

Intermittent Fault Location on Live Electrical Wiring Systems

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ABSTRACT

Intermittent wiring faults are among the most frustrating, time consuming, and expensive problems to diagnose in electrical systems. These sporadic problems occur when wires are wet, vibrating, under pressure, or when the system is in a particular configuration during use. Then when the system is stable and/or powered down, the problems disappear. The best and often the only time to locate these faults is while the faulty wiring is live and in operation. This paper will describe new technology for locating intermittent faults on live wiring systems without interfering with their operation. Spread spectrum time domain reflectometry (SSTDR) has been developed for locating these intermittent faults on live aircraft wires. A pseudo noise (PN) code is injected on the wire, well below the noise margin of the system. The PN code can be self-correlated to give the characteristics of the wiring system – its branches, loads, sources, etc. When an intermittent fault occurs, SSTDR detects and locates the fault. Unlike systems that use voltage and current measurements to detect faults, this method locates impedance changes to the wiring system. It is therefore complimentary to current/voltage analysis methods commonly used for arc fault circuit breakers. It is also highly immune to electromagnetic interference and noise caused by switching loads, etc. This technology is currently being miniaturized into an application specific integrated circuit (ASIC) that can be inte-

grated into many types of electrical systems. The methodology, specifications, and simulated performance of the ASIC are described in detail. Methods to integrate this technology into existing and new electrical systems are also described.

INTRODUCTION

Aging electrical wiring systems have been identified as an area of critical national concern [1], [2]. For aircraft, where both preventative and responsive maintenance are taken very seriously, aging wiring is a very expensive problem. Electrical wiring problems in the US Navy cause an average of two in-flight fires every month, more than 1,077 mission aborts, and over 100,000 lost mission hours each year [3]. Each year the Navy spends from one to two million man-hours finding and fixing wiring problems [4]. A majority of the man hours spent locating faults are on intermittent faults that occur in flight but are not easily replicated on the ground. New arc fault circuit breakers (AFCB) have been developed that are capable of detecting the fault and tripping the circuit before severe damage is done. Although AFCBs will improve the safety of the aircraft, they promise to be a maintenance nightmare, as the faults left behind are too small to detect with typical fault location methods.

This has had a significant impact on the US Navy. The Navy spent \$94 Million on No Fault Found (NFF) equipment removals in one year due to wire faults being undiagnosed [5]. This leads to a drastic imbalance between scheduled and unscheduled maintenance, where five times as much maintenance time was spent on unscheduled than on planned maintenance in 2004 on 10 Navy platforms. About 30% of this was specifically due to wiring. [6]

Unfortunately, electrical wiring failures are not an uncommon event. In 2005 the NAVAIR flew 921, 658 flight hours with a mean time between wiring failures of 637 hours, giving roughly 4 failures per day. Time spent by maintenance technicians trying to rectify these failures amount to 7.3 hours per flight hour for aircraft older than twenty years. [7]

CAUSES OF WIRING FAULTS

The majority of aircraft wiring failures are caused by chafed wires that result in a short circuit [5]. This type of failure is typically intermittent, due to vibration of the wire against a metal structure or another wire resulting in a "dry arc". Another typical cause is the ingress of moisture into damaged insulation, resulting in a "wet arc". Short circuits (both wet and dry arcs) as well as open circuit or high impedance discontinuities can be detected and located by the method proposed in this project. Other reports substantiate this data in other fleets [6, 8, 9].

IMPACT OF WIRE FAULT LOCATION TECHNOLOGY

The objective of the LiveWire project is to integrate sensors that can locate intermittent (and non-intermittent) faults on live (or dead) electrical wiring. It has been predicted by others [10] that Smart Wiring Systems can produce massive savings for the Navy by reducing in flight fires and subsequent loss of aircraft by 80%, reducing maintenance man hours by between 200,000 to 400,000 per year, and generating savings of around \$34.5 Million annual savings from mission aborts and increase mission capable hours.

THE TECHNOLOGY: SPREAD SPECTRUM SENSORS

Several methods are available today for locating electrical faults. These include time domain reflectometry (TDR), frequency domain reflectometry (FDR) [11][12], standing wave reflectometry (SWR), mixed signal reflectometry (MSR) [13], multicarrier reflectometry (MCR) [14], S/SSTDR [15][16] and noise domain reflectometry (NDR) [17]. Reflectometry methods send a high frequen-

cy signal down the wire, where it reflects off impedance discontinuities such as open or short circuits, junctions, loads, etc. and returns like an echo to the sending end of the wire. The time delay between the incident signal and this echo tells the distance to the impedance change. Each of the different reflectometry methods uses different types of incident waveforms in order to test the wires and different types of sensors to receive the echo and compare it to the incident signal. [18]

All of these methods are able to locate "static" faults (otherwise known as "hard" faults), those that are present at the time the test is being done. Unfortunately, in very dynamic electrical environments such as aircraft, the vibration, turning on/off of electrical loads, and moisture ingress can cause faults to occur in flight that cannot be replicated on the ground. These intermittent "no fault found" (NFF) conditions are extremely expensive, time consuming, and frustrating for the maintainer, since they cannot be replicated on the ground. Today, typically maintenance protocols call for replacement of three or more avionics boxes before the wiring itself is ever considered to be the culprit. Only after these expensive, time consuming, and ineffective repairs will the wiring be troubleshot. Methods that can locate faults while the aircraft is in flight are now emerging, and promise to significantly reduce the NFF problem. Being able to locate the fault while the aircraft is in flight means that the information can be given to the maintainer when the aircraft returns to the ground, enabling quick and accurate repair. S/SSTDR, MCR, and NDR can all be used while the aircraft is in flight. Of these, S/SSTDR are the furthest along in their development path. Circuit board versions of these systems are currently available for handheld, on ground maintenance equipment, and are currently undergoing the pre-flight testing required for use on live aircraft in flight.

The SSTDR technology that is the basis of the LiveWire system has been demonstrated to locate open and short circuits and intermittent faults such as wet and dry arcs with an accuracy of +/-1.5 foot on wires over 100 feet long. The entire test can be done in about 1ms, well below the approximately 5ms that wet arcs last. This can be done without interfering with existing signals on the aircraft, and without interference from the existing signals and electromagnetic interference these aircraft present to the test system. The specific parameters for each system can be adjusted by changing the length, frequency, and integration time of the PN code.