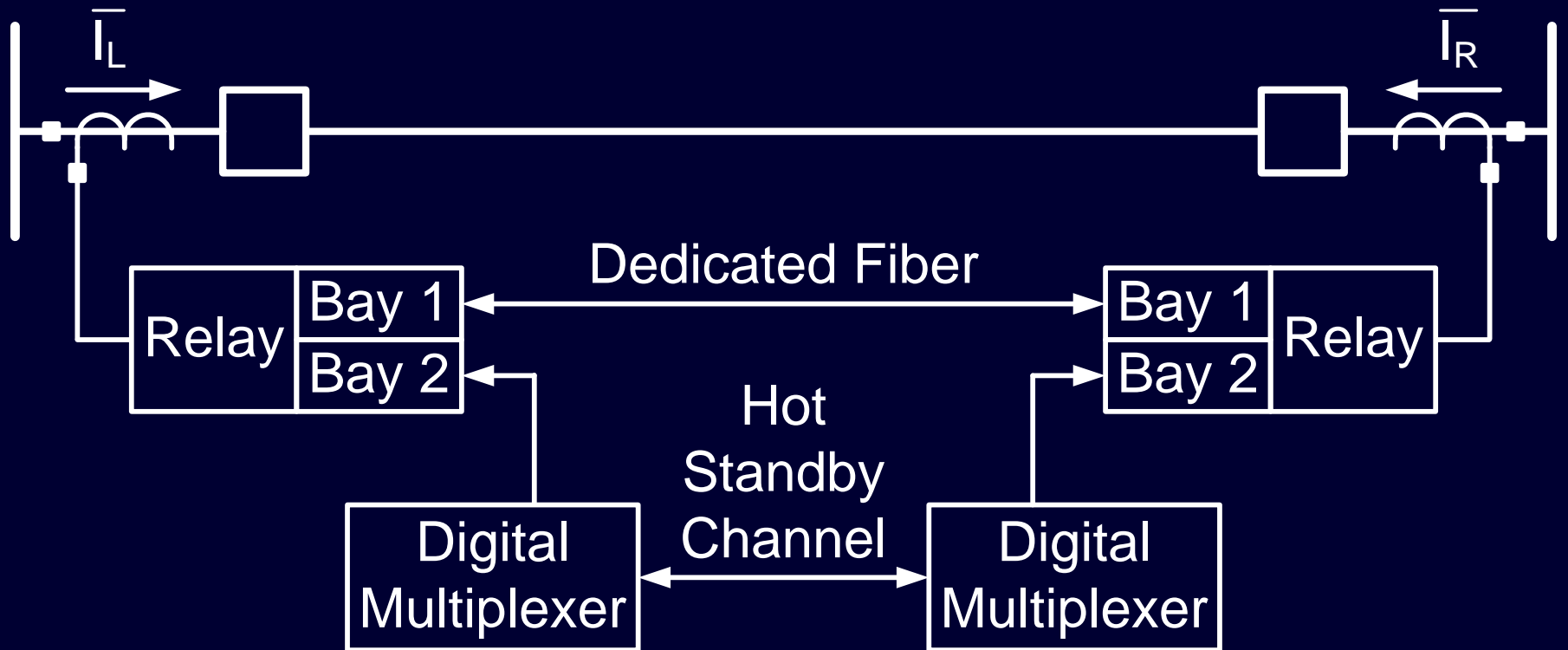


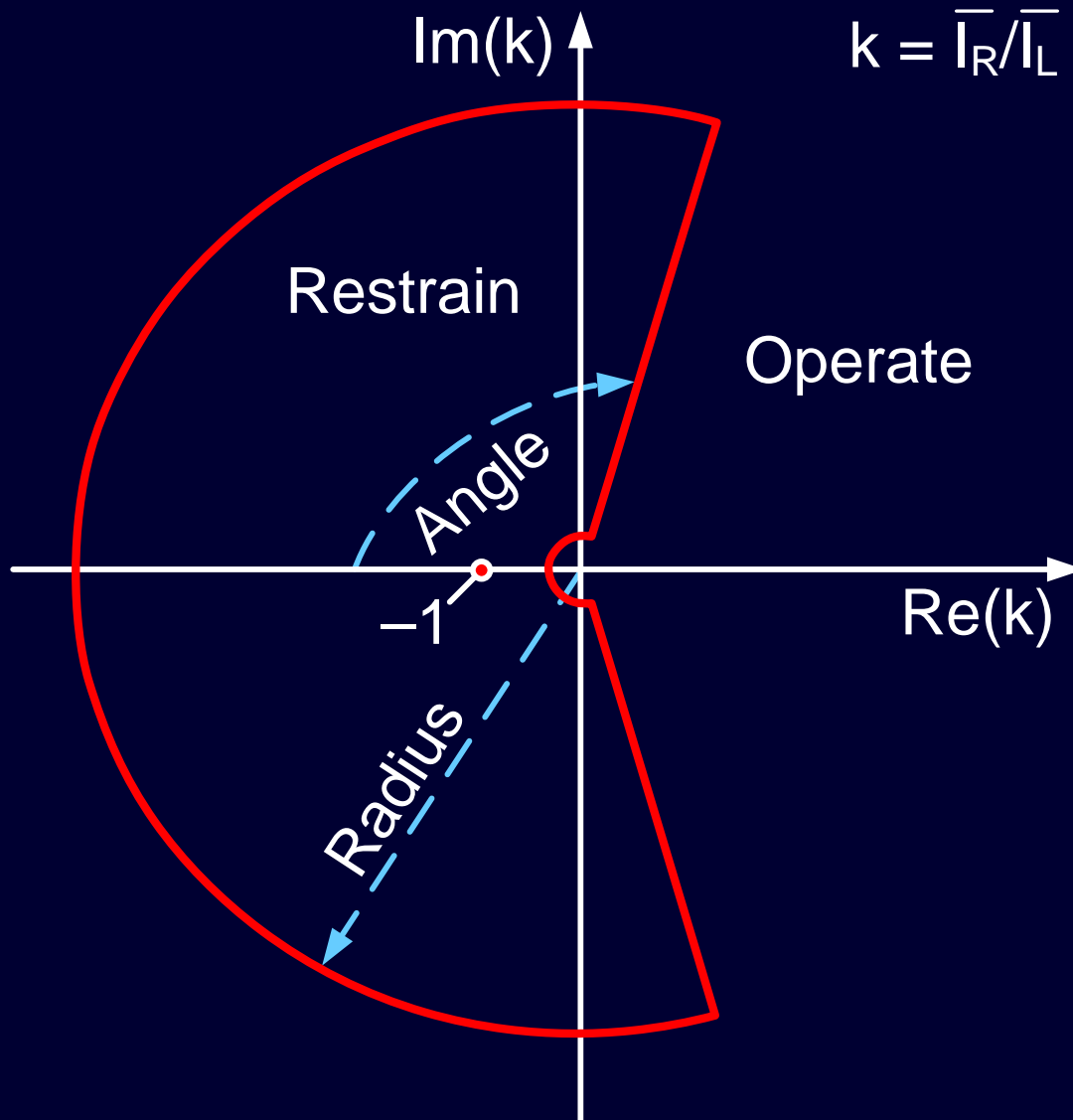
# A Practical Approach to Line Current Differential Testing

Karl Zimmerman and David Costello  
*Schweitzer Engineering Laboratories, Inc.*

# Two-Terminal Digital Line Current Differential Application



# Alpha Plane

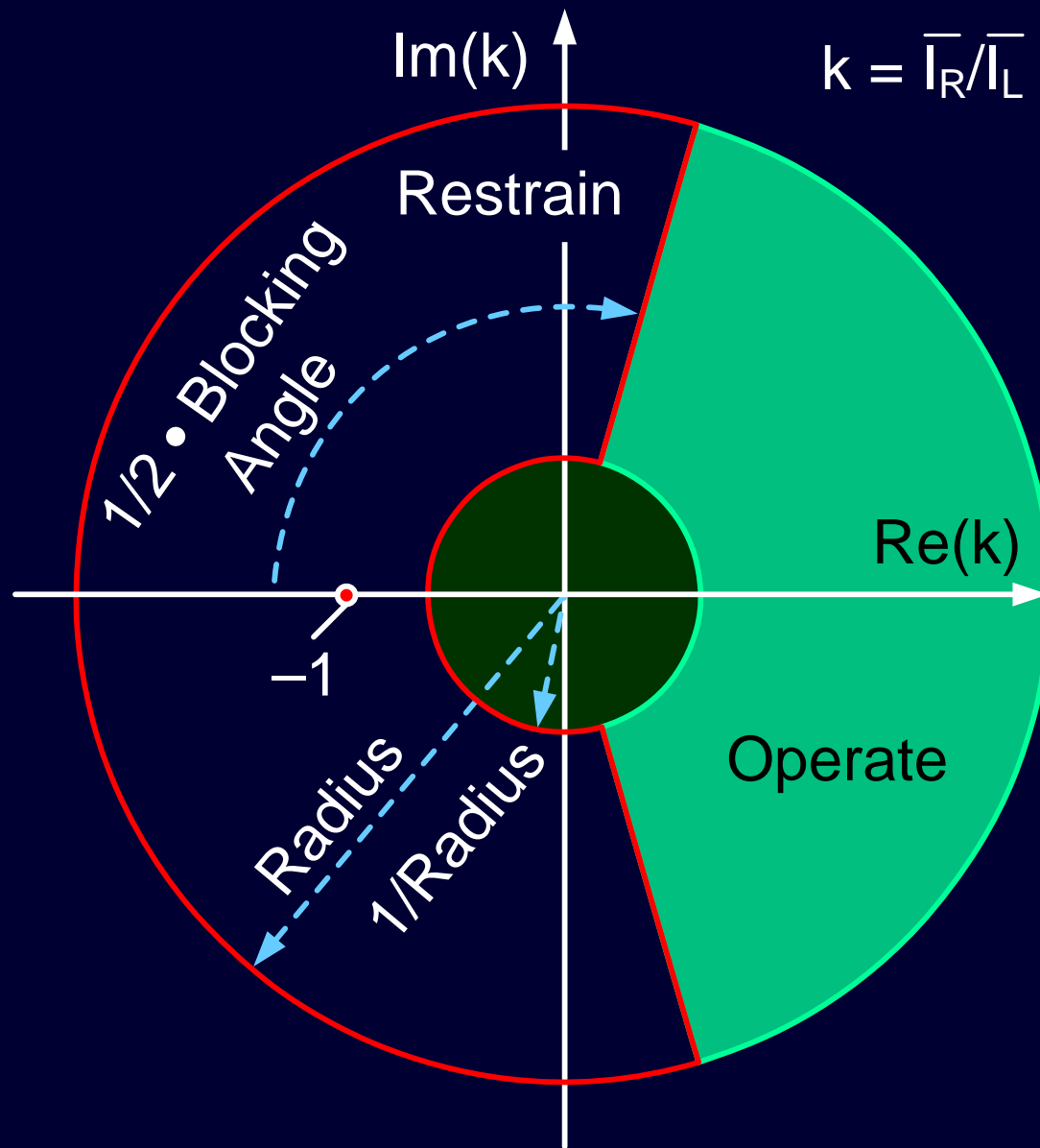


# Operate and Restraint Values

$$I_{L(EQ)} = \left( \frac{\text{Im}(I_x)^2 - [I_{RST} - \text{Re}(I_x)]^2}{2 \cdot [I_{RST} - \text{Re}(I_x)]} + j \cdot \text{Im}(I_x) \right) \cdot 1 \angle \beta$$

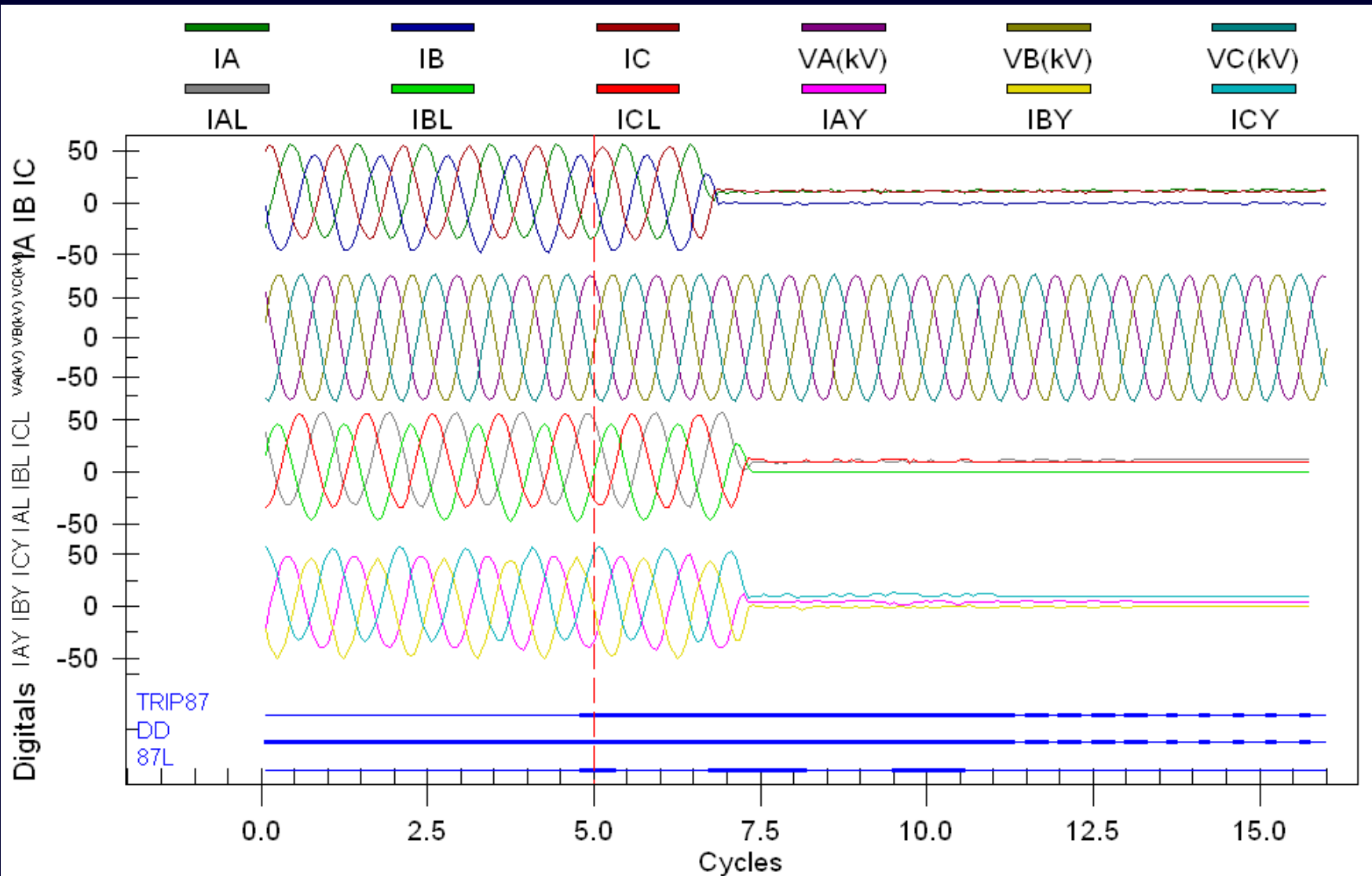
$$I_{R(EQ)} = (I_{RST} - |I_{L(EQ)}|) \cdot 1 \angle \beta$$

# Generalized Alpha Plane



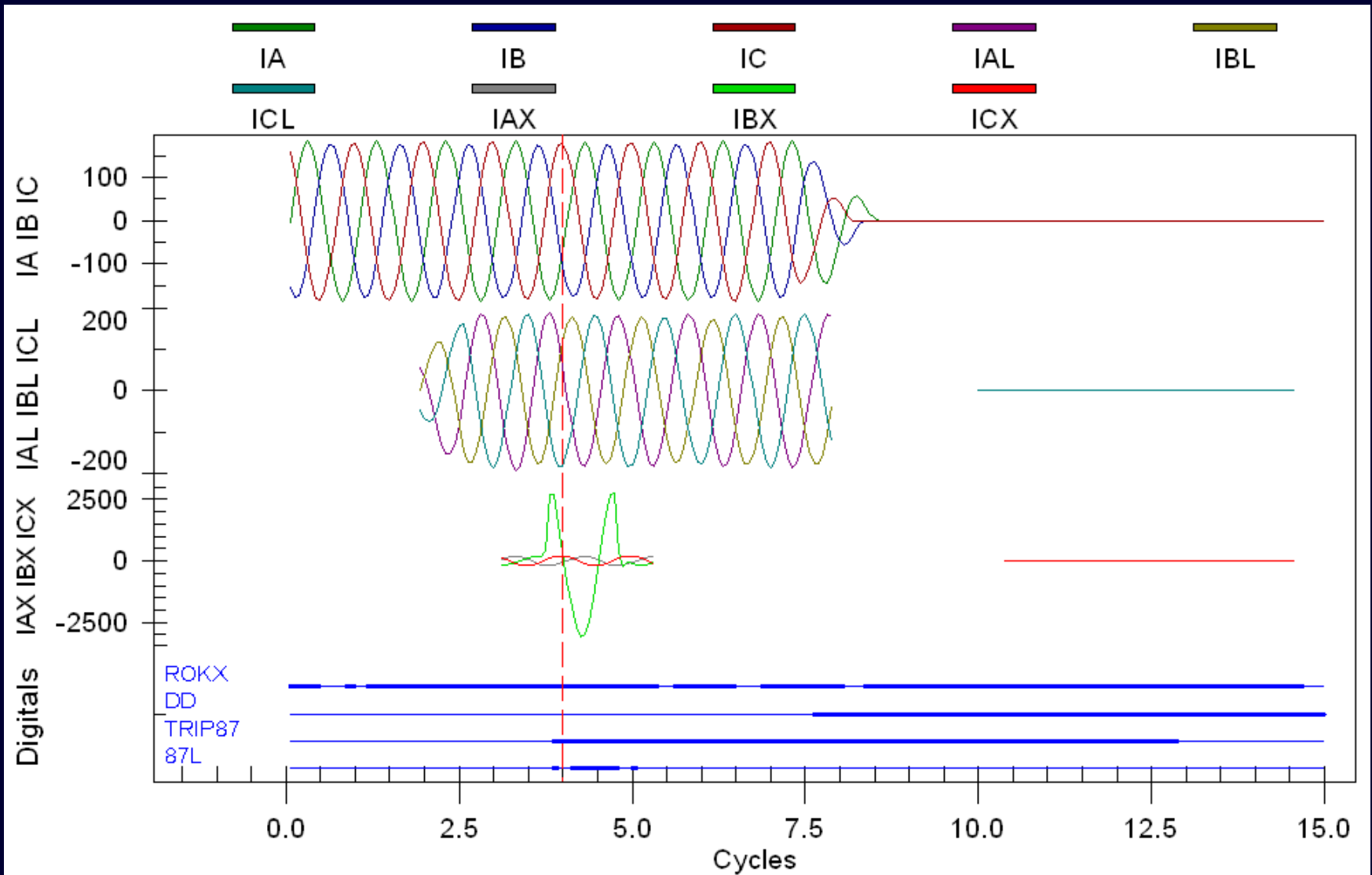
# 87L Asserts for Single Event Upset

## Self-Test Diagnostics Improved



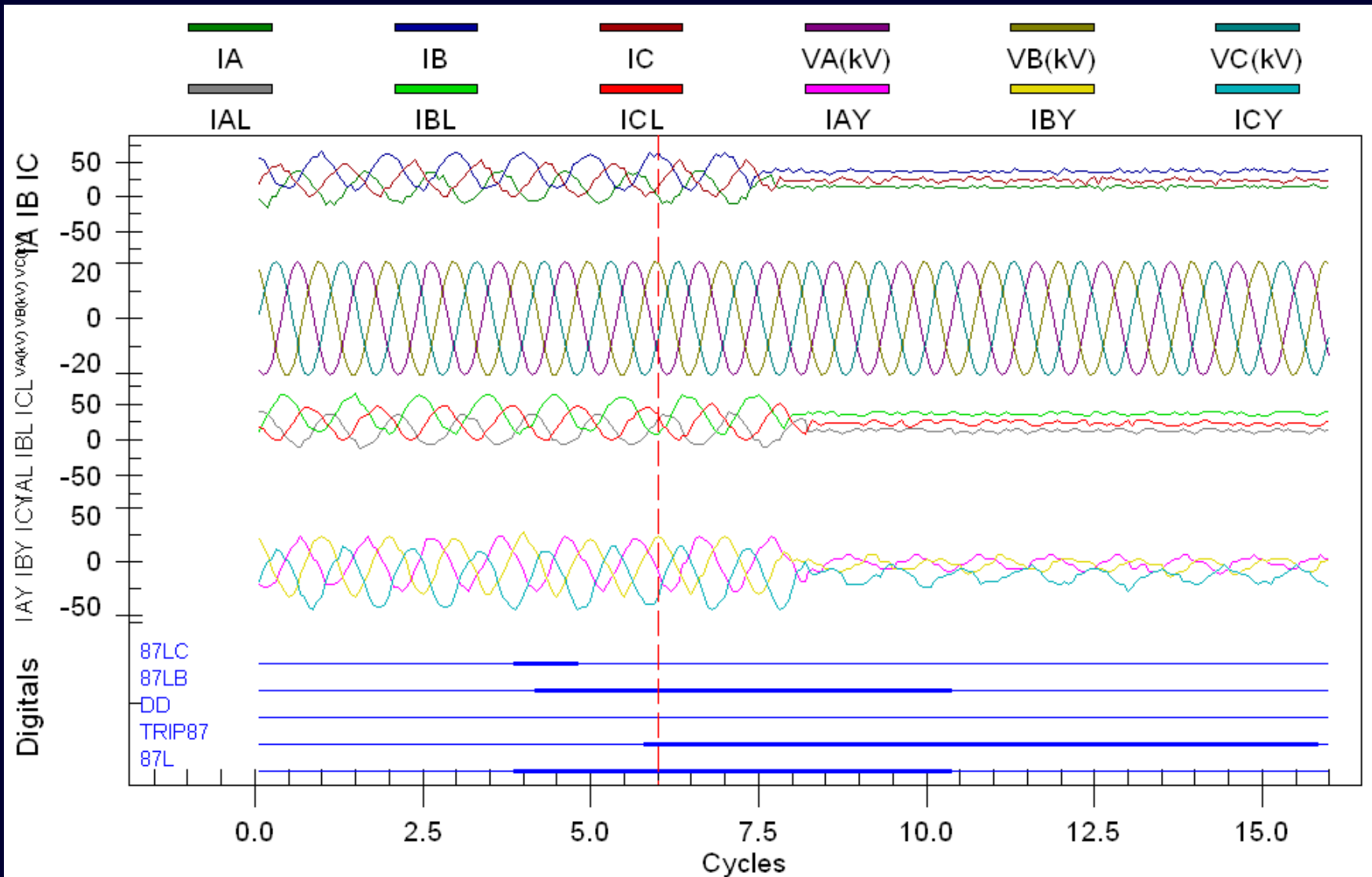
# 87L Produces Undesired Trip

## Enable Disturbance Detection



# Error Produces 87L Misoperation

## Channel Diagnostics Improved

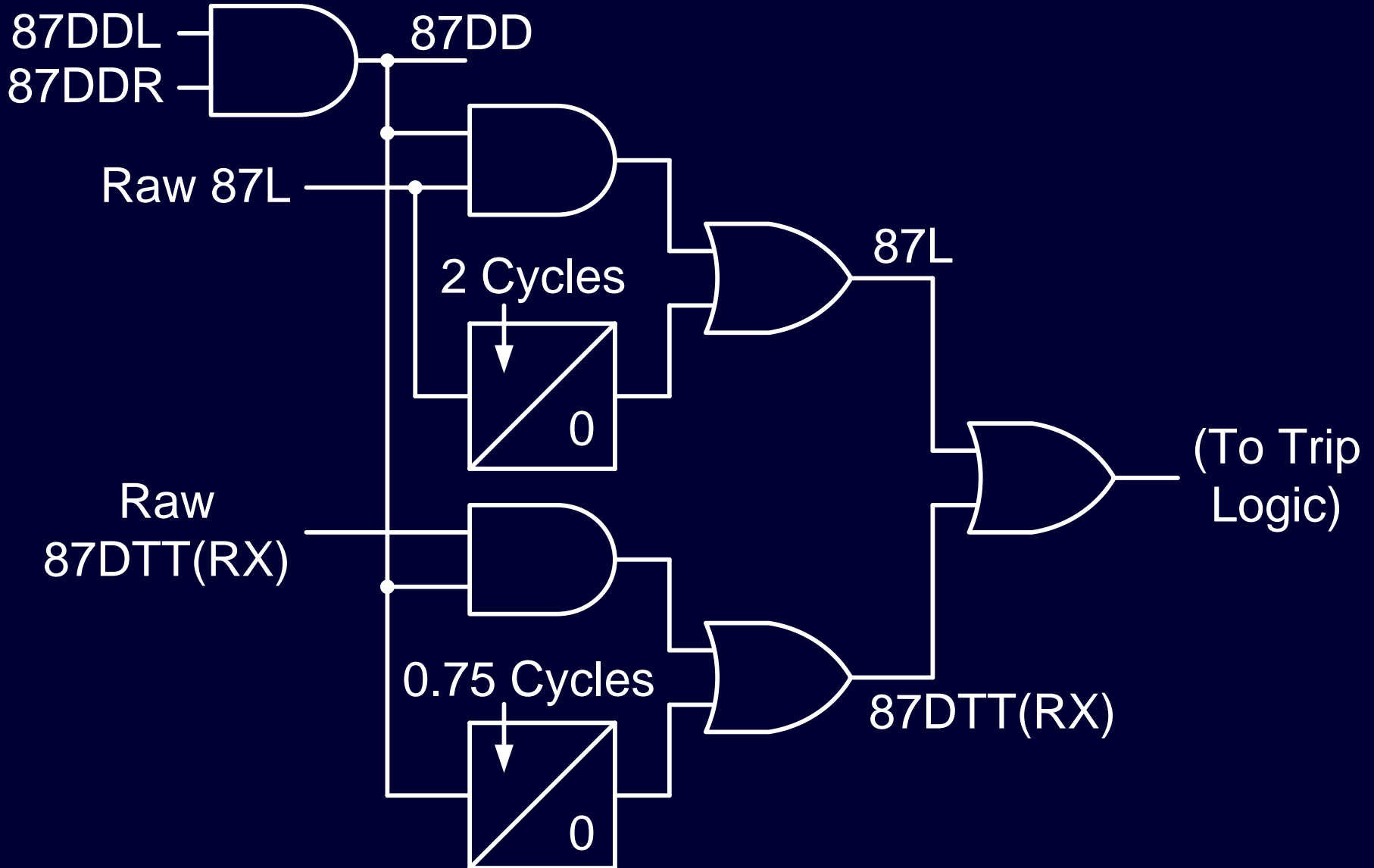




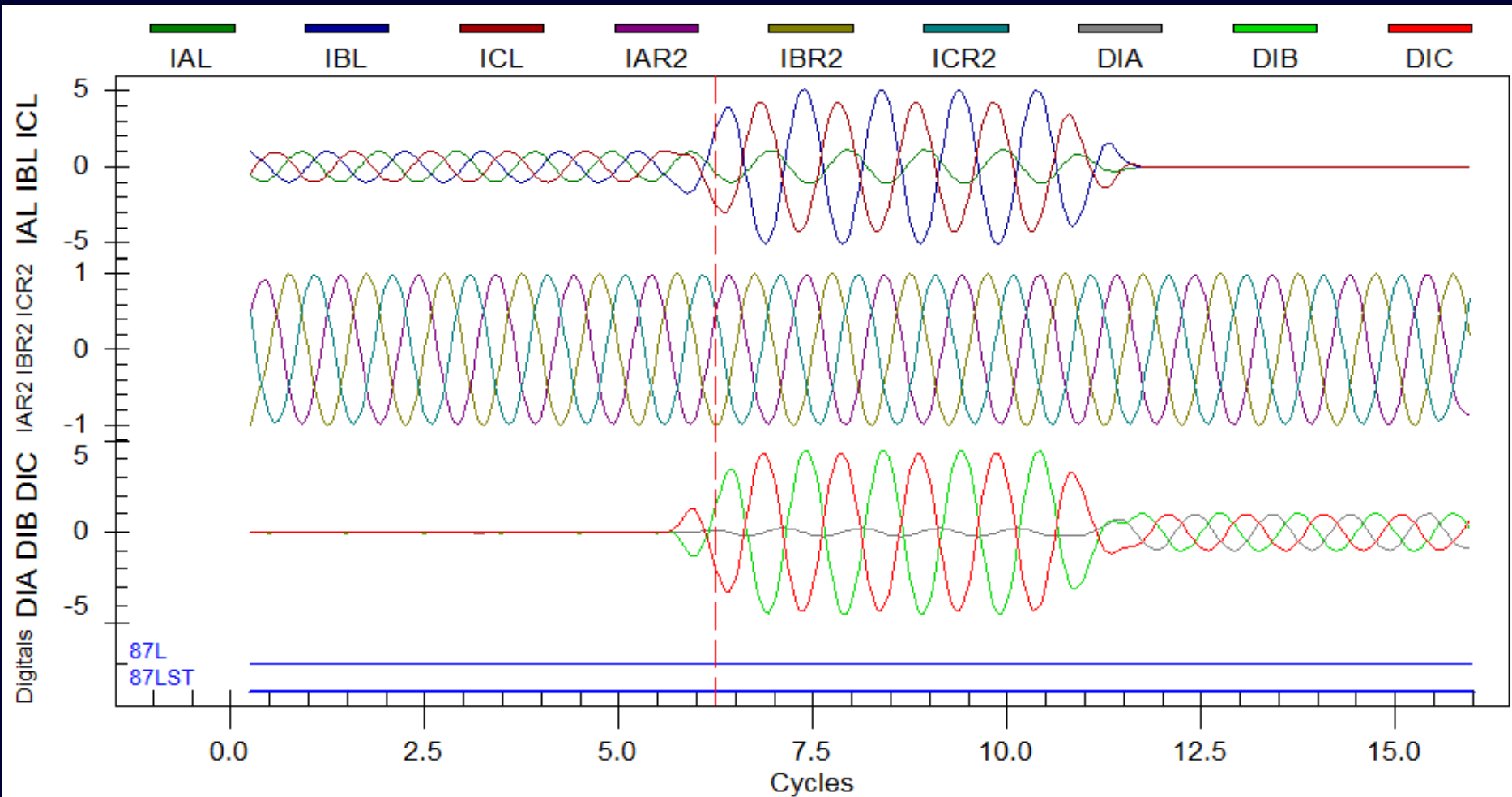
# Recent Security Enhancements

- Data integrity checks
- Disturbance detection supervision
- Watchdog counters
- Generalized Alpha Plane
- Advanced time alignment

# 87L Disturbance Detection Logic



# Unrealistic Power System Fault Simulations Require 87L Test Mode



# Entering 87L Test Mode

=>>TEST 87L

Entering 87L Test Mode.

Select Test: Characteristic or Loopback (C, L)	? L
Loopback Test Channel: (1, 2)	? 1
Loopback Duration: (1-60 minutes)	? 5

Are you sure (Y/N)? Y

The 87L element inhibited, address checking overwritten,

Testing is enabled

Type "COM 87L" to check the loopback status

Warning!

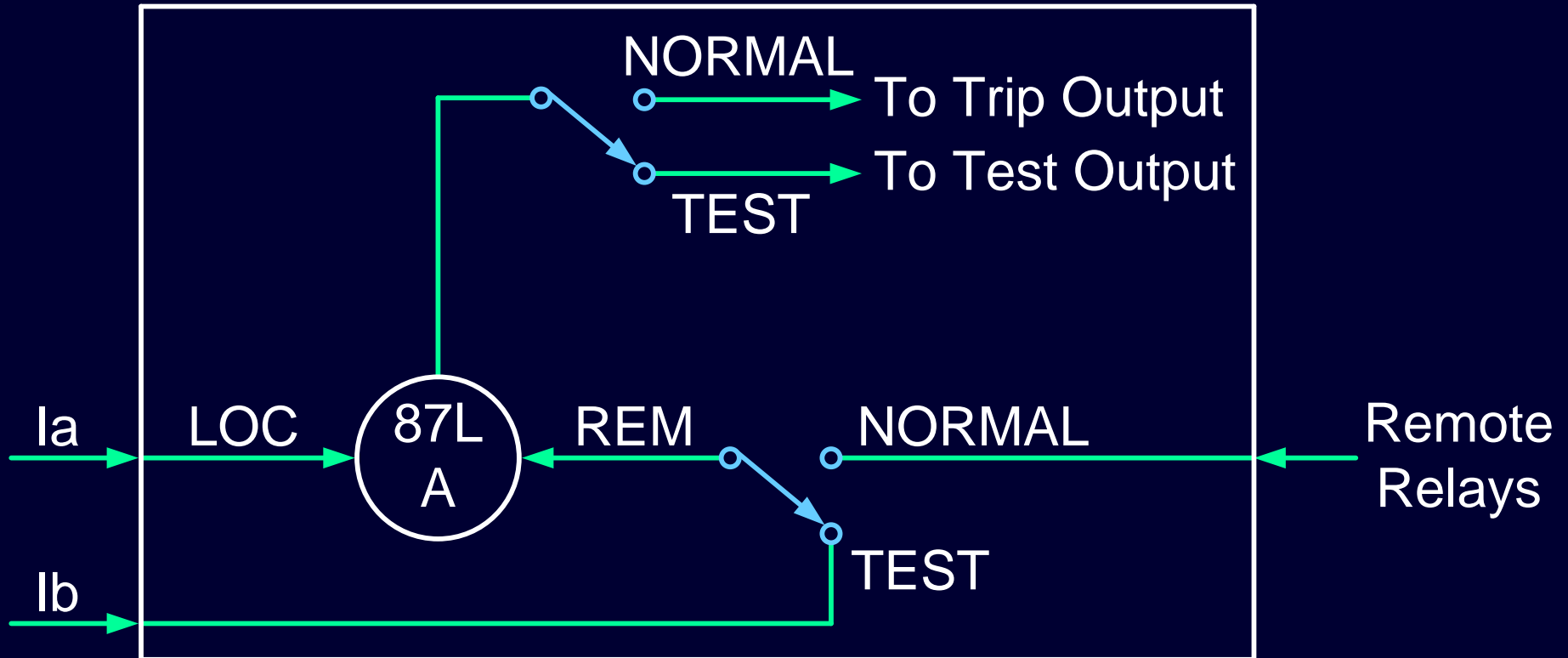
Ctrl X does not exit test mode

Type "TEST 87L OFF" to exit

# Loopback Test



# Single-Relay Characteristic Test



=>>MET DI F

Relay 1  
Station R

Date: 05/11/2012 Time: 10:42:35.698  
Serial Number: 1111240304

87L Communication: Master  
87L Function: Available  
Stub Bus: Disabled

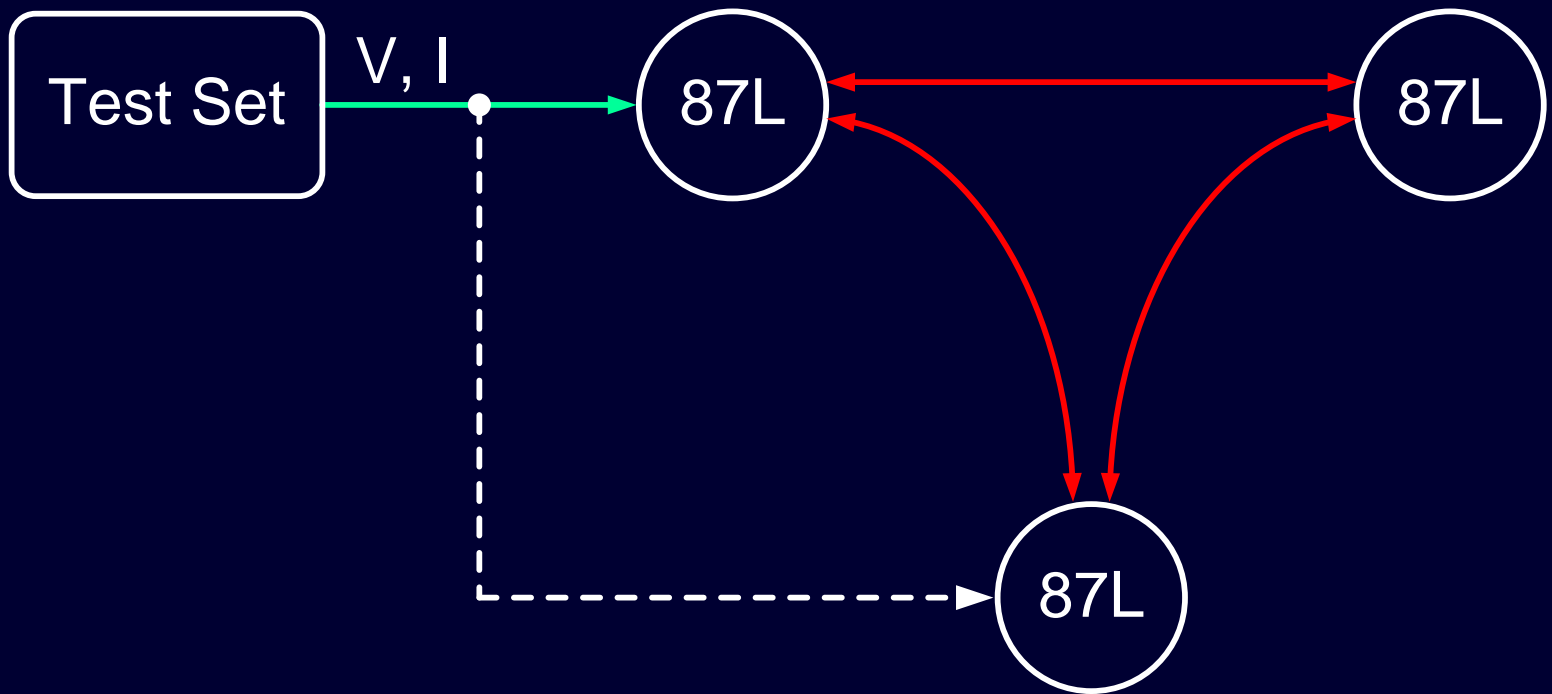
	Local Terminal					
	I A	I B	I C	I 1	3I 2	3I 0
MAG ( pu)	1.634	0.000	0.000	0.545	1.634	1.634
ANG ( DEG)	0.00	37.44	37.44	0.00	0.00	0.00
THROUGH ( pu)	1.634	0.000	0.000		0.000	0.000

	Remote Terminal 1					
	I A	I B	I C	I 1	3I 2	3I 0
MAG ( pu)	6.535	0.000	0.000	2.178	6.535	6.535
ANG ( DEG)	79.97	37.44	37.44	79.97	79.97	79.97
THROUGH ( pu)	6.534	0.000	0.000		0.000	0.000

	Differential					
	I A	I B	I C		3I 2	3I 0
MAG ( pu)	7.007	0.000	0.000		7.007	7.007
ANG ( DEG)	66.70	37.44	37.44		66.70	66.70

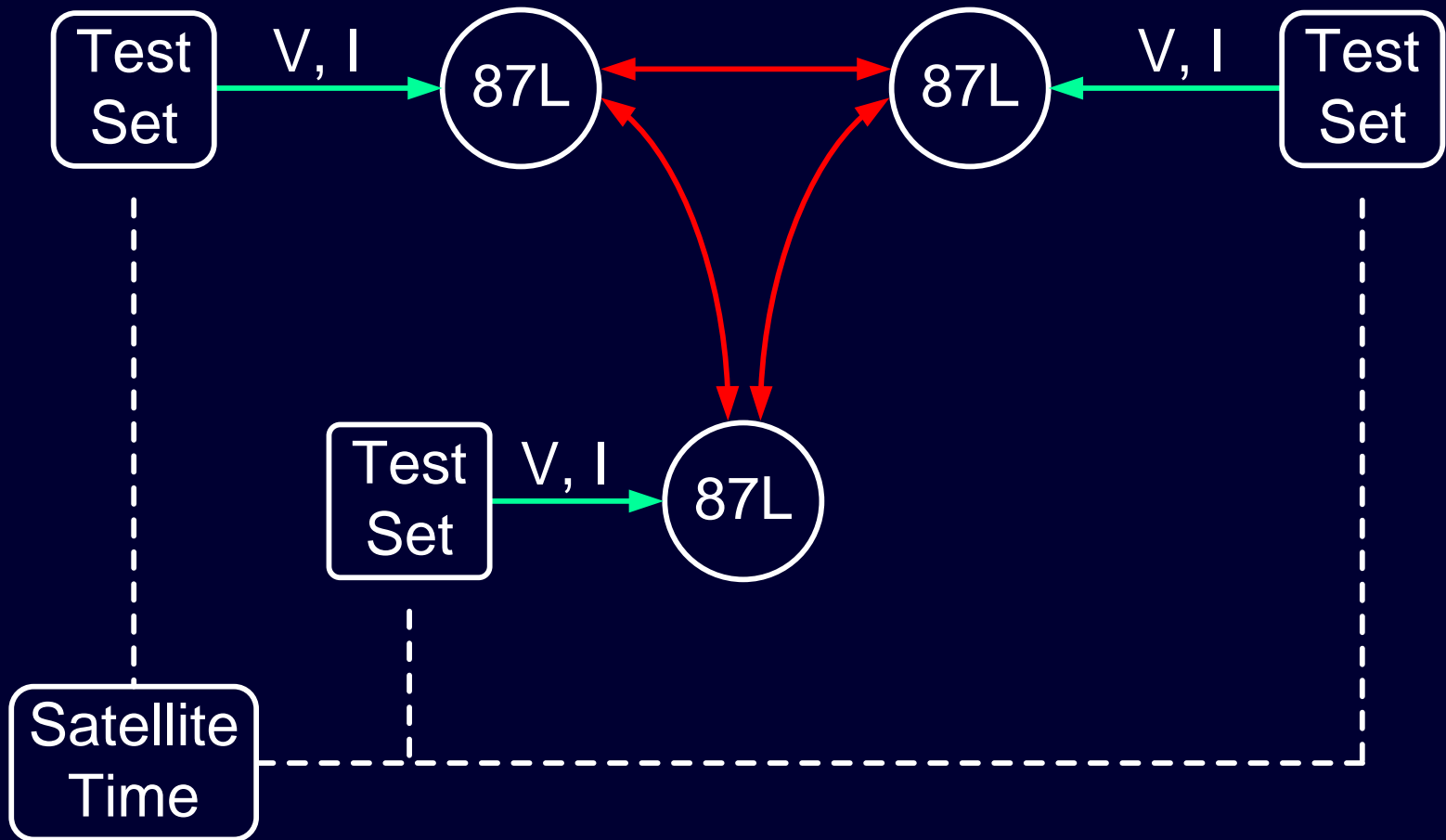
	Alpha Plane					
	87LA	87LB	87LC		87LQ	87LG
k	0.250	1.000	1.000		0.000	0.000
alpha ( DEG)	79.94	180.00	180.00		0.00	0.00

# Multiple-Relay Characteristic Test With One Test Set





# Characteristic Test With Multiple Relays and Test Sets



=>>MET DIF

Relay 1  
Station R

Date: 05/11/2012 Time: 13:59:54.456  
Serial Number: 1111240304

87L Communication: Master  
87L Function: Not Available  
Stub Bus: Disabled

	Local Terminal					
	I A	I B	I C	I 1	3I 2	3I 0
MAG ( pu)	0.001	0.000	0.327	0.109	0.328	0.326
ANG ( DEG)	-88.10	2.56	120.15	0.00	-119.78	120.21
THROUGH ( pu)	0.000	0.000	0.327		0.327	0.327

	Remote Terminal 1					
	I A	I B	I C	I 1	3I 2	3I 0
MAG ( pu)	0.000	0.000	0.409	0.137	0.409	0.408
ANG ( DEG)	-80.87	-118.66	119.57	-0.48	-120.47	119.64
THROUGH ( pu)	0.000	0.000	0.408		0.410	0.408

	Differential					
	I A	I B	I C		3I 2	3I 0
MAG ( pu)	0.001	0.000	0.736		0.737	0.735
ANG ( DEG)	-86.09	-108.81	119.83		-120.16	119.89

	Alpha Plane					
	87LA	87LB	87LC		87LQ	87LG
k	1.000	1.000	0.000		0.000	0.000
alpha ( DEG)	180.00	180.00	0.00		0.00	0.00

# Modern Digital Relay Improvements

- Enhanced channel monitoring
- Satellite time-based time alignment
- Disturbance detection
- Generalized Alpha Plane
- External fault detection

# Modern Digital Relay Improvements

- Adaptive characteristics
- Charging current compensation
- In-line and tapped transformer compensation
- Watchdog counters
- Improved relay self-test diagnostics

# Security Failures Are Rare

- Single event upset caused misoperation – improved diagnostics and memory storage prevent reoccurrence
- Communications error produced misoperation
  - ◆ Disturbance detection prevents reoccurrence
  - ◆ Watchdog counters improve security

# 87L Advancements Require Enhanced Testing

- Channel statistics and monitoring diagnose problems
- Loopback test mode pinpoints channel problems
- Full characteristic testing with locally injected currents
- 87L test mode allows traditional, simple tests

# Real-World Testing Means Real World

- Disturbance detection and watchdog counters log close calls and disable 87L
- Real-world testing requires simultaneously injected realistic power system values into all terminals
- Protective relay algorithms and capabilities adapt and evolve
- Engineers, technicians, and test practices also evolve

**Questions?**