Methods for Characterizing Arc Fault Signatures in Aerospace Applications

Aging Aircraft 2003

ARC SHIELD™

Thomas Potter – Business Unit Manager

Michael Lavado, PE – Senior Design Engineer

Christian Pellon, PE – Design Engineering Manager

Texas Instruments

Aging Aircraft 2003

Arc Fault Circuit Interrupting (AFCI) technology has been proposed as a means to improve aircraft wiring safety.

Arc Fault Circuit Breakers that provide supplemental protection against arc fault conditions are being developed and prototypes have undergone flight testing.

This paper will address the methods for determining and distinguishing between arcing characteristics and normal load conditions on aircraft, and the requirements of arc fault detection algorithms to address these conditions.

The paper will also discuss methods being implemented to provide robust circuit protection against arc fault and the desired product performance of AFCB's.

Aging Aircraft 2003

The need for supplemental protection to protect against arcing events has been well documented over the past seven years.

- At least one “smoke in the cockpit” incident occurs every week on US commercial planes
- Electrical arcing in the fuel probe system is suspected to have caused the loss of TWA 800 (7/96)
- SR111 crash (9/98) was caused by in-flight fire resulting from electrical wire arcing in cockpit ceiling panel.
- A large commercial transport with roughly 500,000 ft of wiring has 200-2000 insulation breaches.
- 64 in-flight fires on Navy aircraft (7/95 to 12/97) - 2.1 per month. 80% - 90% preventable with AFCB.

Aging Aircraft 2003

Although AFCI technology has been in-service in household applications for many years, the challenges associated with adapting this technology for aircraft are significant.

Complicating Factors:

- Higher and variable AC line frequencies
- Need for 28 VDC and 115 VAC, 400 Hz protection
- Single and three phase AC power
- Ability to handle 230 VAC phase-to-phase
- Lack of ground return wires
- 270 VDC and Variable Frequency on new aircraft platforms
- Variation between power quality in older versus newer aircraft

It is readily apparent that an aircraft electrical system presents a much more complex engineering challenge than the household application.

Fortunately, a significant amount of development work has been accomplished that demonstrates these challenges can be overcome.

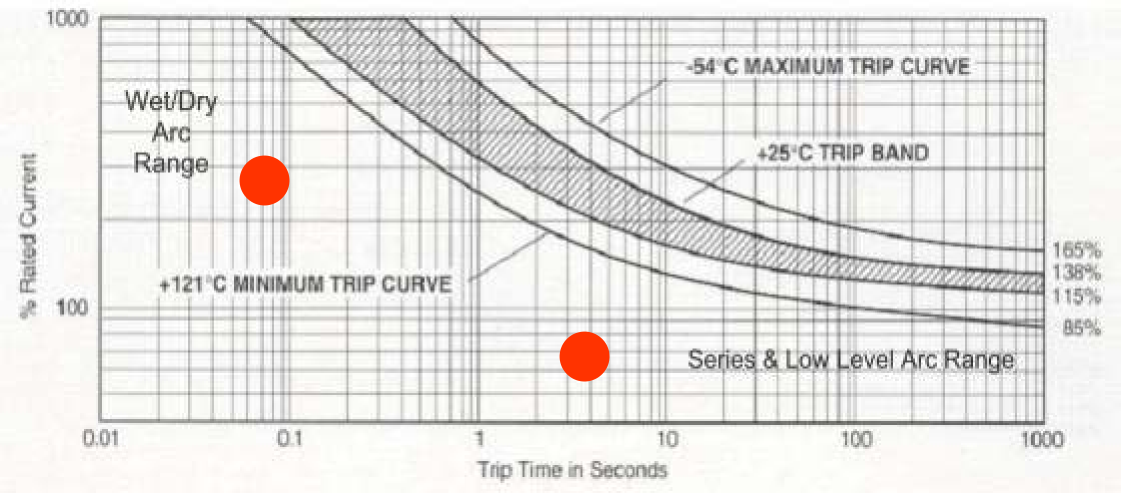
Aging Aircraft 2003

Aircraft wiring safety is not a new issue. Thermal circuit breakers were developed to protect wire insulation against over-heating due to over-current conditions. However there are other conditions that can damage aircraft wiring and result in arcing that cannot be protected solely by thermal devices.

Factors Affecting Wire

Effects of Aging
Environmental Conditions
Chemical Exposure
Location of Wire Bundles
Maintenance Procedures

Typical Time-Current Thermal Overload Curve



These conditions require supplemental protection means to improve the overall level of aircraft wiring safety.

Defining Arcing Characteristics

Four tests have been identified to define undesired arcing conditions:

Guillotine or Point Contact Test

- Simulates a fault between parallel conductors

Wet Arc or Salt Water Drip Test

- Simulates a condition where a conductive contaminant interacts with breached or compromised wire insulation

Loose Terminal Test

- Simulates loose connections in the electrical system

Carbonized Path Test

- Simulates conductive carbon path that can result in flash-over

Aging Aircraft 2003

Guillotine or Point Contact Test

This represents a condition where the wire insulation has been severed or chaffed, and an intermittent parallel path to ground has been created resulting in the discharge of a significant amount of energy.

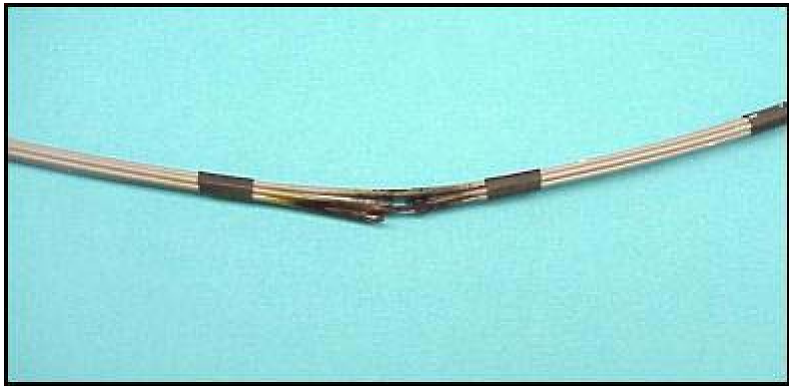
Aging Aircraft 2003

Guillotine or Point Contact Test

Wet Arc or Salt Water Drip Test

The wet arc test simulates a condition where wire insulation has been compromised by some means, and the salt water is used to bridge the gap between two exposed conductors. This test is most commonly performed with conductors at phase-to-phase voltage and with very little resistance in the fault circuit.

Low level Arcing (<10 Amps) Before Flashover



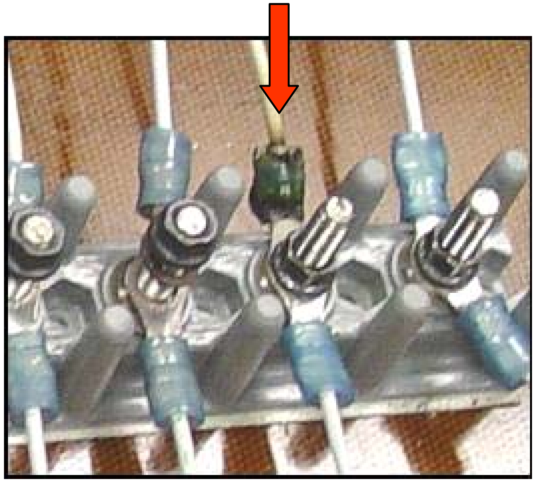
Lab Tested Wire Bundle (Wet Arc) - No Arc Protection

High Level Arcing (>100 Amps) After Flashover

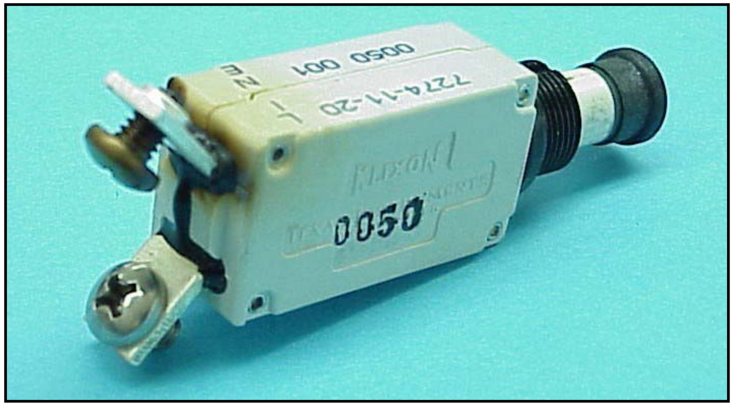
Aging Aircraft 2003

Loose Terminal Test

Loose connections can occur on terminals to connectors, circuit breakers and relays, and other wiring devices. The arcing from loose terminal conditions has been demonstrated to result in damage not only to the pin or lug and associated wiring, but also to the wiring device itself - including ignition of adjacent materials. Moreover, damage can occur at relatively low current levels.



Loose terminal arcing at 4 amps for 15 minutes



Burned circuit breaker due to external heating from loose terminal

Aging Aircraft 2003

Carbonized Path Test

Cracking due to maintenance damage, chaffing, aging, and other various stress-related conditions has been shown to form a conductive arc track over time. The application of voltage to this high resistance conductive path burns this track away, thus resulting in arcing. This arcing subsequently re-deposits the carbon track resulting in another high resistance path that burns away, completing a repetitive cycle that ultimately can reach a flash-over point.

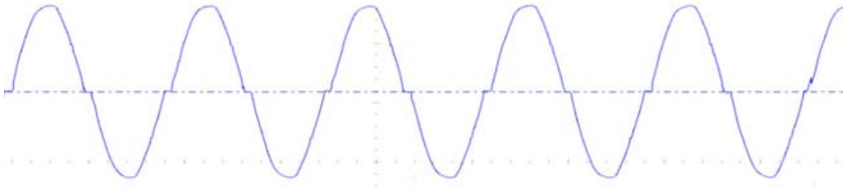
Damaged wires prior prone to arc over

Aging Aircraft 2003

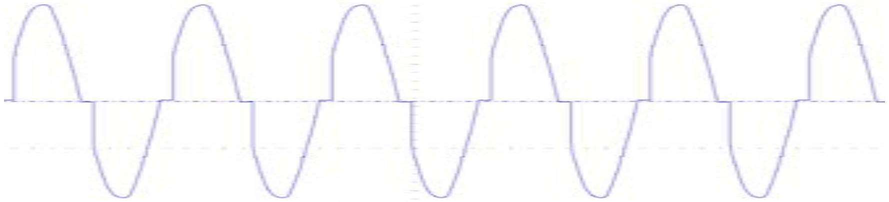
Carbonized Path Test

Understanding the Effects of Normal Steady State and Transients Conditions

It is critical that the AFCI algorithm be able to distinguish between the arcing signatures previously defined and normal steady-state and transient load conditions. In many cases, the signatures of these loads closely resemble or mimic the arcing signatures we are trying to protect against.



Arcing Wave Form



Typical Load Wave Form

Understanding the Effects of Normal Steady State and Transients Conditions

Problematic loads include:

- Bus Transfers
- Motor Loads
- Weather Radar
- Heaters
- Lighting Loads (Fluorescent, Strobe, Landing)
- TRU Supply
- Rectified Power
- Galley Loads

Moreover, the signatures of normal and transient aircraft loads vary from plane to plane (737 compared to a DC-9) and from OEM to OEM.

To understand the effects of normal steady state and transient conditions on the AFCI algorithm, AFCI designers must sample and characterize loads from various aircraft designs and multiple aircraft platforms. Nuisance tripping cannot be tolerated in AFCI circuit design.

Understanding the Effect of Masking Loads, EMI, and Cross-Talk

Primary challenge for AFCI design is not reliable arc detection, but distinguishing an undesired arcing condition in the presence of masking loads and other circuit “noise” while not nuisance tripping.

AFCI circuit requirements:

- Unaffected by EMI conditions (conducted and radiated)
- Arc detection with active capacitive and inductive loads
- Minimal EMI emissions
- Ignore arc-like signals on closely coupled wires
- Immunity to cross-talk

The AFCB must be able to recognize undesired arcing events in the presence of these “noise” conditions, while not nuisance tripping on false arcing signals that may be present in the circuit.

Desired Product Performance Attributes of Arc Fault Circuit Breakers

The requirements for detecting and protecting against arc fault conditions are onerous. AFCI technology must have sufficient discrimination levels to detect arcs, yet this technology cannot result in nuisance tripping.

Key AFCI performance attributes include:

- Fast Response to true arcing events
- Ability to discriminate between normal load signatures and arcing events
- Ability to sense arcing events in the presence of masking loads
- Immunity to filters, EMI, cross-talk, and other circuit “noise”
- Low Level Arc Sensitivity

Methods Employed by Texas Instruments to Detect Arcs

AFCI Algorithm Objectives:

- Robust and versatile
- Low Level arc sensitivity
- Fast response to an arc signature
- Ability to see through intervening filters
- No nuisance trips
- Works over wide range of frequencies

How We Achieved Results:

- Algorithm does not rely on precise correlation between voltage and current
- Do not rely on current level, but on arcing content of the signal
- Recognition of the fundamental randomness of arc signature
- Rely on fundamental characteristics of the arc, not on special case recognition

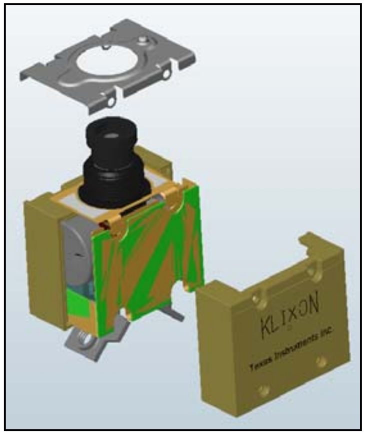
Texas Instruments AFCB Performance Summary

- Meets requirements of AS 5692 for circuit breakers rated to 25 A
- Excellent immunity to AS 5692 nuisance trip loads
- Detects and interrupts arcing faults:
  - With current limited to < 5A on loose terminal test
  - < 8 half cycles with current limited to < 70A (guillotine test)
  - Prior to propagation damage to adjacent wiring after repeated cold start cycles on wet arc test (AS 5692 only requires 1 cold start)
- Even higher level sensitivity can be achieved on lower rated CB's and application specific uses

Application of AFCI Technology in Aircraft Circuit Breakers (AFCBs)

Application of the AFCI circuit in an AFCB presents its own challenges. Desired attributes include:

- Maintain all thermal protection features of present generation ACCBs.
- Line / Load Reversibility
- Small, retro-fittable, package design
- Maximize interchange-ability with present circuit breaker portfolio



Other AFCB Considerations

There are other considerations associated with implementation of AFCI technology on aircraft that require consideration, but are not part of this presentation:

Dual Indication: Distinguish a thermal trip from an arc fault trip
Built-in-Test: Verify functionality of electronics
Ground: Panel ground or other means
Universal Device: 115VAC and 28VDC (same as present ACCBs)
Arc Location: Identify location of arcing event for maintenance

Texas Instruments AFCBs have been designed to address the desired attributes and considerations noted, and we are working with OEM customers, airlines, and regulatory agencies to incorporate these features into our products as appropriate.

Aging Aircraft 2003

Summary

- Aircraft wiring system safety can be greatly enhanced with AFCBs.
- AFCI technology for aircraft requires a robust algorithm that provides:

- Fast Response to true arcing events
- Does not result in nuisance trips
- Ability to discriminate between normal load signatures and arcing events
- Ability to sense arcing events in the presence of masking loads
- Immunity to filters, EMI, cross-talk, and other circuit “noise”
- Low Level Arc Sensitivity

Summary

Texas Instruments has pioneered AFCI technology that addresses these issues and provides the most sensitive algorithm that detects arcing events without nuisance tripping.

We have demonstrated that our AFCI technology can reliably detect true arcing events while discriminating normal steady state and transient load signatures.

Moreover, we have the ability to package this technology across our broad portfolio of products to serve the needs of the global aerospace industry.