Functionality Test of Carrier Signal Data Error for Detecting Aircraft Electrical Wire Intermittent Faults[1]

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Abstract

The long operational lifespan of aircraft contributes to intermittent faults from age degradation. These intermittent faults are the main causes of the unacceptable level of "No Fault Found" (NFF) rate in "shop" tests, worse, of the cabin fire, or, worst, of the explosion of fuel tanks. The capability of real-time detection of intermittent faults, not mere post-diagnosis, is critical for aging aircraft electrical systems. A novel approach which utilizes carrier signal over electric wire and its data transmission is applied to detect errors caused by intermittent faults. This paper reports the results of functionality tests conducted on a laboratory electrical system constructed from aged aircraft wires. The tests are performed with staged intermittent faults produced by rubbing of knife switch blades or by generating arcs in a motorized grooved cylinder drum of copper strips with hanging wires. Fault staging mechanisms and test methods are devised to investigate the functionality of the carrier signal approach under two types of configuration: a single-transmitter and single-receiver (STSR) and multi-transmitter and single-receiver (MTSR) configurations. The tests prove that the PLC approach of date error monitoring is effective in all the staging mechanisms and configurations.

1. Introduction

Intermittent faults of aircraft Electrical Wiring Interconnection System (EWIS) cause many problems including electrical fires or, even worse, fuel tank explosions ignited by arc and sparks generated from the faults. The intermittent faults are the most frustrating, elusive, and expensive faults to detect and locate. Intermittent fault causes are various and numerous. A wire rubbing against a neighboring wire creates a small arc. An over-tightened clamp rubs through the insulation and short the wire into a fault. In addition, a pin can be backed out of the connector, a wire can be broken at the back side of the connector, corrosion can create intermittent non-contact with the pins, or radial cracks on wires and water seepage can create intermittent faults [1]. The long operational lifespan of aircraft make them the prime examples of these intermittent faults in the EWIS due to aging degradation. With a long standing NFF rate in the testing of aging avionics systems, the ability to effectively detect intermittent faults is critical. Since the intermittent faults occur for a short period of time, it is important to locate the intermittent fault when it is active.

With the cause of the root of the intermittent problem still overlooked by the fuzzy or misinformed descriptions and fragmented solutions, the ability to effectively detect intermittent faults is more critical ever. The current method of preventive maintenance of electrical wire system in aircraft involves grounding and observation, which causes loss of flight time of aircraft and thus loss of revenue. Moreover, testing electrical wires in hard-to-see/reach location is tough and challenging. One method of solving the electrical wire fault and fire problem is to develop inflammation-resistance insulation material

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for electrical wire system. However, any electrical wire in service is aging toward failure. In addition, the fact that large transport category aircraft now flying contain hundreds of miles of wiring only further demonstrates the need for a continuous monitoring for detecting intermittent faults that does not result in costly aircraft down-time [2].

Much research has been done on the subject of wiring fault detection. Some of the more publicized techniques are: time or frequency domain reflectometry, standing wave reflectometry, impedance spectroscopy, high voltage inert gas, resistance measurements, and capacitance measurements. However at the present time, these test methods cannot distinguish intermittent faults without the use of high-voltage pulse injection into the wire, which would damage the wire under diagnosis. A recent technique using spread spectrum time domain reflectometry has had some success in detecting faults on controlled impedance coax carrying high-speed digital data [3], but not without the fundamental problems of multiple reflections from all junctions in the wiring system, which would leave the result to the rooms of inaccuracy in interpretation. Further, the method may be effective only when some suspicion is raised and used in diagnostics, but may not be for detecting unexpected, unanticipated events of intermittent faults, or prognosis of the wire system.

Previously, the author developed a novel approach of continuously monitoring EWIS and detecting incipient faults by utilizing carrier signal data stream by the disruptive effect of intermittent faults in electrical wires [4]. The present research now is focused on the functionality of the PLC system under staged intermittent fault conditions. The functionally tests are performed in single transmitter single receiver (STSR) and multiple transmitter single receiver (MTSR) configurations with simulated intermittent fault conditions staged on a wire of exterior complex harness specimen taken from the wheel well of 747 aircraft by rubbing the contact blades of knife switches or by generating arc on a motorized grooved copper strip with hanging wires.

In this paper we investigate the use of PLC in a DC and AC system to detect intermittent faults by monitoring at a receiving station the error rates of the messages sent over electrical wire when intermittent faults were staged and compare them with a baseline, no fault case. The scheme devised in the paper for intermittent fault detection is to use the communication reliability, or message error, of the carrier signal system as an indicator of the transmission medium, which is electrical wire: clean or noisy. This paper details the functionality tests activities and achievement of using carrier signal to detect intermittent faults in an electrical wire to further develop it into aging systems. The results, with data error rate as the main discriminator between no-fault and intermittent fault conditions, demonstrate the effectiveness of the carrier signal system in detecting intermittent faults in electrical wires once under in aircraft. The results of two separate configurations show remarkable consistency in the data error rate.

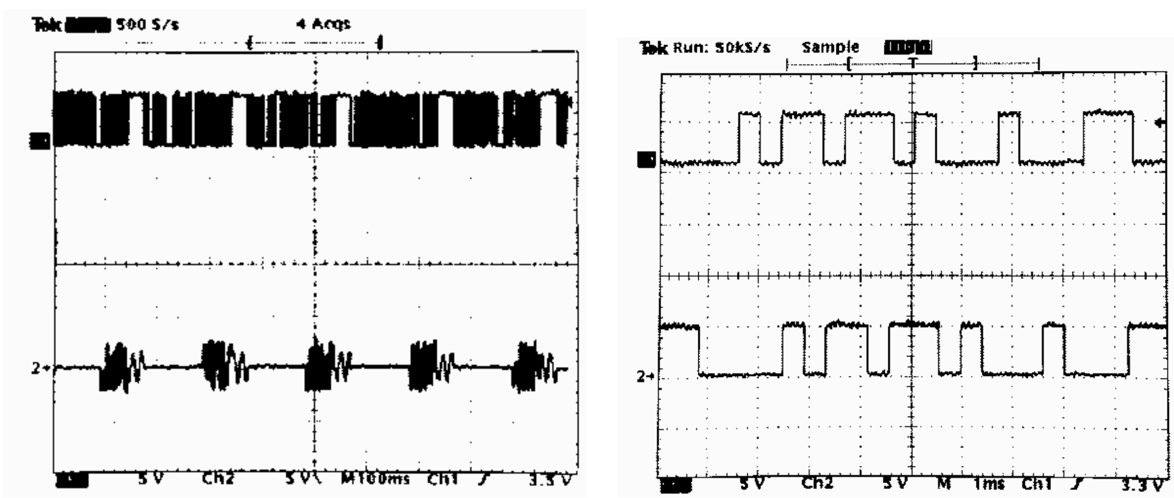
2. Carrier Signal Technology

Carrier signal technology is a method of transmitting data through existing electrical cables alongside electrical current. The carrier signal technology now stands even as an enabling technology for high-rate home networking due to the ability to transmit data over the existing power lines for homes and offices [5]. Even though most of the recent research being done using carrier signal technology involves the use of carrier signal in broadband networking, called BPL (Broadband over Power Lines), there are more traditional applications of using narrowband carrier signal in remote monitoring along with some limited applications in the development of a smart motor that combines both the power and control lines into a single wire [6]. However, the carrier signal system got caught some researchers as a detection tool for power line faults. Taylor and Faulkner proposed direct-sequence spread-spectrum modulation on power line carrier for this application, and outlined optimal signal processing techniques and frequency domain correlation techniques for the on-line test in high voltage line [7]. Lately, the use of spread spectrum was reported from the research result of on detecting avionic wire problem [3].

A carrier signal system can be implemented using an off-the-shelf modem chip which transmits data over the power line and a microprocessor which controls the data stream. The in-house carrier signal system developed for the tests consists of a ST7537HS1, a half duplex, asynchronous 2400bps FSK modem, and a microcontroller. Additional circuits needed are external line driver and transformer to interface the carrier signal system with DC or AC power line. Any digital data stream generated from the microprocessor is modulated by the modem into few KHz sinusoid signals of slightly different frequencies to indicate 1 or 0 of binary value. Two stations are set up: a transmitting station that transmits message over the wires and a receiving station that receives the message and compare it with the expected data. The structure of the transmitter and the receiver share the same configuration of a carrier signal modem and a microprocessor along with other interface circuitry. The only difference is the code residing in the microprocessor as either transmitter or receiver [8].

As shown in Figure 1(a), the digital data stream (upper trace) is converted to the carrier signal of sinusoids (lower trace), and this carrier signal, once amplified, passes through the filtering circuit into the power line. In other words, in the power line, in addition to the usual power signal of DC, 60Hz, or 400Hz power, this modulated signal of a few 100 KHz co-exists.

At the receiver side, the modulated signals are demodulated and decoded according to the frequency differences of 1 or 0 binary values at the modem, and the byte date stream is reconditioned at the microprocessor for monitoring and comparing purpose. In other words, if the received data stream matches with the transmitted data stream, we would say the communication medium, the power line, is quiescent and not disrupted. In such quiescent duration, we expect to have the following digital data stream shown in Figure 1(b), where the upper trace is transmitted one and the lower one, received one. The time shift between two data streams is also clearly seen in the figure.



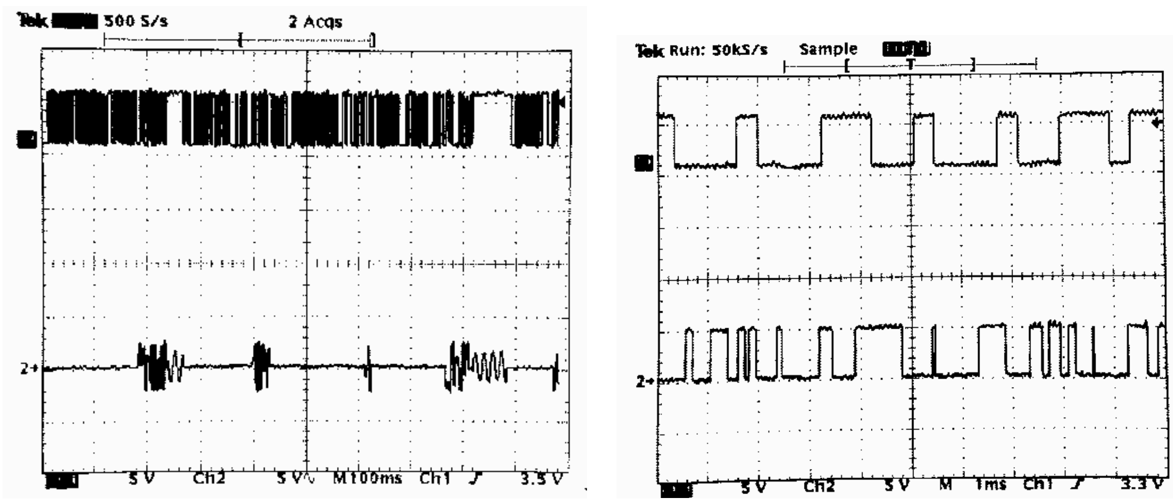
(a) (b)

Figure 1. (a) Transmitted Digital Data Stream (Upper Trace) and Corresponding Carrier Signals (Lower Trace), and (b) Transmitted and Received Digital Data Streams in the Quiescent States in Power Line.

When the carrier signal communication channel, the power line, is disrupted by intermittent fault or incipient fault, the signal over the power line would also be interrupted. Figure 2(a) shows the disrupted carrier signal by the intermitted fault condition staged in the experiment. The carrier signal doe not follow the expected transmitted digital stream, but much changed sinusoids.

In cases shown in Figure 2(a) of the intermittent electrical fault in the power line, the received data stream would be different from the transmitted data stream whether the error is in the bit pattern, byte patter, or missed byte, or missed whole data stream. Figure 2(b) shows the disrupted and thus erred received digital data in the receiver side of the PLC system. The received data in lower trace is starkly different from the transmitted byte stream of the upper trace.

As illustrated, the main idea behind the carrier signal technologyscheme is by analyzing the erred received data stream, to actively detect abnormalities in the power line on-line real-time and to detect intermittent fault in electrical wire system.



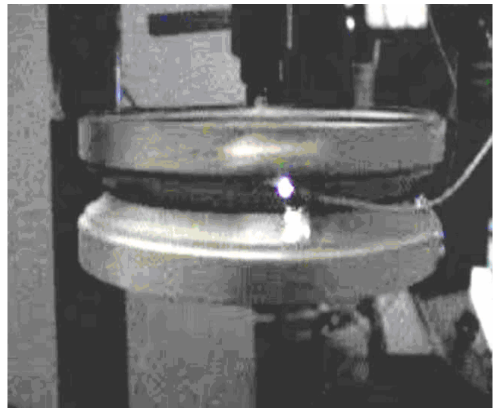
(a) (b)

Figure 2. (a) Disrupted Carrier Signal Example (lower trace) and (b) Disrupted and Erred Received Data (lower trace) from the Transmitted Data (upper trace) Caused by Intermittent Fault.

Detecting and measuring the disruptions in the message sent over the wire, three types of data errors are considered caused by the intermittent fault conditions: the message error rate (MER), lost message rate (LMR), and total error rate (TER). MER is defined as the percentage of the number of messages arrived with error per total number of received messages. Apart from observed errors which result from distortion in the message as displayed by the receiver, some messages are completely lost in transit and can not be seen by the receiver. This observation leads to consider LMR, which is defined as the percentage of messages that are lost in transit per total number of sent messages. To accommodate and consider the intrinsic errors by the carrier signal, TER is defined as the percentage of errors plus lost messages out of the total number of sent messages.

3. Experiments for Carrier Signal Functionality in Intermittent Fault Detection

The main purpose of the functionality test is to evaluate the carrier signal capability of discriminating fault conditions against normal conditions in the electrical wire. The principle of the test is to send a message of prescribed data protocol over electrical wire from the transmitting station and to compare the message received at the receiving station for possible distortion or complete loss of message. As mentioned before, a carrier signal system can be used as either transmitter or receiver by the program resided in the main processor of the system. Following the in-house protocol, the received message is checked for correctness in comparison with the transmitted data. The experiment are carried out on a wire from the bundle of exterior complex harness wiring specimen taken from the wheel well of 747 aircraft. Staging of the intermittent faults are done by rubbing the contact blades of a few knife switches and/or by generating arcs/sparks using a motorized copper strip drum with hanging wire. Figure 3(a) and (b) show an example of the intermittent fault generated by each of the staging methods.



(a) (b)

Figure 3. Intermittent faults staging by (a) knife switch blade rubbing and (b) motorized grooved copper strip drum with hanging wire.

Two separate carrier signal configurations are set up for the testing, namely the single transmitter with single receiver (STSR) and multiple transmitters with single receiver (MTSR). The intermittent fault is staged at the point indicated in the figure by the rubbing action of the knife switch or the motorized copper strip drum with hanging wire. For each test run, a number of message transmissions with a pause time between transmissions are sent from a transmitter. The results are used to calculate the error rate under normal and intermittent fault conditions. The STSR configuration has only one point of staging intermittent fault as shown in Figure 4. In the STSR configuration, the message from the transmitter is injected into the system at point T1 and receives at the receiving station at point R1. The test results from this setup show a direct relationship between the staged intermittent faults and the number of errors observed in all three categories.

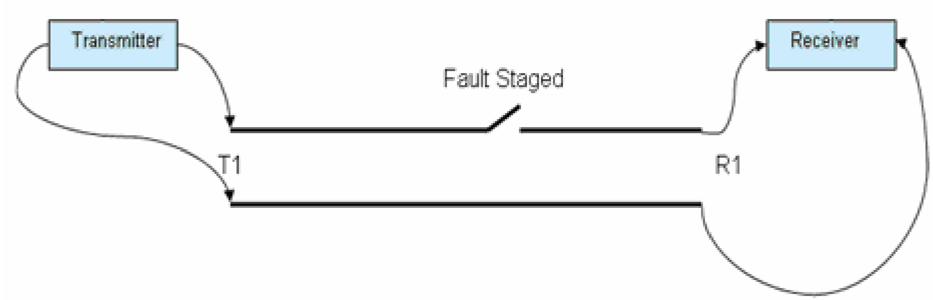


Figure 4. STSR configuration for carrier signal-based intermittent detection.

The MTSR configuration, as illustrated in Figure 5, is for general multi-transmitter and single receiver scheme as the most plausible application of the carrier signal technology approach in aircraft or ship. In this particular experiment case, two distinct cases of intermittent fault locations for the analysis of the carrier signal system are tested, with W1 always in a closed position, and SW2 and SW3 interchangeably in the condition of intermittent fault or normal condition. Similar to the observations made in the STSR configuration, higher error rates in all three categories are observed in this configuration.

In conclusion, the functionally tests of the carrier signal system under STSR and MTSR configurations demonstrate the promise of the approach in detecting intermittent fault in electrical wires. The results on two separate configurations of the system show remarkable consistency in the error rates. In both STSR and MTSR configuration, a certain pause time between successive message transmissions is important in the successful application of the carrier signal technology.

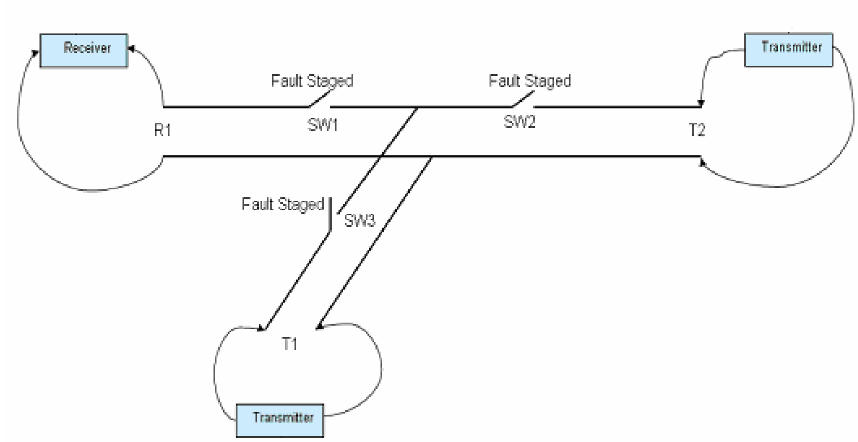


Figure 5. MTSR configuration for carrier signal-based detection.

4. Conclusions

The functionally tests of the carrier signal system under STSR and MTSR configurations demonstrated the effectiveness in detecting intermittent fault of serial and parallel kinds in electrical wires. The results on two configurations showed remarkable consistency in the observed error rates. Experimental observations proved that the pause time between successive message transmissions, which we devised in the functionality tests, that it could greatly affect the successful application of the carrier signal data error scheme for intermittent fault detection.

5. References

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