



Detection and Location of Intermittent Faults by Monitoring Carrier Signal Channel Behavior of Electrical Interconnection System

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Charles Kim, Ph.D.

Department of Electrical and Computer Engineering

Howard University

Washington, DC

ckim@howard.edu

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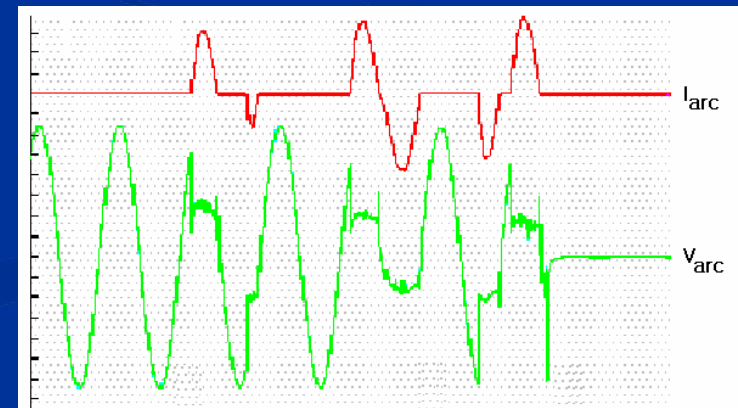
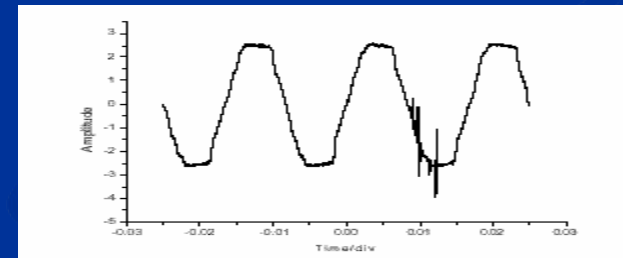




Intermittent Faults

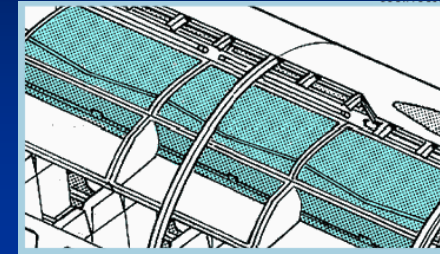
■ Intermittent Faults

- Due to long process and aging of wire degradation
- Manifest intermittently in an unpredictable manner
- Cause fires and possibly explosion by arc and spark
- Multiple causes and reasons
- Random Occurrence
- No persistent arcing
- Very short duration
- No reproduction
- Precursor of faults



Intermittent Electrical Faults

- Fire
- Mission abortion
- Loss of Life
 - Swiss Air 111
 - Fires and possibly explosion by arc and spark
- Quick start and fast spread into big

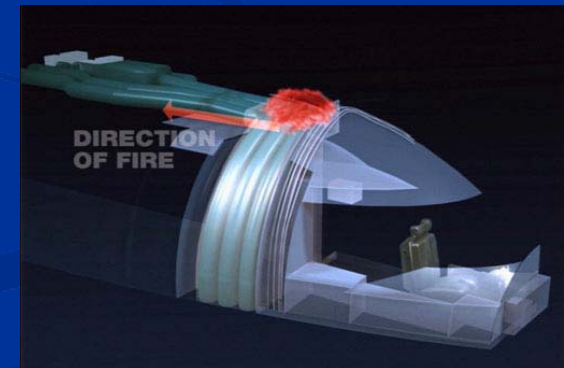


TWA Flight 800 | July 17, 1996

focused on the flammability of the 747's fuel tank, including its potential ignition sources, design, and certification standards, and on the maintenance and aging of the aircraft's other systems, particularly wiring and fittings that could spark or overheat. Within two years of the crash, new fuel-management procedures were required for all 747s.

Swissair Flight 111 | September 2, 1998

After a four-and-a-half-year investigation, which revealed evidence of an in-flight fire above the cockpit caused by faulty wiring and fueled by flammable airframe insulation, Canada's Transportation Safety Board published its final recommendations.



Intermittent Electrical Faults



■ USS Parche (683) – Arc Damage

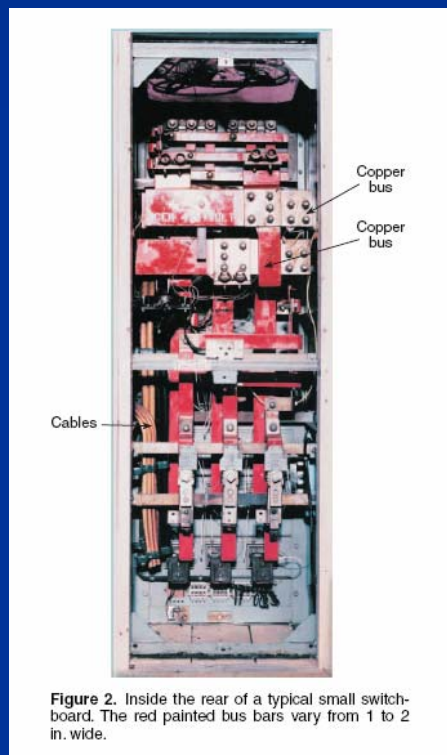


Figure 1. Arcing damage sustained on USS *Parche* (SSN 683). Note that some of the copper bus, cables, insulators, and switchboard structure are missing.

Evolution of Arc Fault Protection Technology at APL

H. Bruce Land III, Christopher L. Eddins, and John M. Klimek



NFF (“No Fault Found”)

■ Chronic Problem of Intermittent Faults: NFF

- Problem reported by crew is not reproduced.
- Average NFF figure for avionics is approx. 30%.
- Off-Line Testing Problem with Random, Intermittent Nature of the Electrical Faults

Saturday
Dec 18, 2004

Aviation Today

No-fault-found findings are turning up at the extraordinarily high rate of 50 to 60 percent at commercial airlines and military repair depots. Much of this is attributable to the failure of ramp and bench tests to detect age-related problems found in avionics boxes and other aircraft components, not to mention old wiring.

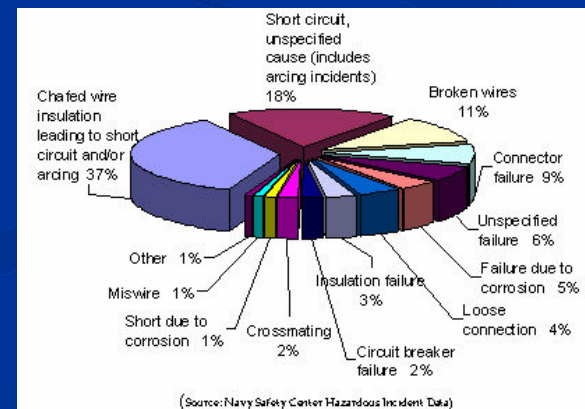


Figure 10. Typical wire system failure modes for aircraft (1980-1999).



Current Status of Fault Detection

■ Detection of Intermittent Faults

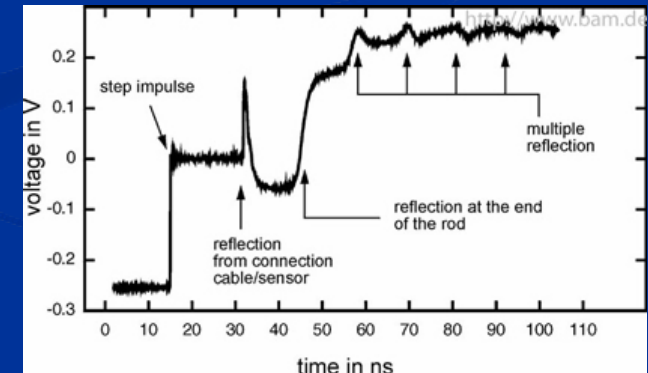
- Most frustrating, elusive, and expensive to locate
- Have to locate it when it is active – it occurs for a short period of time
- Detection Methods
 - Preventative maintenance
 - Grounding and observation
 - Loss of revenue
 - Loss of flight time
 - Current and Voltage Sensing for Arc/Spark Presence
 - Time/Frequency Domain Reflectometry
 - Spread Spectrum Time Domain Reflectometry



Wire Fault Detection/Location Approaches

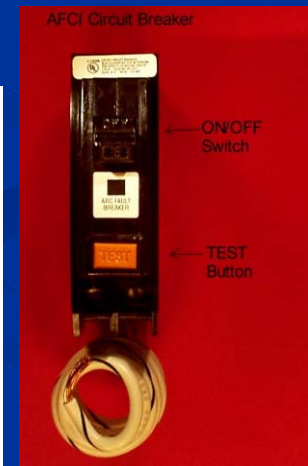
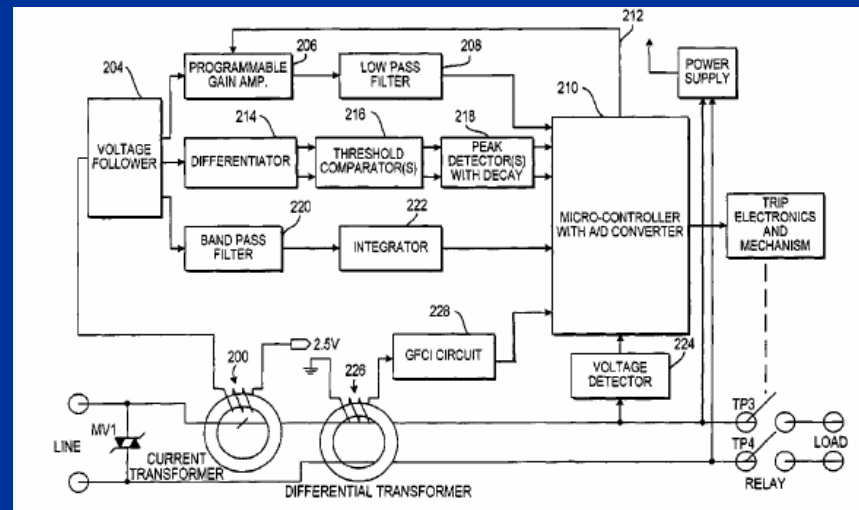
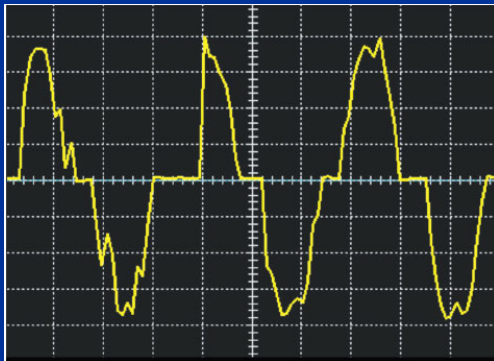
– on line and continuous monitoring

- AFCI
 - Arcing fault detection and trip
 - Arc Voltage and Current Behavior
- Live Wire - Spread Spectrum TDR
 - Time Domain Reflectometry (TDR)
 - Transmission of pulsed signal and reception of reflected signal from mismatch
 - Single-Ended
 - TDR
 - Spread spectrum TDR
 - Sequence TDR
- Spot Arcing/Spark Radiation



AFCI

- Purpose: Arcing Fault Clearing
- Approach: Characteristics Arc Voltage and Arc Current
- Basic Theory: Harmonics and Current Shape (shoulder)
- Usage: Installation in Circuit System
- Commercially Available



Live Wire Technology

- Purpose: Wire Fault Location
- Approach:
 - Reflection of wave from Impedance Mismatch (against cable characteristic impedance)
- Basic Theory:
 - Spread Spectrum TDR & Sequence TDR
 - Injection of pulse of 30-100MHz into wire
 - Correlation of the injected signal and reflected signal
- Usage:
 - 400Hz AC Line and High Speed Digital Data Line for momentary open, short, arc circuits
- *University of Utah and Live Wire Test Labs*
- Possible Problems:
 - Loss over the wire
 - Different wave speed over different wire types connected
 - Multiple reflection
 - Location Limitation





New Approach

■ Paradox in the current approach

- Problems
 - Random
 - Incipient
 - Unpredictable and “intermittent”
- Test Method
 - Static
 - Under assumption of “permanent fault,” not “intermittent fault”

■ New Approach

- Continuous, online monitoring would increase detection
- Put the “intermittent” on the horizon of watch
- Novel approach to monitoring electrical wire health (lower voltage)
- Using Carrier Signal Technology
 - Electric Wire is the communication medium (“channel”)
 - Carrier Signal message (error rate) transmission/reception as a status of the channel: quiet or noisy



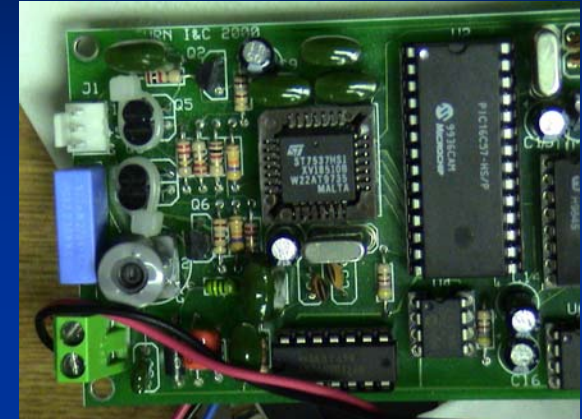
Carrier Signal Technology

- Purpose: Wire Intermittent Fault Detection and Wire Health Monitoring
- Approach:
 - Communication Channel
 - Data error cause by Channel Disruption from wire problems
- Basic Theory: Data over Carrier Signal Disruption
- Usage: AC/DC line for any event which disrupts the carrier signal
- Possible Problems:
 - EM Conduction level and Reach of the Signal
 - Multi-path
 - Location of wire problem is given with zone of transmitter - receiver



Carrier Signal Controller

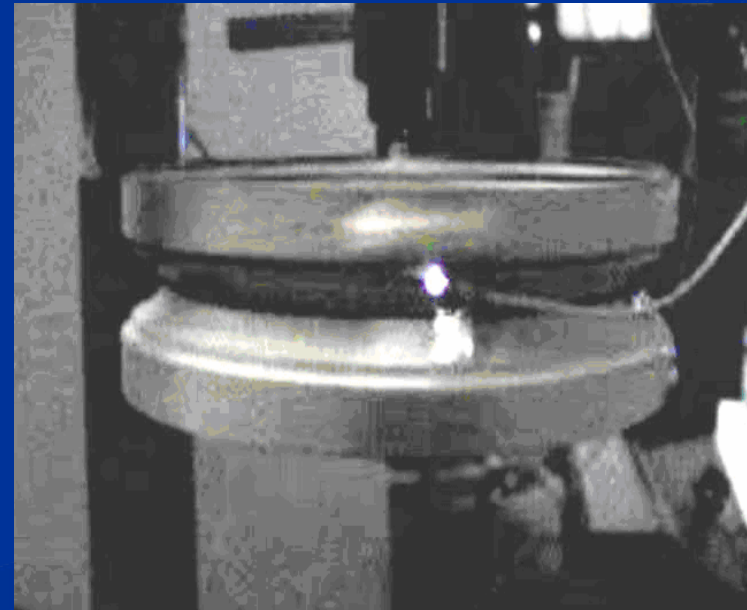
- protoboard
 - Carrier modem chip
 - ST7537HS1 from STMicroelectronics
 - Half duplex
 - Asynchronous 2400 bps FSK modem
 - Carrier frequency: 132.45 kHz
 - Band-pass filter: 126.45 kHz – 138.45 kHz
 - Microcontroller
 - Low-end PIC microcontroller from Microchip



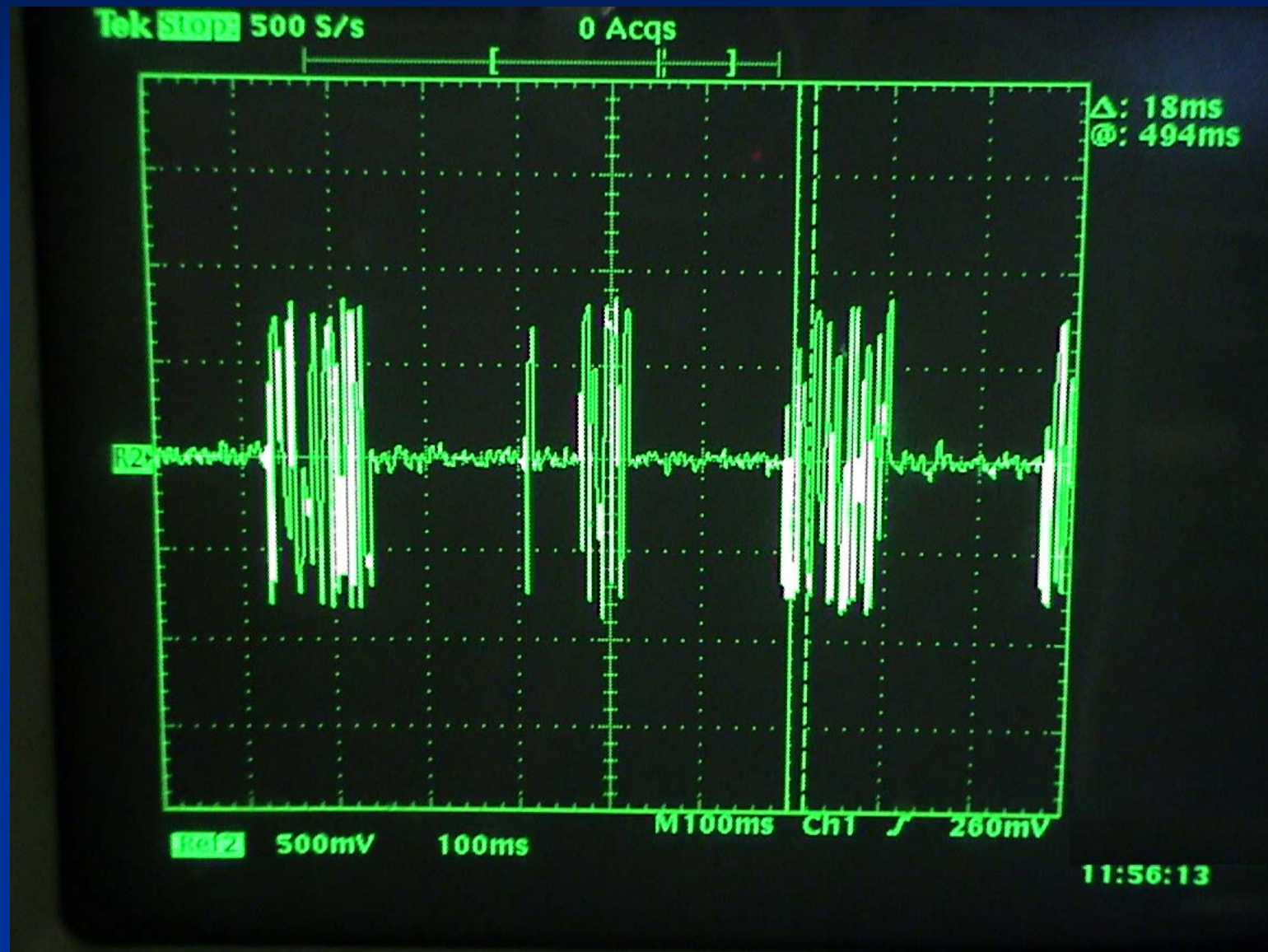


Intermittent Fault Simulation - Staging

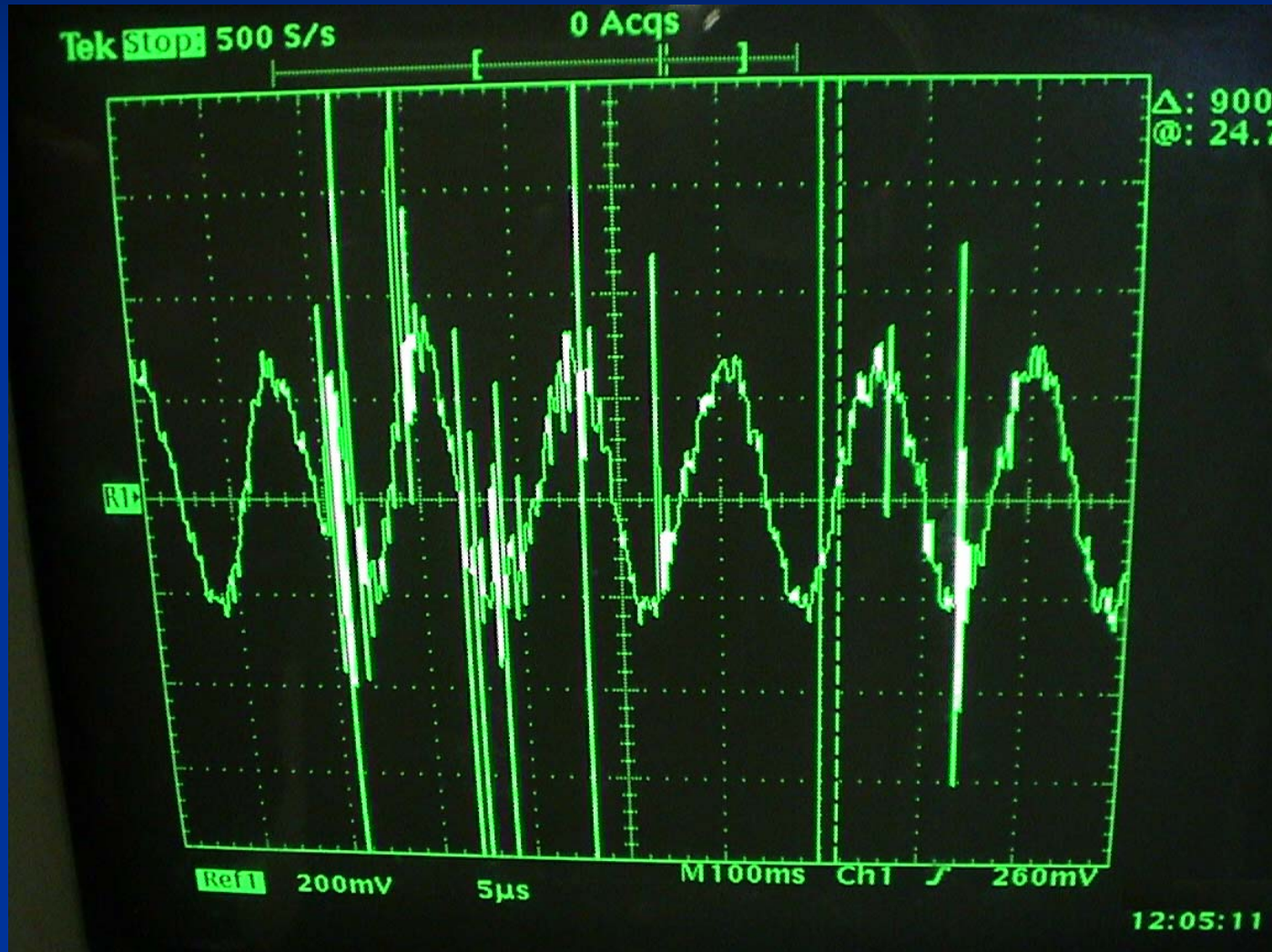
- Intermittent fault creation
 - Rubbing switch blades
 - Hanging wire over the copper strips on the motorized grooved cylinder



Carrier Signal over the wire



Distortion of Carrier Signal by Staged Faults

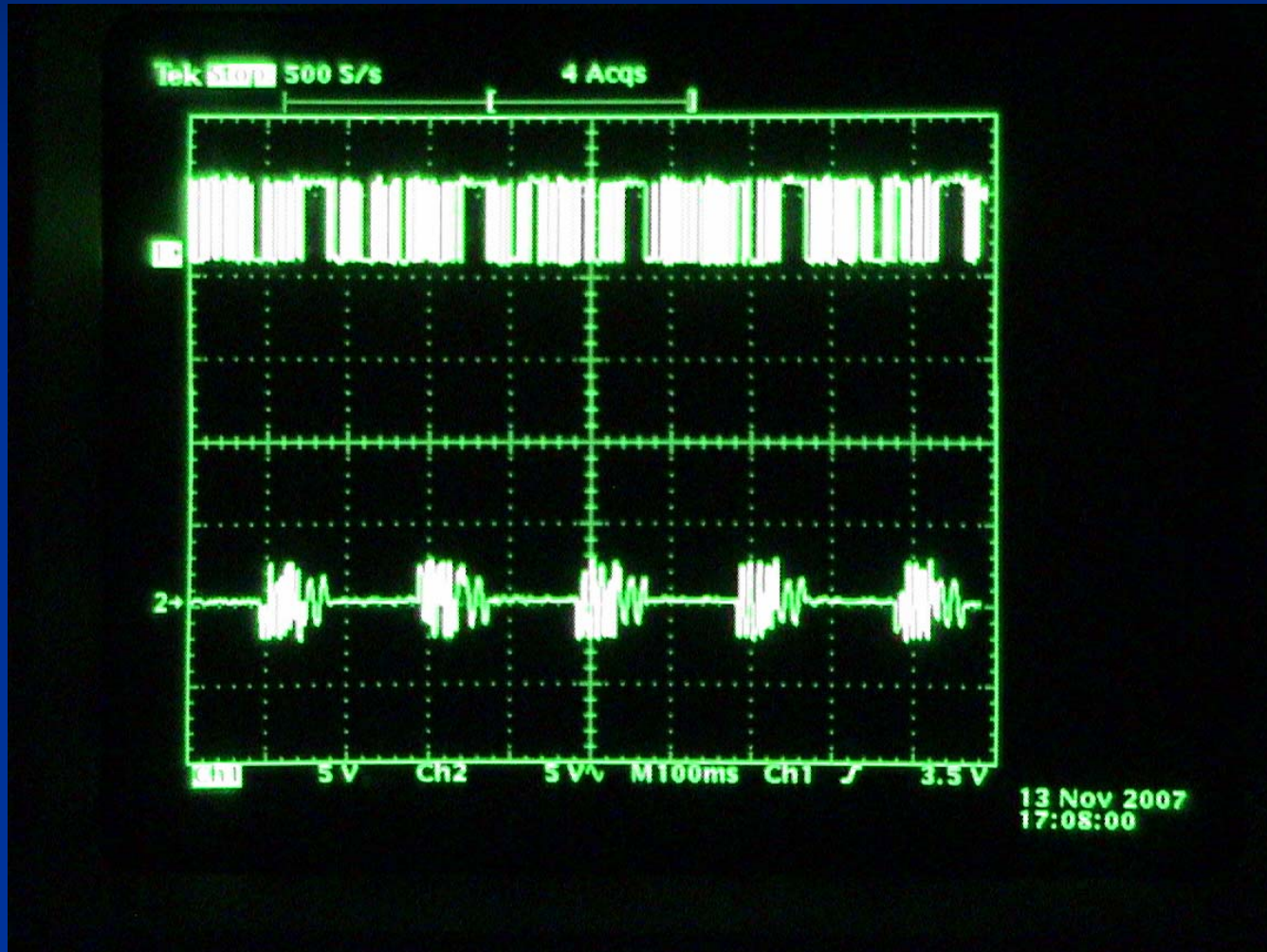




Receiver Side (normal)

Top: Digitized Message

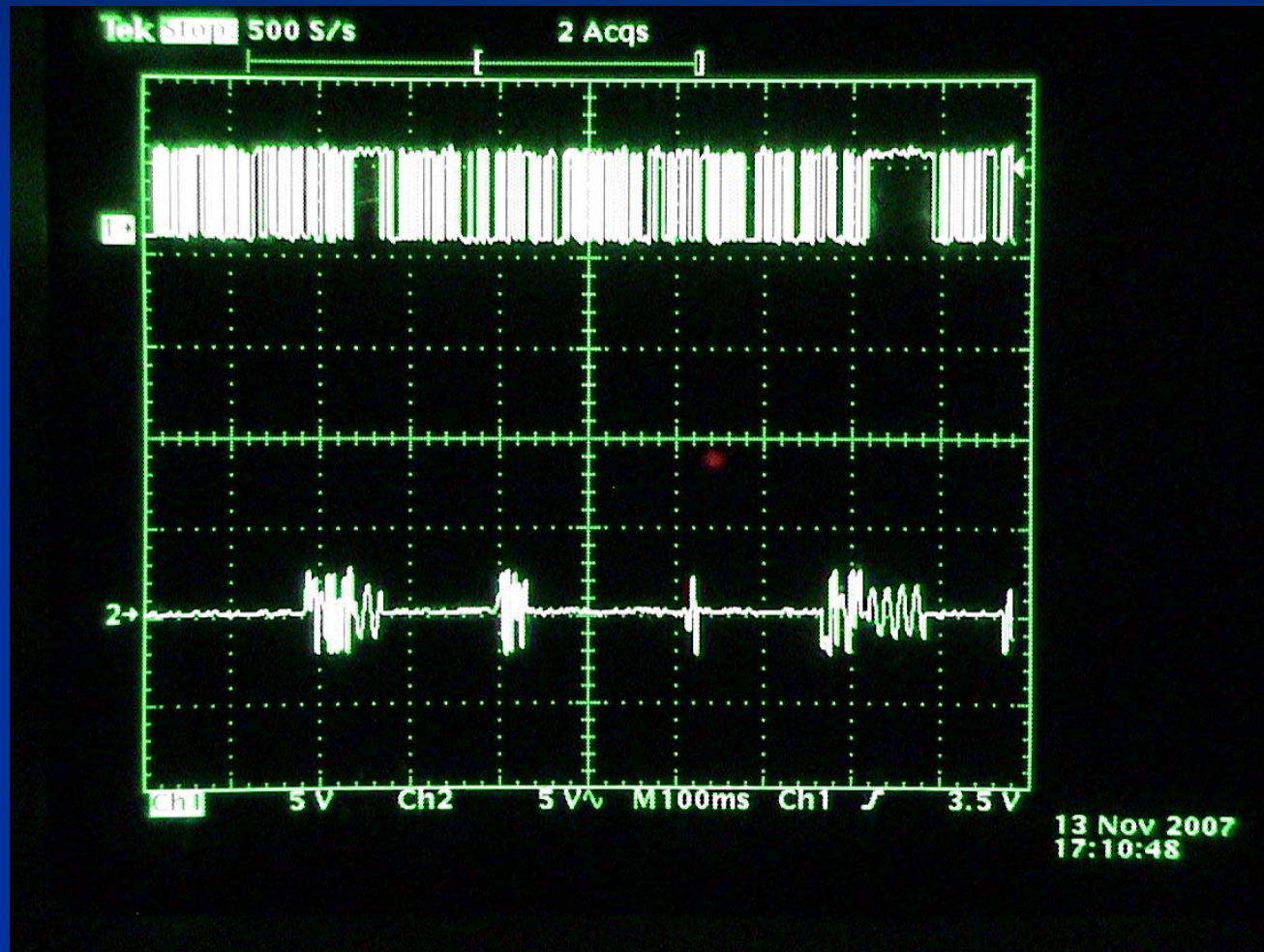
Bottom: Carrier Signal



Receiver Side (Fault in Channel)

Top: Digitized Message

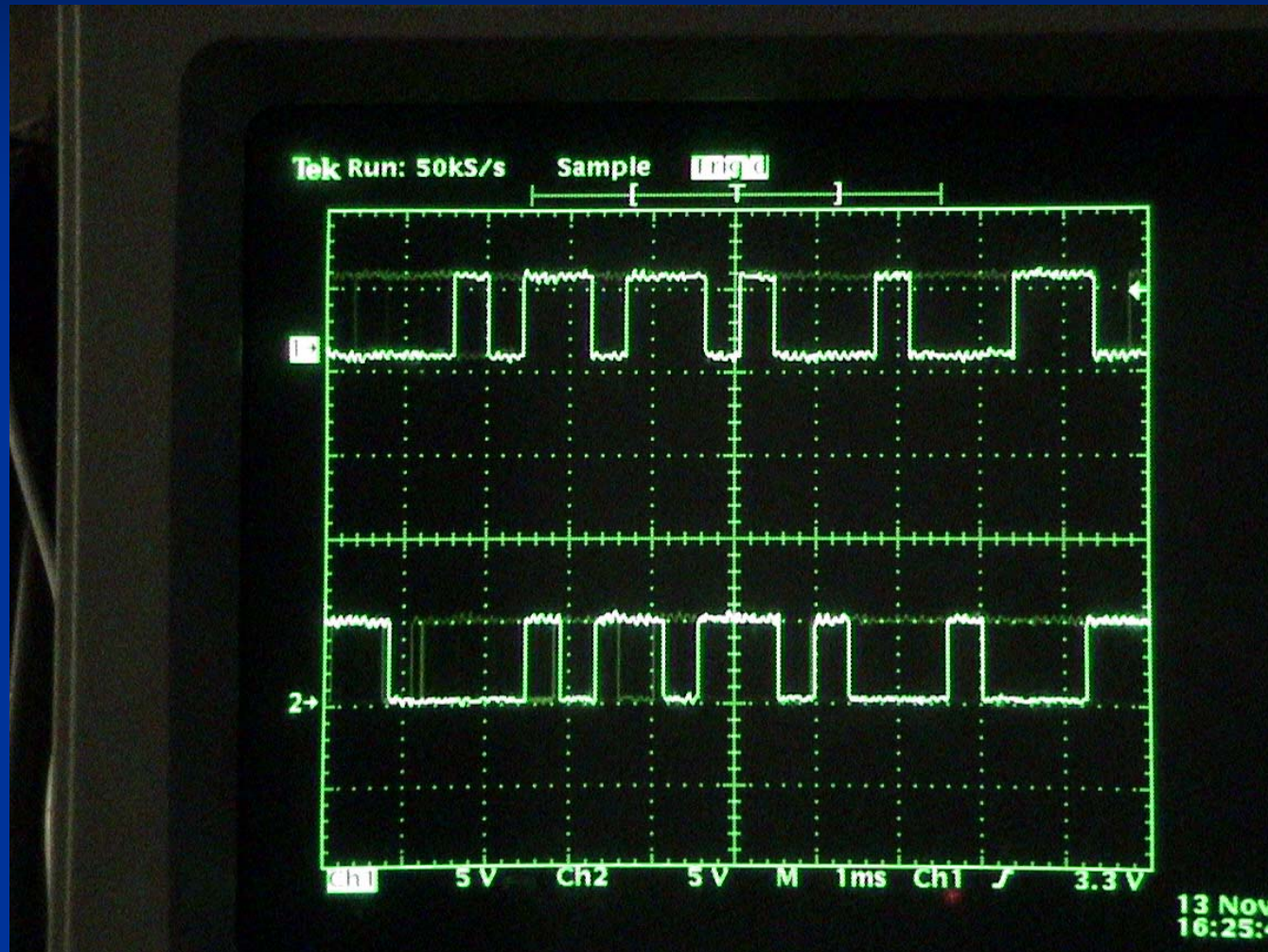
Bottom: Carrier Signal



Transmitter – Receiver (Normal)

Top: Transmitted message

Bottom: Received message

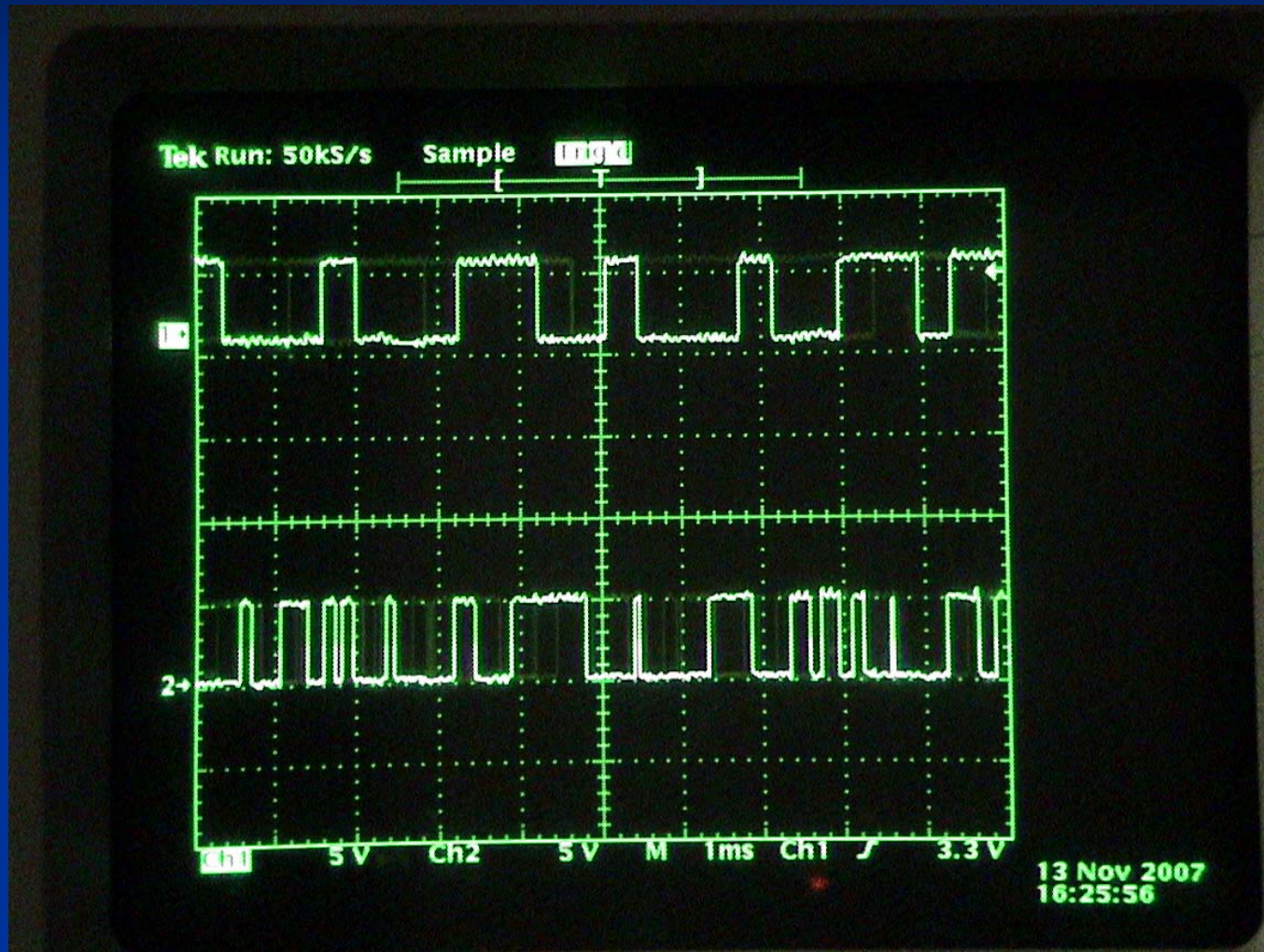




Transmitter – Receiver (Fault in Channel)

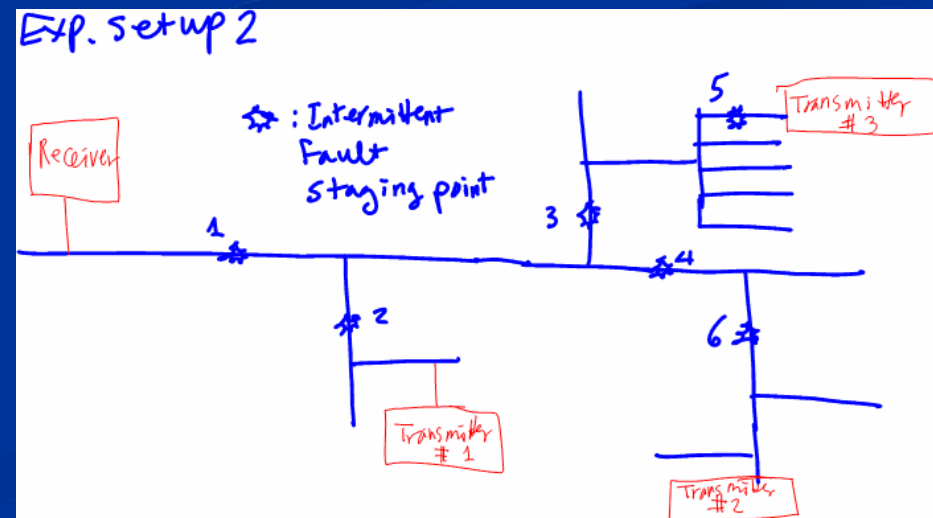
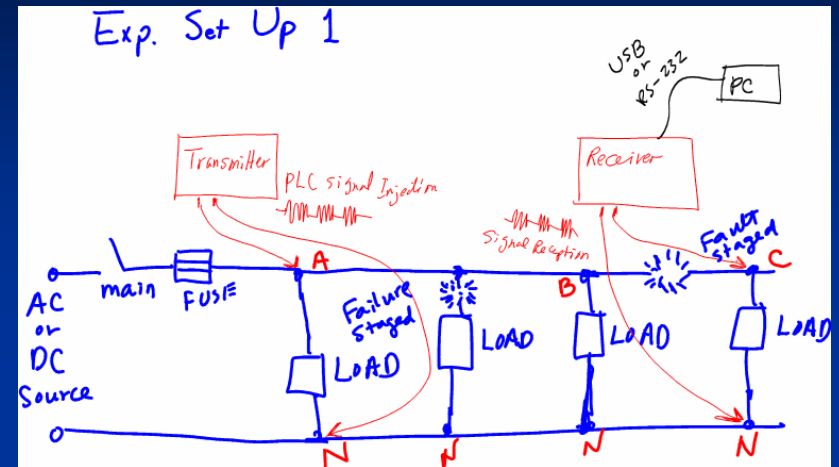
Top: Transmitted message

Bottom: Received message



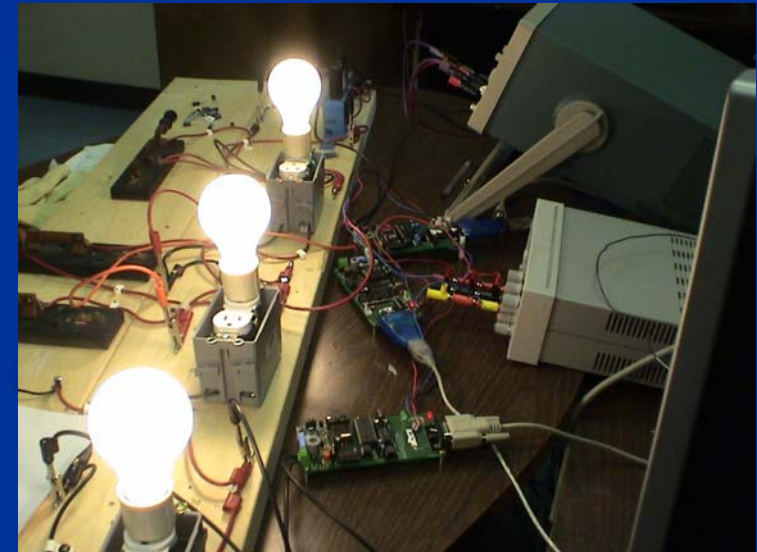
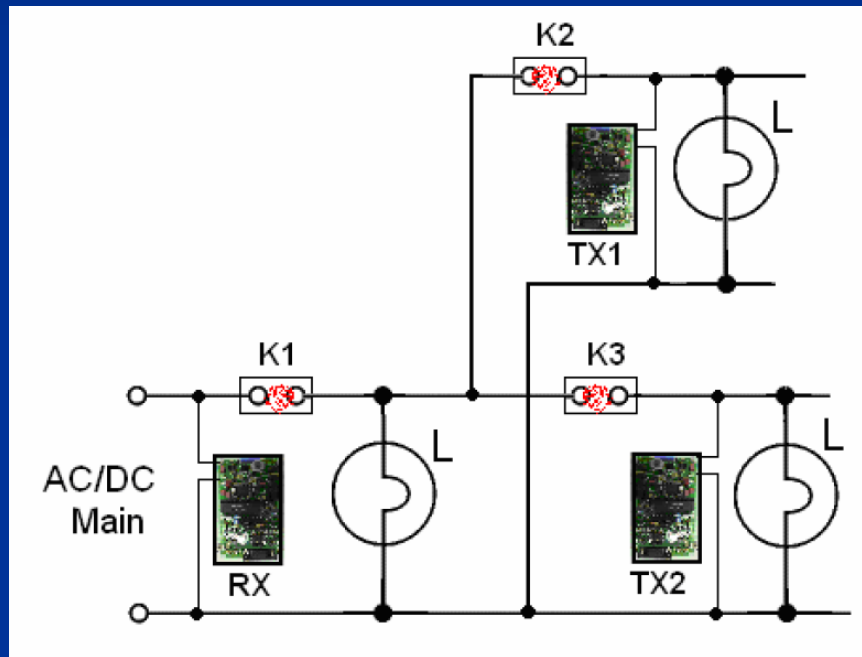
Carrier Messaging Setup

- **Single Transmitter Single Receiver Configuration**
 - 1 Transmitter
 - 1 Receiver
 - Transmitter Master Protocol
- **Multi-Transmitter Single Receiver Configuration**
 - 2 Transmitters
 - 1 Receiver
 - Transmitter-master Protocol with CD
 - Receiver-Master Protocol
- **Messages (In-house protocol)**
 - 11 bytes long
 - Preamble - 1 byte
 - Sync Bytes – 2 bytes
 - TX number – 1 byte
 - TX St. Address – 1 byte
 - RX St. Address – 1 byte
 - Data – n bytes



Fault Detection -- Single Transmitter Case

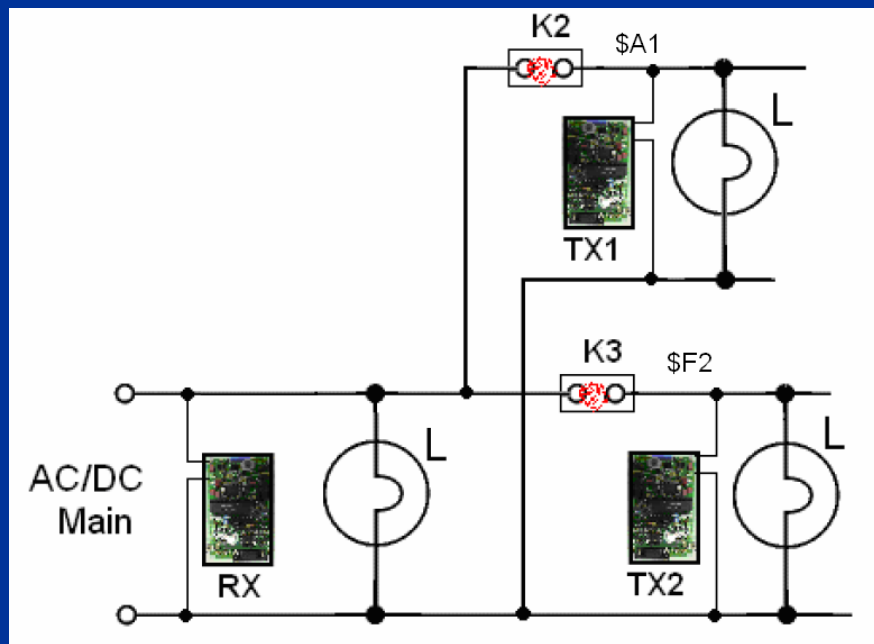
- Transmitter Master Protocol
- NER (Noise Error Rate): 1 or 2 bit error in an erred signal



Experiment Condition	NER
No intermittent fault (baseline)	0.34
Intermittent faults condition	9.18

Fault Detection – Multi-Transmitter Case

- Correct Data Rate
- Transmitter Master Protocol with Carrier-On Detection



Debug Terminal #1

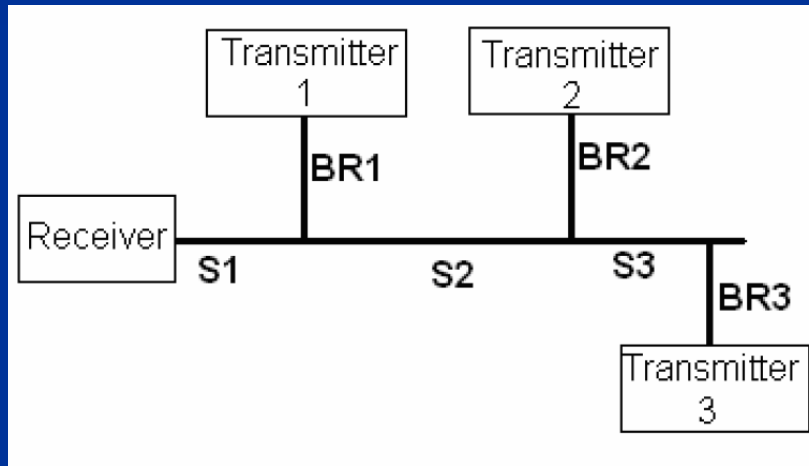
```

A1 091/096   F2 091/100
F2A1F2A1F2F2F2A1
A1 097/100   F2 093/098
F2A1F2F2F2F2A1A1F2
A1 097/100   F2 090/096
F2F2F2A1A1F2A1A1A1A1F2
A1 094/100   F2 087/092
F2F2A1A1F2F2A1F2F2F2A1
A1 096/100   F2 088/095
F2F2F2A1F2F2F2A1A1F2
A1 092/095   F2 093/100
A1F2F2A1A1A1A1A1A1F2A1A1A1A1A1F2A1F2F2A1F2F2F2F2F2
A1 086/099   F2 089/100
A1F2F2F2F2A1A1F2A1F2F2F2F2
A1 094/098   F2 091/100
F2A1F2
  
```

Macros... Pause Clear Close



Fault Location Method



Transmitter 1	Transmitter 2	Transmitter 3	Fault Location Section
0	0	0	No Fault
0	0	1	BR3 or S3
0	1	0	BR2
0	1	1	S2 or (BR2 and BR3)
1	0	0	BR1
1	0	1	BR1 and (BR3 or S3)
1	1	0	BR1 and BR2
1	1	1	S1 or (BR1 and BR2 and BR3)



Conclusions

- Problem in early detection of intermittent electrical faults/failures.
- Carrier Signal Technology for Continuous monitoring of random intermittent fault in wire.
- Experiments confirmed that generated noise affects the transmitted carrier signal
- Simple Location Method Suggested