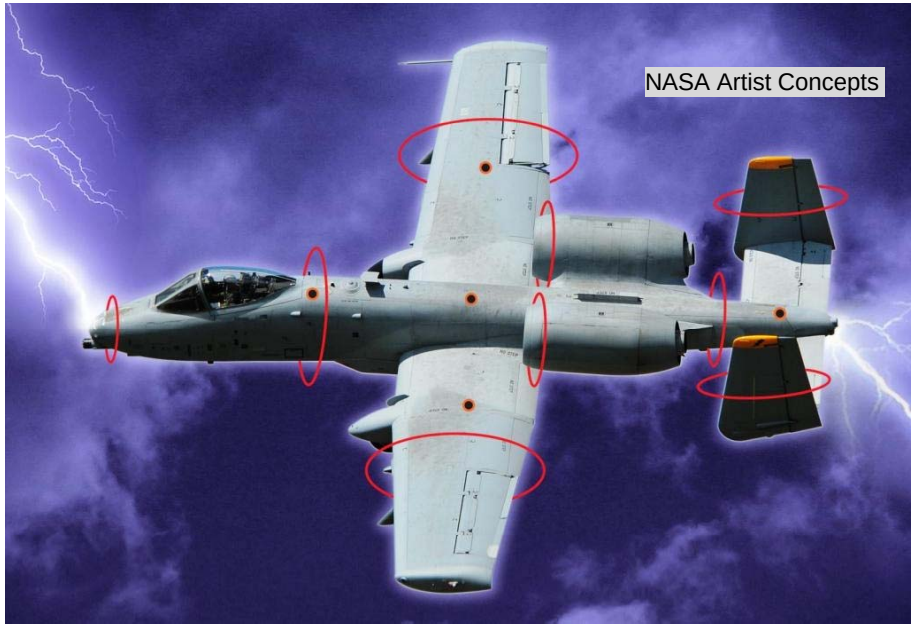
Lightning Electric Current Measurement On-Board the Storm Penetrating Aircraft

- On Board Measurement: History, Why Now?
- Fiber Optic Electric Current Sensing
- Instrumentation System
- Operations Strategy
- Summary/Questions



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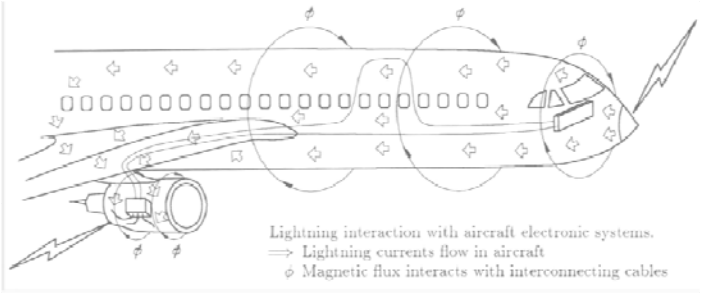
On-Board Measurement: History

- **NASA F106, FAA CV-580, ONERA/DEV Transall C-160 Data**
  - Form basis of Aircraft Certification for Indirect Effects.
  - Lacking in-flight Cloud-to-Ground data
  - Source Database (FAA R&D Electromagnetic Database “FRED”) Lost
  - F106 max data window of 327uS at 100MHz sampling rate (12 Channels)

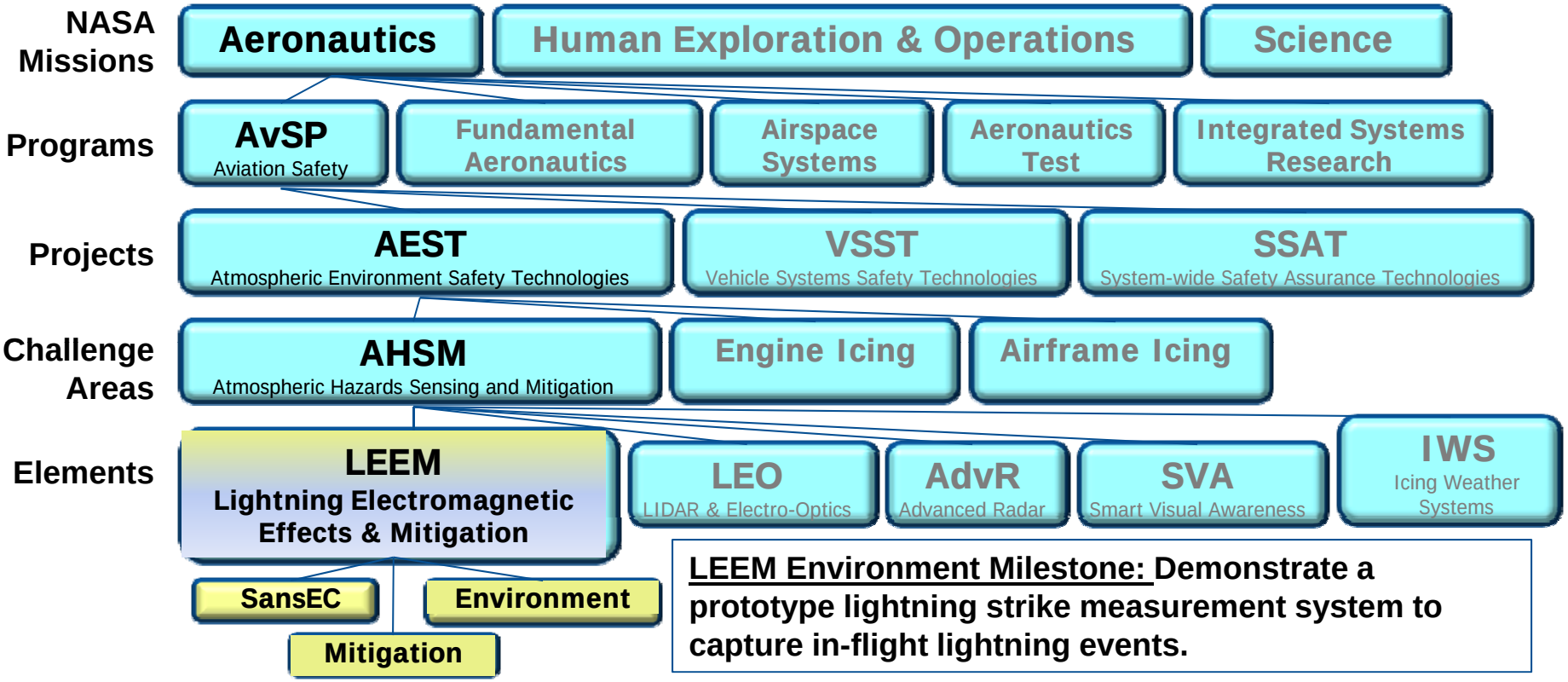


- **SAE ARP5412**
  - “Generalized Environment” selected to produce damage and effects similar to nature.
  - Cloud-to-Ground data from tower and rocket-triggered flashes
  - Uncertainty regarding origin of some data
- **European ILDAS Program (In-flight Lightning Damage Assessment System)**
  - Prototype System Developed but with Limited Use.
  - Classic Sensor technologies not easily integrated onto aircraft.
  - Point measurements and computational modeling required.
  - EU Support Ended in 2008
- **Technology Trends**
  - Composite Materials (all-metal fuselages are history)
  - Instrumentation Technologies (higher speed, increased memory)
  - Damage Assessment, Diagnosis, Prognosis

On-Board Measurement: Why Now?

- **Aviation Safety**
  - Damage Assessment of Composite Materials
    - Varying EM properties (σ, ε, μ)
    - Non-homogeneous
  - Improved Understanding of Lightning Phenomena
    - Lightning Certification Environment Update
    - Electrodynamic Indicator of Storm Hazards
  - Enable All-Weather Operations
    - In-Flight Damage Diagnosis & Mitigation
    - New Sensor Technologies for Avoidance
  - 30 Years Advancement in Instrumentation Technology
- **Meteorological Science**
  - Lightning Peak Current, Stroke Multiplicity, Charge Transfer
    - Validation of Lightning Mapping Arrays
  - Lightning Attachment Assessment for research vehicles

On-Board Measurement is a Milestone under the "LEEM" Project-Element



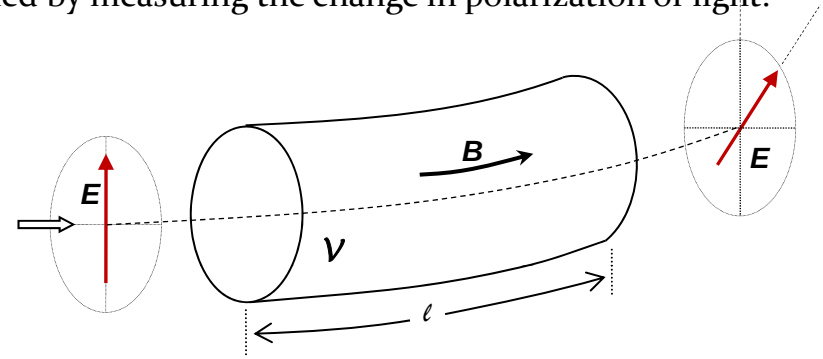
LEEM Environment Milestone: Demonstrate a prototype lightning strike measurement system to capture in-flight lightning events.

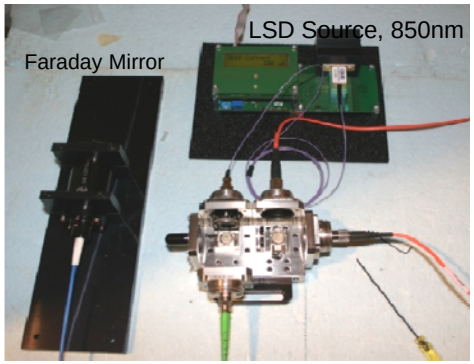
LEEM Project-Element Goal: Make Composite aircraft safer and more robust in a lightning environment, and to assess damage.

AHSM Technical Challenge: Improving and expanding remote sensing and mitigation of hazardous atmospheric environments and phenomena.

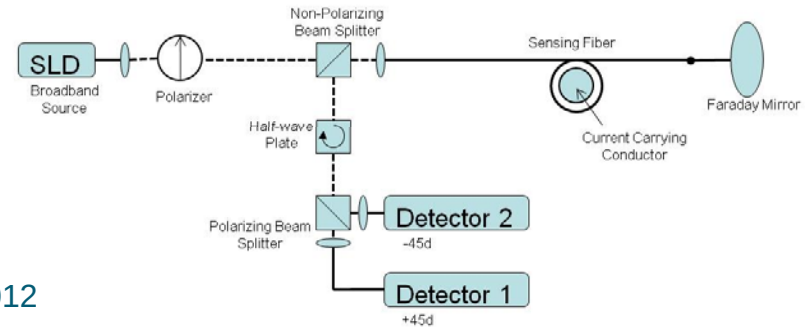
Fiber Optic Faraday Current Sensor

- **Faraday Effect:**
  - Light and magnetic field interaction in a dielectric material, in which the rotation of the plane of polarization is proportional to the intensity of the component of the magnetic field in the beam of light
  - The strength of the magnetic field is determined by measuring the change in polarization of light.
- **Fiber Optic Advantages Over "Traditional" Sensors**
  - Measure Total Lightning Current Waveforms (DC & up)
  - Lightweight, Low-power, EMI-Immune
  - Measure enclosed current through arbitrary-shaped area
- **Advantages of Reflective Design (versus transmissive):**
  - Reduced sensitivity to Vibration & Power Fluctuation
  - Better Sensitivity
  - Easier Polarization Tuning



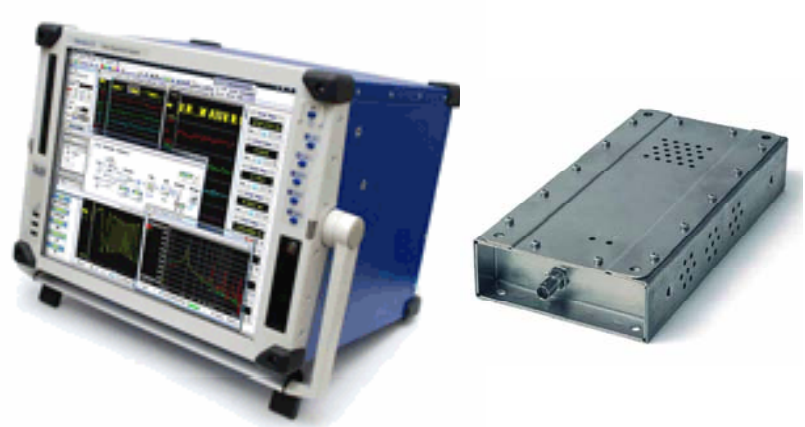


Lightning Waveform Generator



Instrumentation

- **System Requirements**
  - Channels: 4 to 8 Desired
  - Dynamic Range: 60dB or Greater
    - 100 amp to 100, 000 amp
    - 10 Bit or higher resolution, 2^{10}=1024, 20log 1024=60dB
  - Sample Rate: 10MS/sec (100ns time interval)
  - RAM:
    - ~1 Second Flash Duration
    - 10MS/sec
    - ~ 1GB per Flash
  - Storage: Multiple Mission Desired: ~100GB
  - Isolation: Fiber Optic. No conductive path to personnel or other equipment.
  - Size, Weight: Dependent on Test Airplane
  - Power: 90-264V, 47-63Hz, 500VA max
  - Automatic Bootup, Intialization, Trigger, Data Save & Reset for next event.
- **Inputs/Outputs**
  - I: Remote Soft Power-ON/OFF
  - I: Self Test Command
  - I^2: Timing & Position (IRIG-B, GPS)
  - O: Status Indication- "OFF", "ON", "Ready"
  - O: Status Indication- Self-Test Pass/Fail
  - O: Data: Ethernet/USB (depot connect)



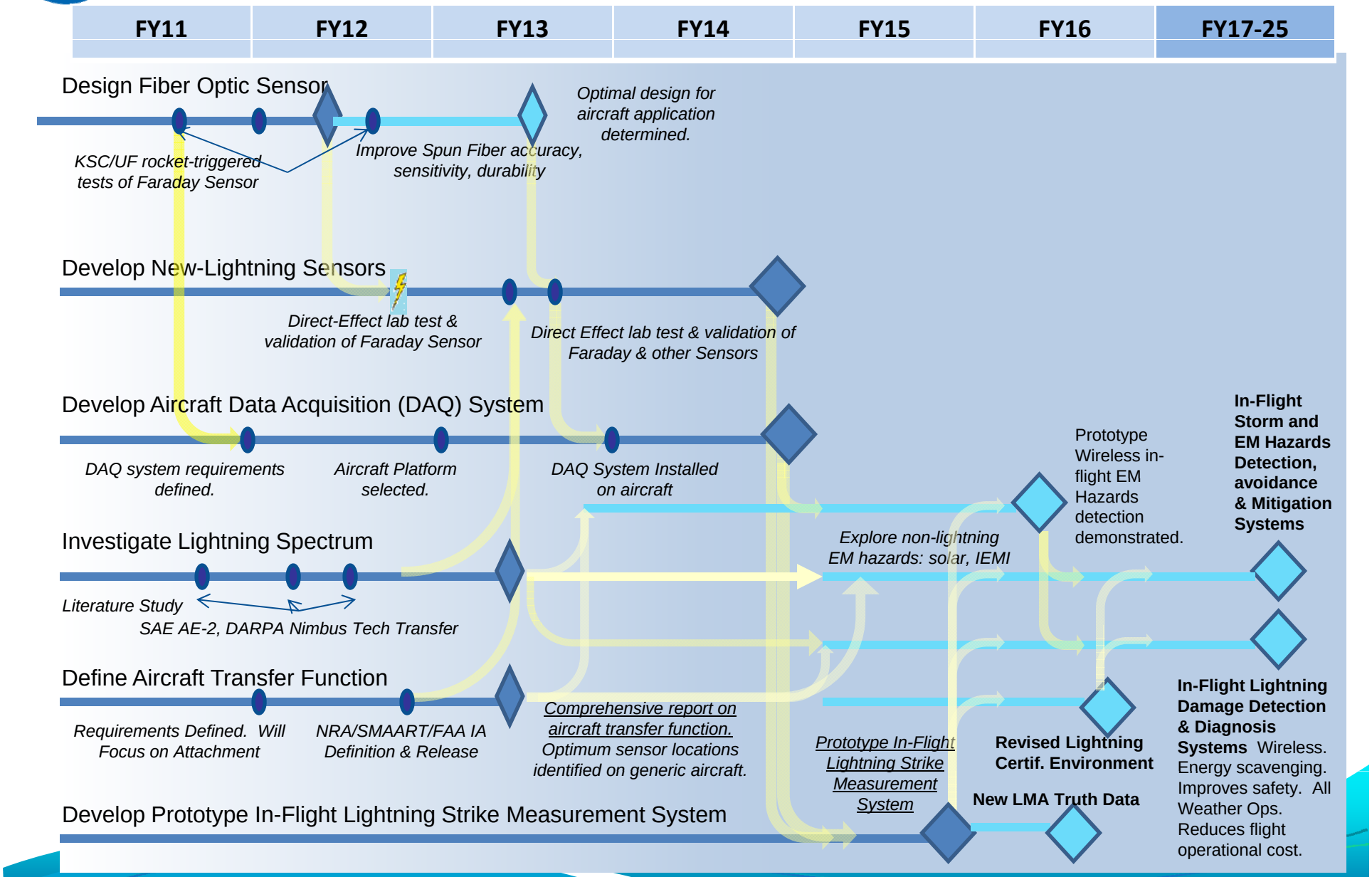
Example of a portable data acquisition system and fiber-optic-connected digitizer unit that can obtain 100Ms/s, exceeds 80dB dynamic range (14 bit resolution) and supports up to 20 high-speed channels. Up to 2GB RAM per channel is possible (with 5 channels). (Photos courtesy of HBM, Inc. http://www.hbm.com/ .)

- **Fuselage Exterior Interface-**
  - Fiber Loops covered by non-conductive "Speed Tape" Polyimide Film Tape
  - Modify Access-Panel for Hull Penetration.
- **Environmental Specifications**
  - Thermal/Vibration/Humidity/Pressure
  - EMI
- **Operations**
  - Power-ON & Bootup
  - Pre-flight Check/Self-Test
    - Installed Test Coil & Transient Generator
  - Data Offload/Storage/Handling

Operations and Schedule

- Sensor Development: Fiber Optic Current & Others (2010 to 2013)
- Instrumentation Development (2011 to 2013)
- Establish Flight Partnerships (2012 to 2015)
  - NSF A-10 SPA?
  - NASA DC-8 for DC-3 Experiment?
  - NMT Langmuir Balloons?
  - DARPA/Quasar UAV?
  - NOAA WP3D Hurricane Hunter?
  - USAF: WC-130J Weatherbird
  - Commercial Transports struck about once per year.
  - Anyone Else Fly Through Thunderstorms?
- Installation & Flight Integration (2013 to 2015)
- Air Worthiness & Safety Review (2013 to 2015)
- Flight Research Campaign (2014 to 2016)

AEST LEEM Environment Roadmap



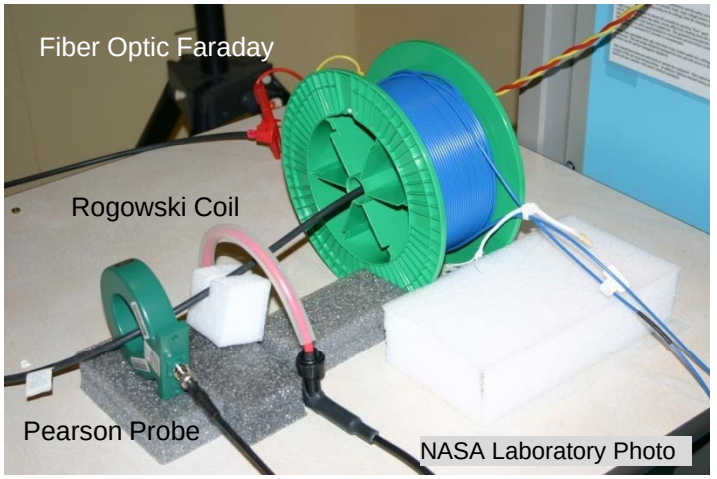
Summary/Questions: LAOF

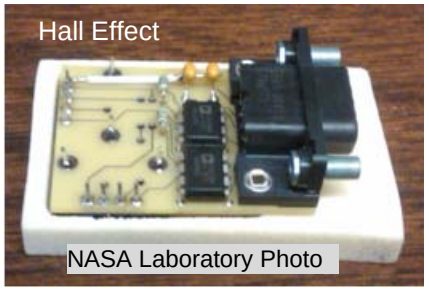
- Installation as Secondary System on A-10?
  - Utilize or Augment On-Board Instrumentation
  - Weight, Size, Power
  - Sample Rate, Dynamic Range, Memory, Channels
  - Telemetry
  - Airworthiness & Safety Review
  - Funding Requirements?
- Value of Meteorological Science Data?
  - Lightning Peak Current, Stroke Multiplicity, Charge Transfer
  - Validation of Lightning Mapping Arrays
  - Lightning Attachment Assessment for Research Vehicles
- Partnership Opportunities?
  - NASA Research Announcement
    - (architecture, packaging, instrumentation and environmental qualification)
  - IA's/CA's/Grants/Contracts?

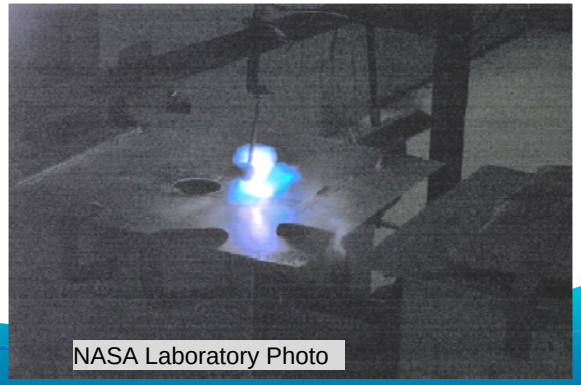
Extra Charts

Other Sensors

- Electric Current: Fiber Optic Sensing using Polarization Rotation (Faraday effect)
  - Bandwidth from DC to > 10MHz
  - Dynamic Range >60dB (100 to 100kA)
  - Circumferential Measurements **without modeling**
- Attachment Localization
  - Surface-born Time-Of-Reception Measurements (STORM) Invocon, Inc. Conroe, TX
- Others (attachment)
  - Hall Effect (diffusion current)
  - Piezoelectric/SAW
  - Thermal
  - Acoustic
- Others (nearby flashes)
  - μW, mm, THz, X-Ray, G-Ray

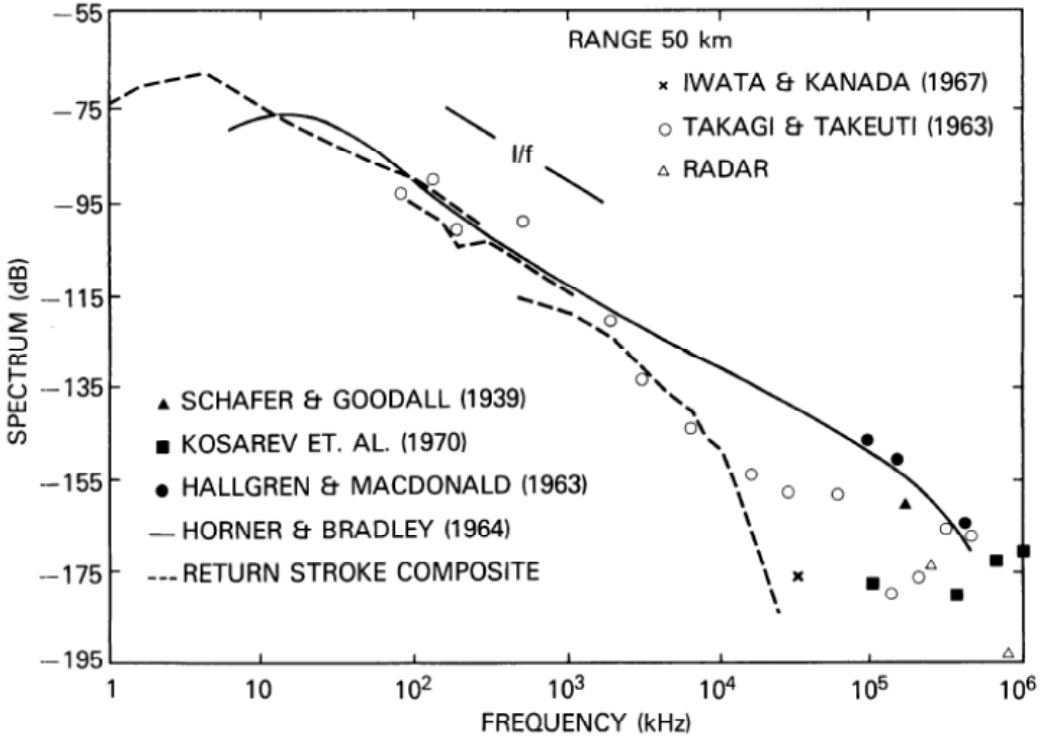






Spectrum

- 1986 D. LeVine Report
- Lightning Detection and Mapping Networks
  - WWLLN (VLF)
  - NLDN (LF, VHF)
  - ENTLN (HF)
- Satellite Detection and Localization
  - TRMM
  - GOES (777.4nm)
- X-Rays and Gamma-Rays
- Applications:
  - Triggering for onboard meas.
  - New Sensor Technologies

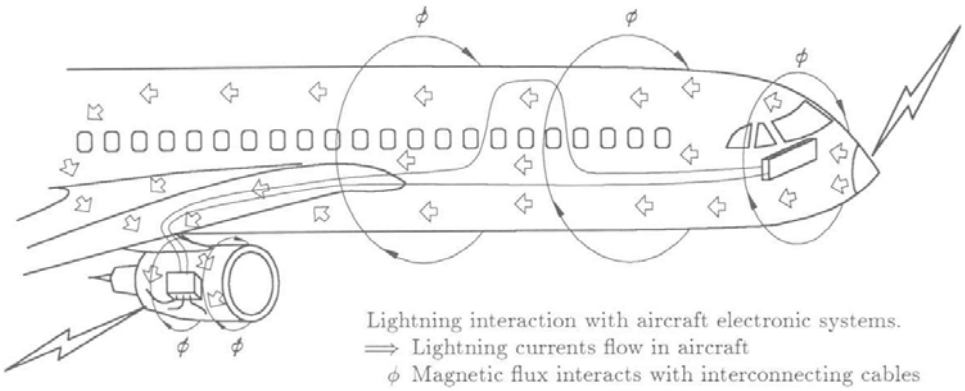


Composite spectrum of radiation from lightning normalized to 50km.
(From D. M. LeVine, NASA TM87788, 3/1986)

Band	Hz	System/ Type/ Technique
VLF	3k to 30k	WWLLN /IC&CG /TOA
LF	30k to 300k	NLDN /CG /MDF&TOA
HF	3M to 30M	ENTLN /IC&CG /TOA
VHF	30M to 300M	NLDN /CG /TOA&IF

LEEM Milestone: Compile lightning radio emissions data from available sources. Add new data for X-Ray and G-Ray, as well as millimeter and other spectrum. Categorize according to parameters such as cloud-to-ground, cloud-to-cloud, geographic location, atmospheric conditions, etc. Convert to common units as appropriate (i.e. E (f) at a common distance). Evaluate for correlation between lightning radiated emissions and storm hazards.

Transfer Function


Lightning interaction with aircraft electronic systems.
⟹ Lightning currents flow in aircraft
ϕ Magnetic flux interacts with interconnecting cables

- Aircraft Certification
  - Focus on Attachment
  - FAA AC 20-136
    - "ATLs (Aircraft Transient Levels) are the voltage and current amplitudes and waveforms actually generated on the aircraft wiring when the aircraft is exposed to lightning, as determined by aircraft test, analysis, or similarity."
    - Aircraft Certification Requires Lightning Protection 14 CFR 23.1306, 25.1316, 27.1316, and 29.1316
  - SAE ARP5412/ARP5415/ARP5416
    - "Idealized" environment
    - 100Hz to 50 MHz
    - Waveforms for Aluminum vs. Composite

LEEM Milestone: Compile existing aircraft transfer function data available from the FAA, industry and universities.

- Nearby Flashes MIL-461-G RS106 (Nearby Strike), RS108 (Direct Attach) coming soon
- Less-Common Atmospheric Electric Phenomena
  - (Jets, Sprites, Compact Intra-cloud Discharges, etc.)
- Applications
  - Improved understanding of avionics electromagnetic environment
  - Improved understanding of shielding properties of new fuselage materials
  - Diagnosis & Prognosis: Placement of sensors to determine external environment and estimate airframe damage.