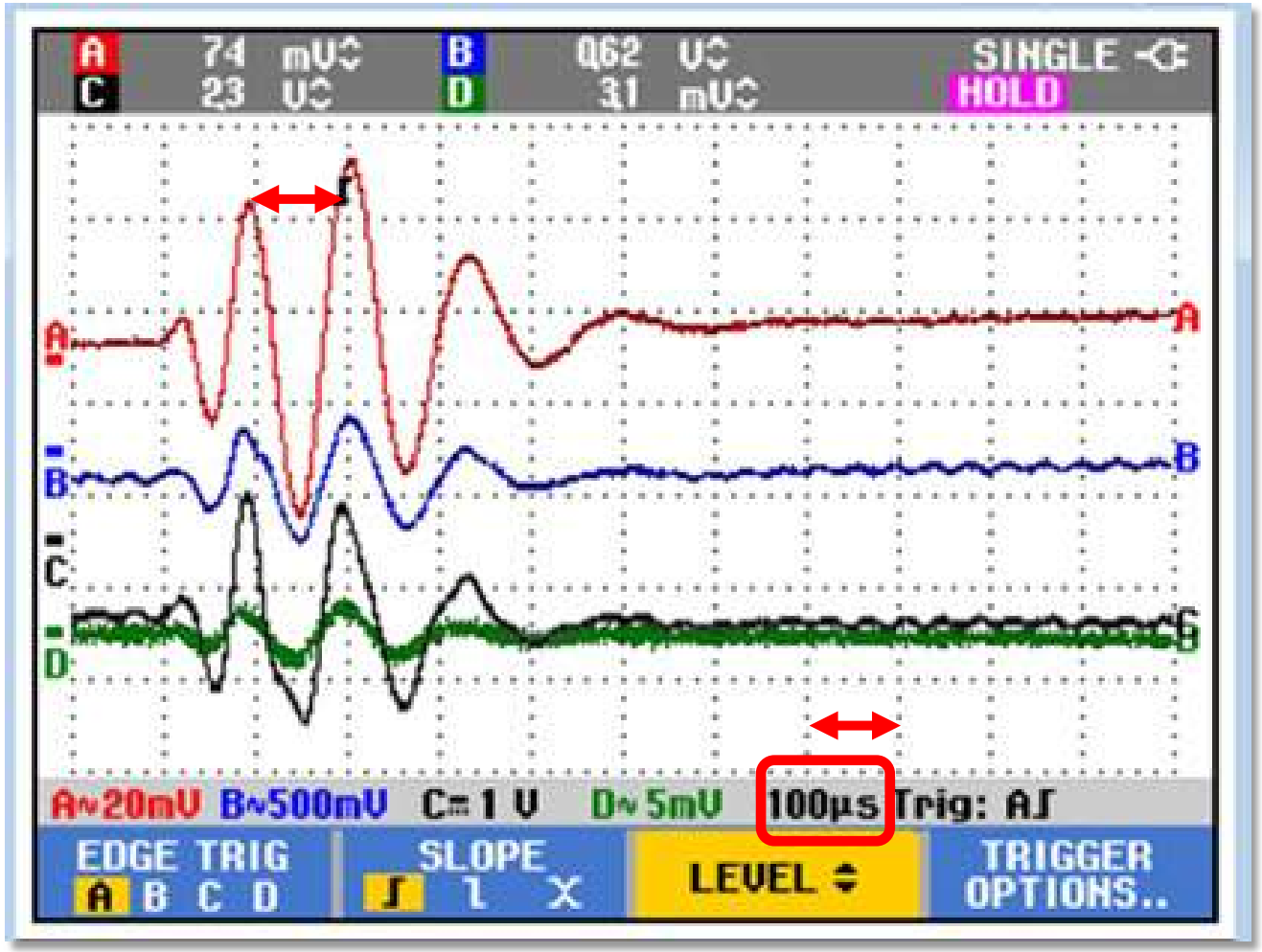
Hertz (Hz) = cycles per second

***kilo*Hertz (kHz) = *thousands* of cycles/sec**

***megaH*ertz (MHz) = *millions* of cycles/sec**

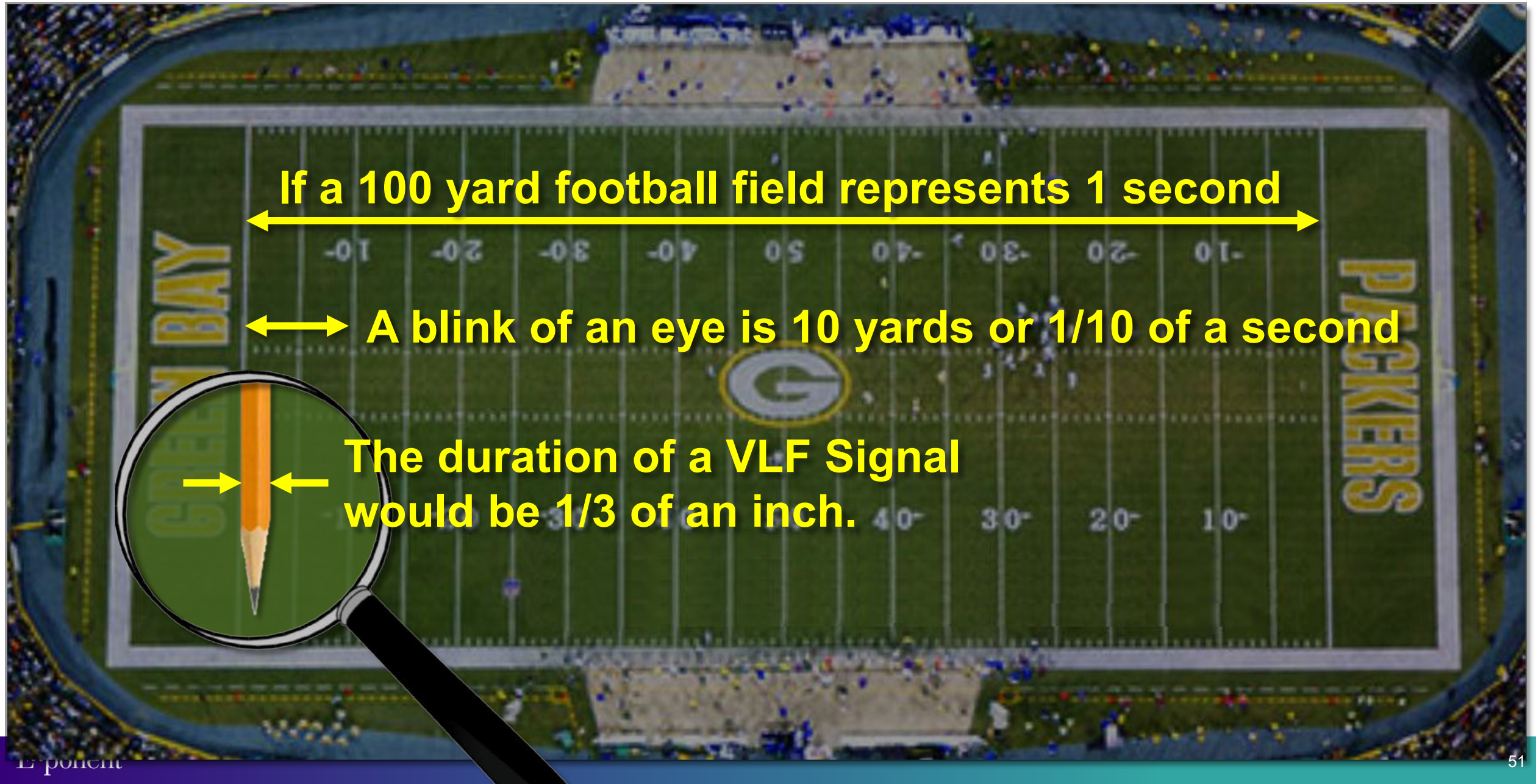
Power Lines	**60 Hz**
VLF	**3,000 to 30,000 Hz**

Duration



- About 100 microseconds per cycle
- About 100-400 microseconds to decay to zero

What is the Duration of a VLF Signal?

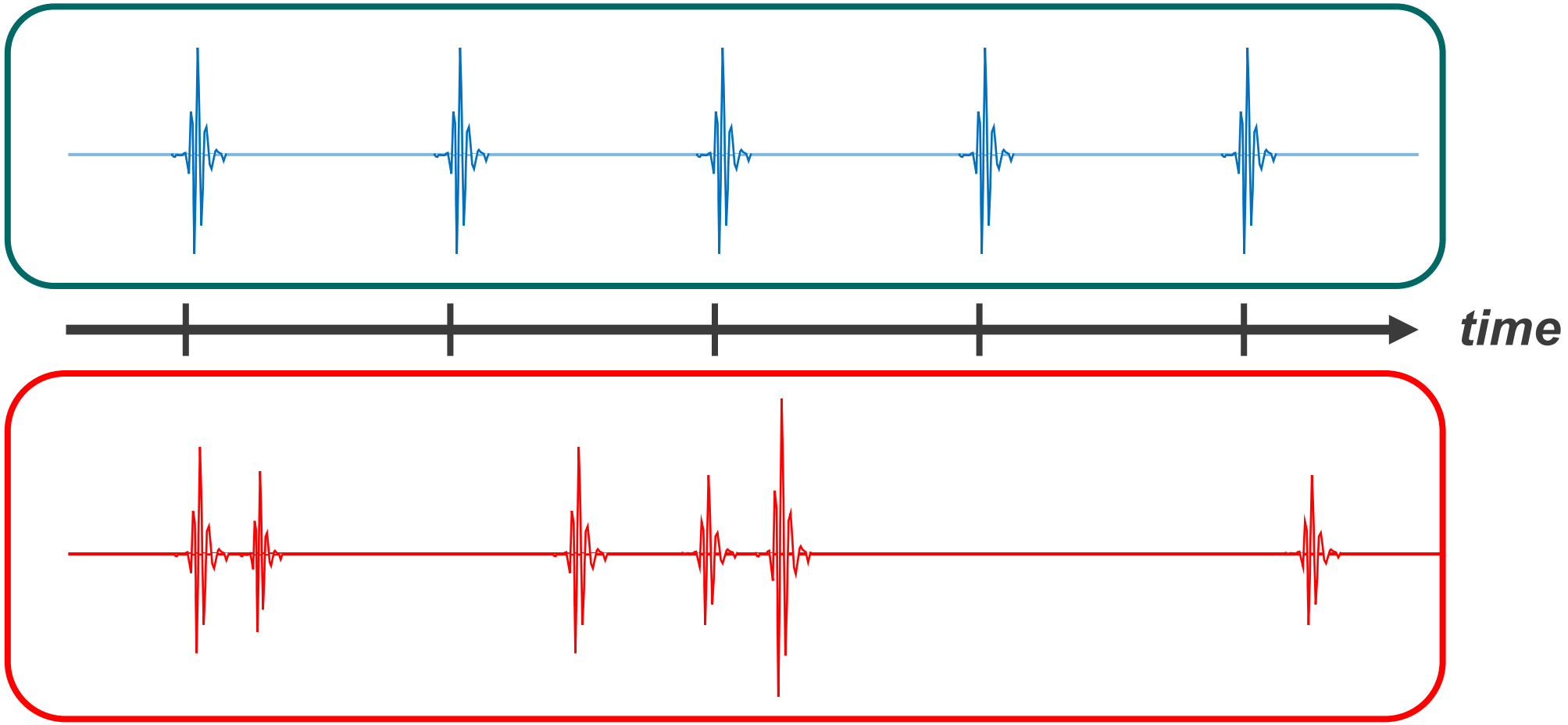


What is the Duration of a VLF Signal?

- Blink of an eye:
  ~0.1 to 0.4 seconds
- VLF Signal:
  ~1000 times faster than the blink of an eye

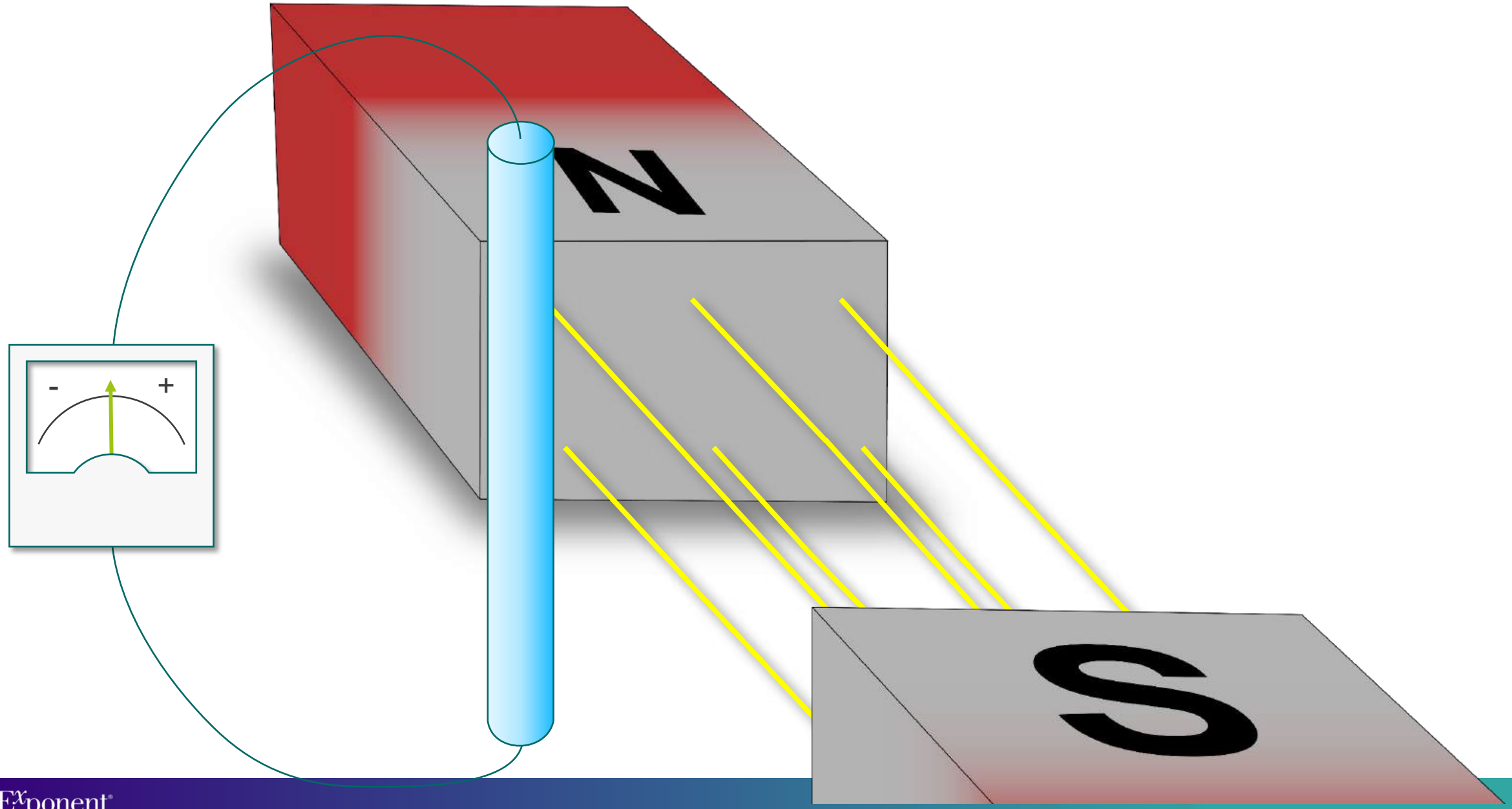
SOURCE: https://bionumbers.hms.harvard.edu/bionumber.aspx?id=100706&ver=0

Periodic vs. Non-Periodic

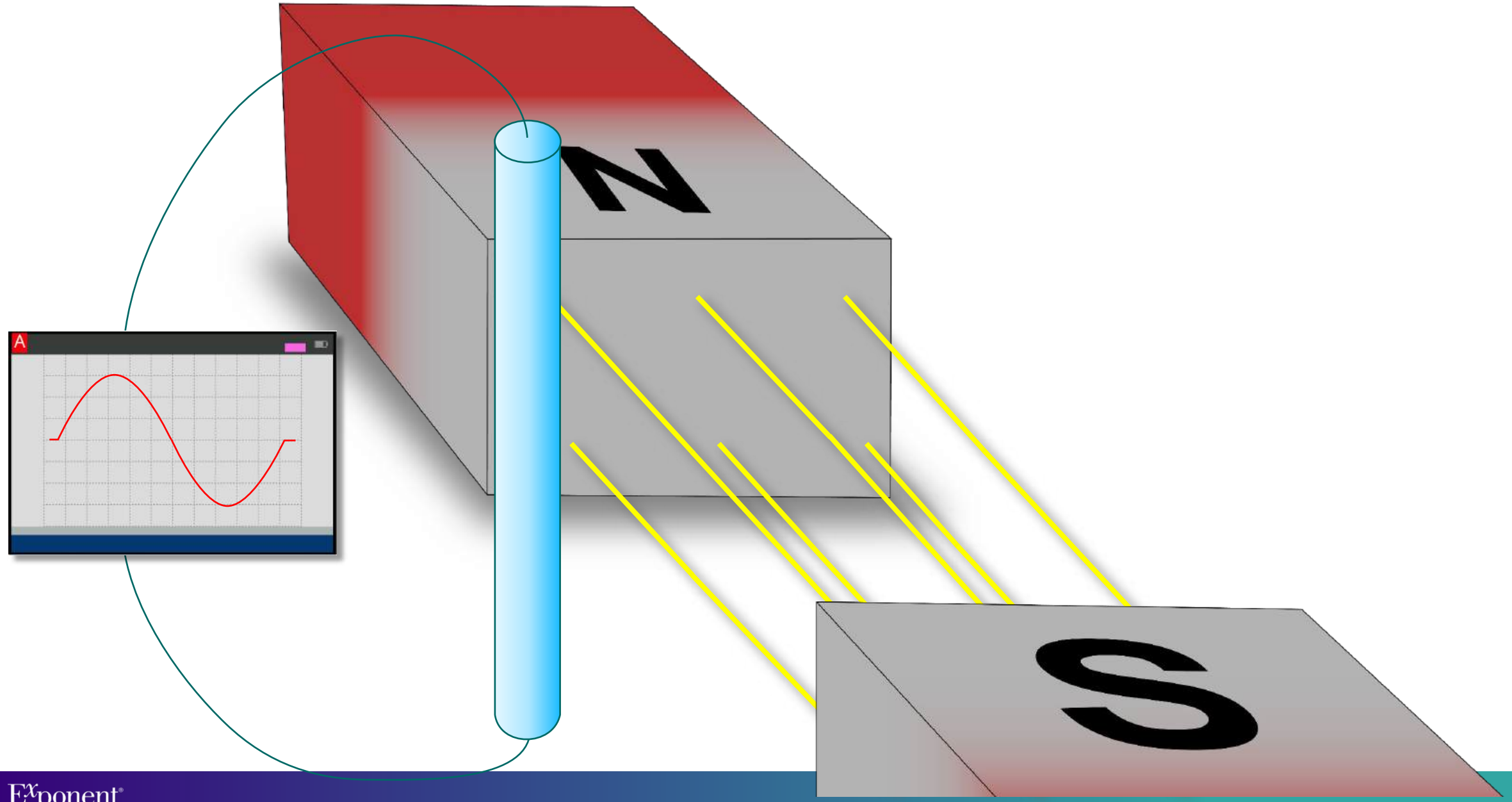


Physics of Induction

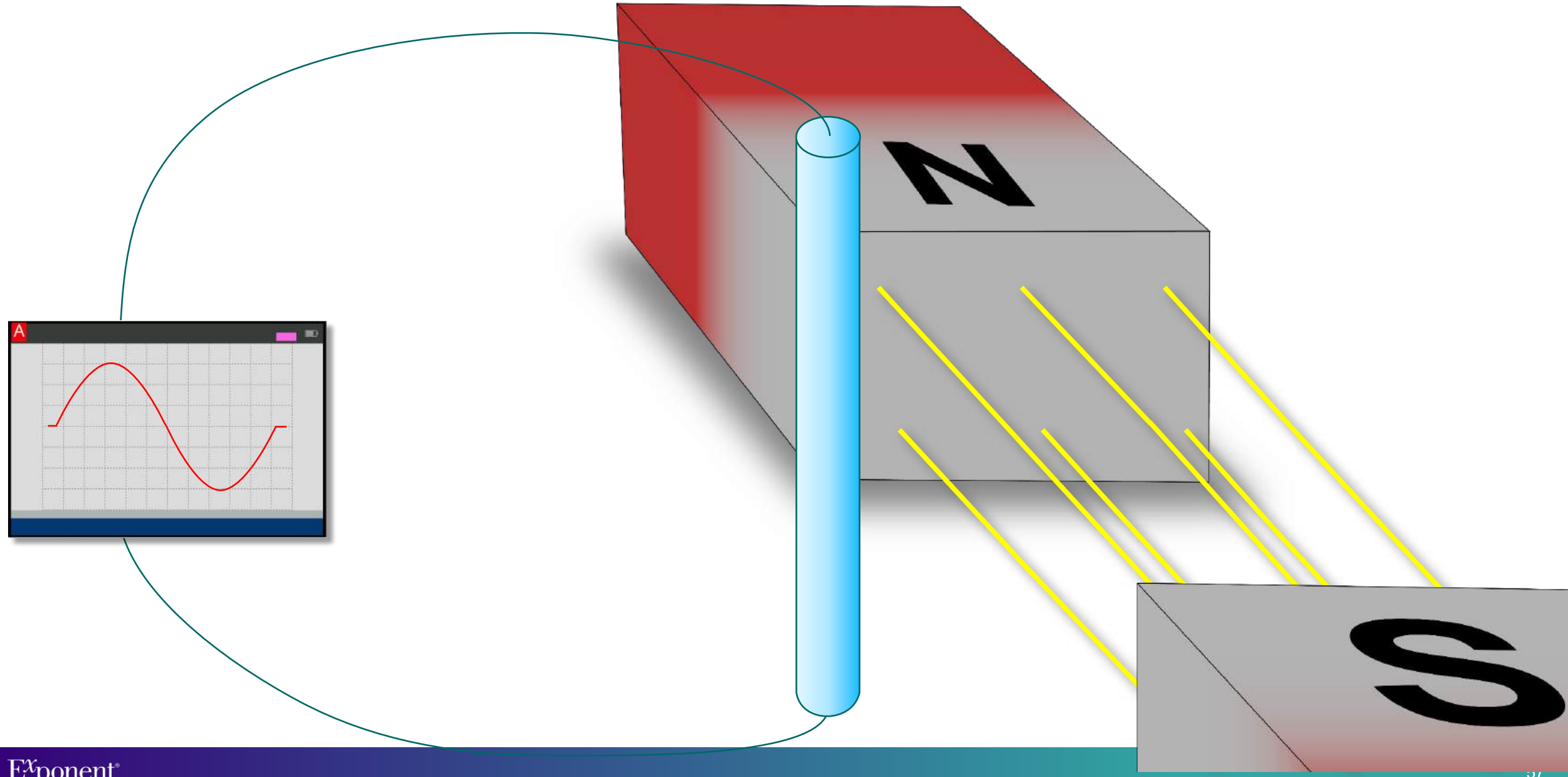
Moving A Conductor Through A Magnetic Field



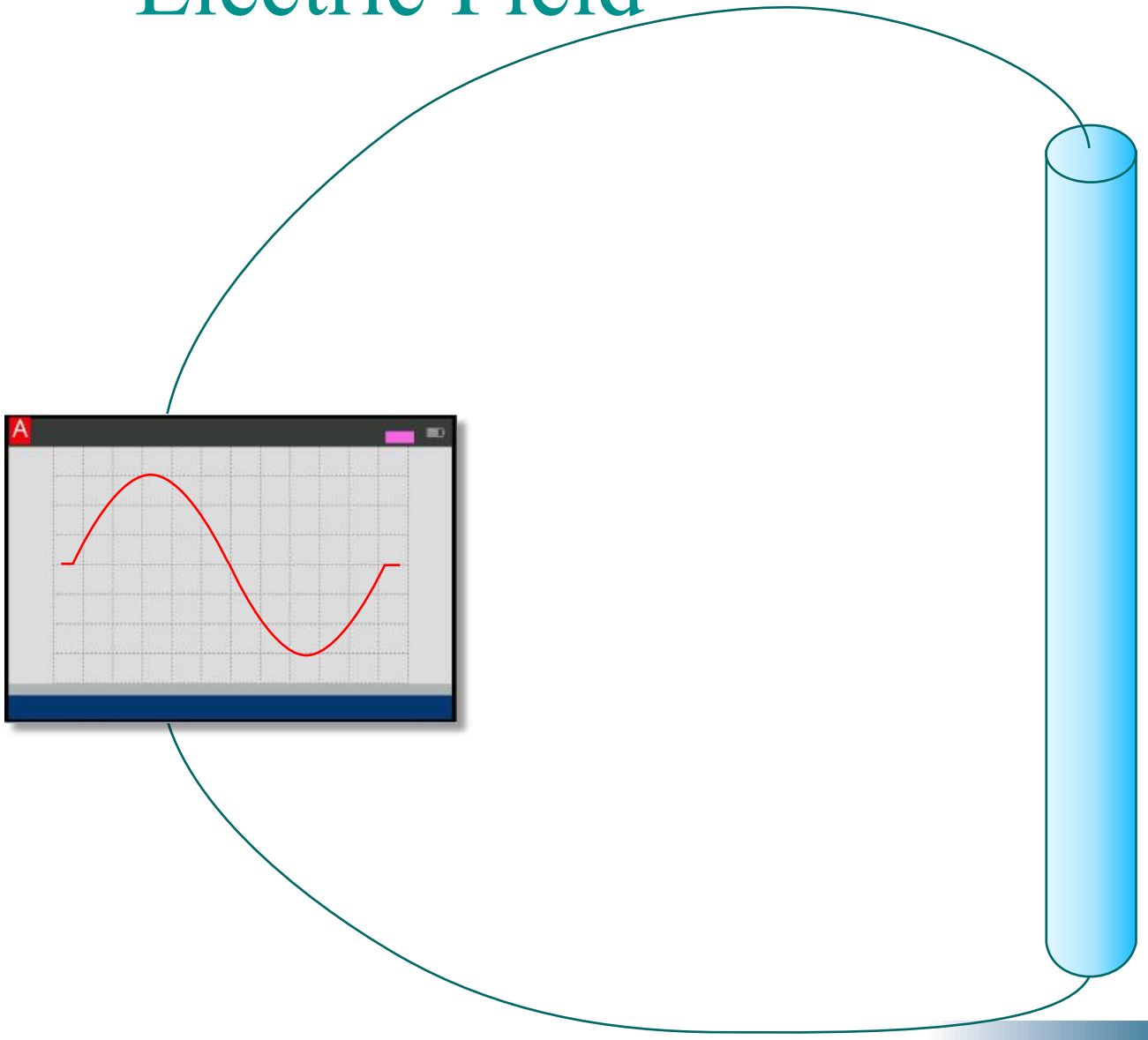
Moving A Conductor Through A Magnetic Field



Moving A Magnetic Field Through A Conductor



Electric Field



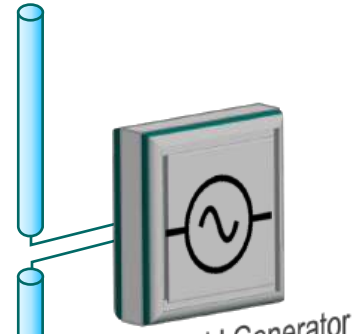
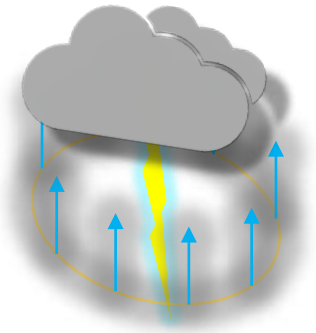
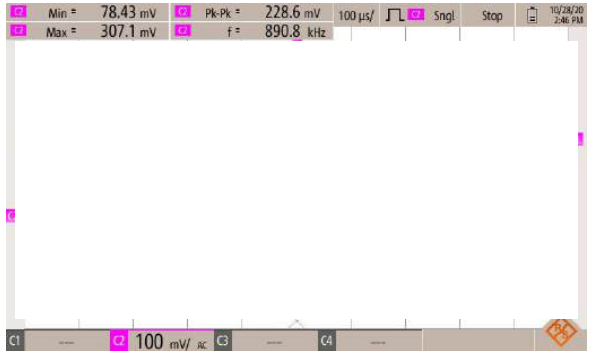


Illustration: How a VLF Signal from Lightning Shows up on an Oscilloscope at a Distant Farm

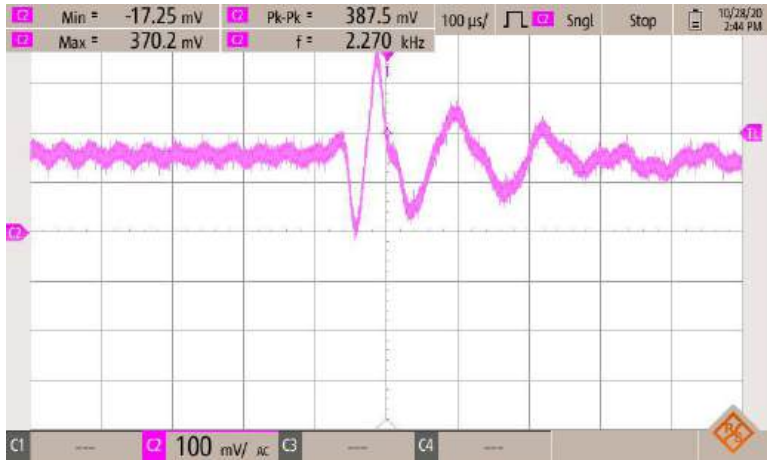


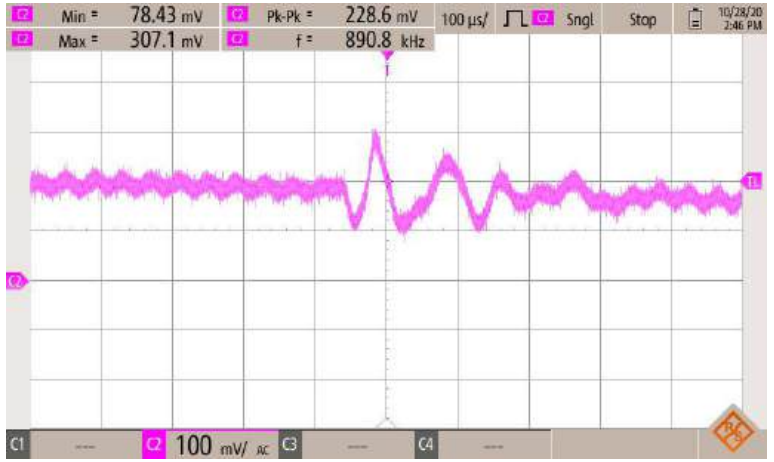
Lightning Strike



- Lightning occurs when enough charge builds up.
- Electric current flowing in the lightning stroke, generates a magnetic field.
- The growing magnetic field creates an electric field
- The magnetic and electric fields spread outward at the speed of light.
- Inducing voltage in all conductive object they pass.

Shed Antenna



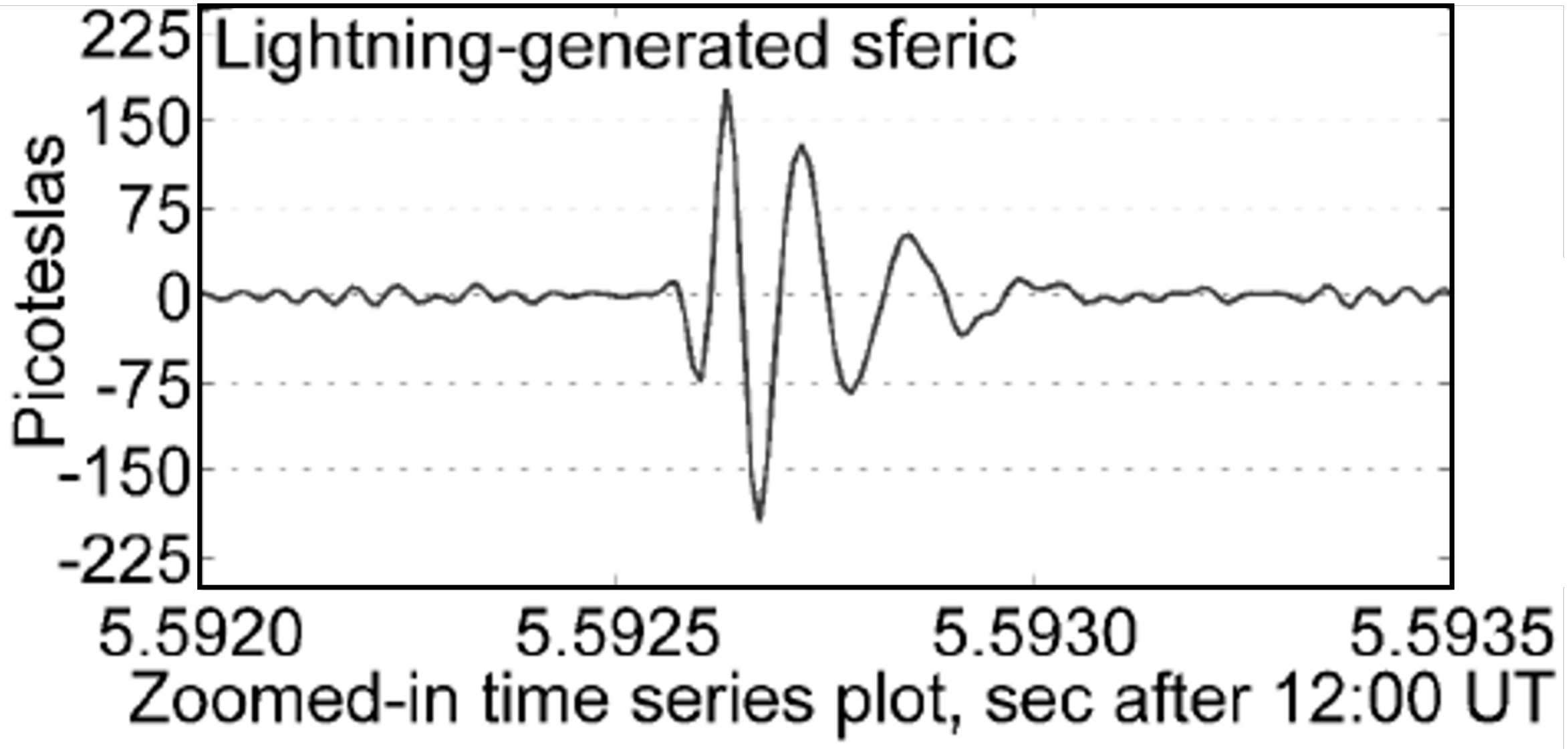


Radio Atmospherics (Sferics)

VLF Signals: Sferic

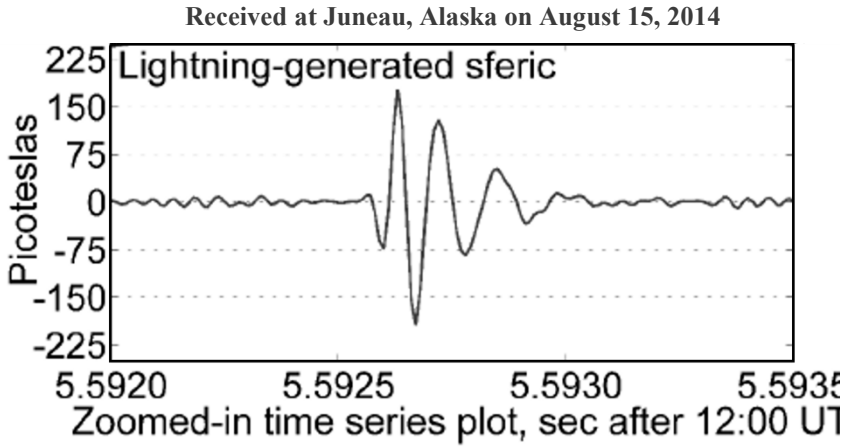
- Most common source of non-periodic VLF signals on Earth: *lightning*.
  - > 50 strokes/sec
- Detectable > 6,200 miles (10,000 km)
- Studied ~100 years
- Broadband
  - Many frequencies
  - Highest energy: VLF range
  - Signals from North and Central America easily detectable in Wisconsin/Minnesota etc.

Received at Juneau Alaska on August 15, 2014

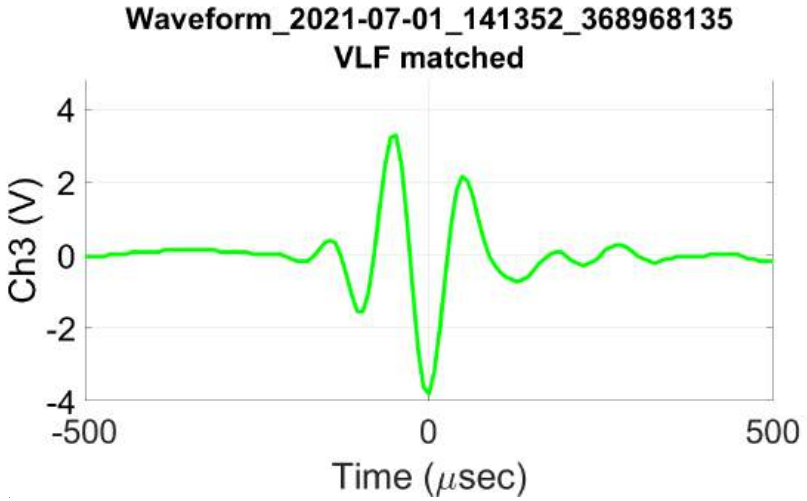


http://lf.gatech.edu/science.html

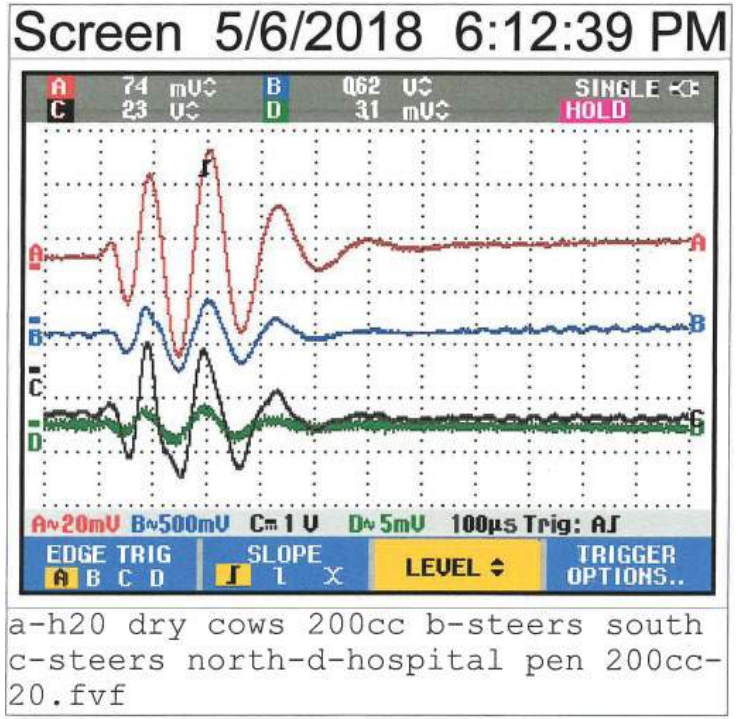
SOURCE: Georgia Tech LF Radio Lab. (http://lf.gatech.edu)



SOURCE: Dry Cow Facility

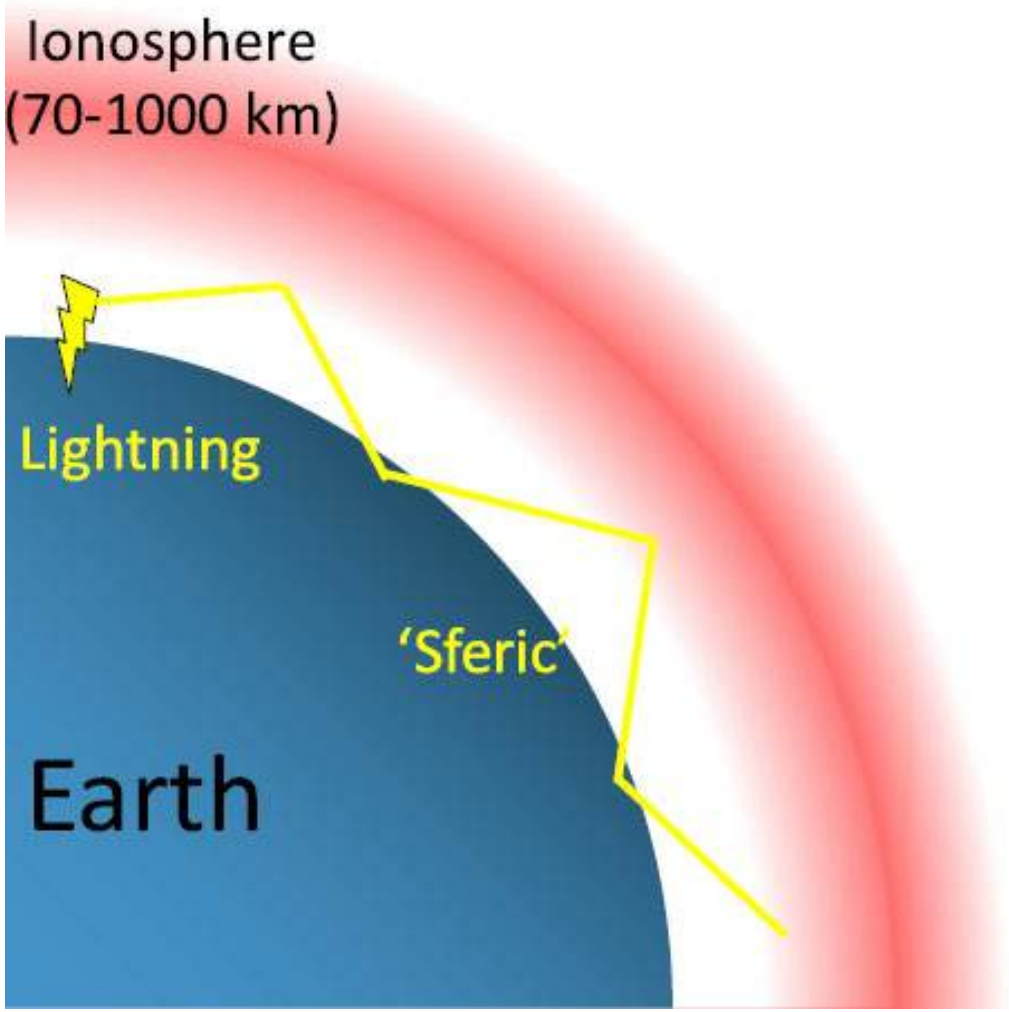


SOURCE: Robot Barn



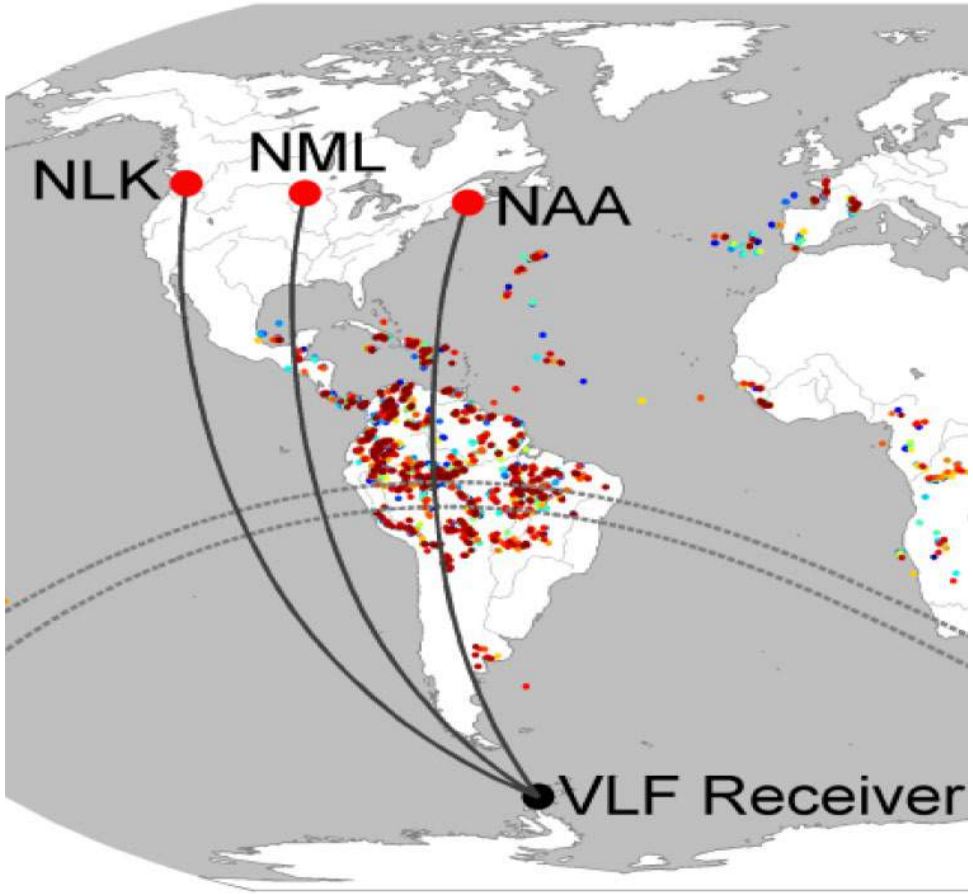
How Can Lightning-Generated VLF Signals Travel from So Far Away?

Earth-Ionosphere Waveguide



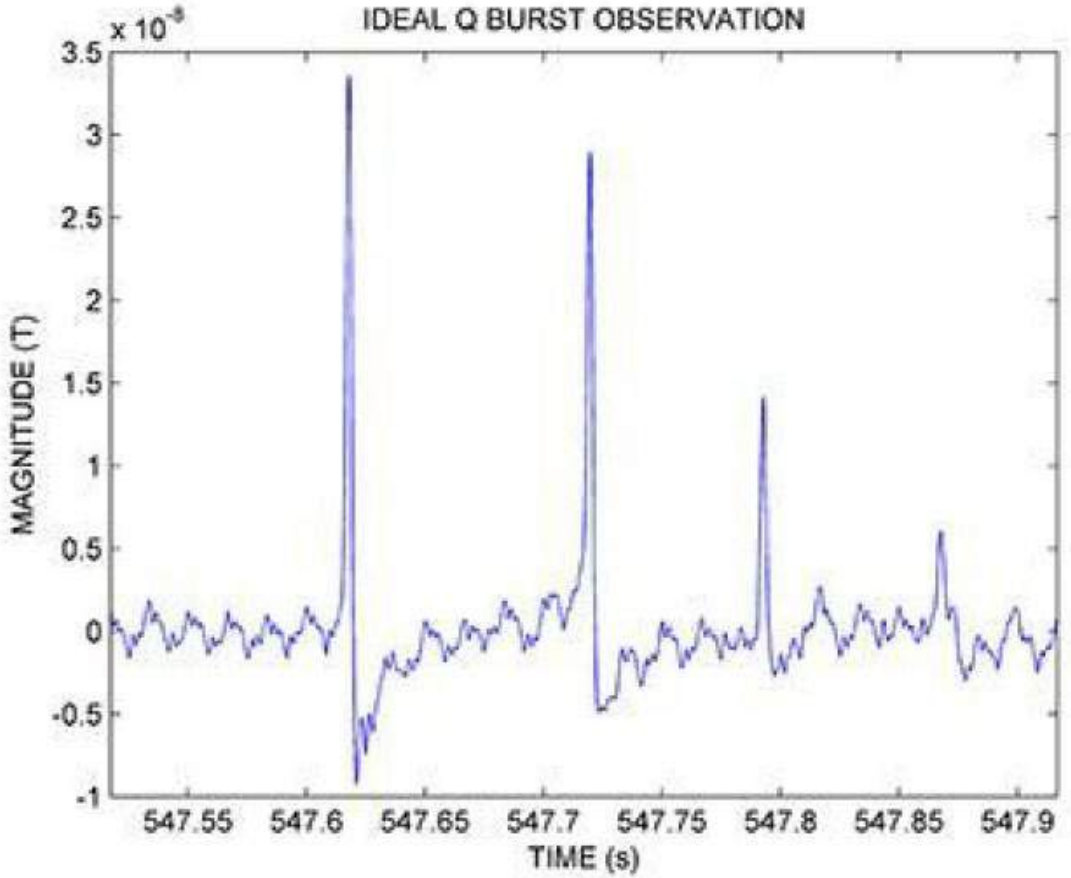
Example VLF Signals: VLF Navy Transmitter; Sferic

VLF Navy Transmitter



Source: GATech_LF_Group_Overview.pdf

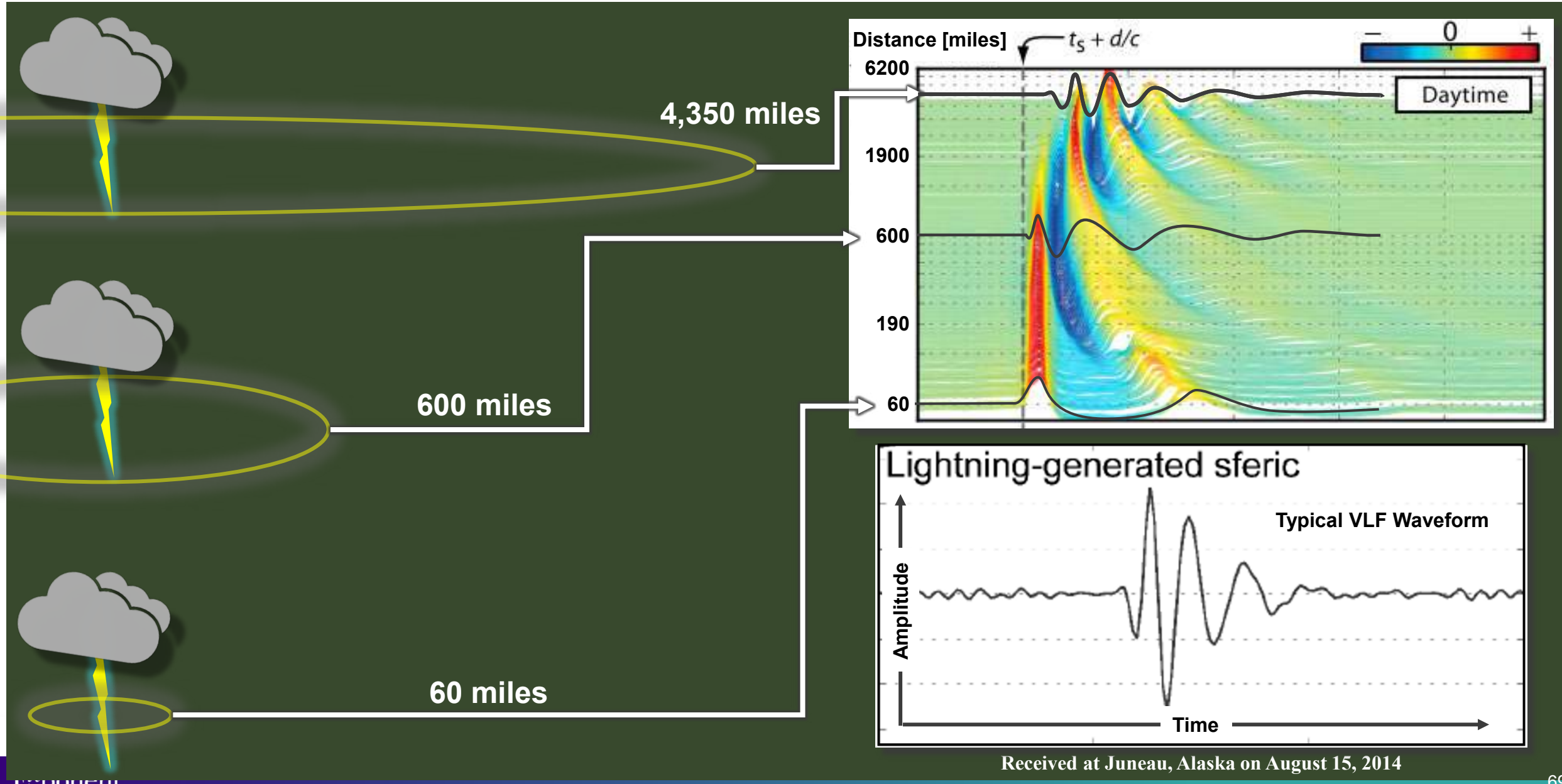
Lightning



Source: UF_Ionospheric_Radio_Lab_Global_ELFVLF_Propagation.pdf

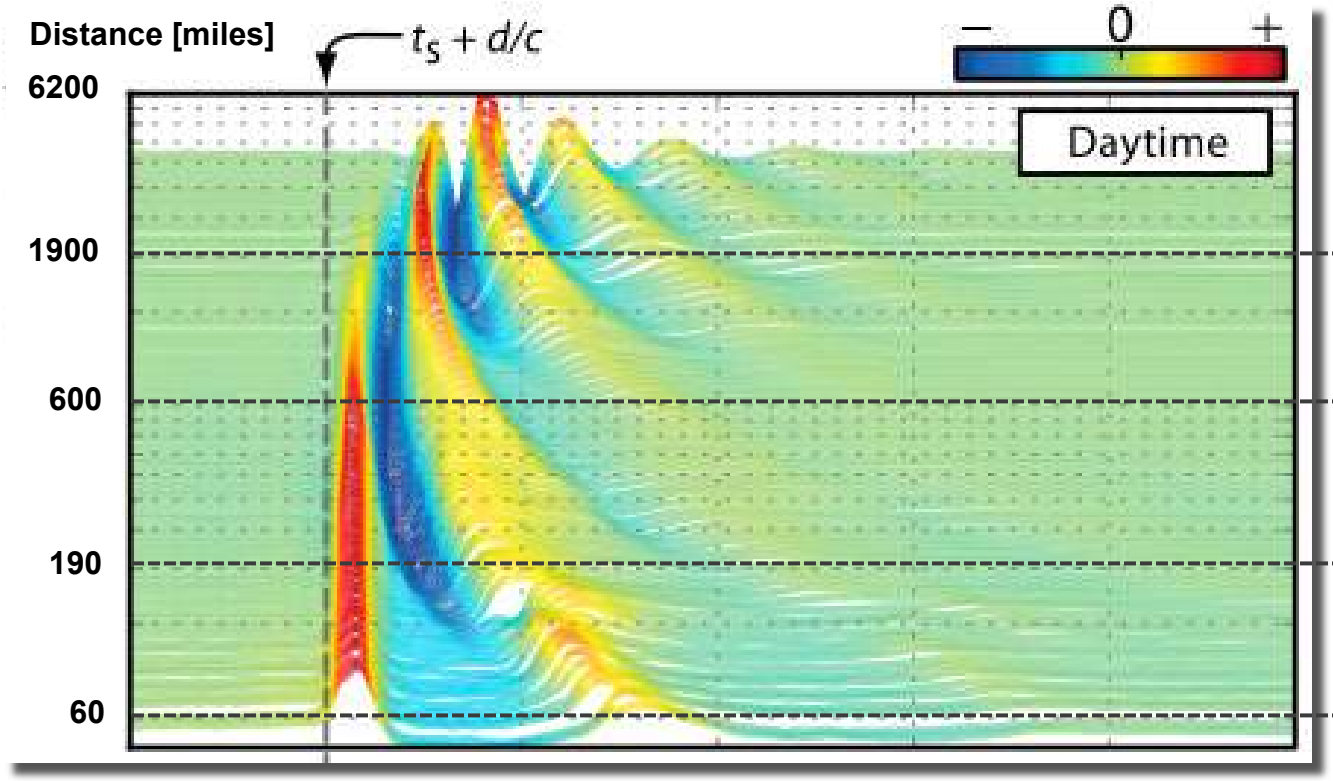
Do the VLF signals always look identical?

VLF Variation with Distance

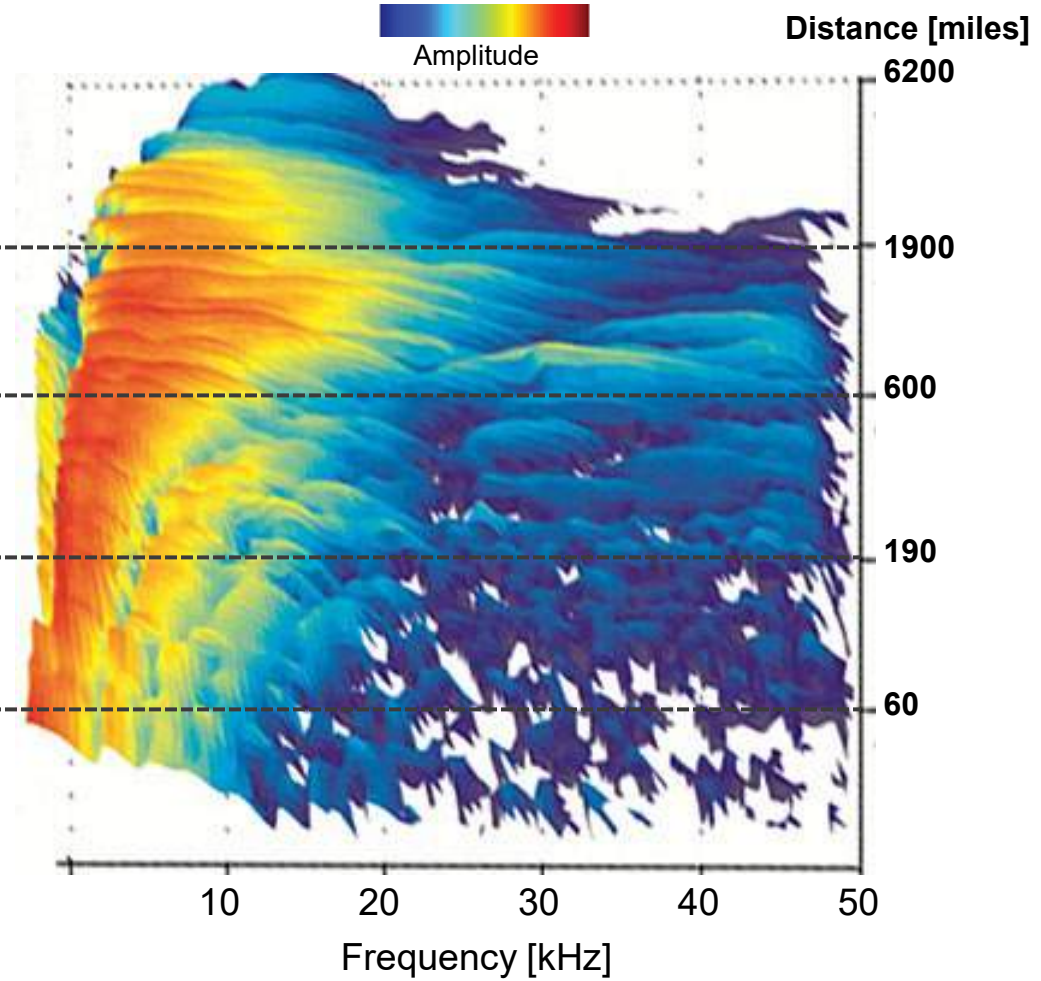


VLF Variation with Distance

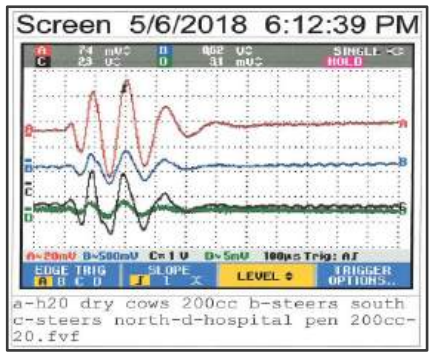
Time – Distance Variation

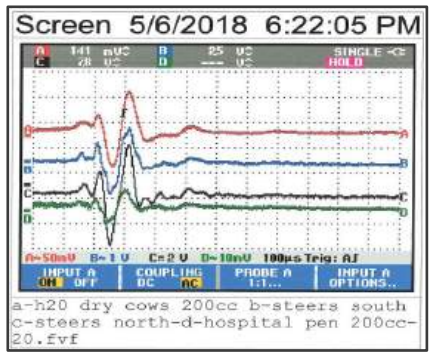


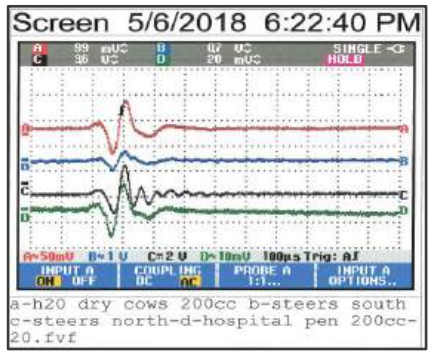
Frequency – Distance Variation (FFT)

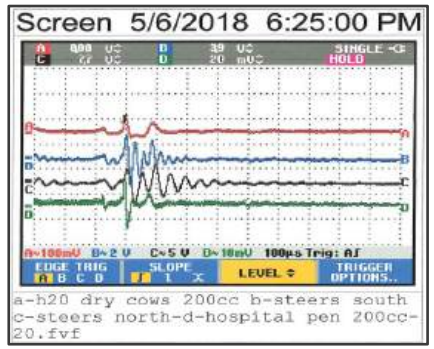


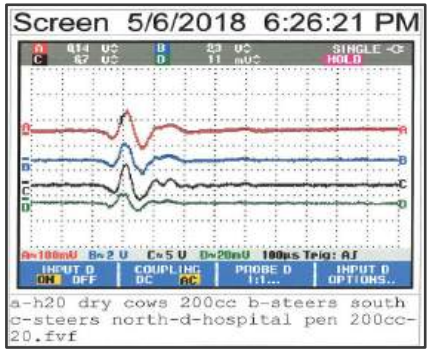
May 2018 - Exemplar VLF Signals Measured

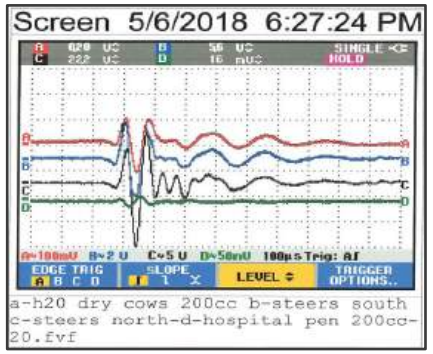


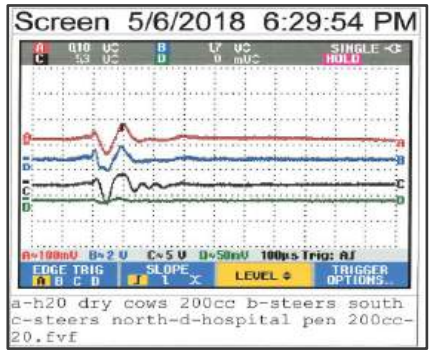


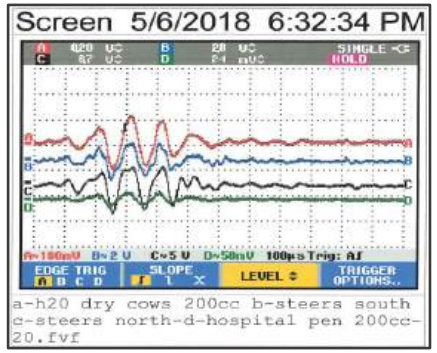


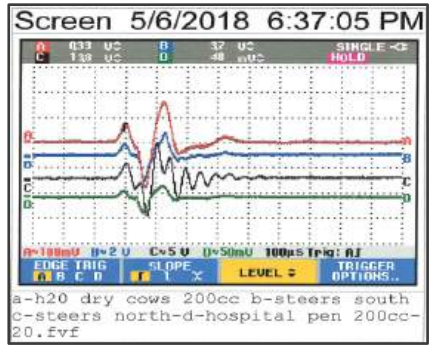


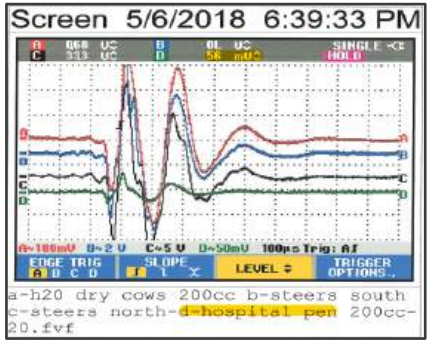


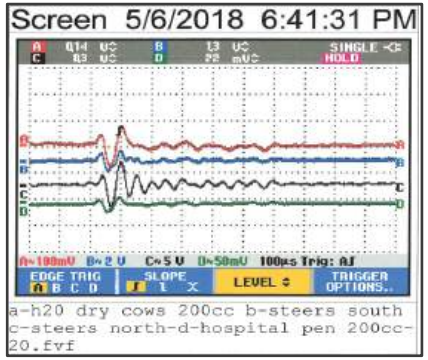


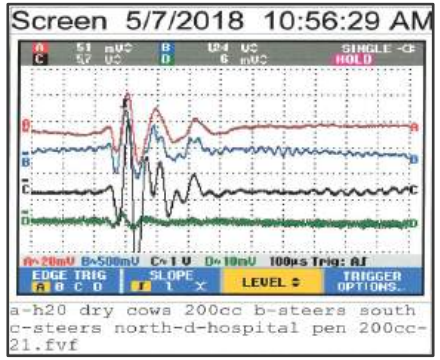


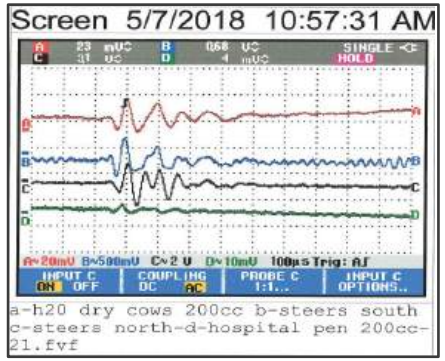


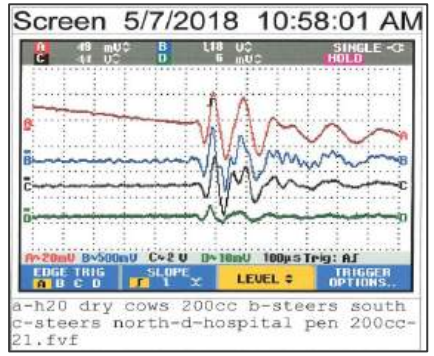


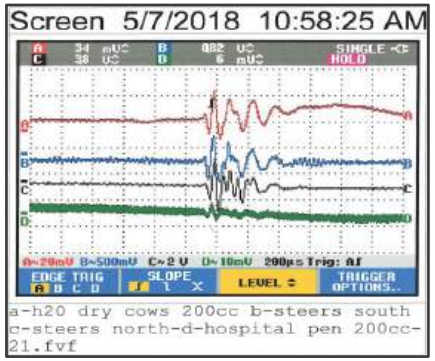












Methodology for Identifying Source of Non-Periodic VLF Signals

Methodology: Timing is Everything

- Determine *precisely* what time the recorded VLF signal occurred.
- Source known lightning data.
- Identify causative lightning stroke.
- Match the recorded waveform to causative stroke.
- Statistical analyses to quantify probability matches due to chance or any cause other than lightning.

GPS Clock

- **Example: Arbiter Model 1095A/C**
- **Industrial GPS Clock**
- **Outputs a 1 pulse-per-second (pps) signal**
  - **±250 ns peak;**
  - **±100 ns typical**
- **Outputs IRIG-B: Date Code**

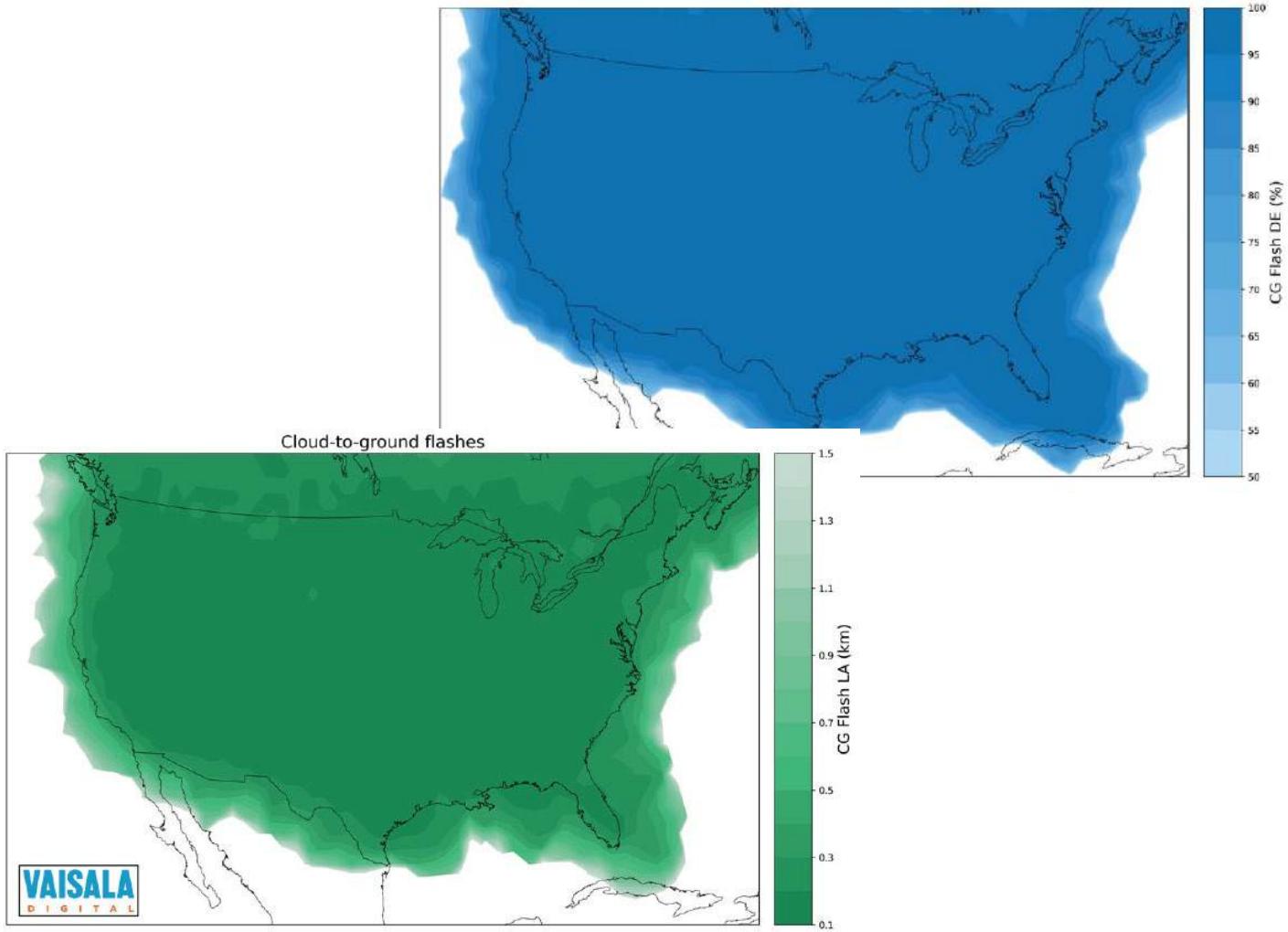
GPS Clock

GPS Antenna

Vaisala Lightning Detection Networks: NLDN/NALDN

NLDN (LF/MF Receivers)

- Coverage of the continental U.S.
- **Microsecond timing accuracy**
- Time of arrival
- Magnetic direction-finding
- **<150 meter location accuracy**
- >95% detection efficiency

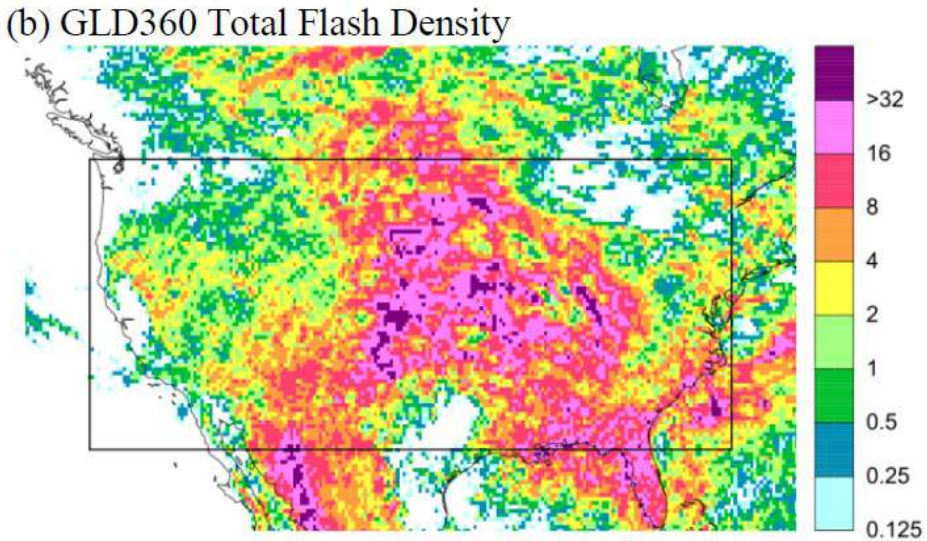


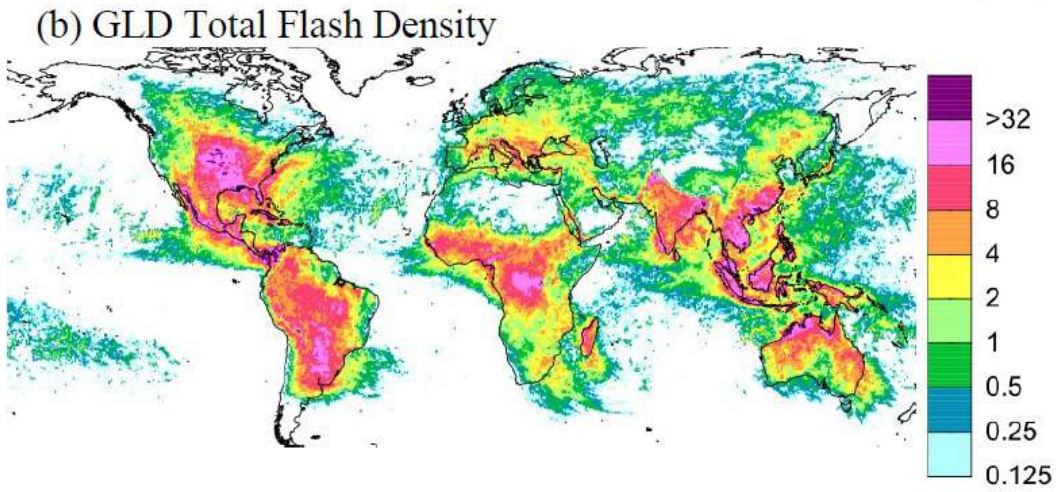
Source; Vaisala_NLDN_2020_Brochure.pdf

Vaisala Lightning Detection Networks: GLD360

GLD360 (VLF Receivers)

- Global coverage
- **Microsecond timing accuracy**
- Time of arrival
- Magnetic direction-finding
- <1.8 km LA in CONUS
- ~81% DE in CONUS
- CG ≲70% DE



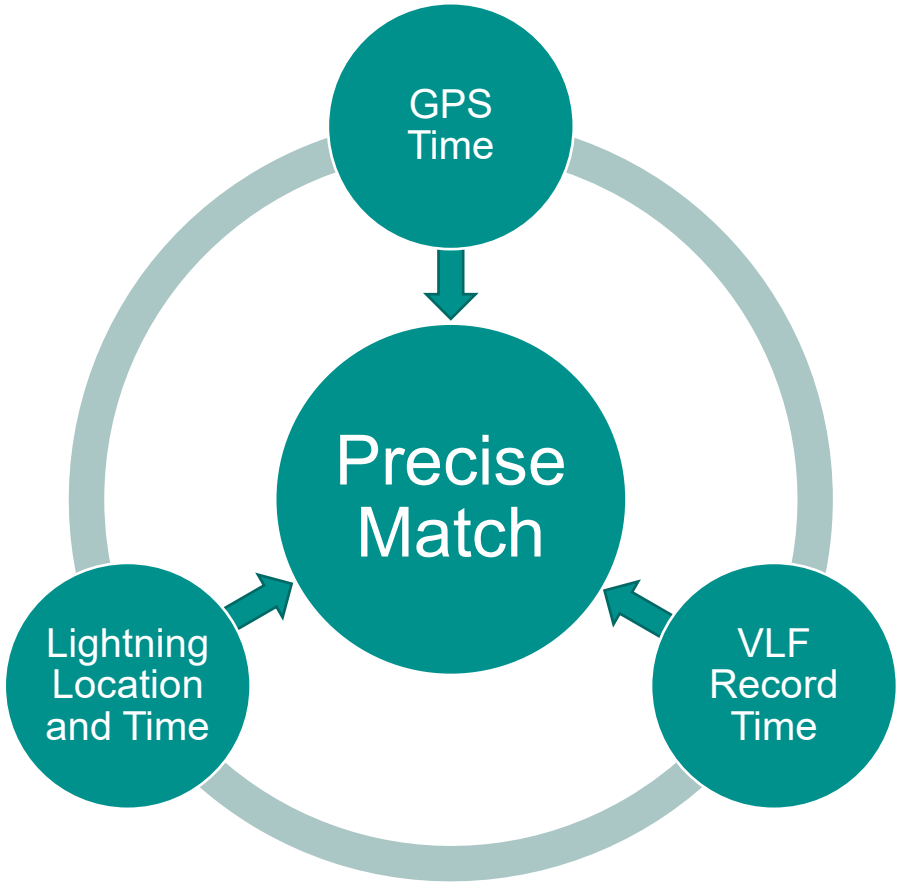


Source: Rudlosky2017_GLD360_Performance_Relative_to_TRMM_LIS.pdf; Said_and_Murphy_2016_GLD360_Upgrade_Performance.pdf

Known Lightning Strokes – National Lightning Detection Network

- Precise GPS time
- Precise time of VLF
- Lightning info
  - Precise time
  - Precise location

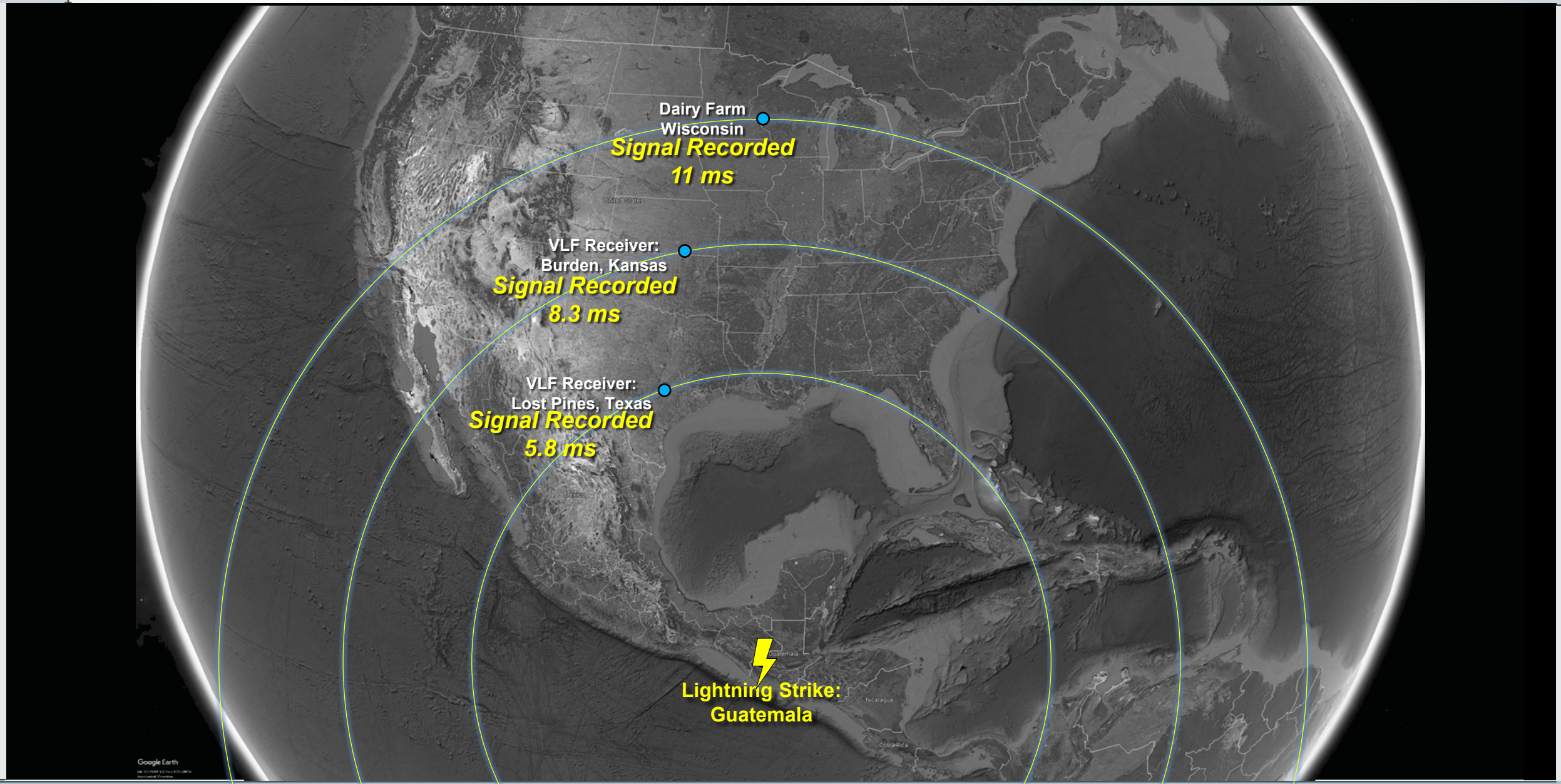
- Match within 1/1000th of a second



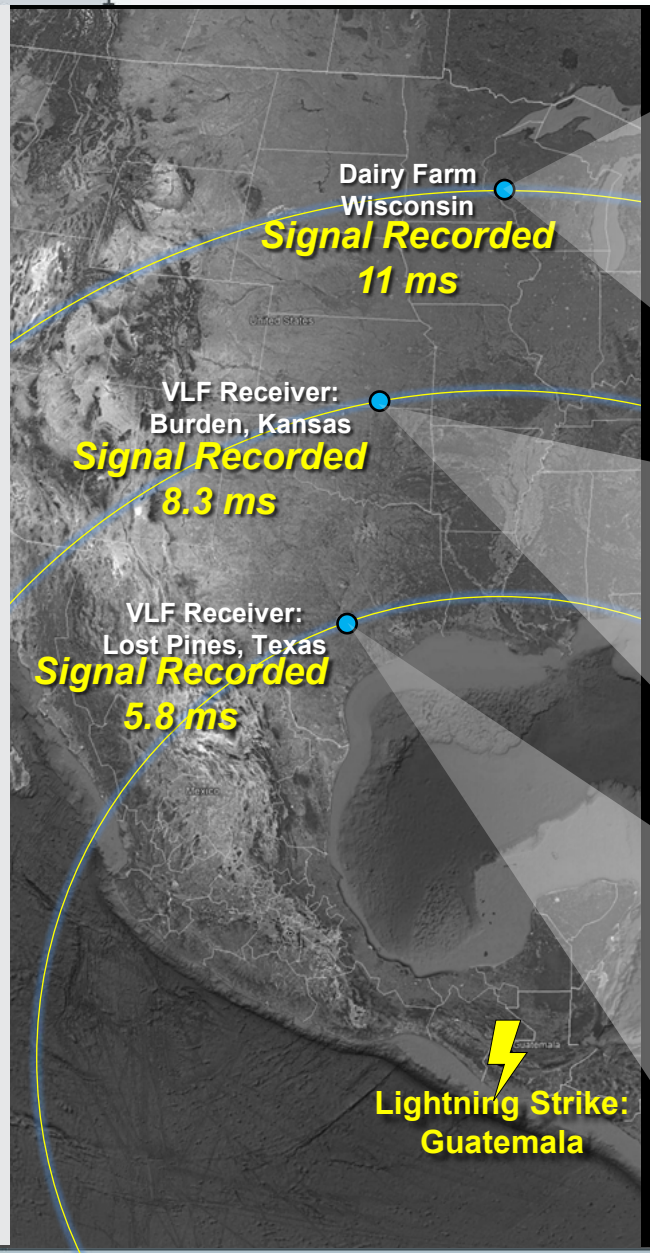
How much of all Lightning were we able to Analyze?

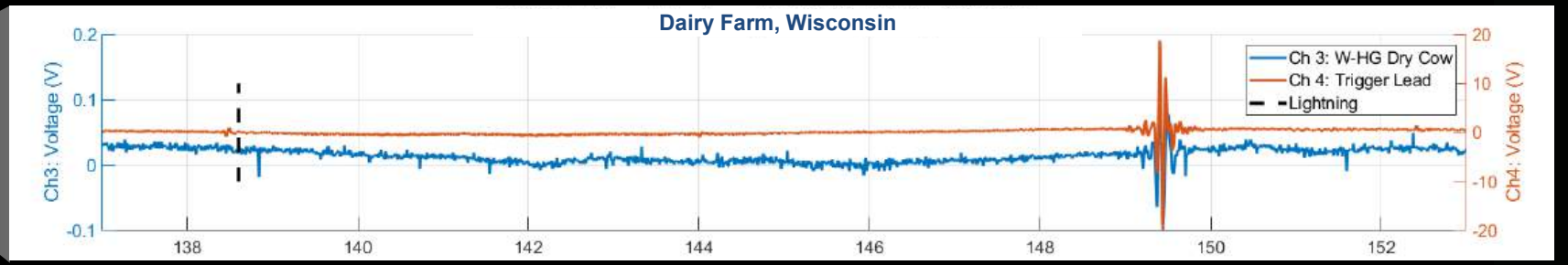
- NLDN: ~95% detection efficiency
- GLD360: ~81% detection efficiency
- Radius: only 6,200 miles
- Expected matching rate if all VLF signals are from lightning: ~81 to 95%

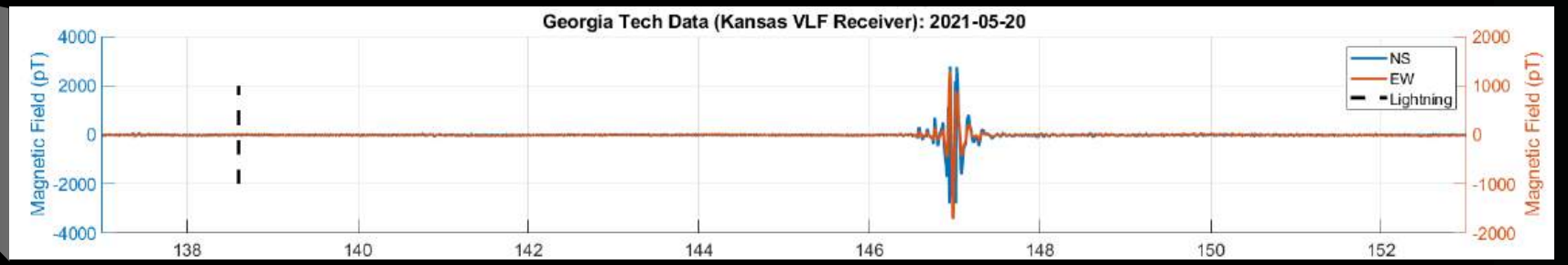
Lightning Strike in Guatemala

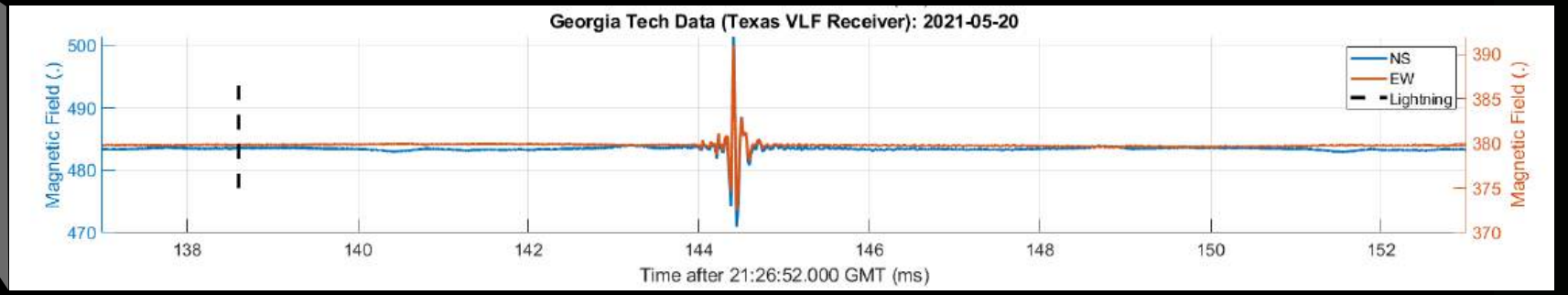


Lightning Strike in Guatemala

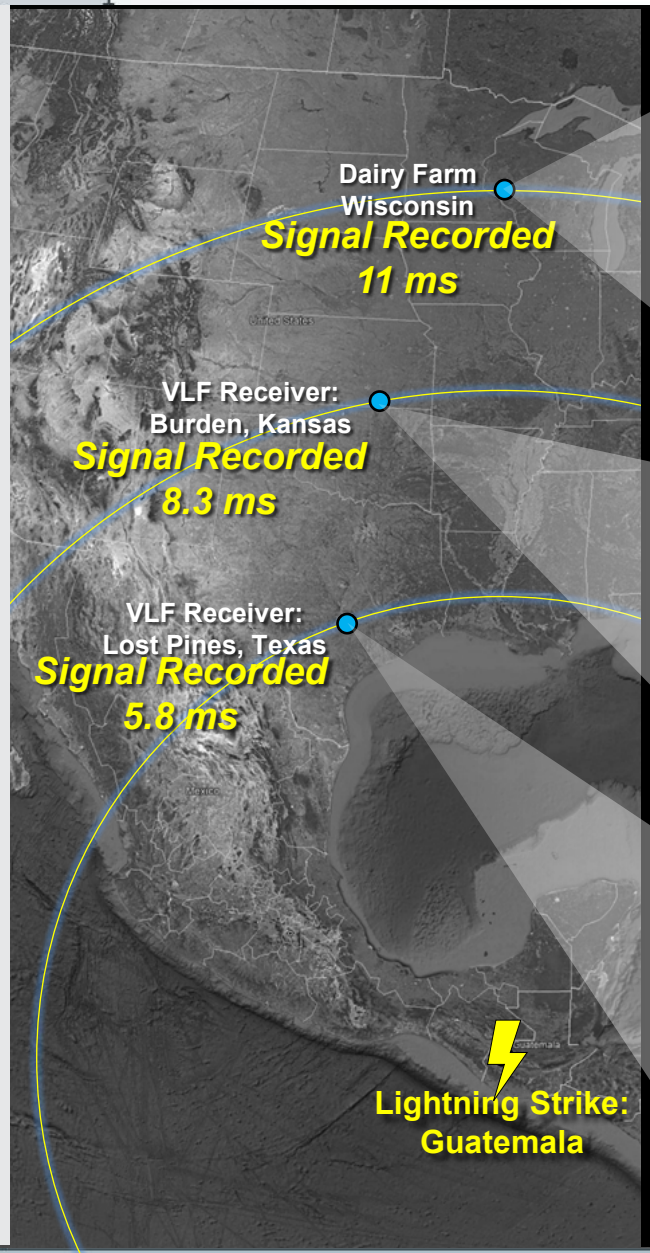


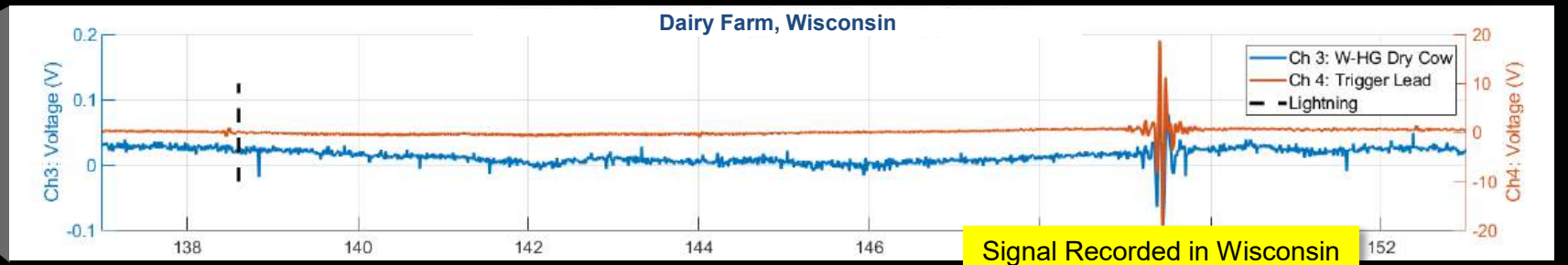




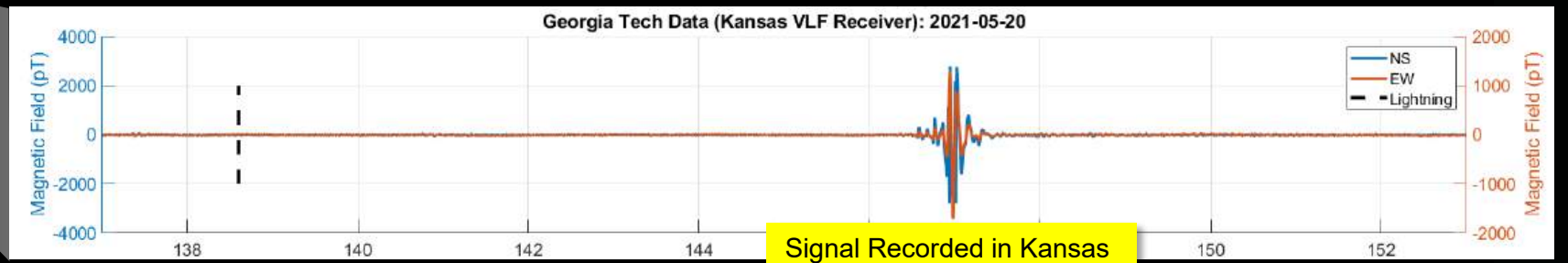


Lightning Strike in Guatemala

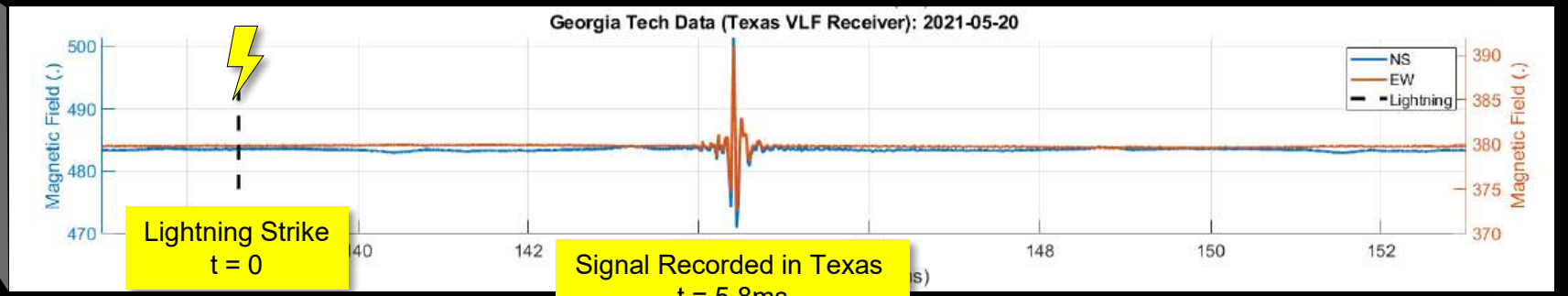




Signal Recorded in Wisconsin
t = 11 ms



Signal Recorded in Kansas
t = 8.3 ms



Lightning Strike
t = 0

Signal Recorded in Texas
t = 5.8ms

Lightning Event Matching: Summary

Dataset	# of events	Matched within 1/1000th of a Second
Wisconsin (Spring/Summer 2021)	446	96 %
Minnesota (Summer 2021)	387	91 %
Wisconsin (Spring 2022)	1,692*	92 %
Maryland (Fall 2022)	1,659*	89 %
Minnesota (Fall 2022)	430	95 %
Wisconsin (Spring 2023)	1,174†	87 %
Wisconsin (Fall 2023)	5,986*	92 %
TOTAL	**12,204**	**91 %**

* In these data, no effort was made to remove other sources of noise so identified matching rate reported is a very conservative lower bound of actual matching rate.

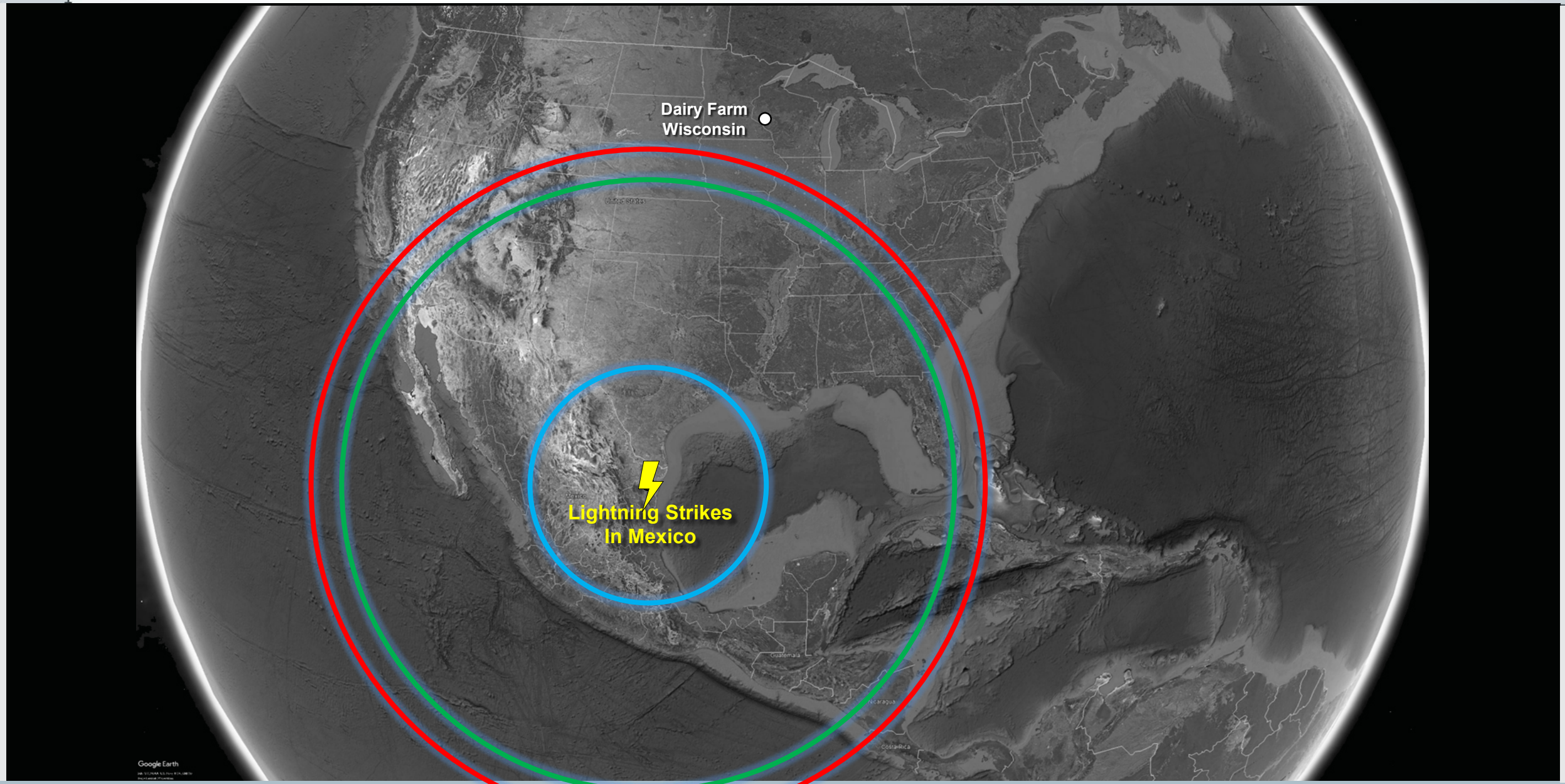
† Significant VLF noise from other sources (e.g., **fencers & VFDs**) present during these measurements

Recall: The expected matching rate if <u>all</u> VLF signals are from lightning: ~81 to 95%

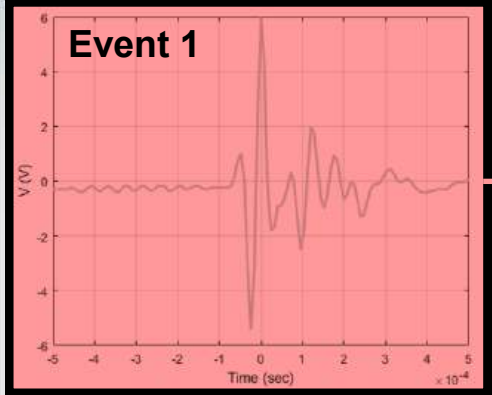
Are there even more?

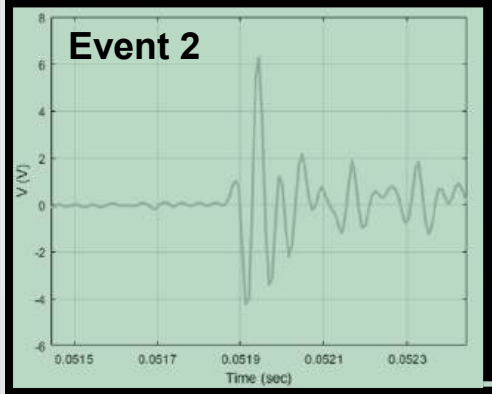
Yes…thousands more

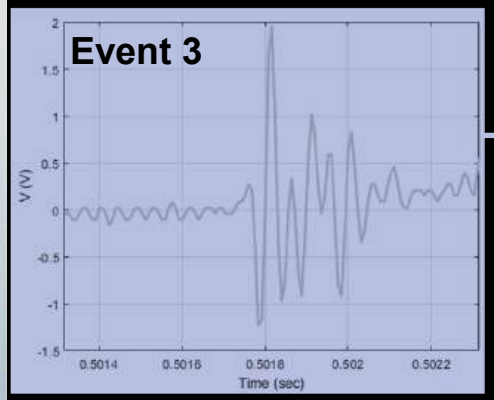
Three Lightning Strikes in Under a Second from the Same Storm in Mexico



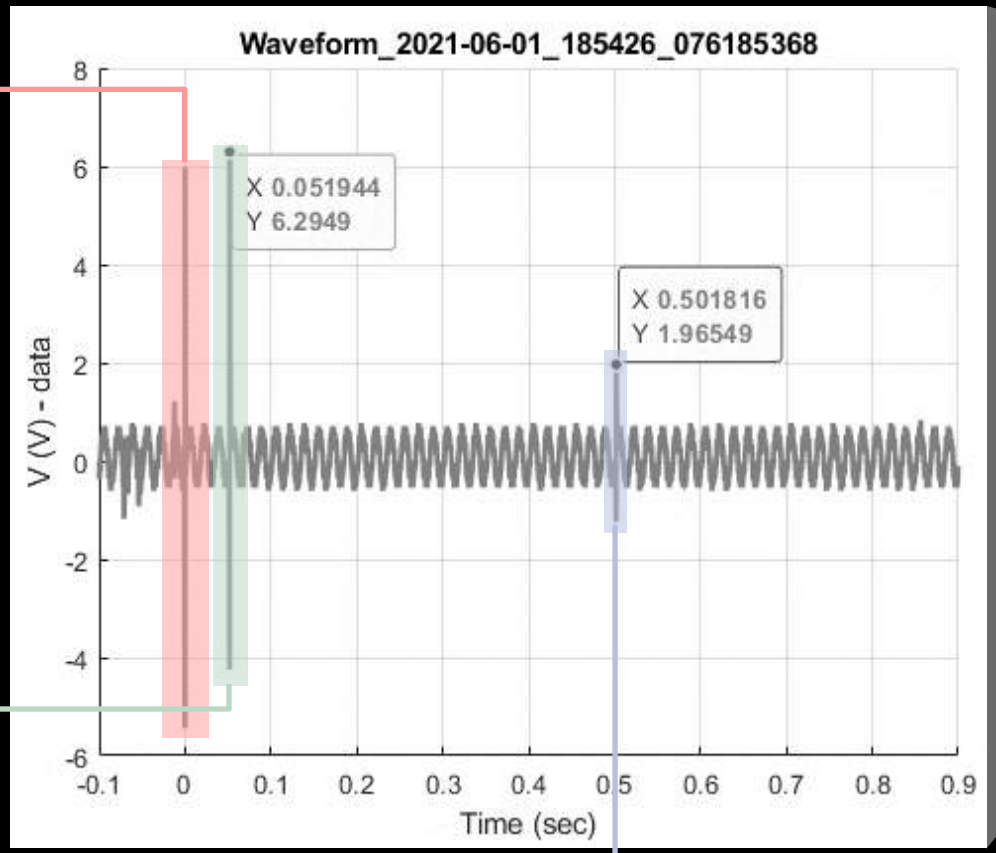
Matching of Multiple VLF events to Lightning at Dairy

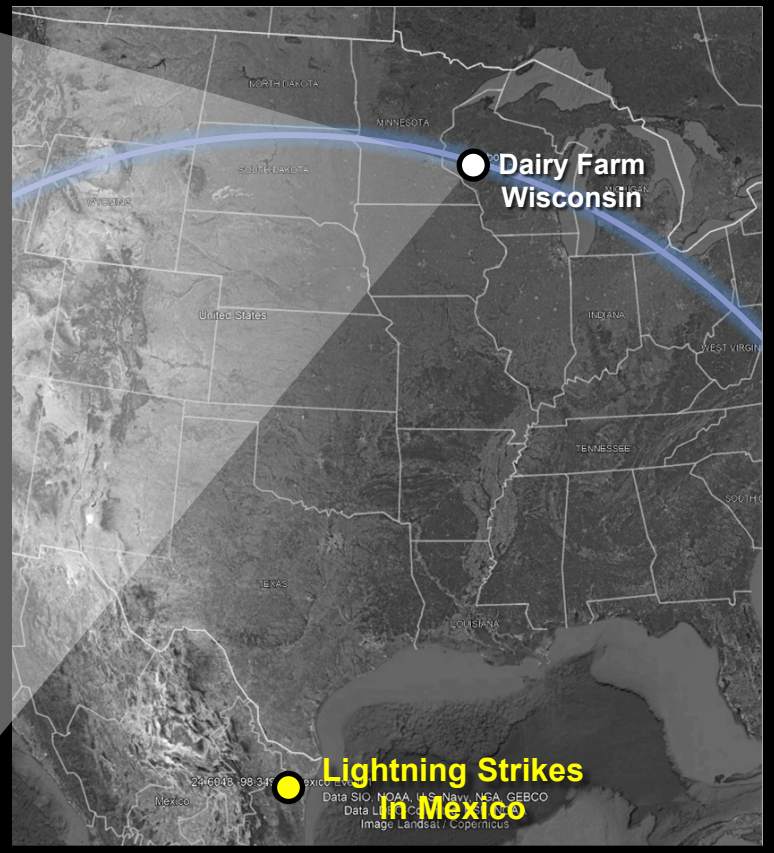






Parameters of lightning event matched within less than 1 ms





	Event time	Peak Current (kA)	Distance (mile)	Latitude (deg)	Longitude (deg)
Event 1	18:54:41.203	-74	1427	24.6048	-98.3492
Event 2	18:54:41.255	-75.4	1426	24.6094	-98.3469
Event 3	18:54:41.705	-23.8	1427	24.6029	-98.3462

Telling the Technical Story

Monopole Antenna

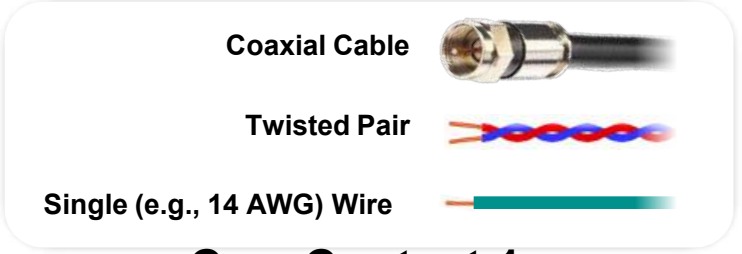
Off-Grid: California

Off-Grid: Wisconsin

Swing Set

Context: How Certain are We?

Replicating "Expert" Measurements



LTW to Remote Rod

Long Trigger Wires (LTW) Or Neutral-connected Long Trigger Wire (NLTW)

Resistor switch boxes

Cow Contact 1 or NLTW*

Ground

Cow Contact 2 or NLTW*

Ground

GPS

GPS Receiver

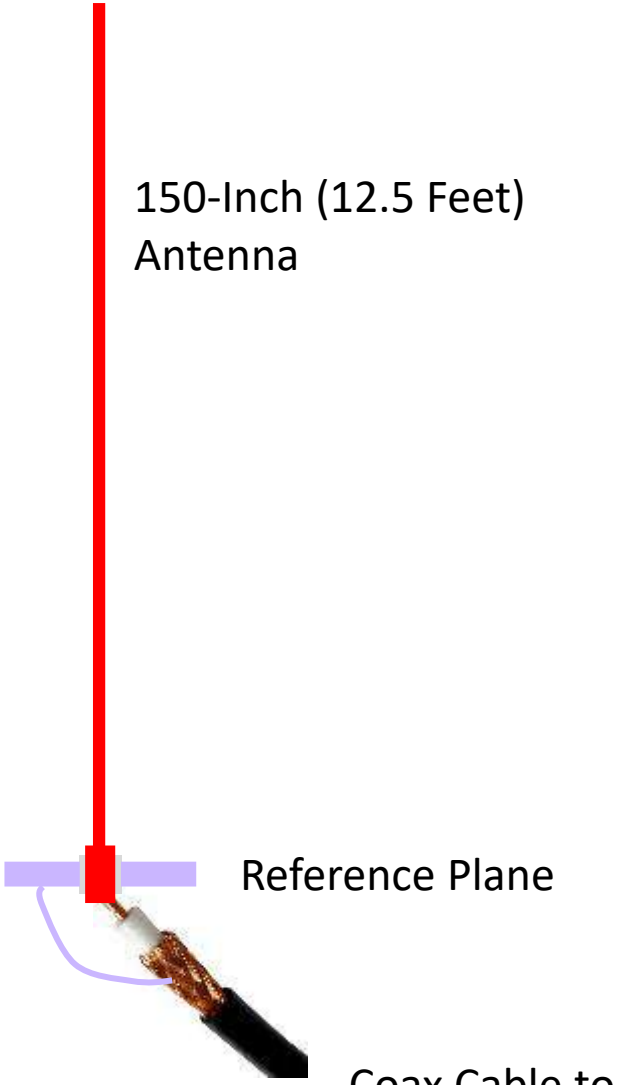
Oscilloscope

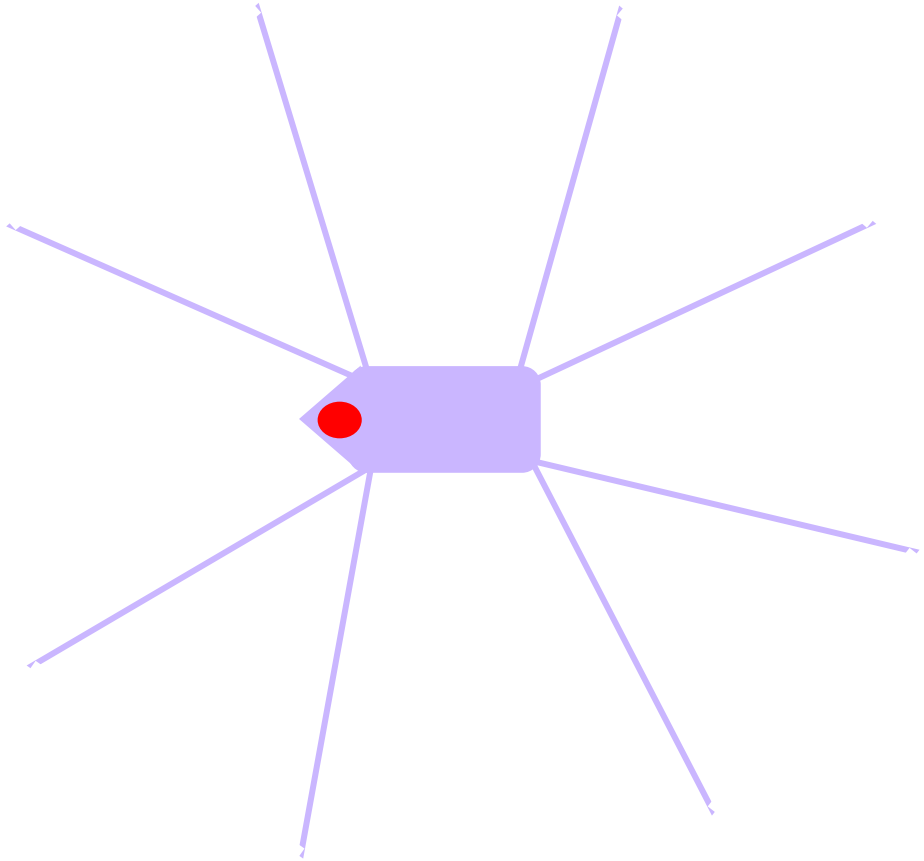
* NLTW are not connected with twisted pair wires, they are single wire with the reference to a remote rod

Monopole Antenna

Monopole Antenna

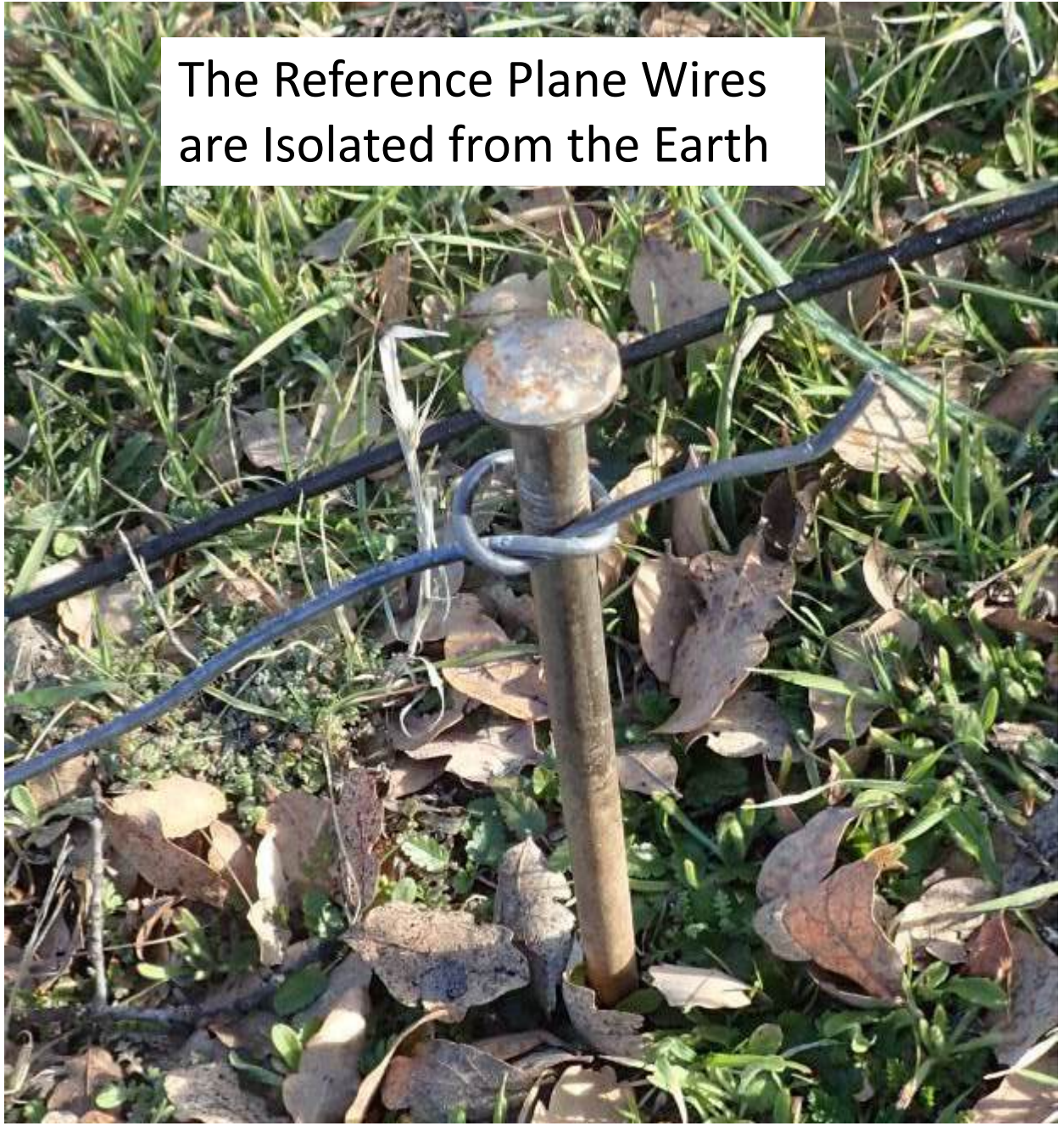
(Illustrative – Not to Scale)



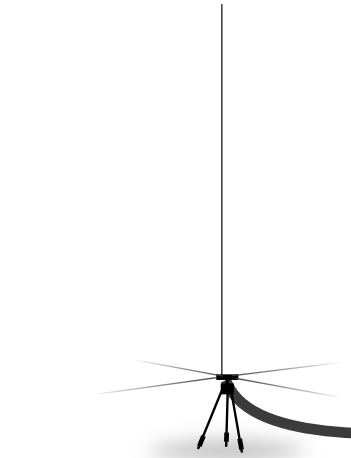


Reference Plane Comprised of

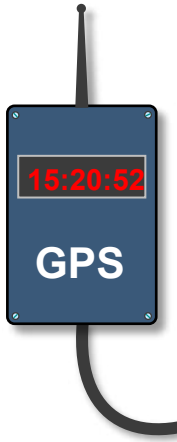
- Mounting plate
- 8: Isolated 16-foot wires


The Reference Plane Wires
are Isolated from the Earth

VLF Monopole Measurement Setup



Monopole Antenna



GPS Receiver

Oscilloscope

Resistor switch boxes

Ground

Cow Contact 1 or NLTW*

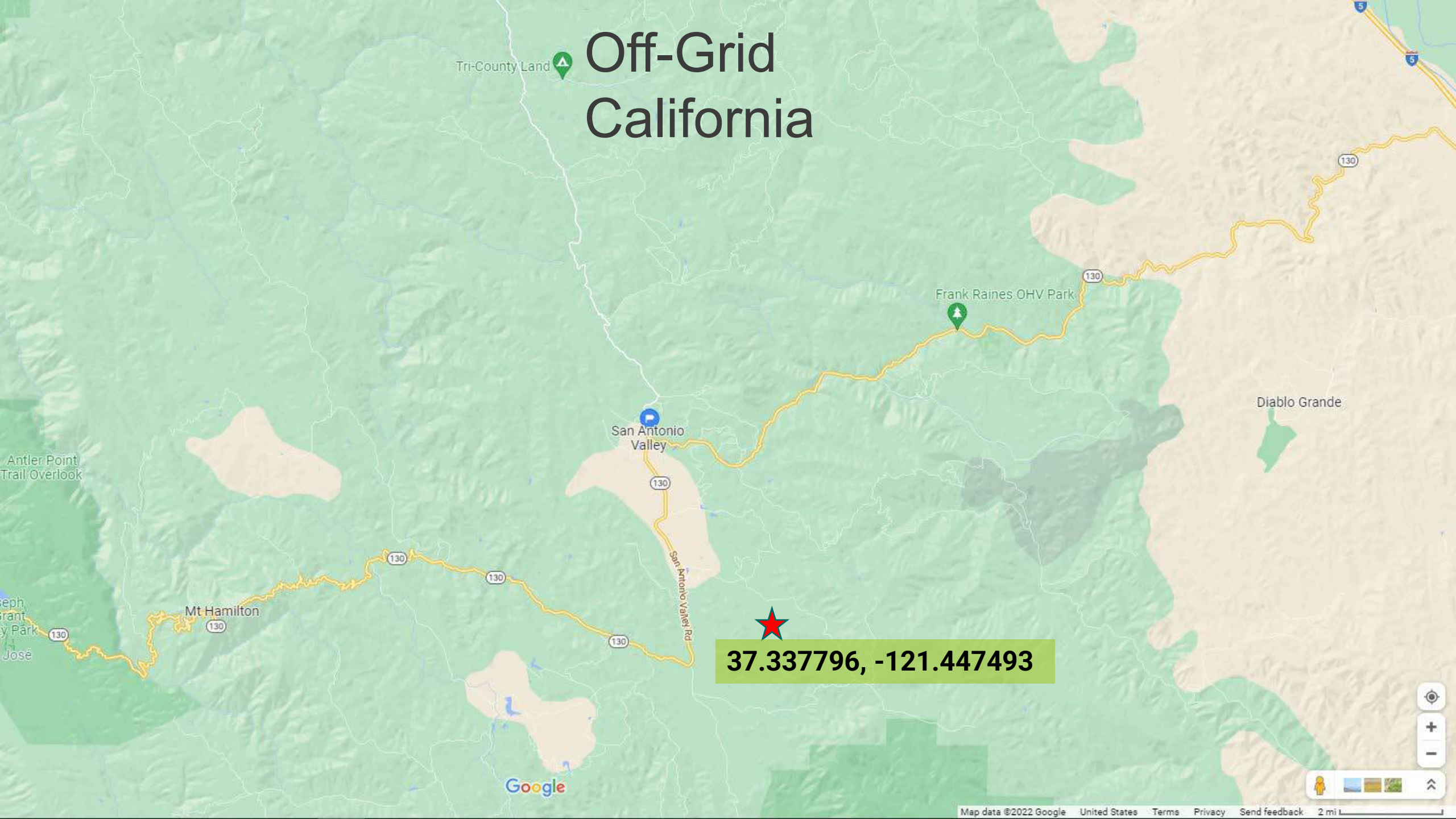
Ground

Cow Contact

Coaxial Cable (GPS/Monopole)

Twisted Pair (Cow Contacts)

Off-Grid California



Cow Contact

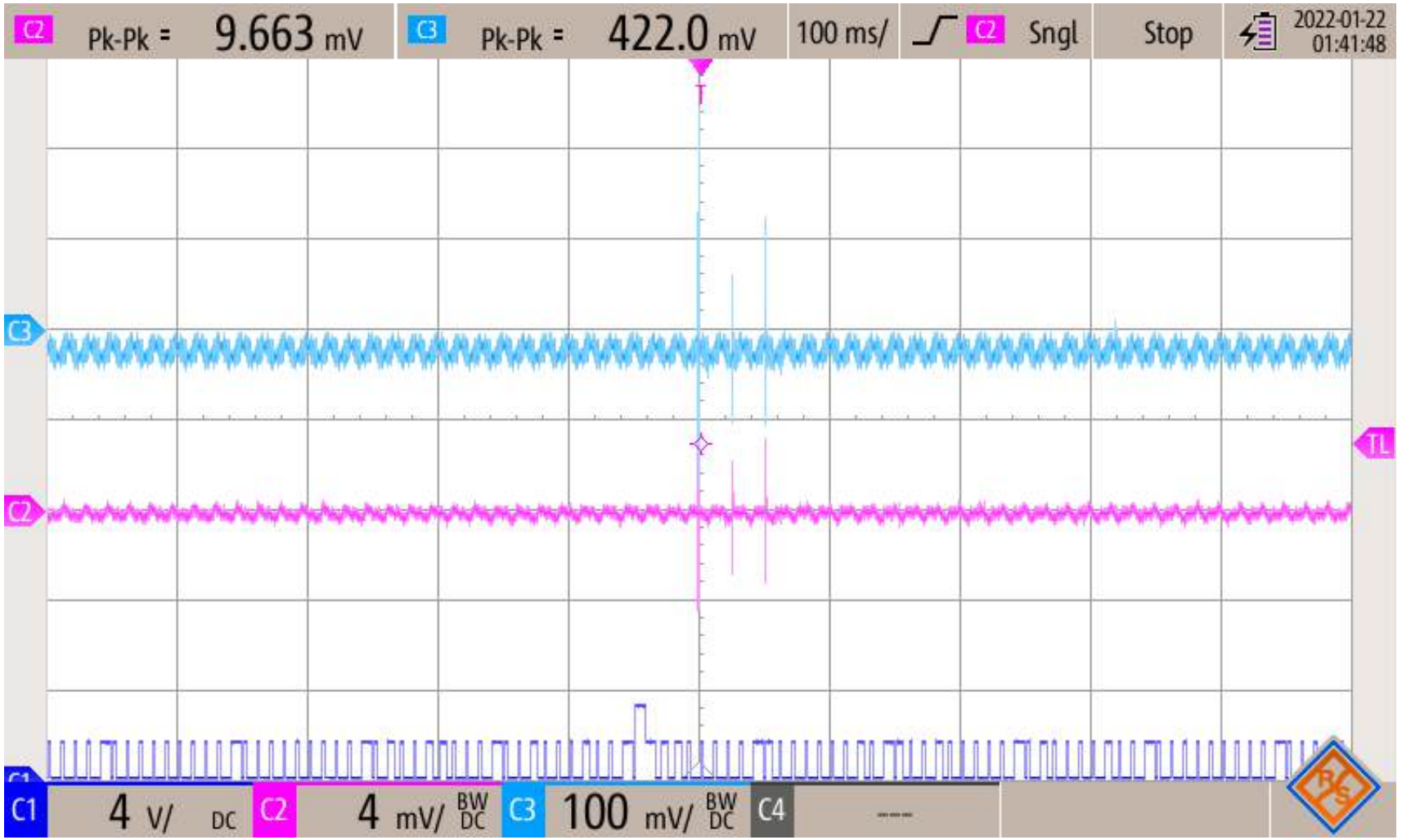
- Cow Fence to Earth
- 500Ω at Oscilloscope

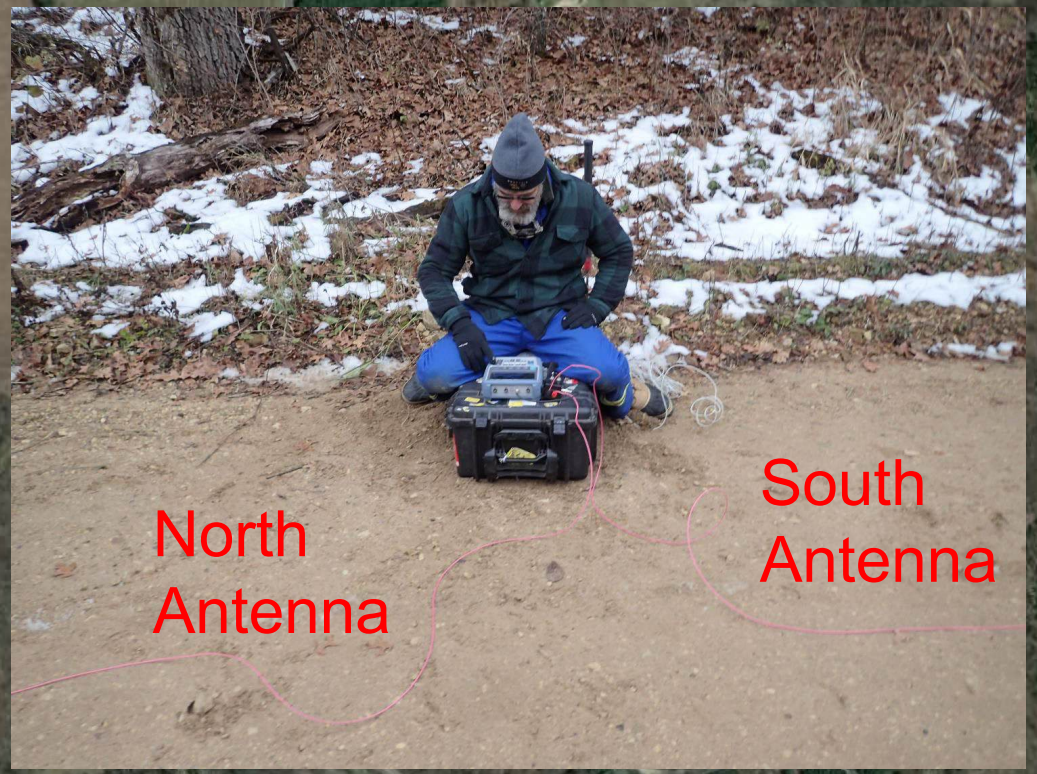
Example VLF Recording

CC-500Ω

MPA

GPS





Antenna Location Shown in Red (0.4+0.3=0.7mi)
M: Marks where midpoint testing was performed
E: Marks where the end point testing was performed

Miles from nearest power infrastructure

M

E

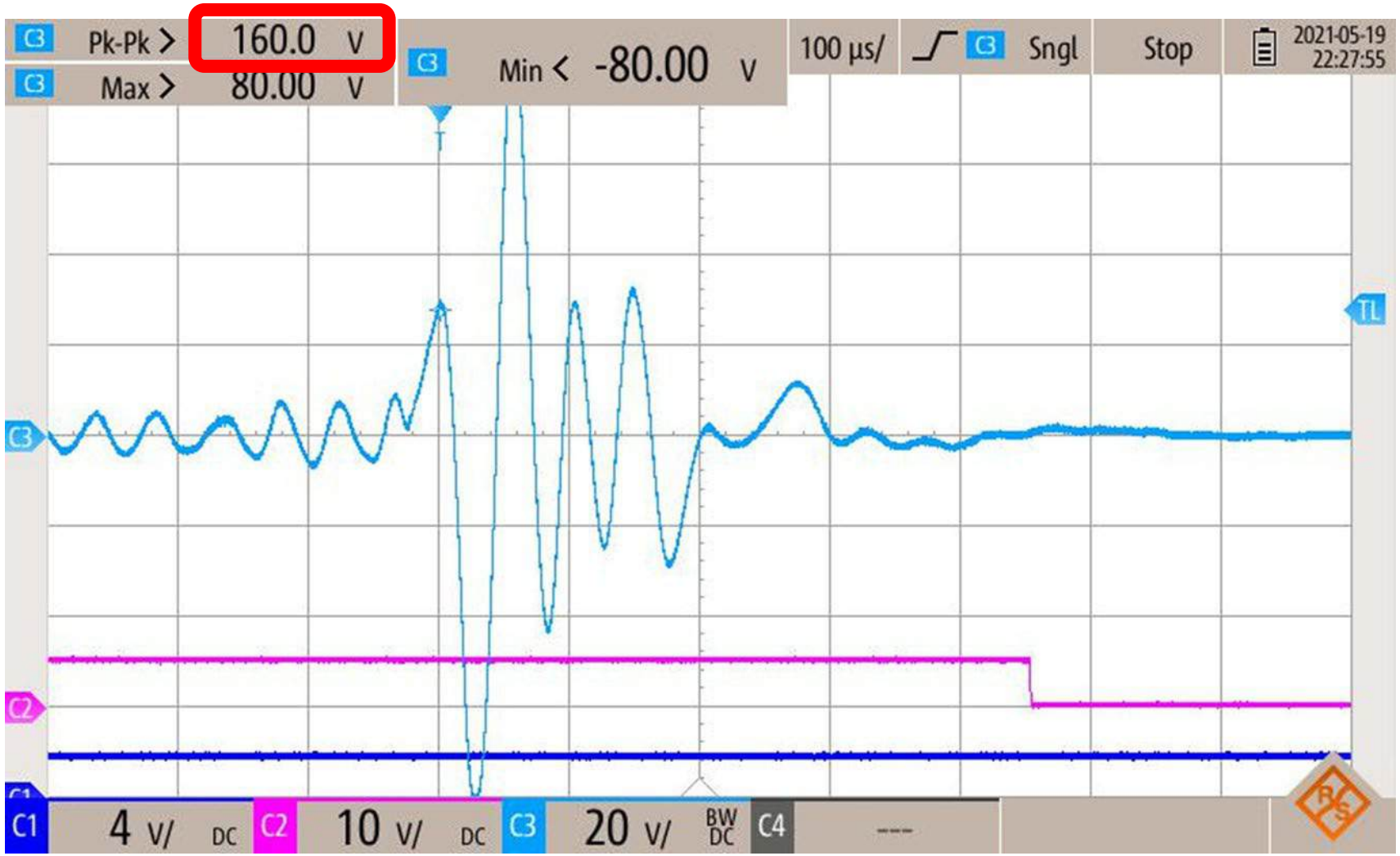
Upper
Dunnville
Bottoms

560th St

564th St

Google

Example VLF Recording

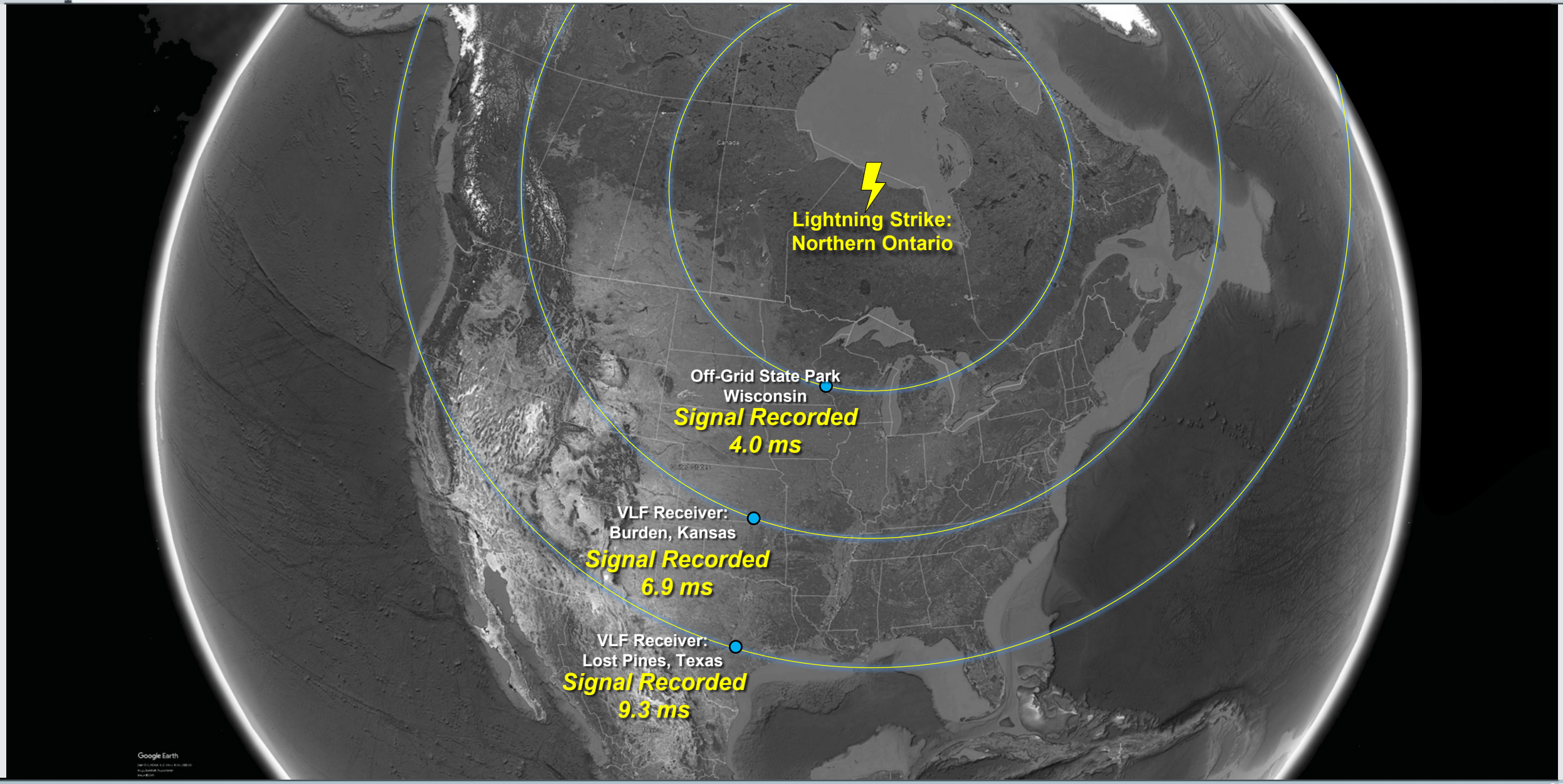


Long Antenna

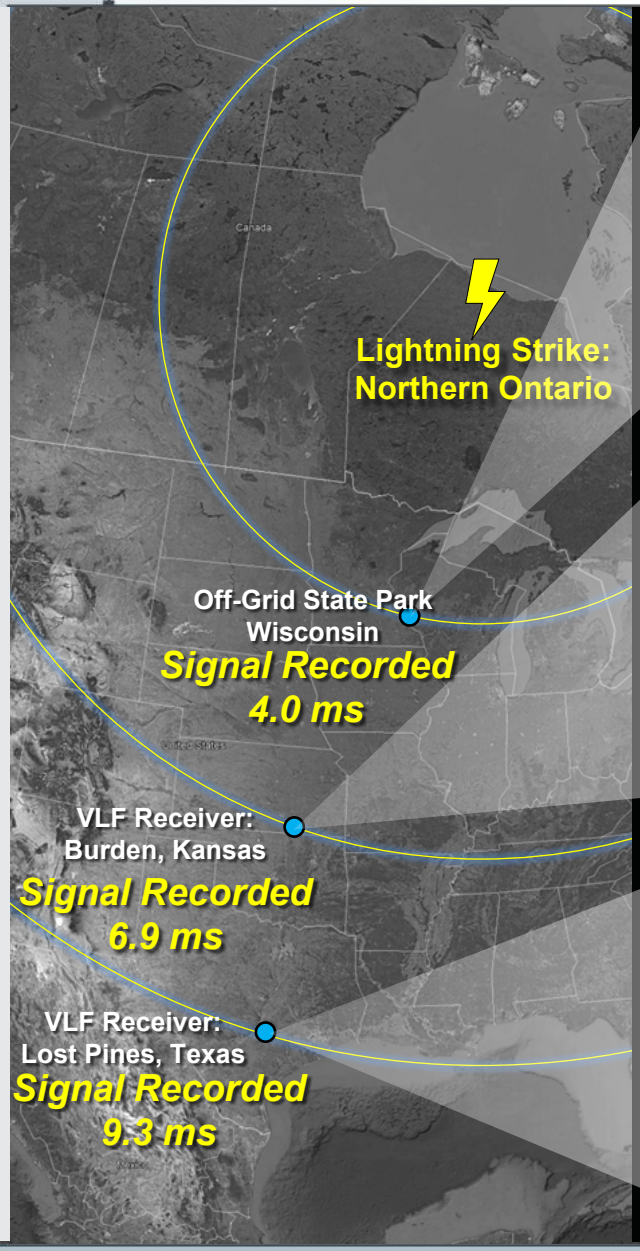
GPS (IRIG-B)

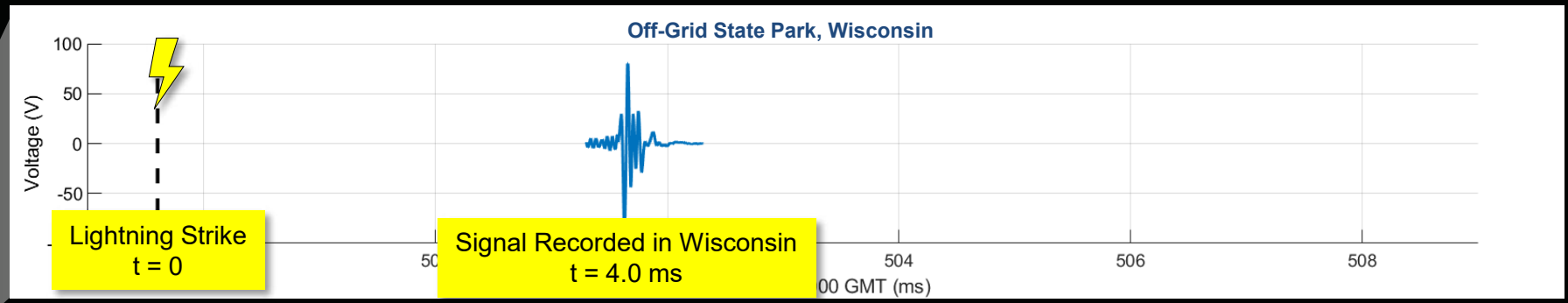
GPS (1pps)

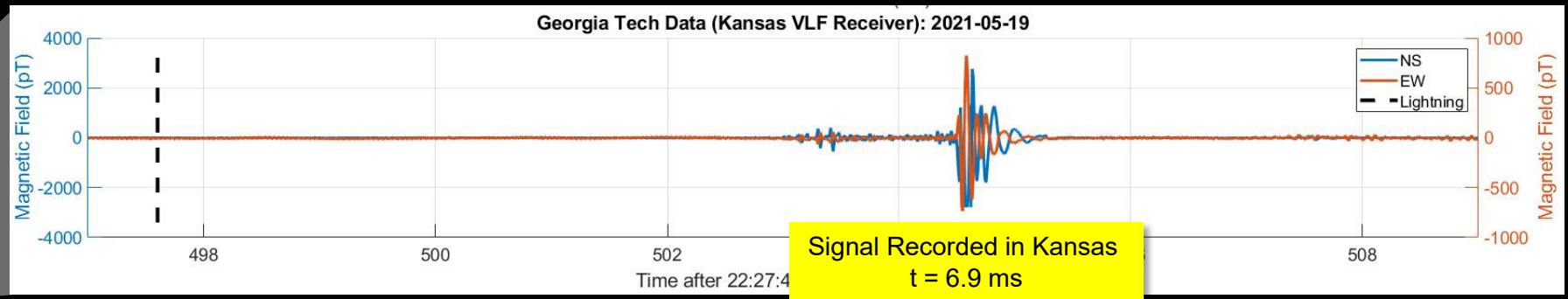
Lightning Strike in Northern Ontario

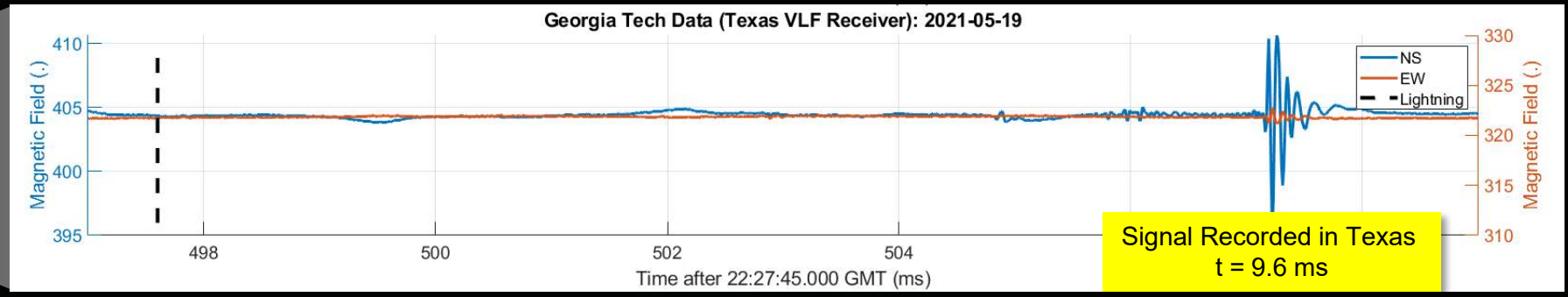


Lightning Strike in Northern Ontario



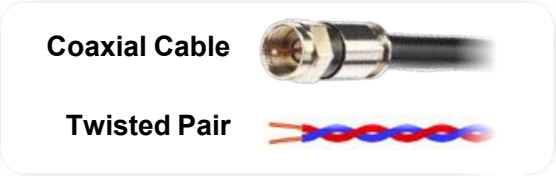


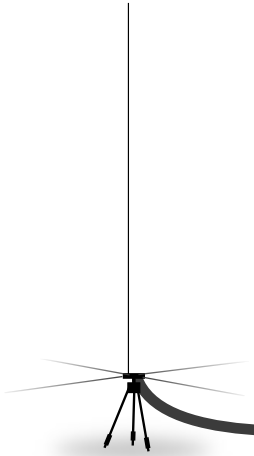




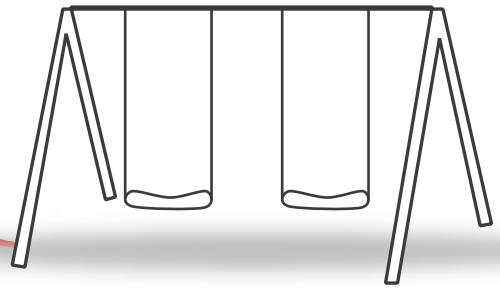
Swing Set & Gutter "Contacts"

Measurements On a Swing Set and Gutter





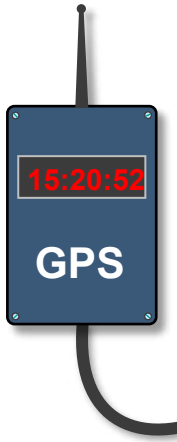
Monopole Antenna



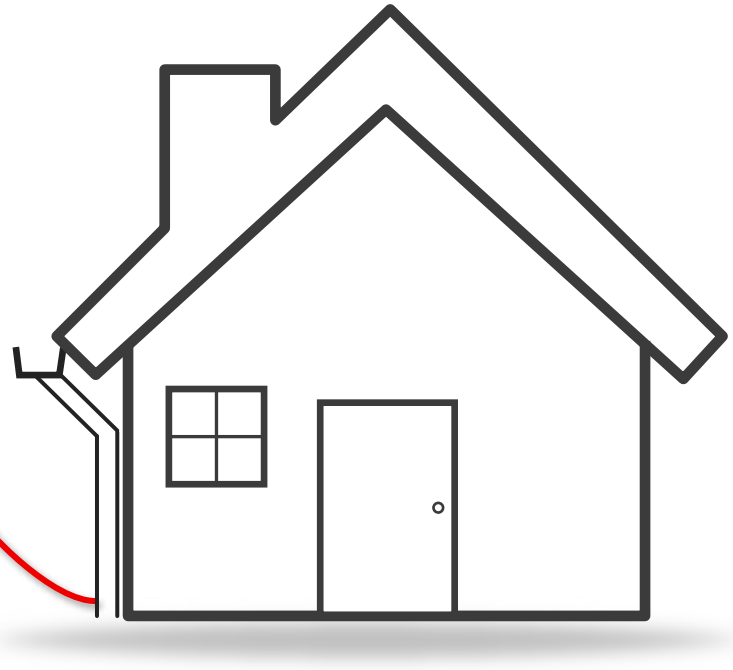
Ground

Resistor switch boxes

Oscilloscope



GPS Receiver



Ground

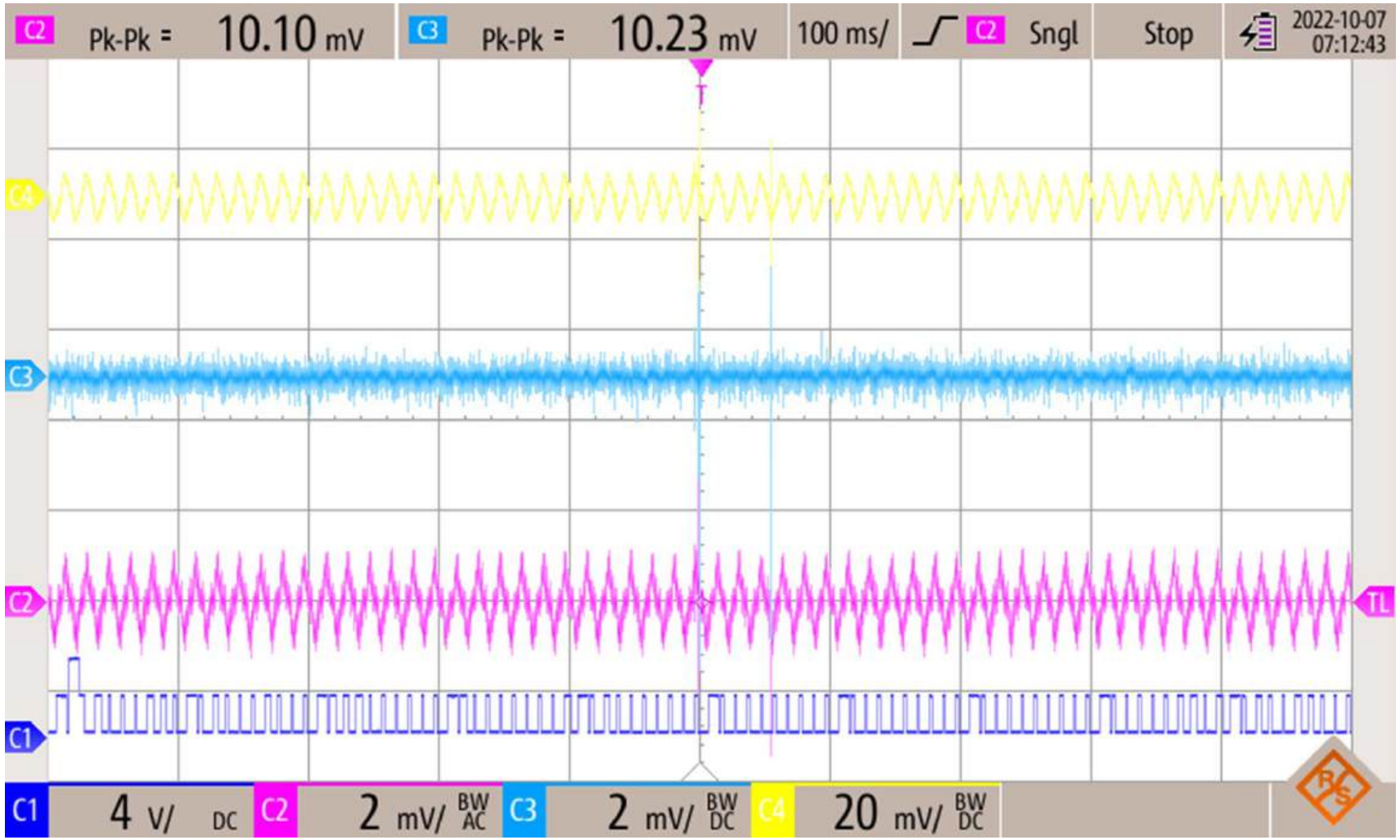
Example VLF Recording

Gutter Downspout (500Ω)

Swing Set (500Ω)

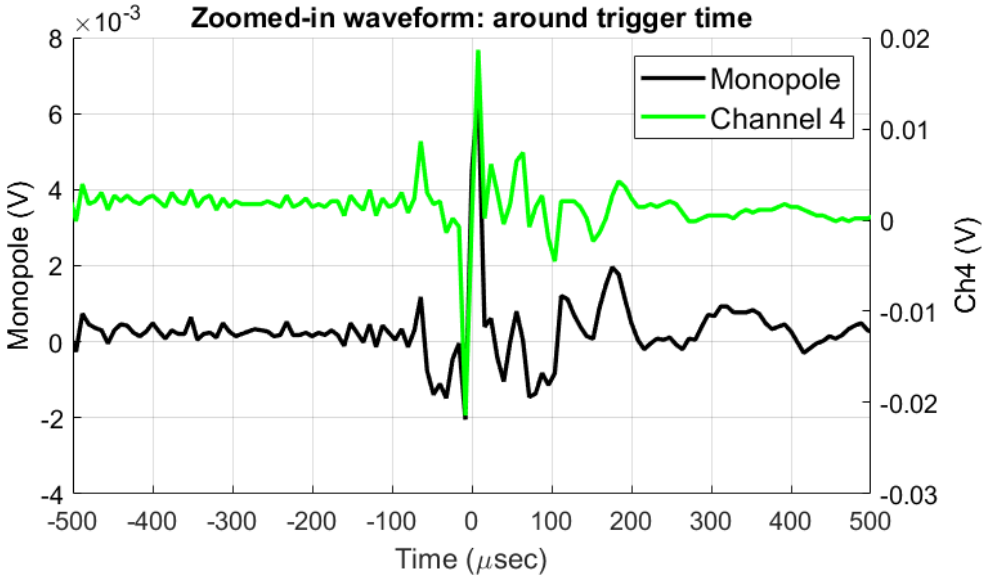
MPA

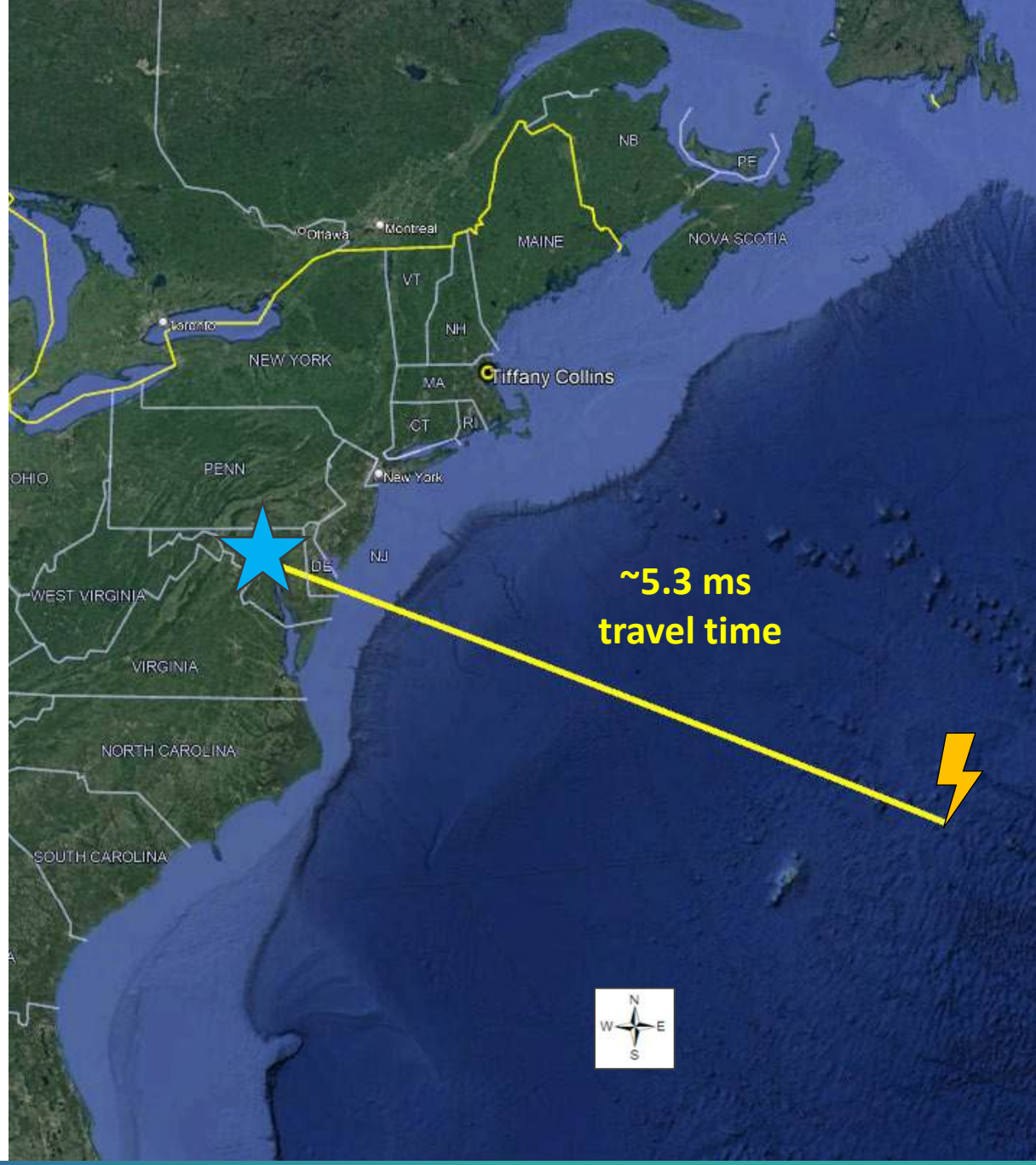
GPS



Case Study: Matching on a Swing Set

- 2021-10-08, Waveform 07-13-28
  - Measured on a Swing Set and a Gutter Downspout
  - **Trigger on Monopole Antenna**
  - **Channel 3 Vpp: 10 mV (Swing Set, 500 Ω)**
  - **Channel 4 Vpp: 40 mV (Gutter Downspout, 500 Ω)**
  - Causative lightning event:
    - 0.1 ms residual difference;
    - 1,000 miles (1600 km) away (~5.3 ms);
    - -252.4 kA





Lightning Event Matching: Summary

Dataset	# of events	Matched within 1/1000th of a Second
Spring/Summer 2021 (Wisconsin)	446	96 %
Minnesota (Summer 2021)	387	91 %
Wisconsin (Spring 2022)	1,692*	92%
Maryland (Fall 2022)	1,659*	89 %
Minnesota (Fall 2022)	430	95 %
Wisconsin (Spring 2023)	1,174†	87 %
Wisconsin (Fall 2023)	5,986*	92 %
TOTAL	12,204	91 %

Notable Examples	# of events	Matched within 1/1000th of a Second
Off-Grid State Park (Wisconsin)	20	100 %
High-Producing Dairy (Wisconsin)	35	94 %
Swing Set / Gutter (Maryland)	1,659*	89 %
Wisconsin: Sept 15, 2023	1,409	97%

Chance VLFs are not from Lightning?

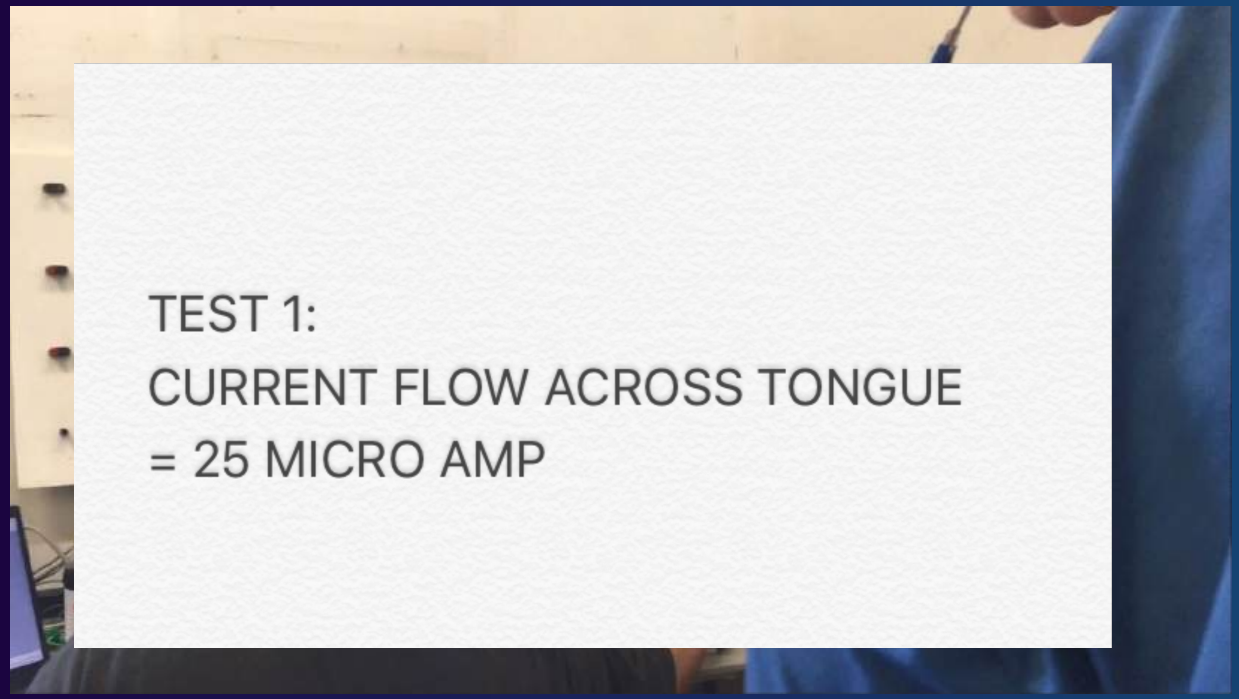
Chance of winning the Powerball Jackpot Lottery is about 1 in 292 Million.

Chance that the recorded non-periodic VLF events recorded on September 15, 2023 are unrelated to lightning is less than the same person winning the Powerball Jackpot 150 times in a row.

Powerball _ California State Lottery.pdf, Mega Millions _ California State Lottery.pdf

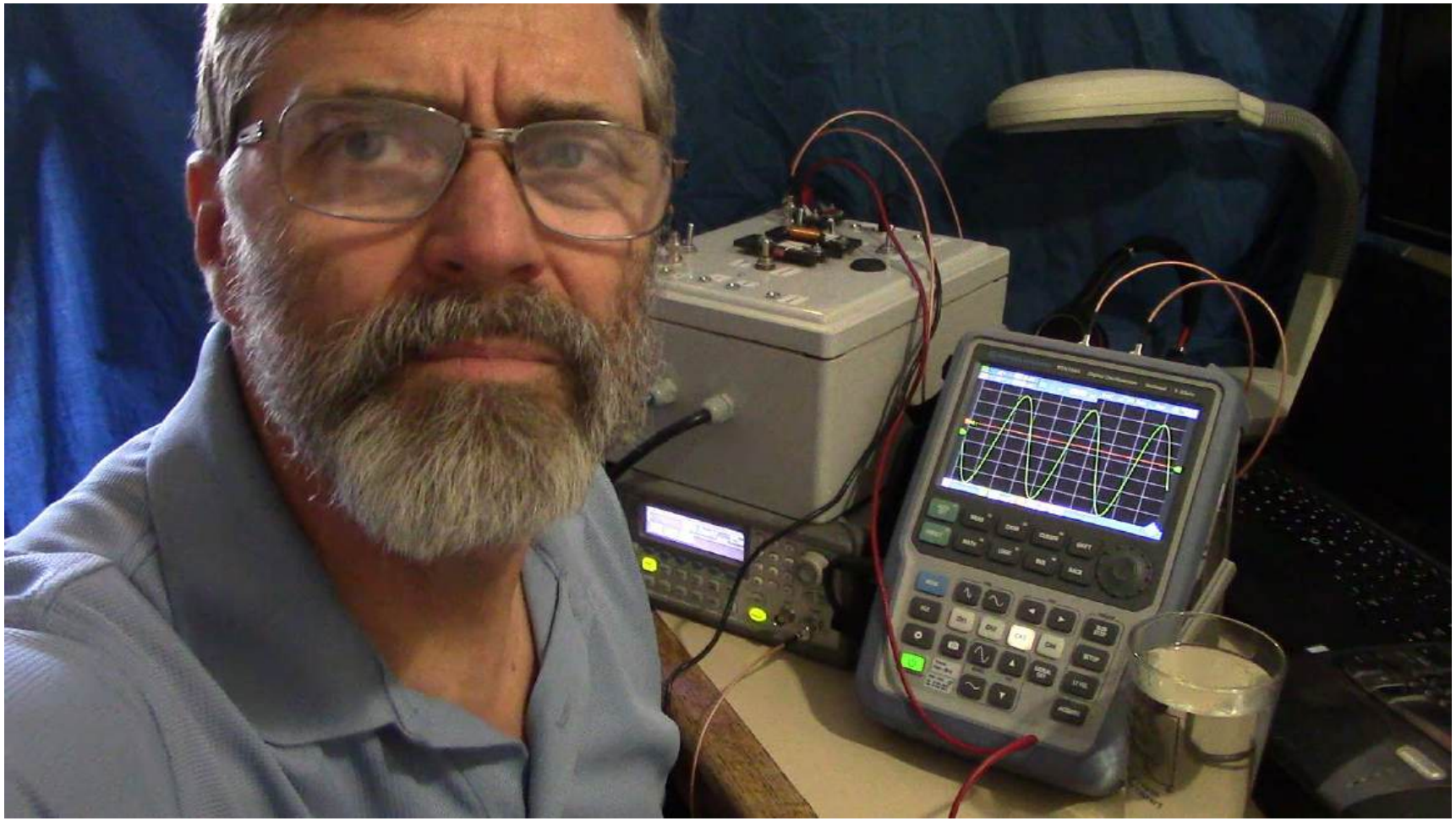
Alleged Harm to Dairy Cows

DVM Demonstration of Harm to Cows 12 kHz Signal to the Human Tongue



- **Verbally signaled and coached**
- **Direct view of screens - showing applied current**
- **Direct view of instrument**

Human Sensitivity at 60 Hz



Human Sensitivity at 12,000 Hz

Utility Personnel: Blinded 12kHz Continuous Current Perception Testing

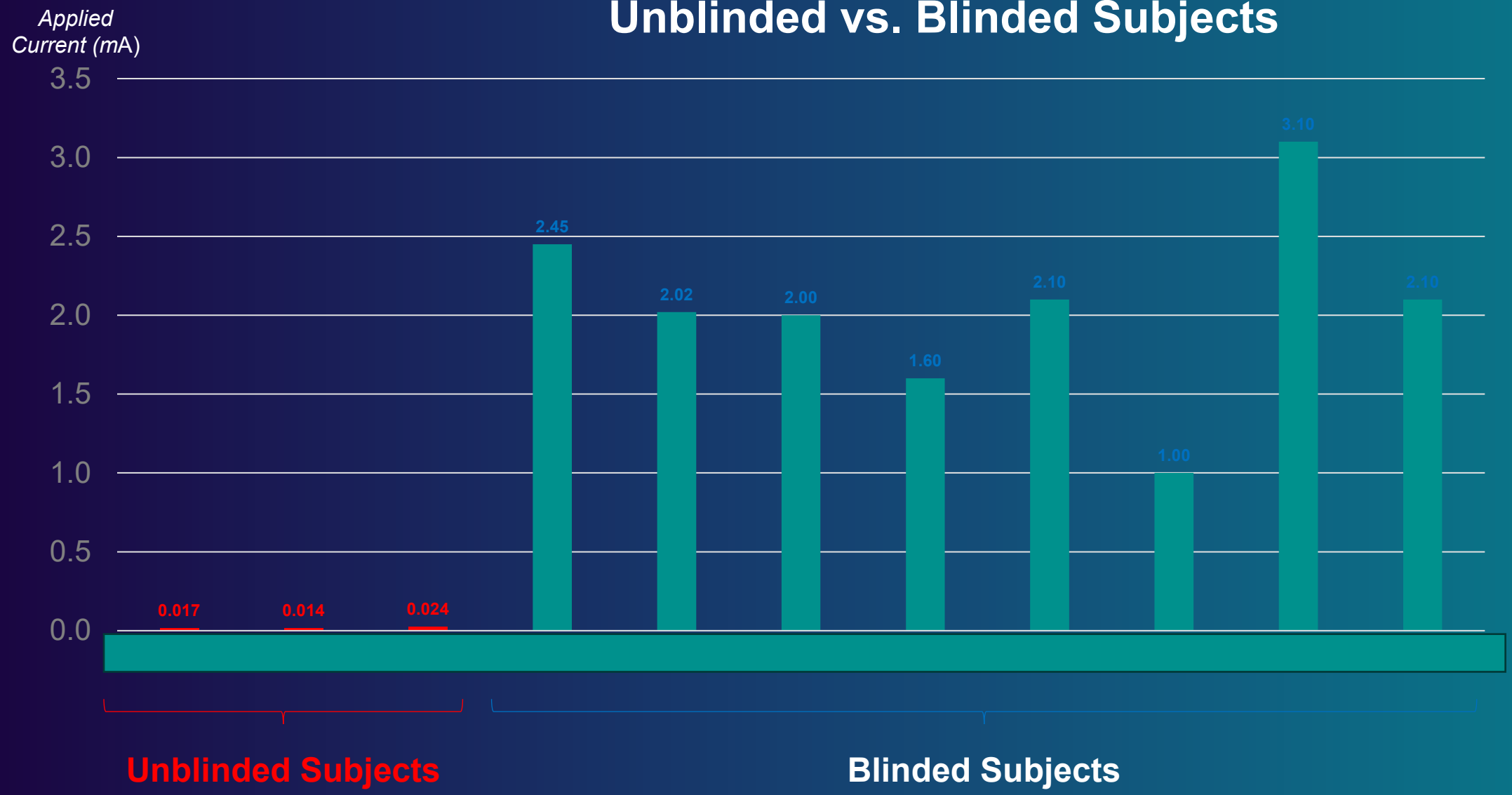
Step 1: Indicate when current is first perceived on the tongue with a small metal probe contact.







Reported Perception
Continuous 12 kHz Current - Metal Probe on Tongue
Unblinded vs. Blinded Subjects



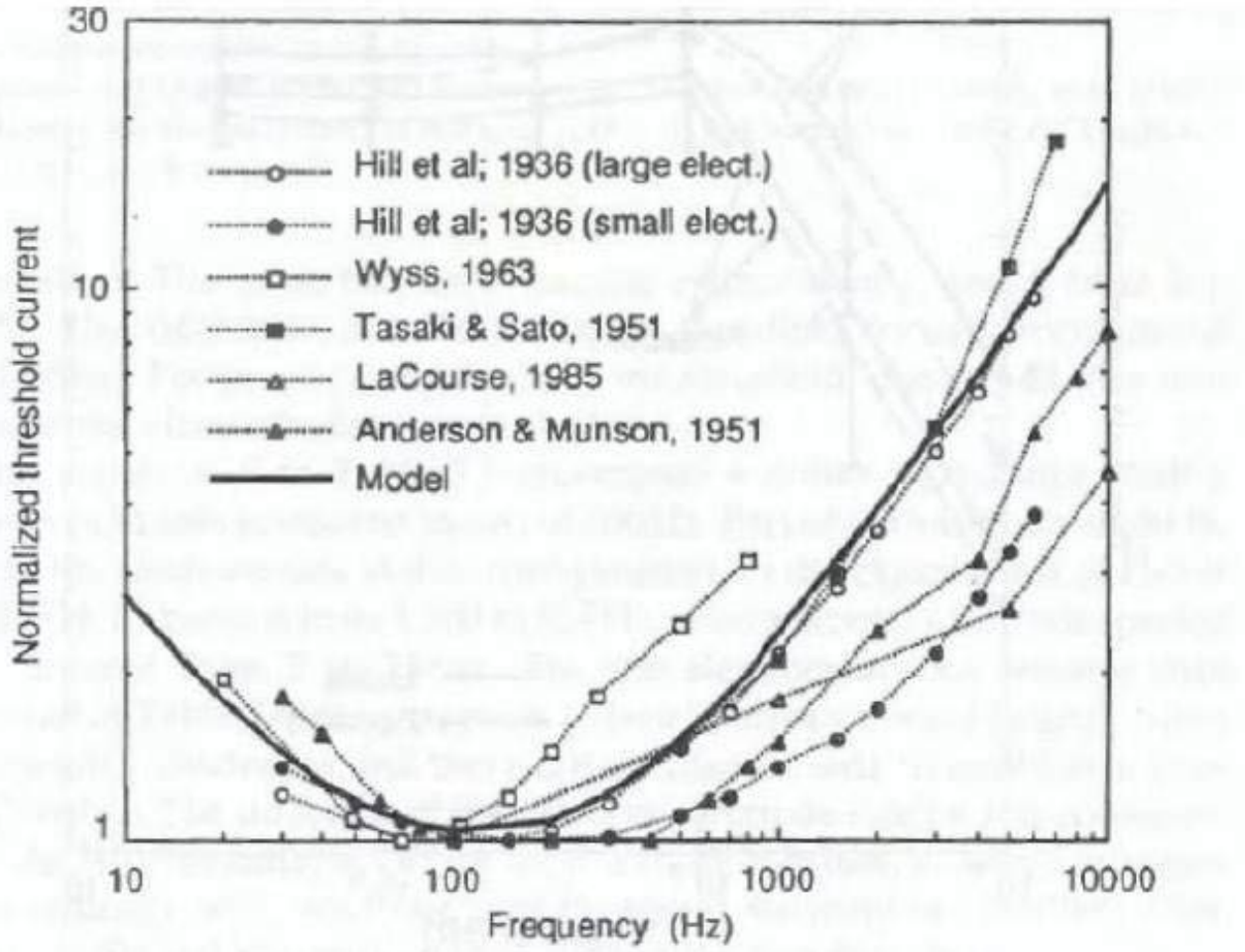


FIGURE 7.13. Strength-frequency curves for perception of sinusoidal currents applied cutaneously. Symbols represent experimental data from several investigators. Solid curve is analytic expression with $f_c = 500$ Hz and $f_o = 30$ Hz.

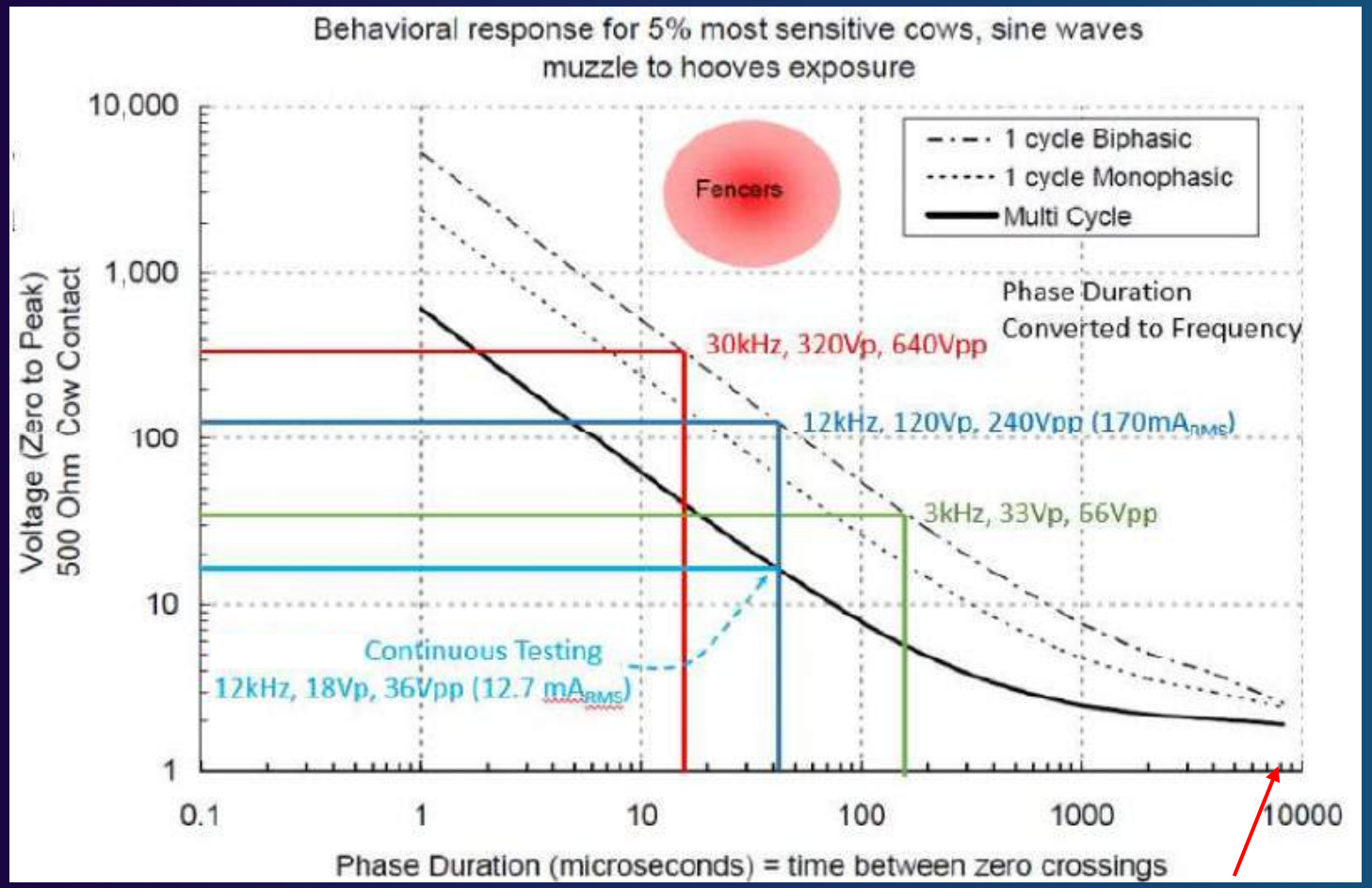
Human research is consistent: higher frequency currents require higher current levels for perception.

SOURCE: Reilly, Applied Bioelectricity (1998).

Metal Probe on Tongue Perception

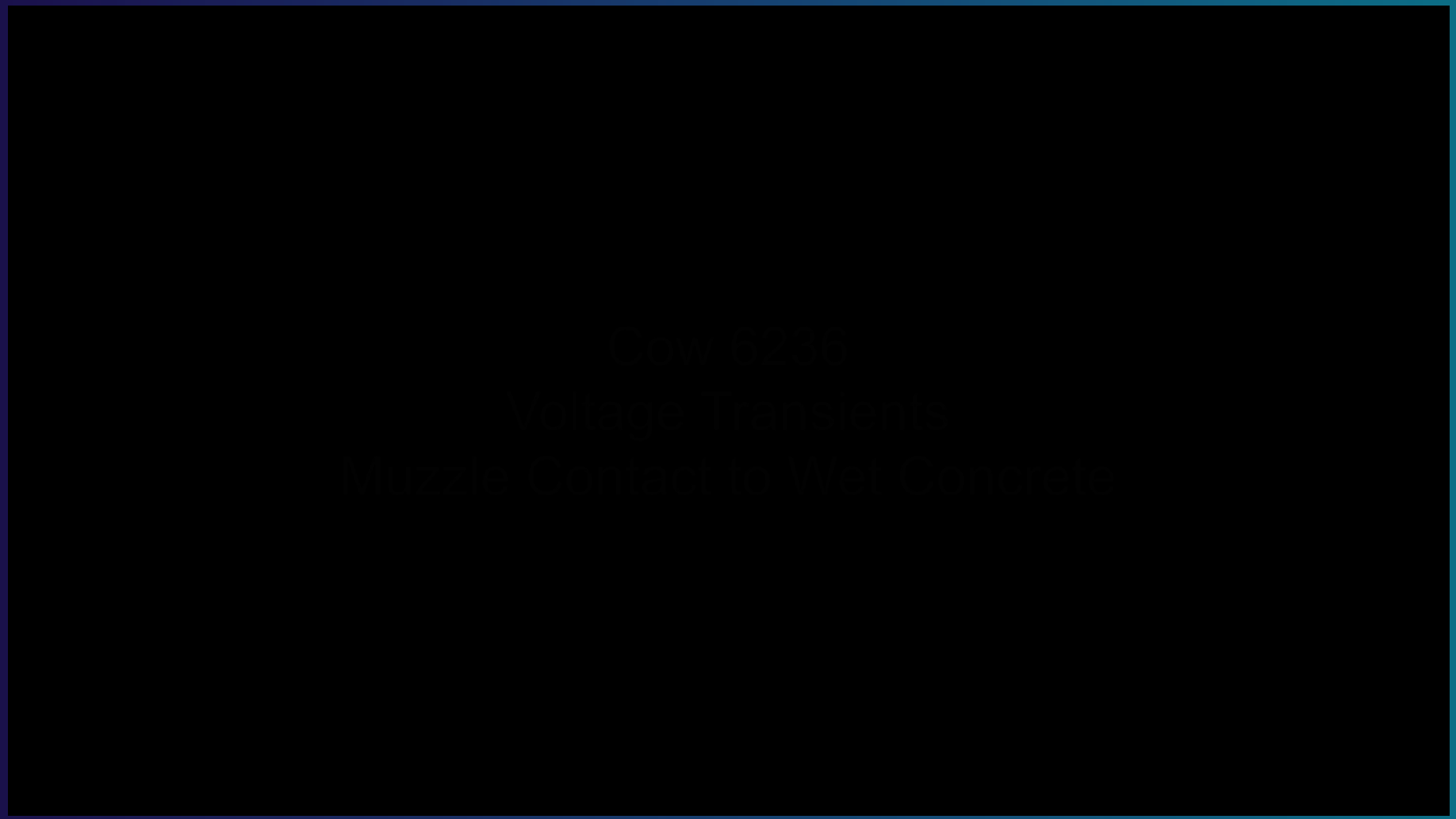
Test	Frequency	Perception (mA)	Importance
Dalziel (1956)	60 Hz	0.045	Probe-on-tongue 60 Hz perception threshold reported in the scientific literature.
"Expert"	12,000 Hz	0.014 0.017 0.024 AVG: 0.018	Unblinded subjects with higher frequency current report two to three times lower perception level. *Opposite of published relationship.
Utility Personnel	12,000 Hz	2.45 2.02 2.00 1.60 2.10 1.00 3.10 2.10 AVG: 2.04	Blinded subjects with higher frequency current report 44 times higher perception level. *Consistent with published relationship.

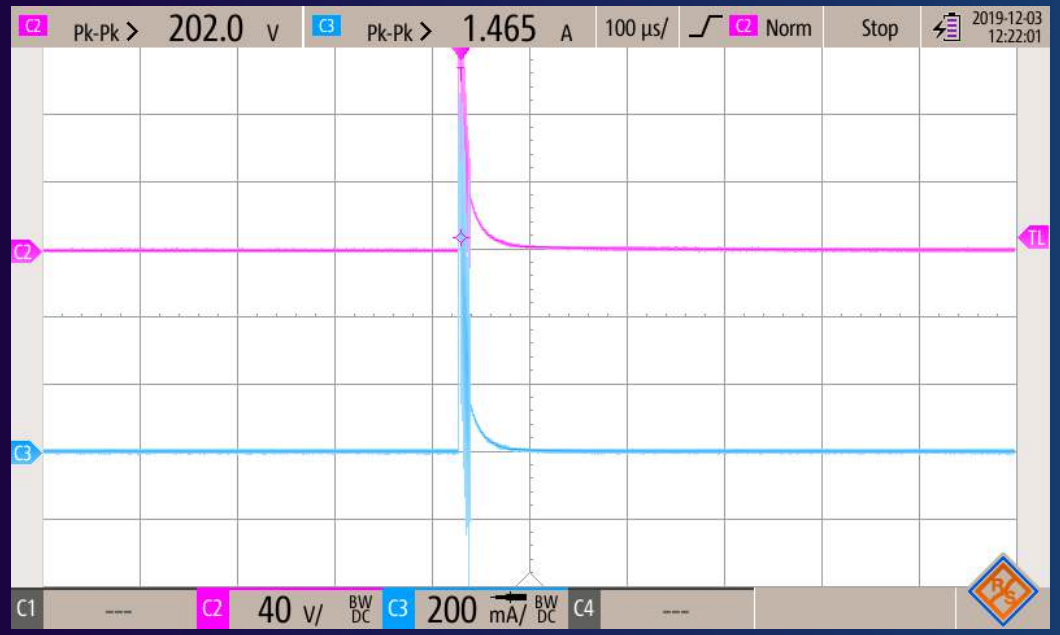
Higher Frequency Requires *Higher* Current
Brief Signals Require *Higher* Current



University of Wisconsin research: Cattle are about seven times <u>less</u> sensitive to a brief 12 kHz pulse (a transient VLF signal) than they are to the continuous 12 kHz current applied to "unblinded" subjects.

Cow Exposed to VLF Signals




C2 Pk-Pk > 202.0 V
C3 Pk-Pk > 1.465 A
100 µs/
C2 Norm
Stop
2019-12-03
12:22:01
C1 --- C2 40 V/ BW DC C3 200 mA/ BW DC C4 ---


C2 Pk-Pk > 170.0 V
C3 Pk-Pk = 1.208 A
100 µs/
C2 Norm
Stop
2019-12-03
12:22:56
C1 --- C2 40 V/ BW DC C3 200 mA/ BW DC C4 ---


C2 Pk-Pk > 172.5 V
C3 Pk-Pk = 1.095 A
100 µs/
C2 Norm
Stop
2019-12-03
12:22:33
C1 --- C2 40 V/ BW DC C3 200 mA/ BW DC C4 ---

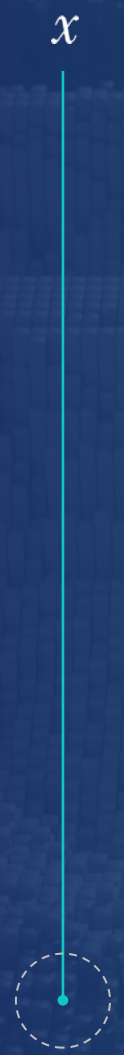
Conclusion

VLF Essentials

- GPS Clock (precise timing)
- High resolution oscilloscope
  - Capable of saving sufficient data
- Lightning data
  - microsecond timing accuracy
- Monopole antenna
  - Isolated/ guaranteed radiated
- Automated signal capture and record

- Mandate that these data be recorded with all VLF signals
  - Legal Precedent

Breakout Session Outline



Tools

Methods & Matching

Identifying Non-Lightning Sources of VLF Signals

Responding to Alleged Utility Sources of VLF Signals

Questions?

Thank You

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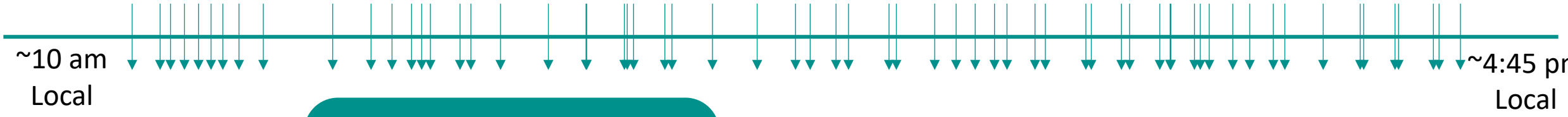
Backup Slides

Simulations – Example Day 6/1/2020 – 147 Events

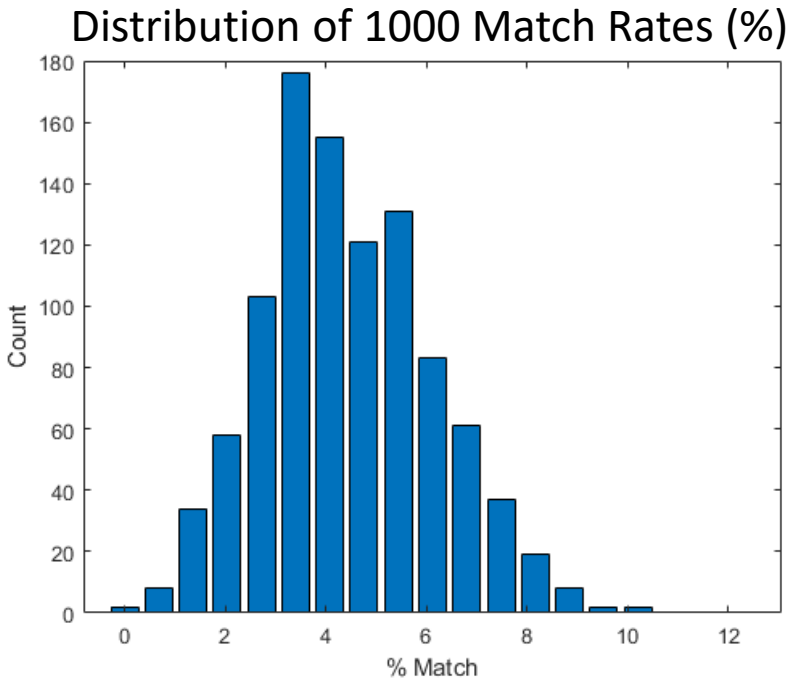


Randomly generate 147 event times

Match time to Vaisala Data

Calculate Percent Match = Number of Matches/Events

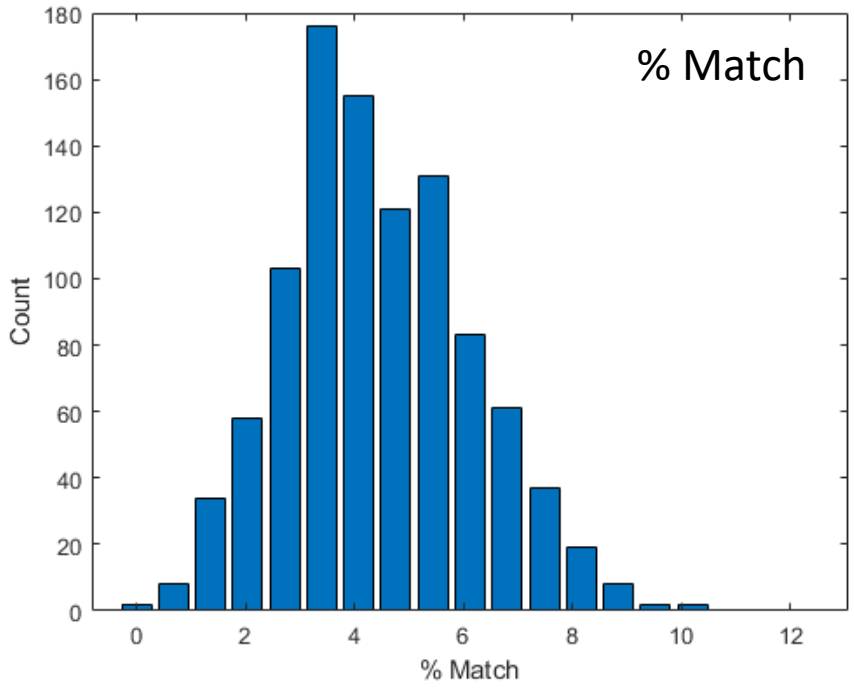
Repeat 1000x

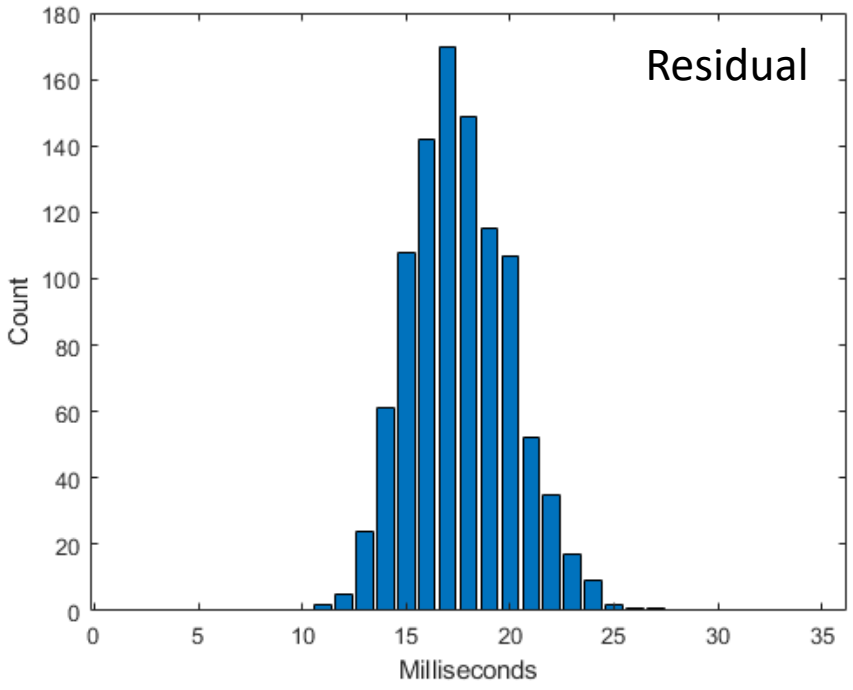


Monte Carlo Simulations: Random Matching Example:2021-06-01

- Lightning data: average of ~23 strokes/second
- 2021-06-01 data:
  - **147 VLF waveforms;**
  - **98% matched within 1 ms**
  - **median residual 0.2 ms**
- 1000 random simulations were run:
  - 147 randomly generated times within the same measurement interval;
  - On average, 4% matched within 1 ms (maximum matching 11%);
  - Median residual 17.4 ms

A 98% match is ~29 standard deviations from the mean matching rate of the random trials





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- Describe the history of measurements and how the addition of each element was necessitated by some kind of obfuscation or another

VLF Measurement Setup

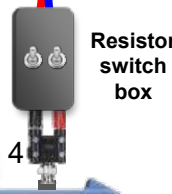
Coaxial Cable (GPS)

Single Conductor (Long Trigger Wire)

Twisted Pair (Cow Contact)

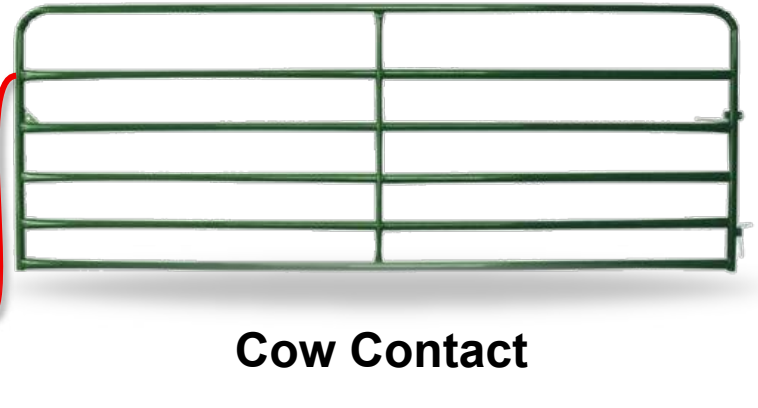
Long (Antenna) Wires

GPS Clock



Oscilloscope

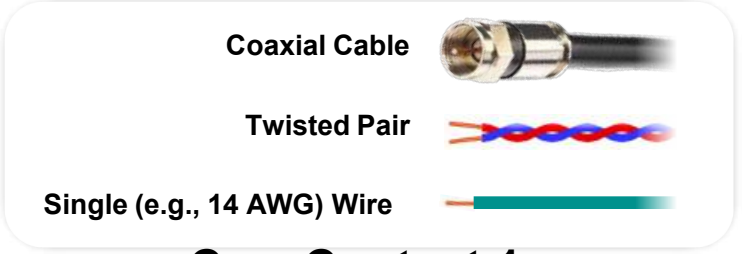
Cow Contact test leads with and without a resistor



Cow Contact

Ground

Replicating Plaintiff Measurements



LTW to Remote Rod

Long Trigger Wires (LTW) Or Neutral-connected Long Trigger Wire (NLTW)

Resistor switch boxes

Cow Contact 1 or NLTW*

Ground

Cow Contact 2 or NLTW*

Ground

GPS

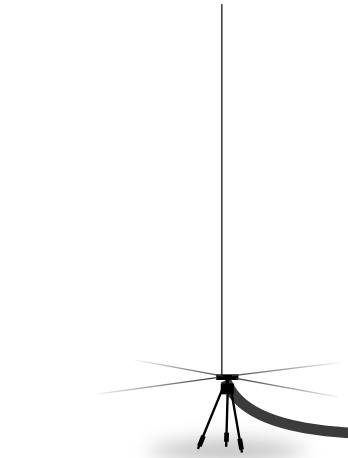
15:20:52

GPS Receiver

Oscilloscope

* **NLTW** are not connected with twisted pair wires, they are single wire with the reference to a remote rod

VLF Monopole Measurement Setup

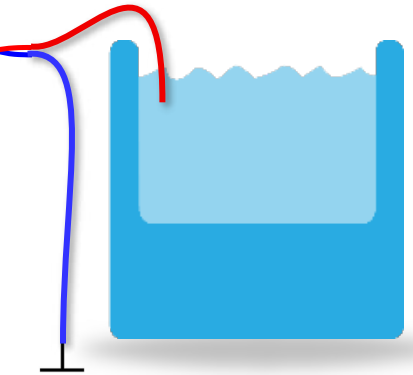


Monopole Antenna

GPS Receiver

Oscilloscope

Resistor switch boxes



Waterer

Ground

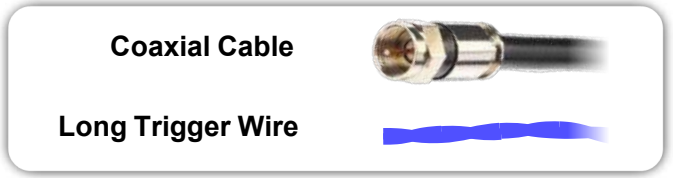
Cow Contact

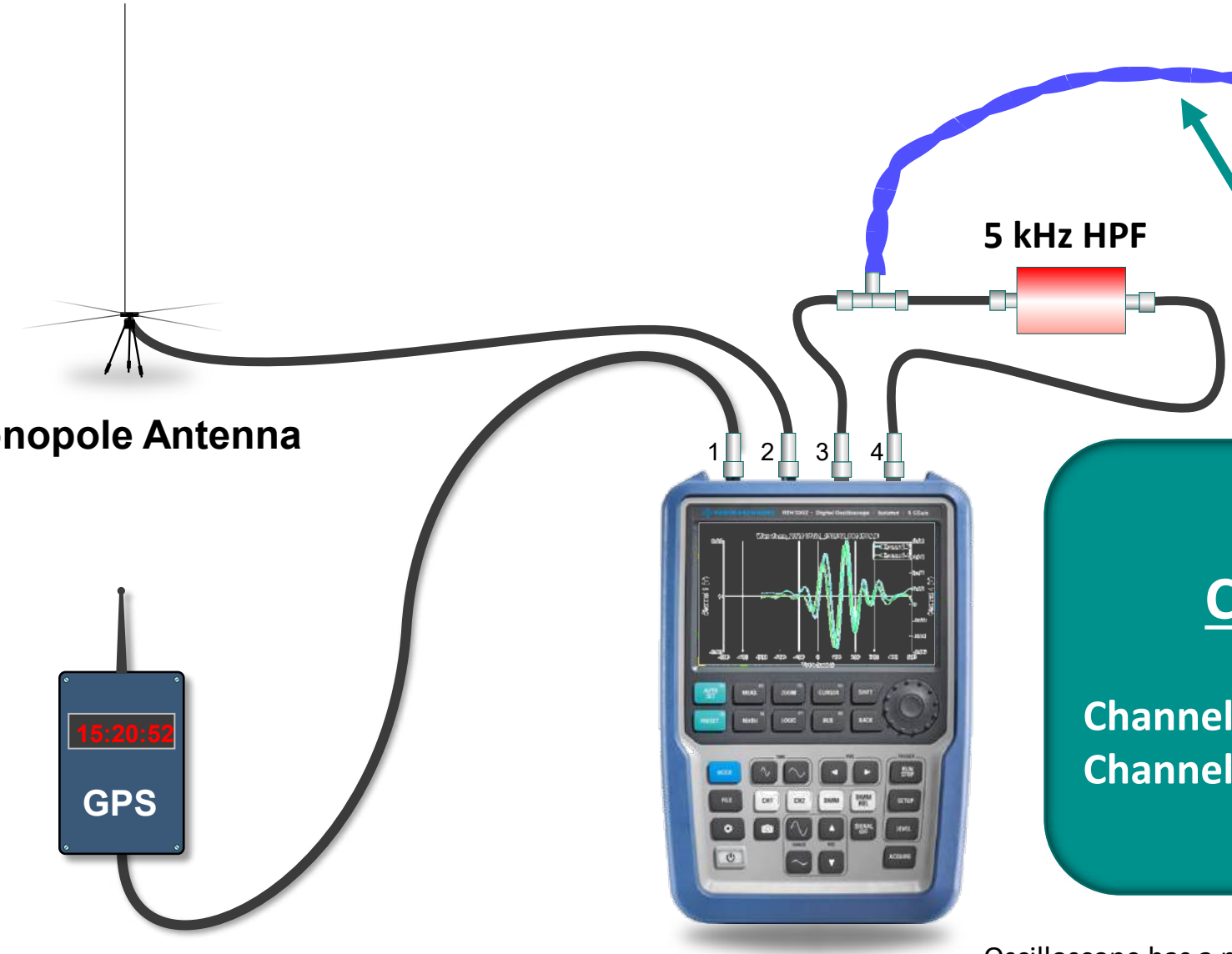
Ground

Coaxial Cable (GPS/Monopole)

Twisted Pair (Cow Contacts)

Determining the Effect of Filtering





Identical Data Input to Channel 3 and Channel 4

Channel 3: Straight in; no internal 10 kHz filter
Channel 4: 5 kHz high-pass filter AND internal 10 kHz low-pass filter

Oscilloscope has a number of optional low-pass filters

Determining the Effect of an Amplifier