Maximizing Line Protection Reliability, Speed, and Sensitivity

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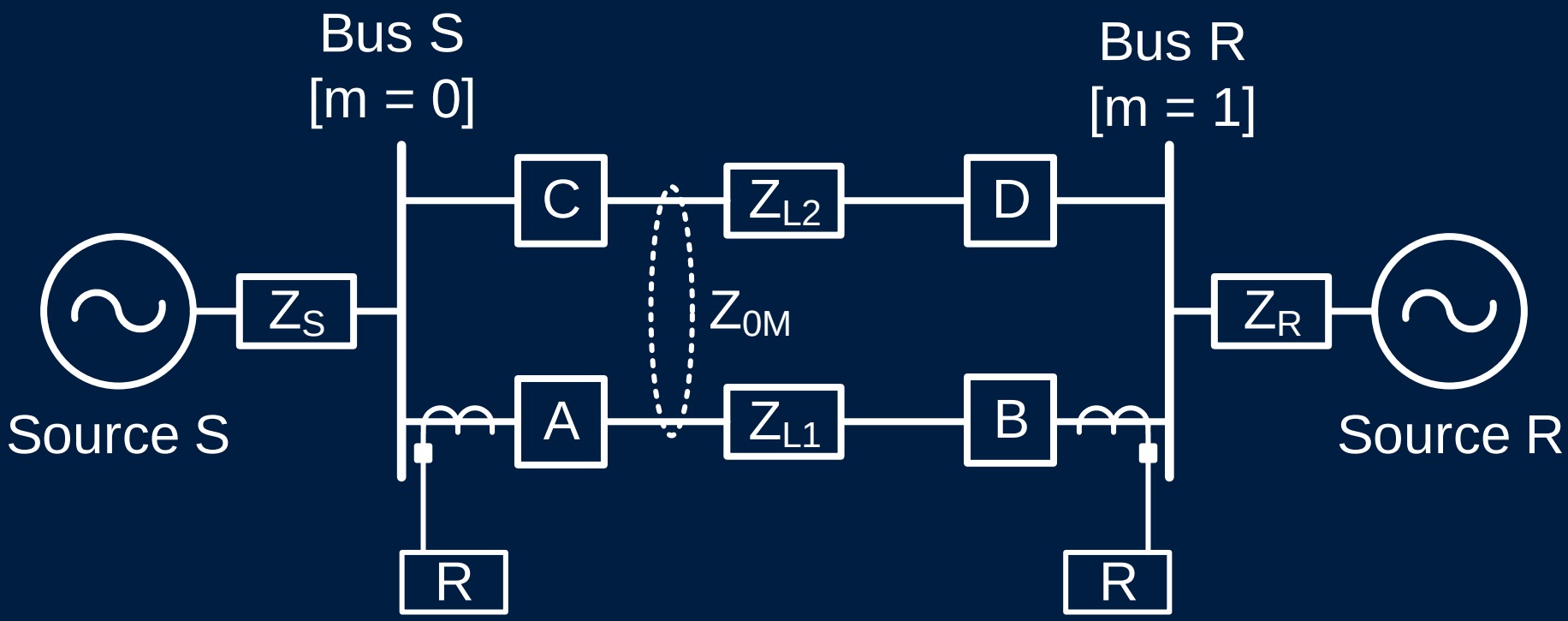
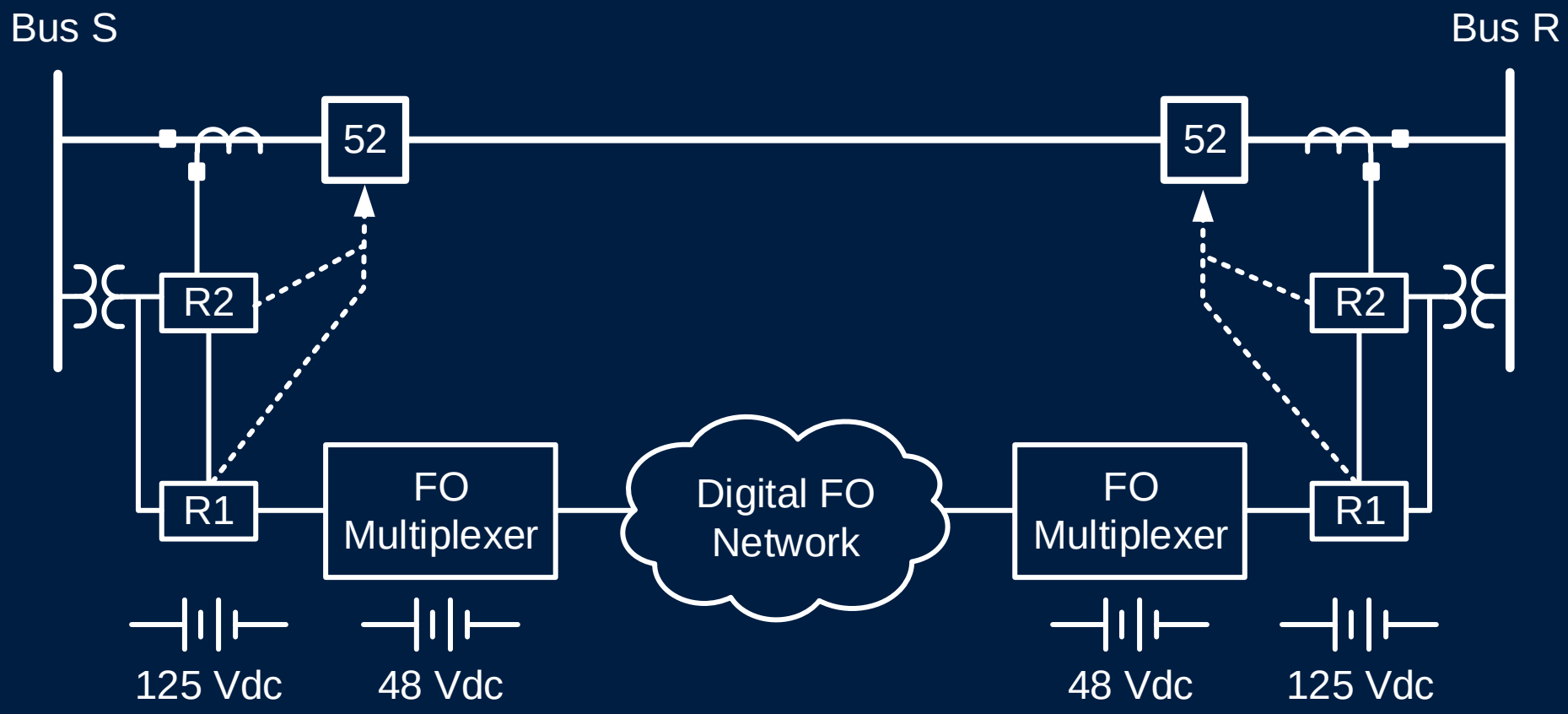
Outline

- Introduction
- Example systems
- Speed
- Sensitivity
- Reliability
- Selectivity
- Conclusions

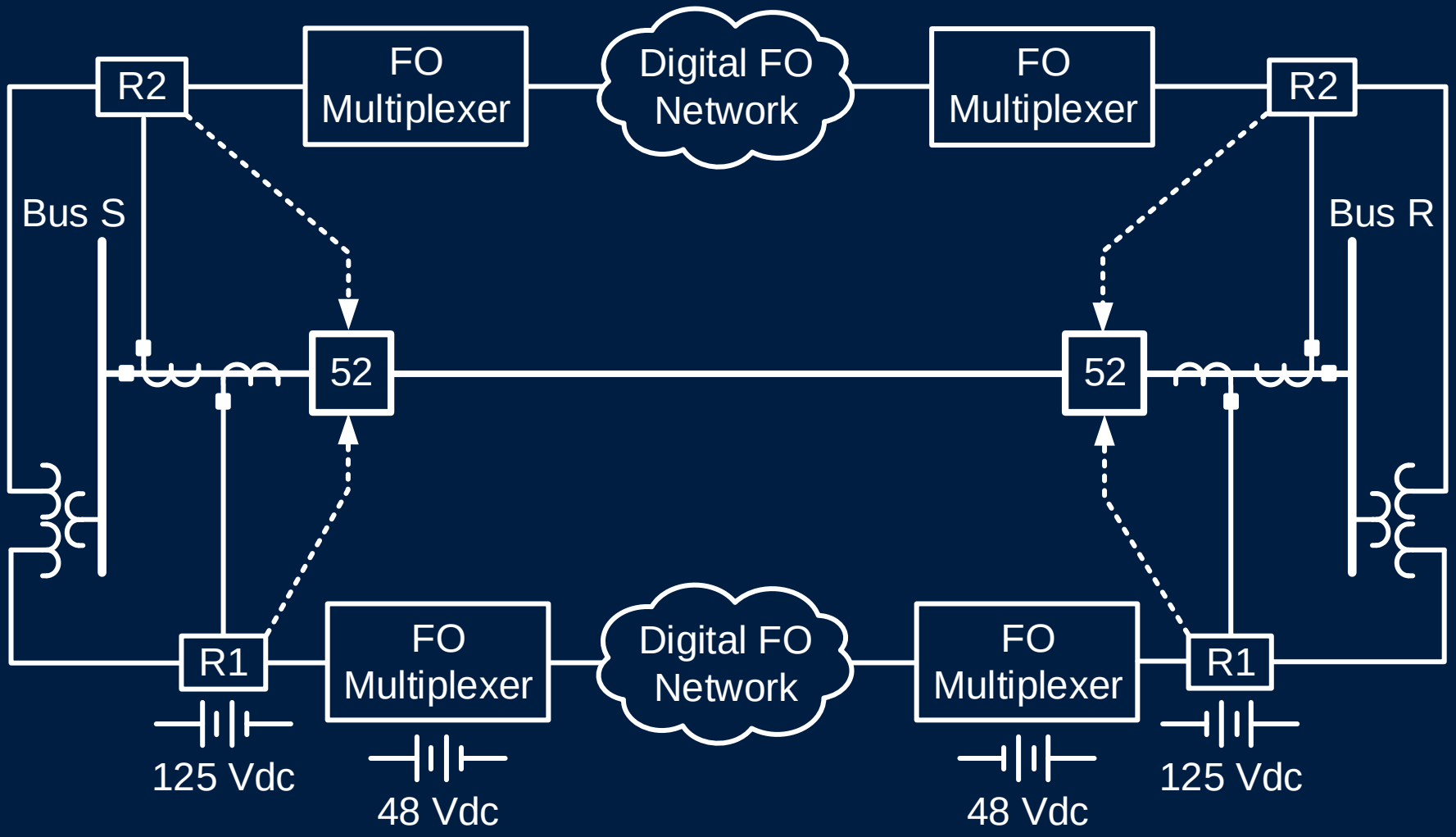
Example Power System



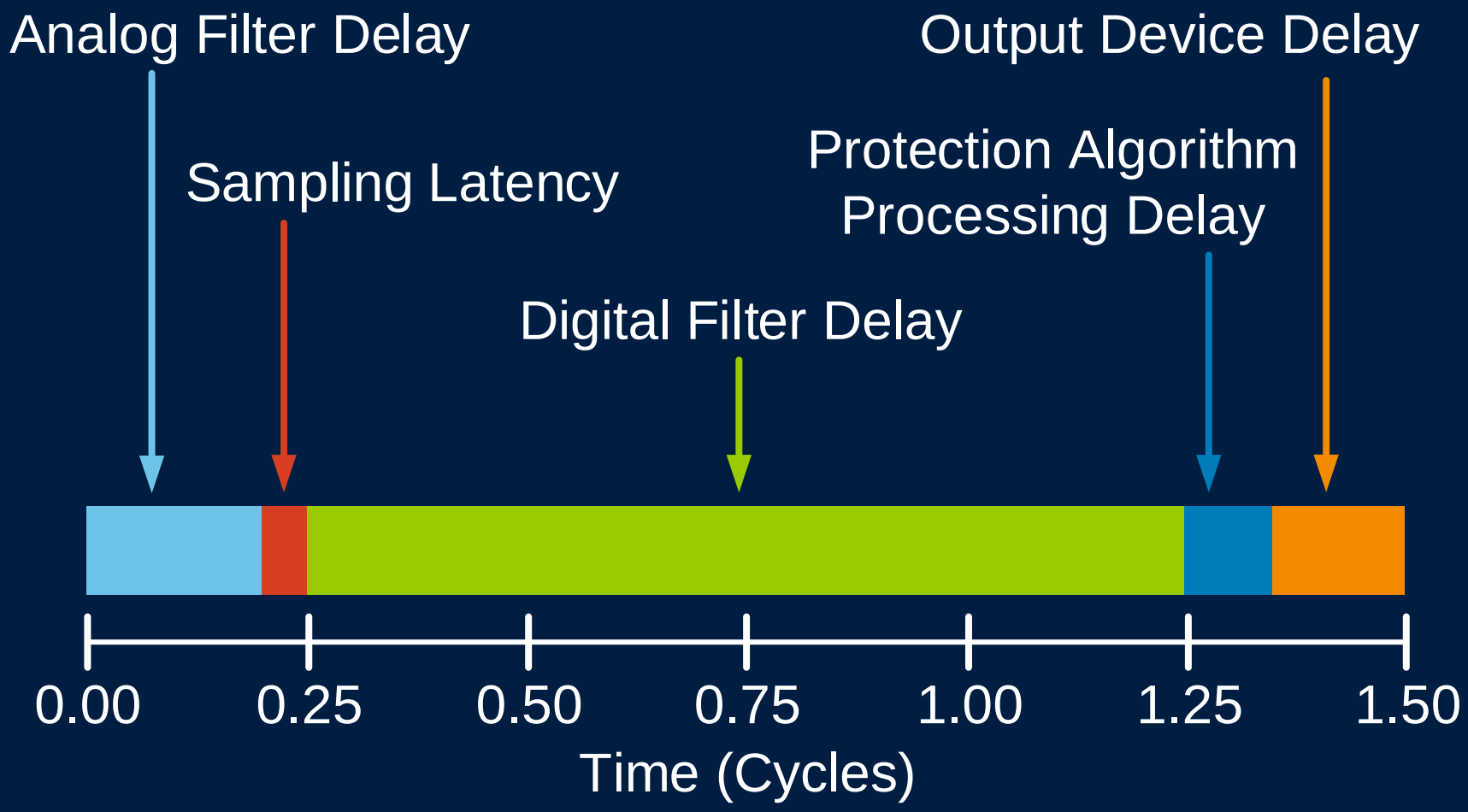
Example Single-Redundant Protection System



Example Dual-Redundant Protection System

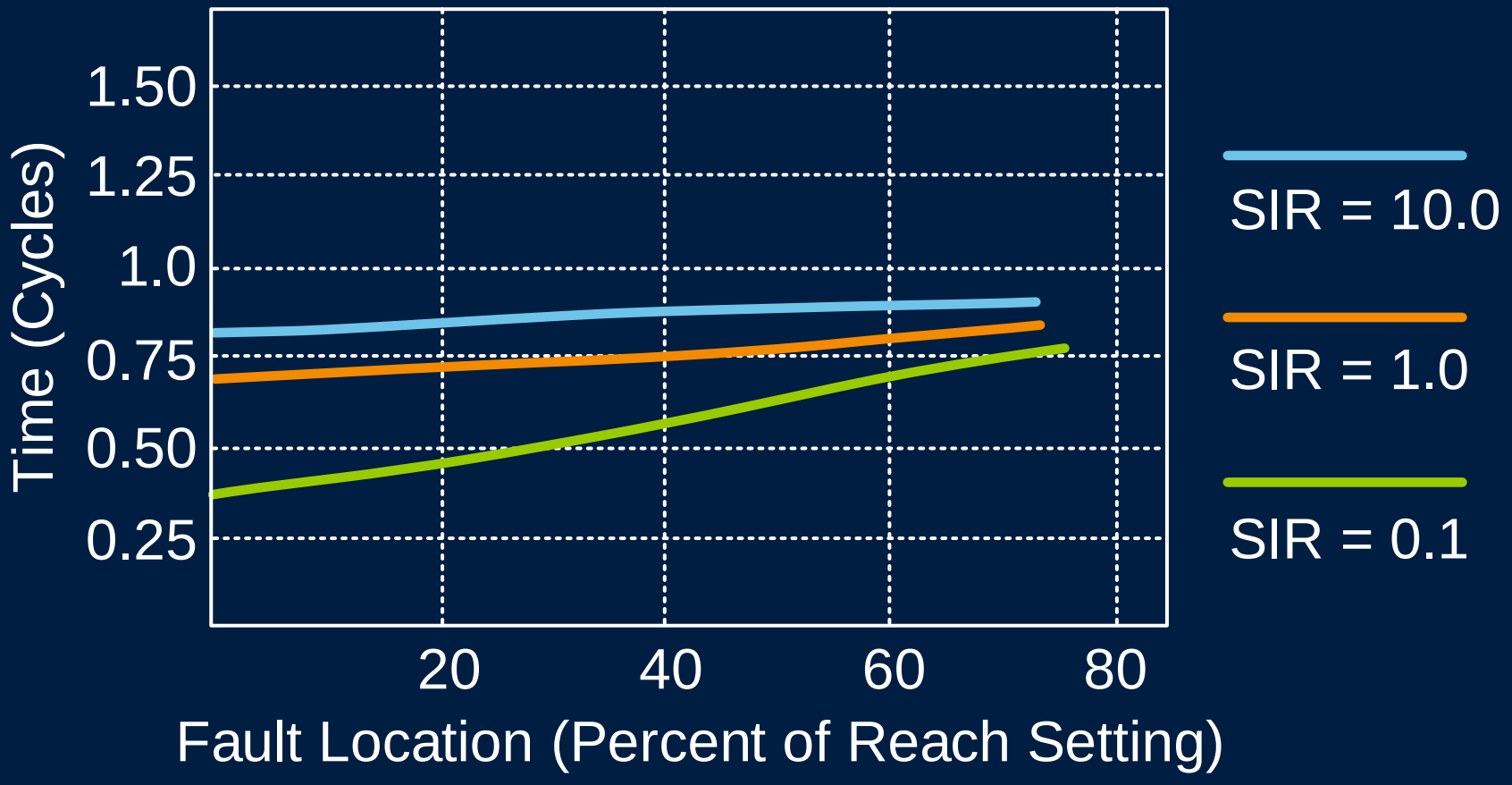


Phasor-Based Element Operating Time



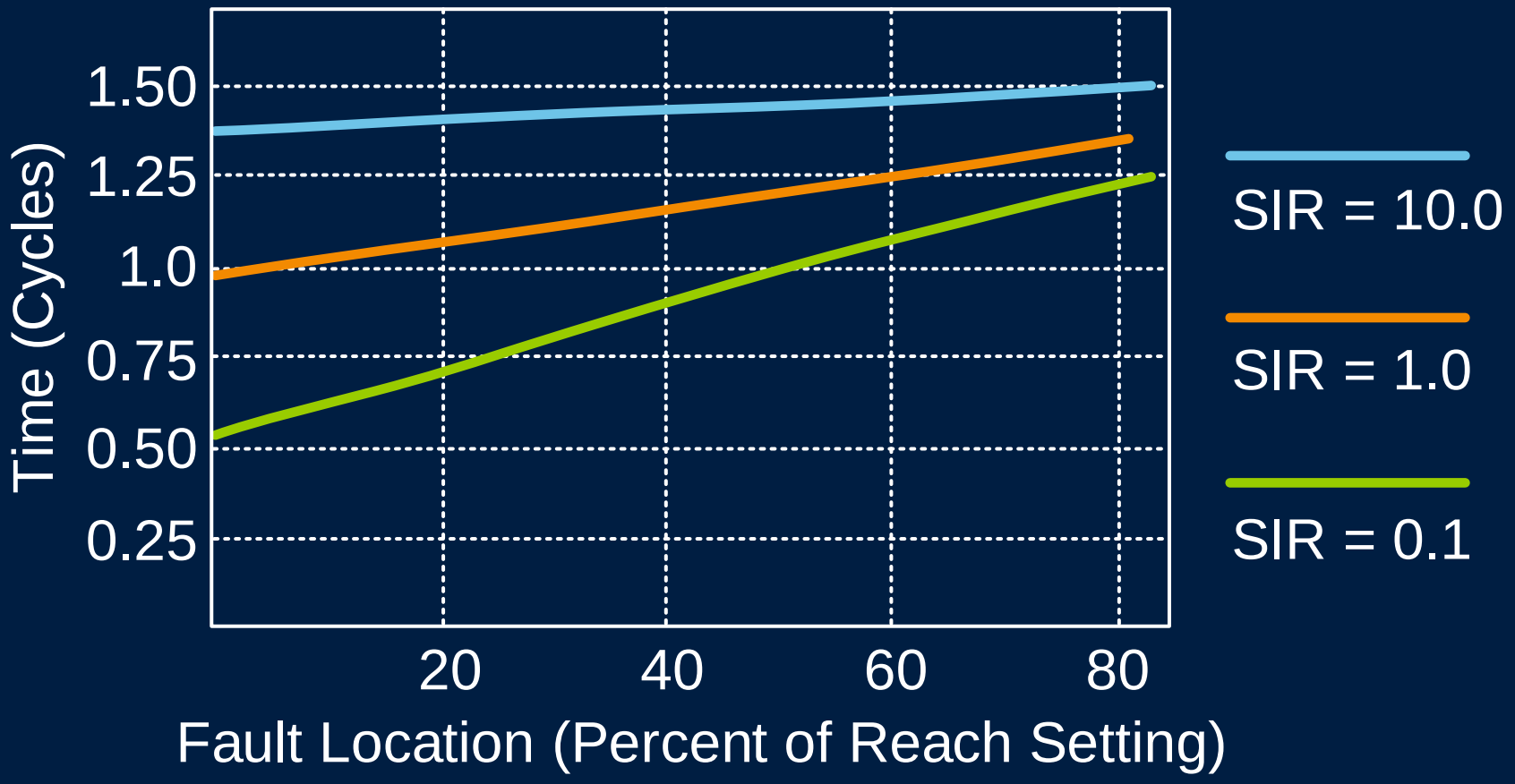
Dual-Filter Schemes Speed Up Distance Elements

High-Speed Elements

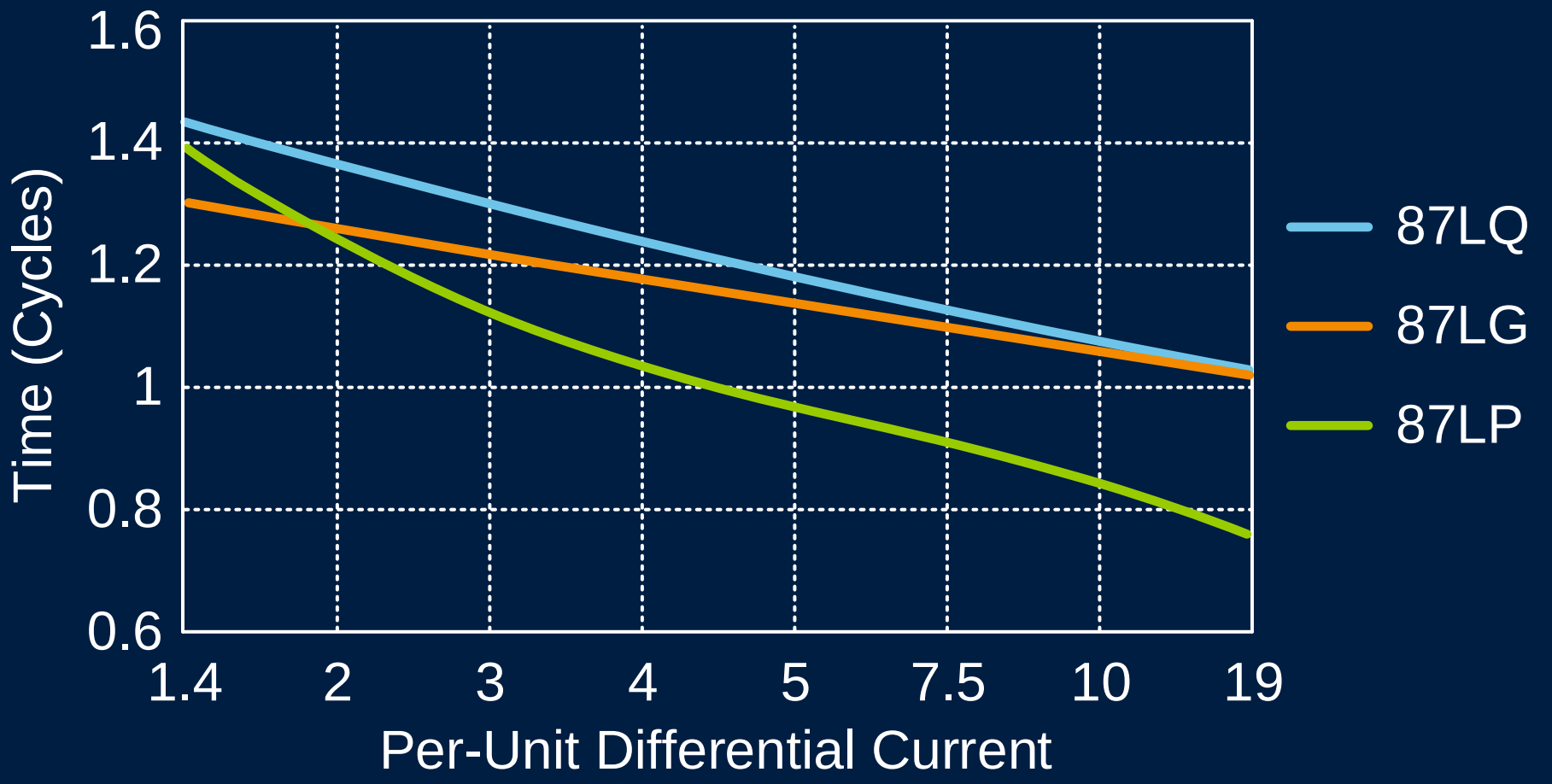


Dual-Filter Schemes Speed Up Distance Elements

Standard-Speed Elements

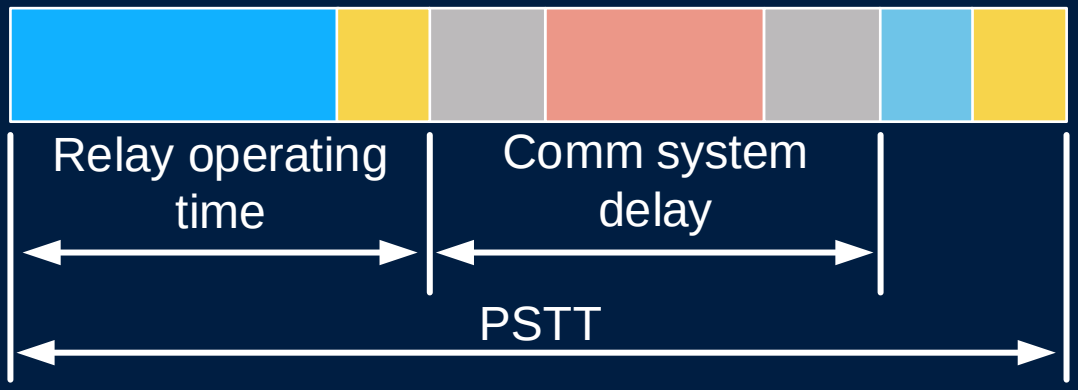


87LP Elements Are Fast!

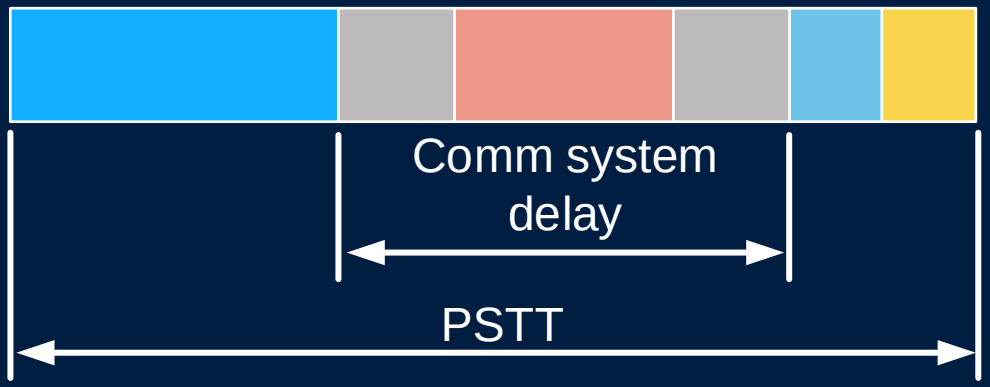


Components of PSTT in Pilot Schemes

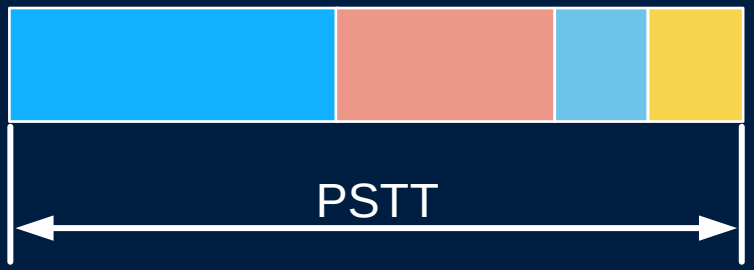
PLC or analog microwave



Digital microwave or fiber-optic network



Direct fiber



Protection element operating time

Output device delay

Comm equipment delay

Channel delay

Relay processing delay

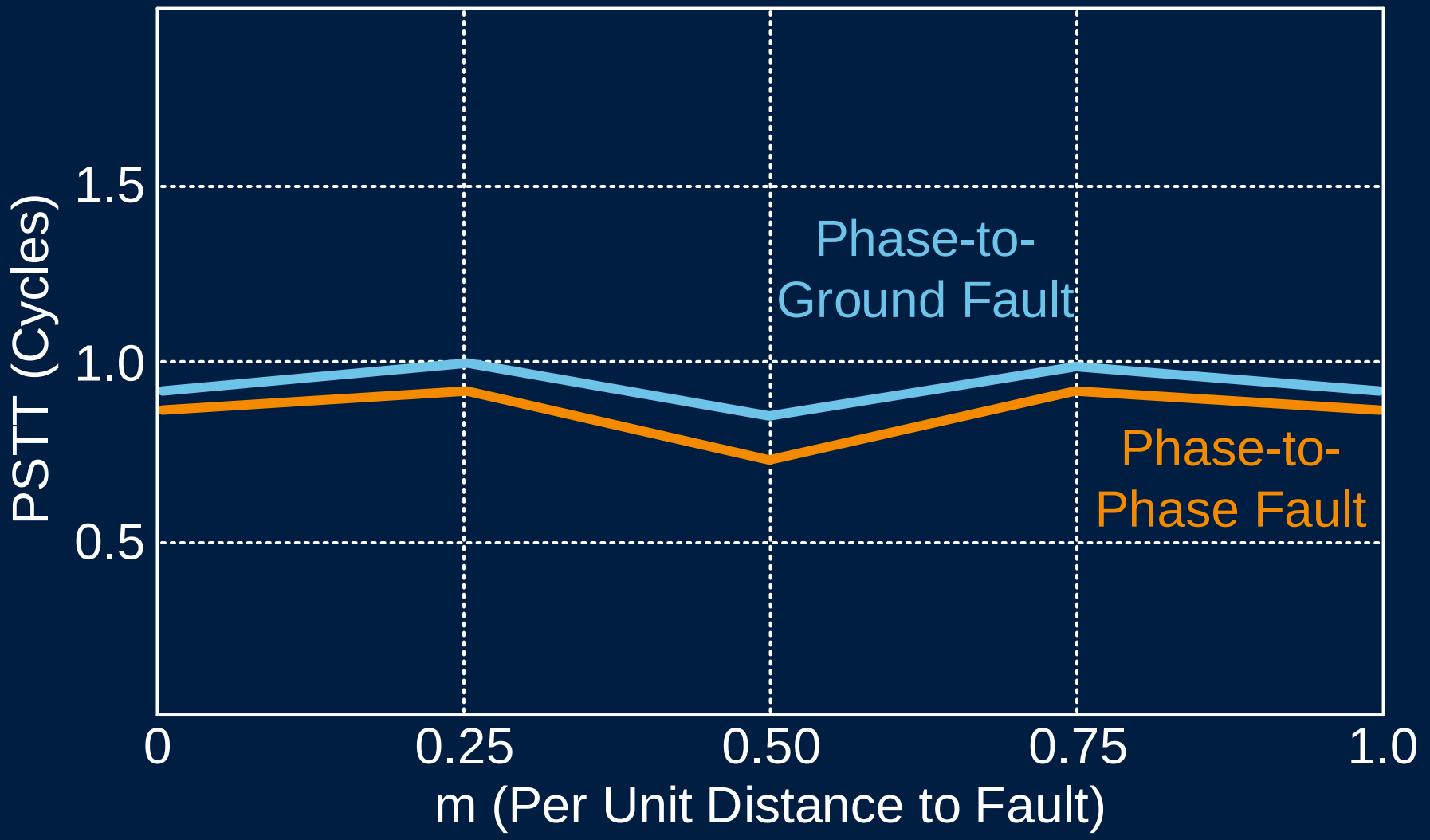
Traditional PLC System Delays

Communications Equipment	Delay (ms)
PLC (wide or narrow band)	4 to 8
PLC (on / off DCB)	2 to 4

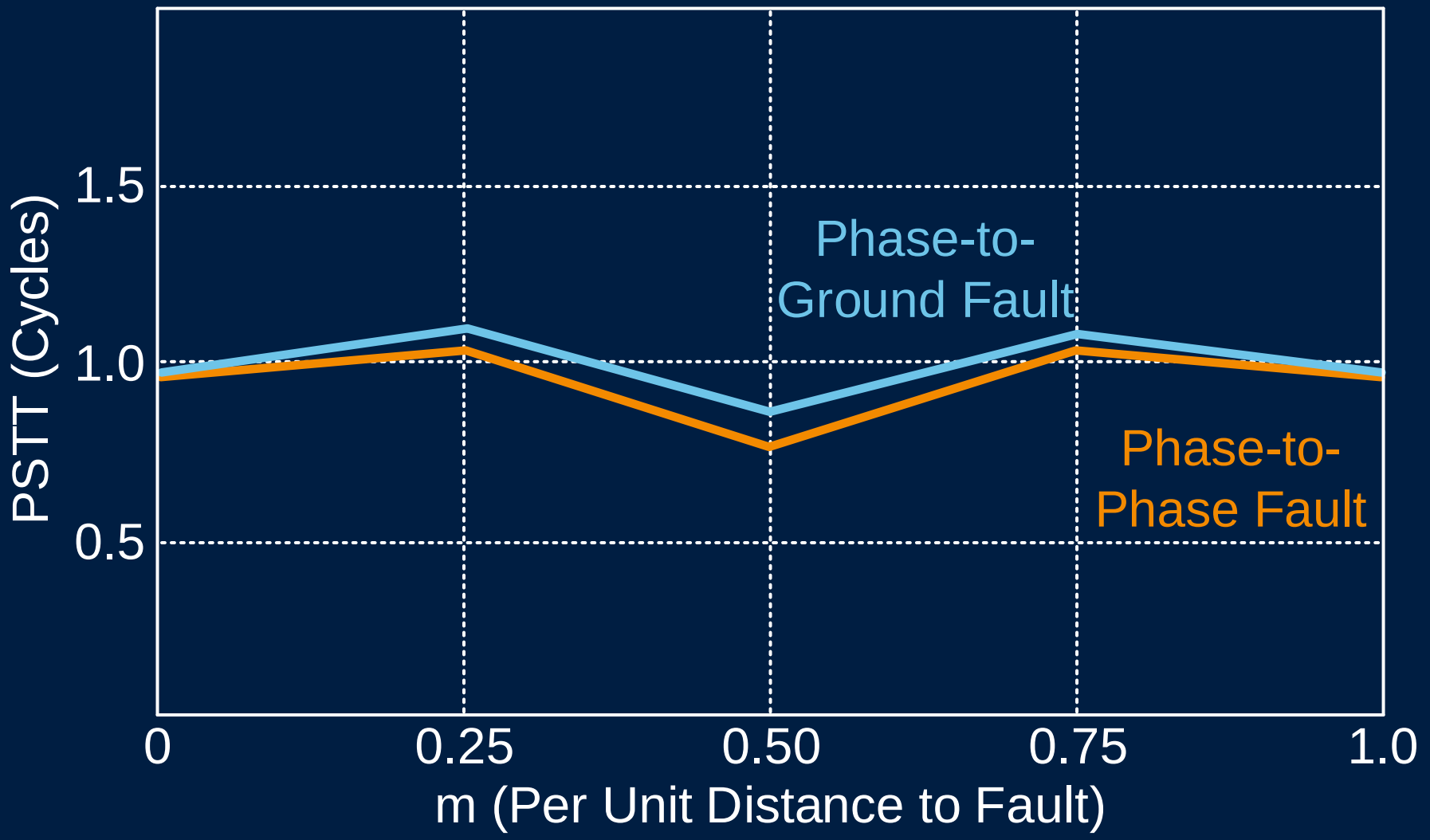
Delays for Relay-to-Relay Communication Over FO Channels

Communications System Component	Delay
Optical fiber	0.8 ms per 100 miles
Protection-class multiplexer	0.5 ms
Nonprotection-class multiplexer	6 to 8 ms
Repeater	24 μs / repeater

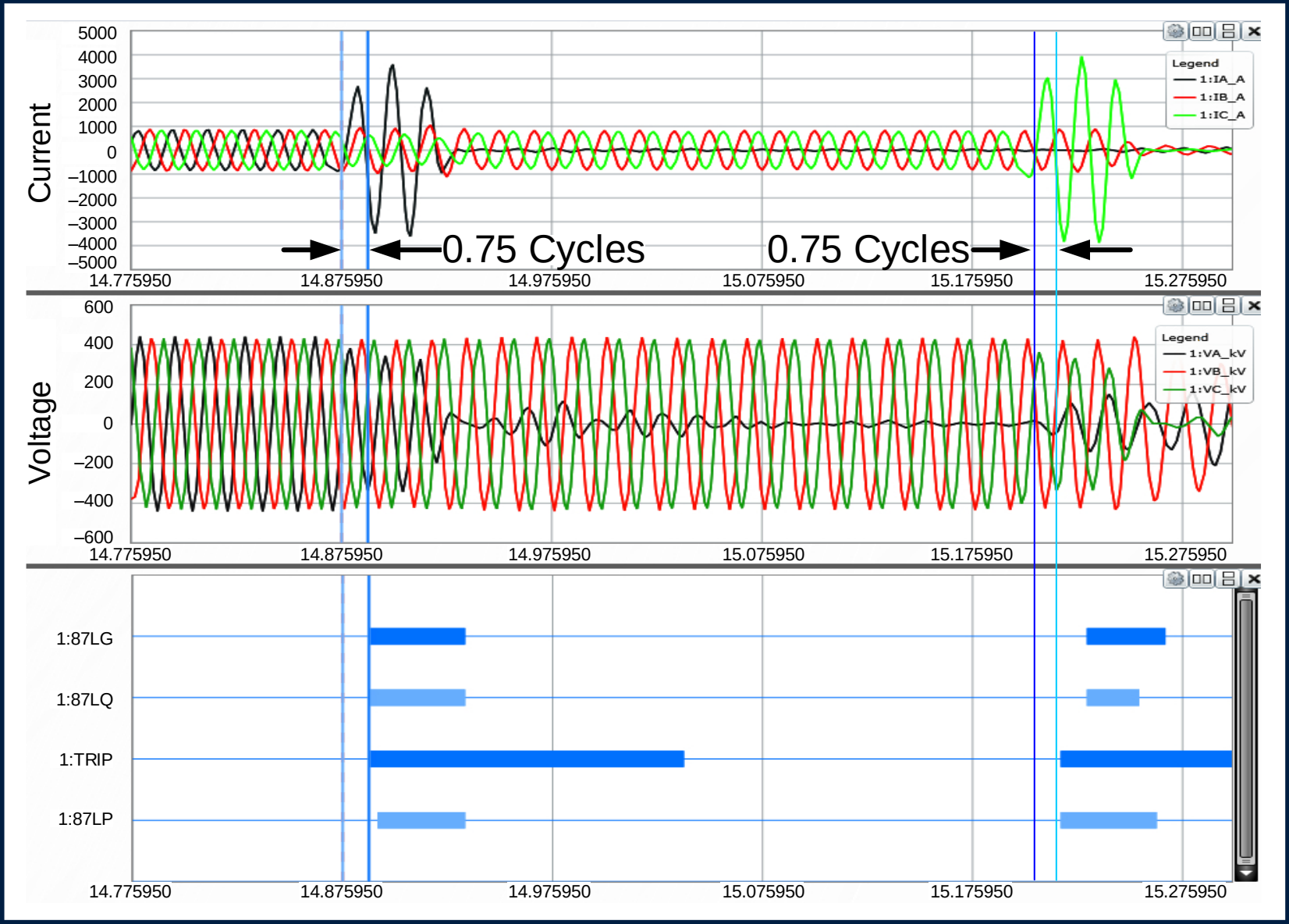
Average PSTT for POTT Scheme



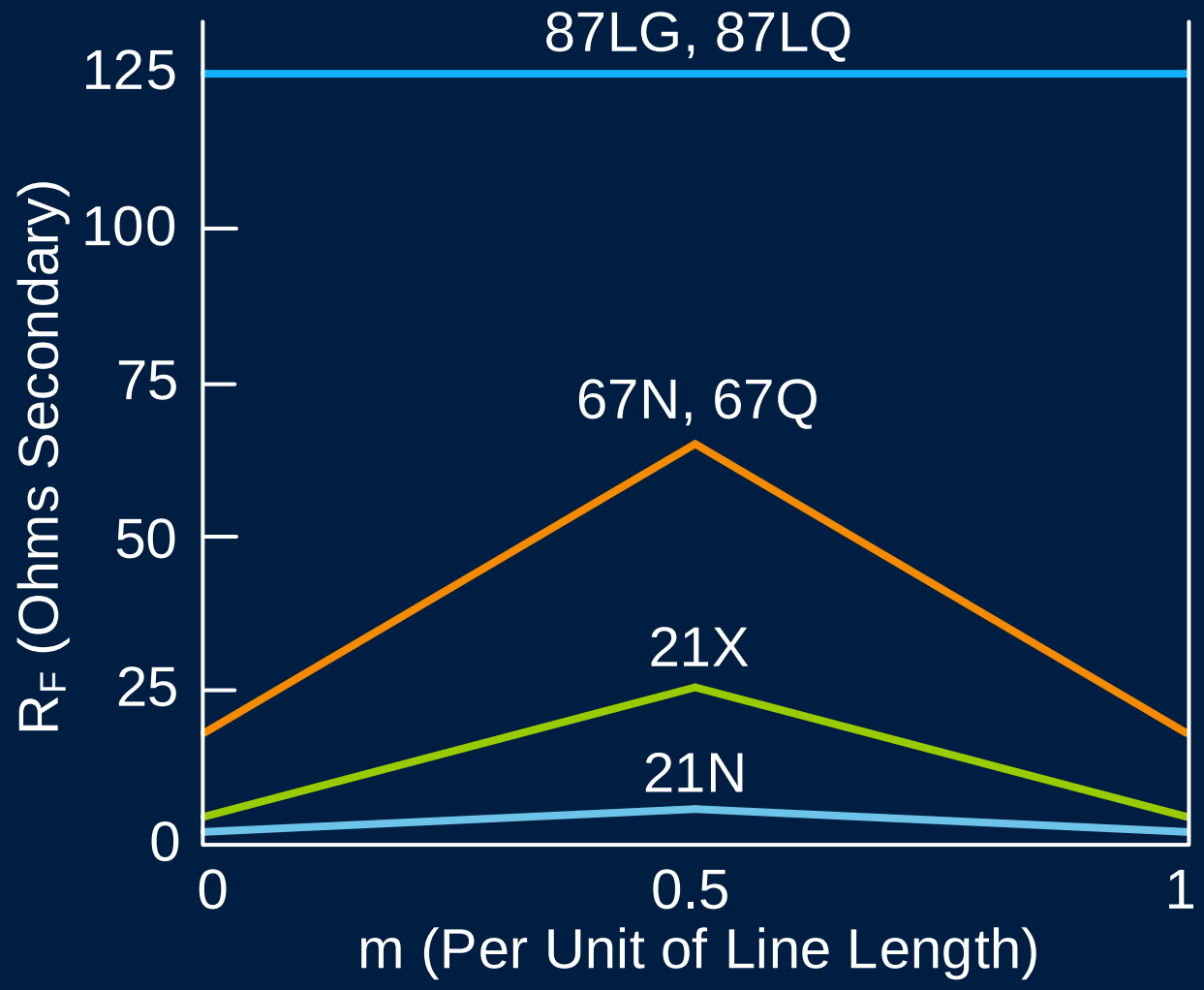
Average PSTT for 87L Scheme



87L Detects Two Faults in 0.75 Cycles



87L Provides Highest Sensitivity and Speed



Actual 525 kV Line Fault With 500 Ohms Resistance

- Pilot scheme with 67N elements detected fault
- 87L scheme would measure 3I2 = 3I0 = 1.425 A secondary
- 87LQ and 87LG elements set to 0.5 A would easily detect fault

Fault Tree Analysis

- Compare protection system reliability
- Analyze top event
  - Dependability – fails to trip (unavailabilities)
  - Security – undesirably trips (failure rates)
- Combine basic events with OR, AND, and other gates
- Obtain order-of-magnitude results

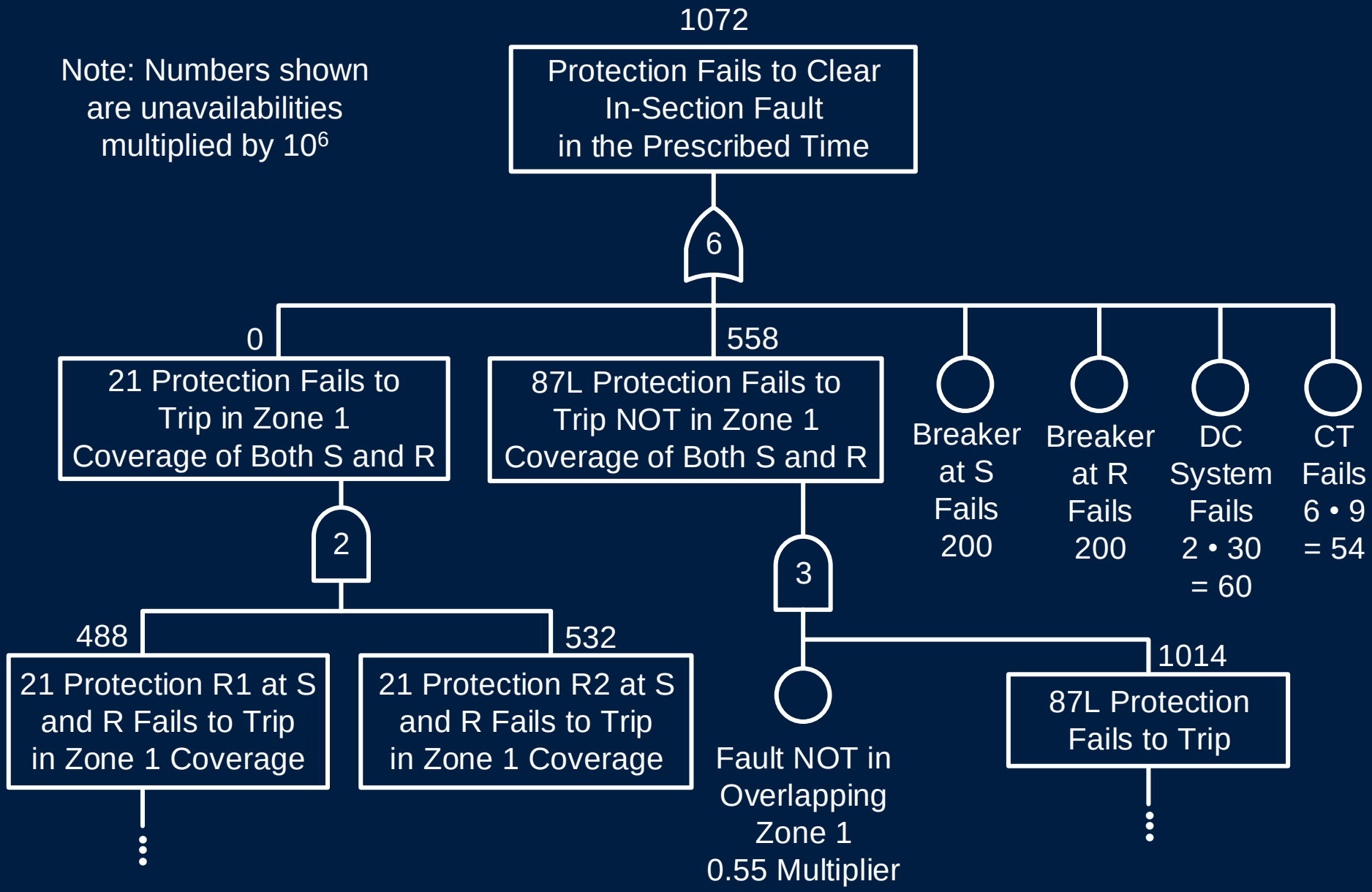
Reliability Concepts

- Failure rate (λ) = # failures per operating time
- Data collected from field observations
- Mean time between failures (MTBF) = average time between failures = λ^{-1}
- Mean time to repair (MTTR) = average time to correct failure and restore operation

Availability

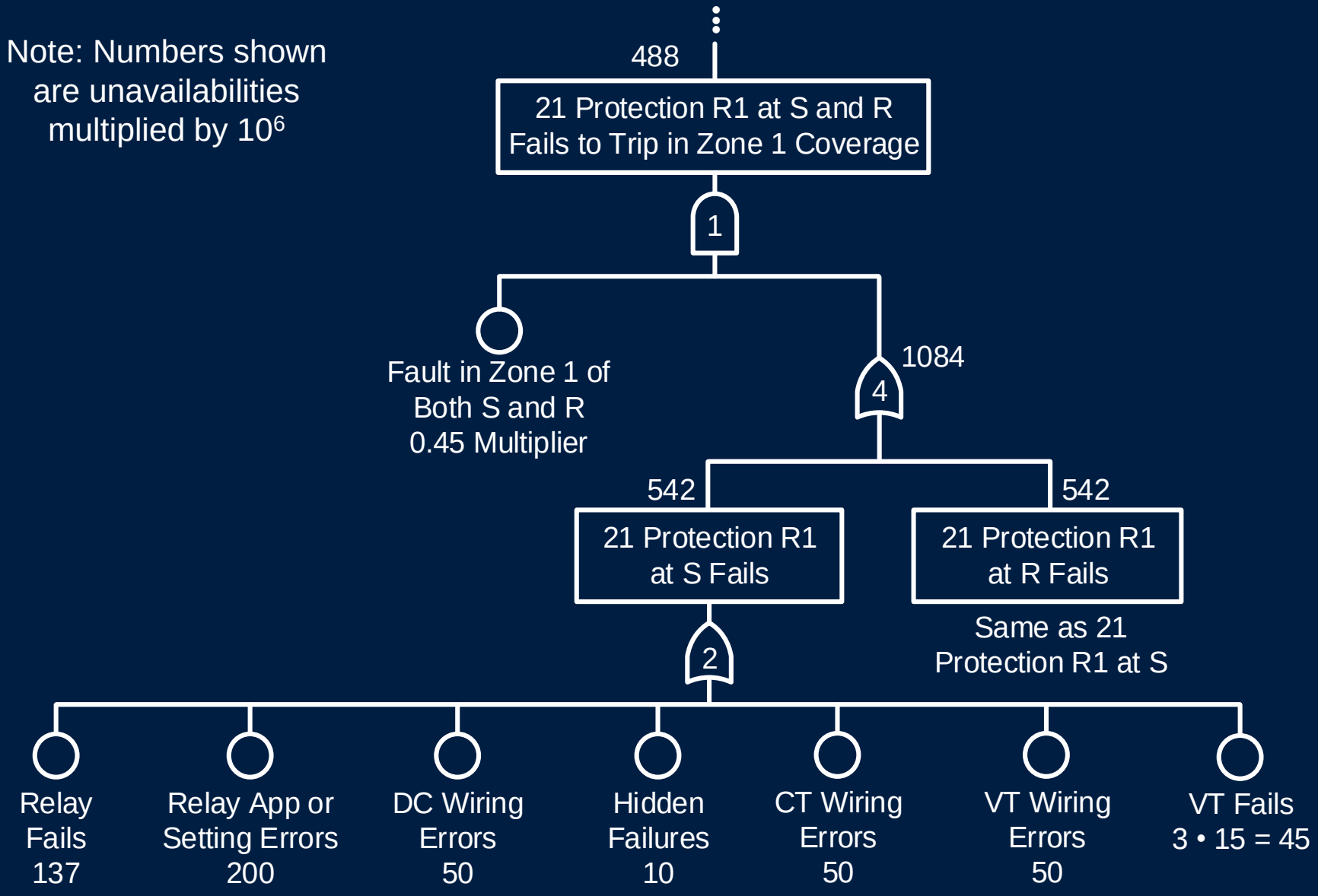
- Availability (A) = fraction of time device is able to operate
- $A \approx MTBF / (MTBF + MTTR)$
- Unavailability (U) = fraction of time device is unable to perform its function
- $U = 1 - A \approx \lambda \cdot MTTR$
- U and A are dimensionless but can be converted to time using appropriate factors

Dependability FT for 87L/21 and 21



Dependability FT for 87L/21 and 21

Note: Numbers shown are unavailabilities multiplied by 10^6



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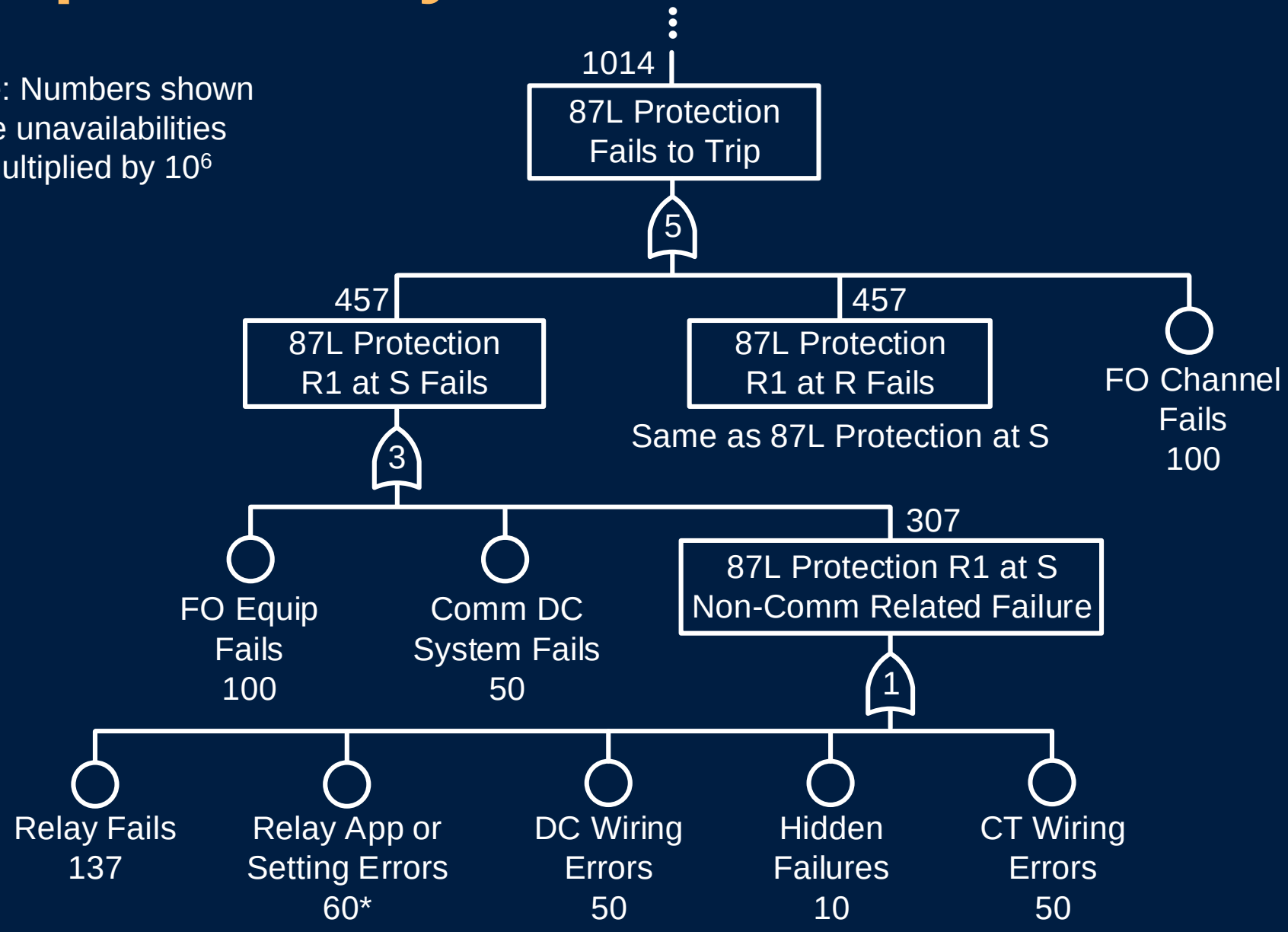
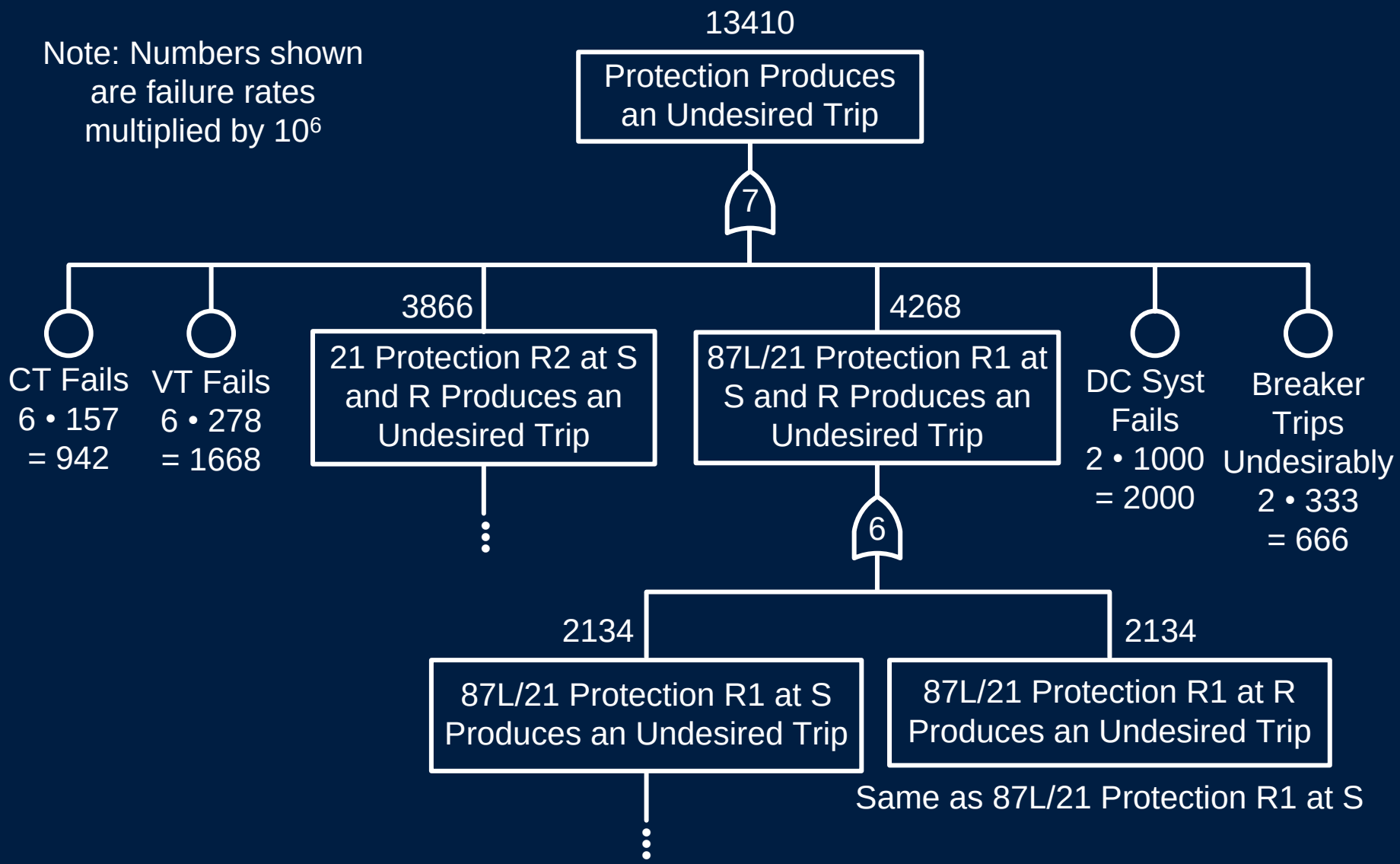


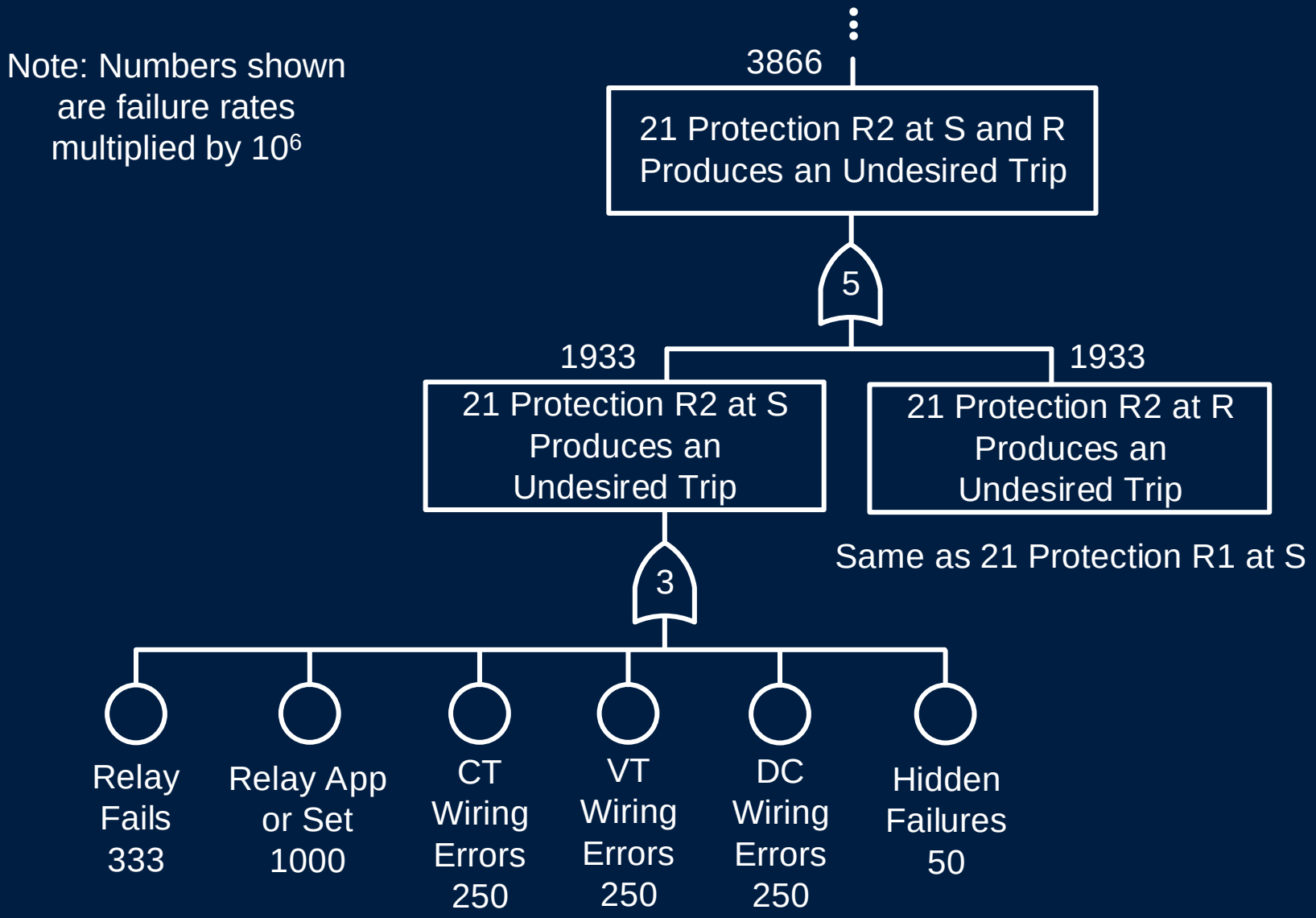
* Because of the simplicity of 87L settings

Security FT for 87L/21 and 21



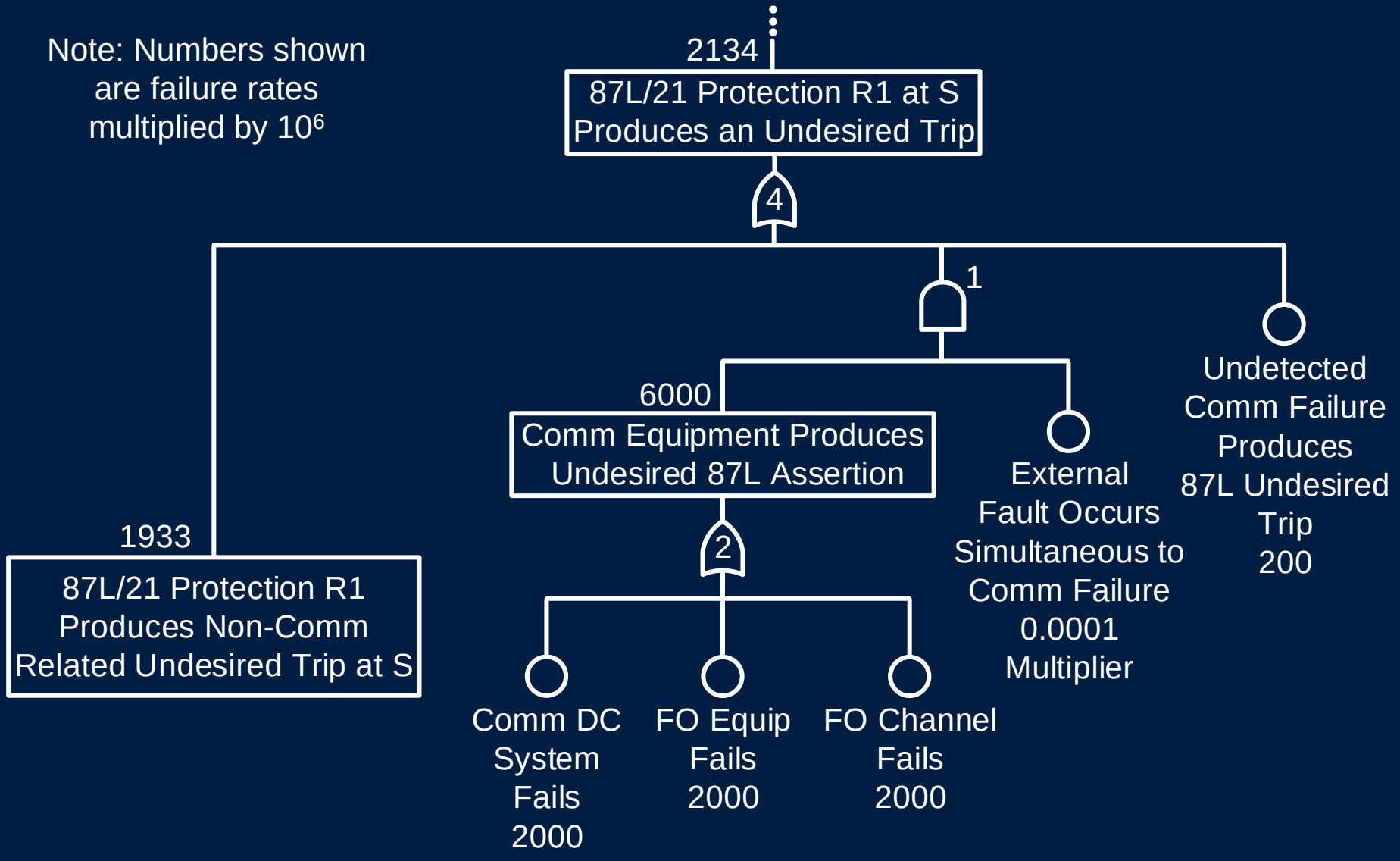
Security FT for 87L/21 and 21

Note: Numbers shown are failure rates multiplied by 10^6



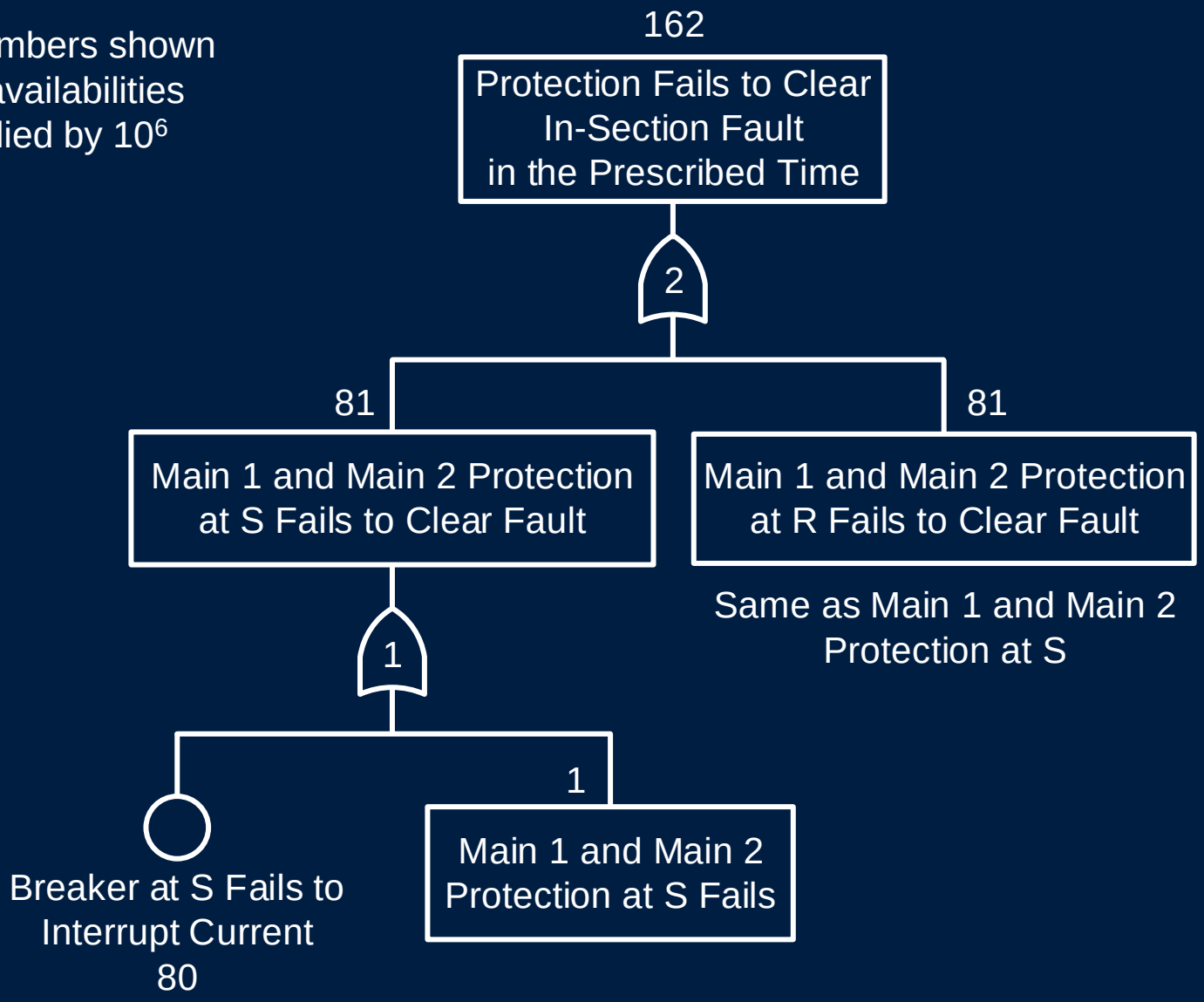
Security FT for 87L/21 and 21

Note: Numbers shown are failure rates multiplied by 10^6



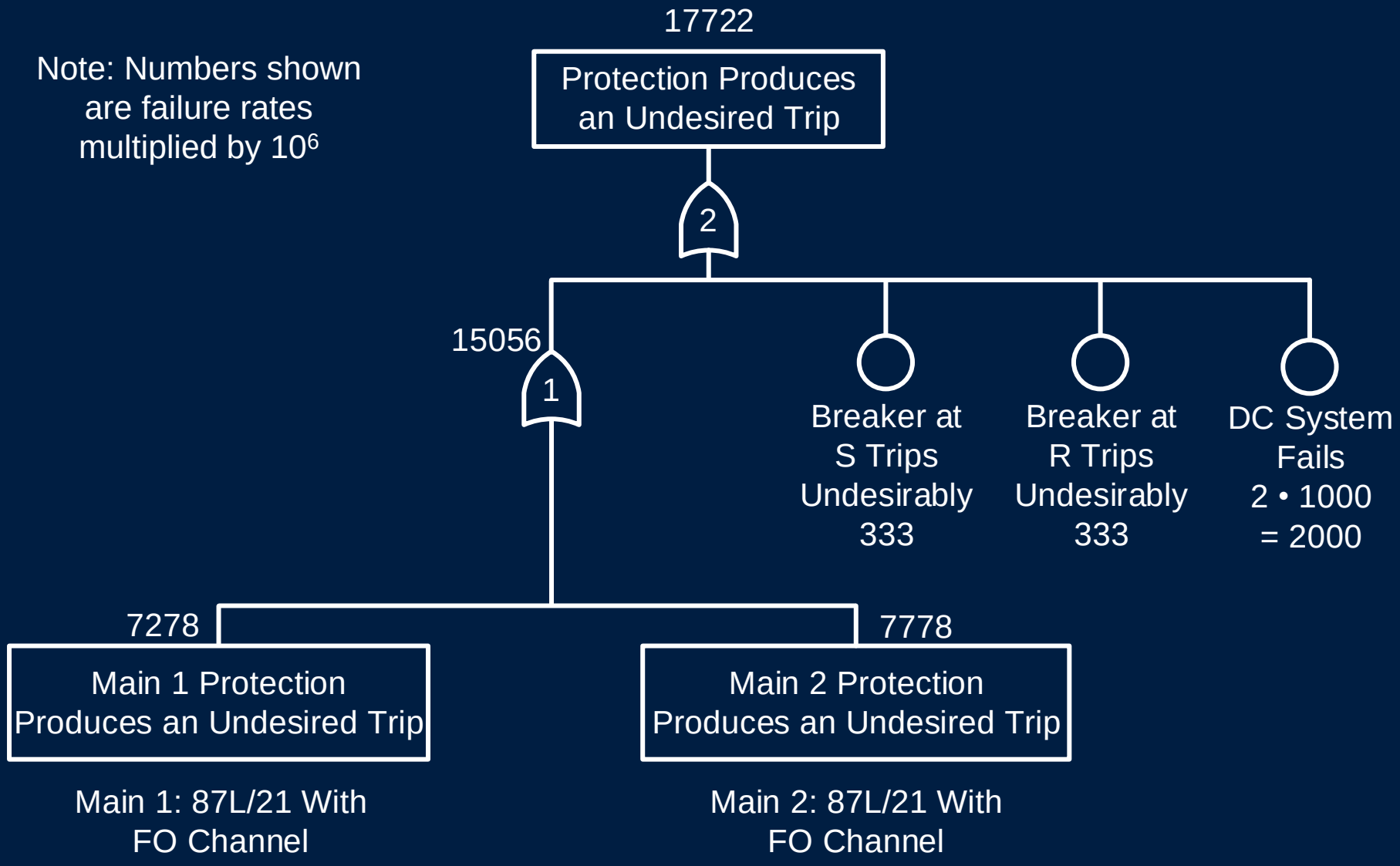
Dependability FT for Dual 87L/21

Note: Numbers shown are unavailabilities multiplied by 10^6



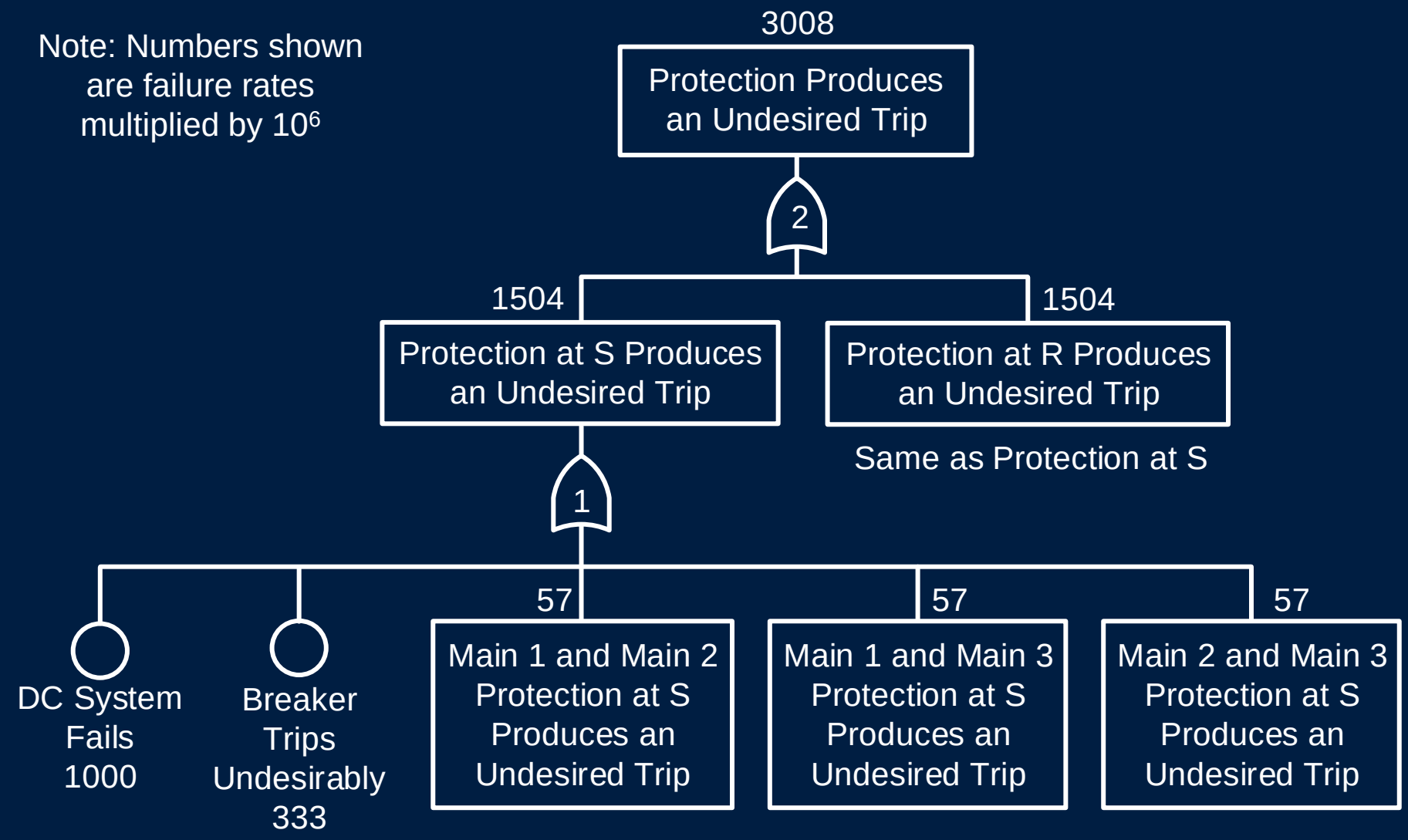
Security FT for Dual 87L/21

Note: Numbers shown are failure rates multiplied by 10^6

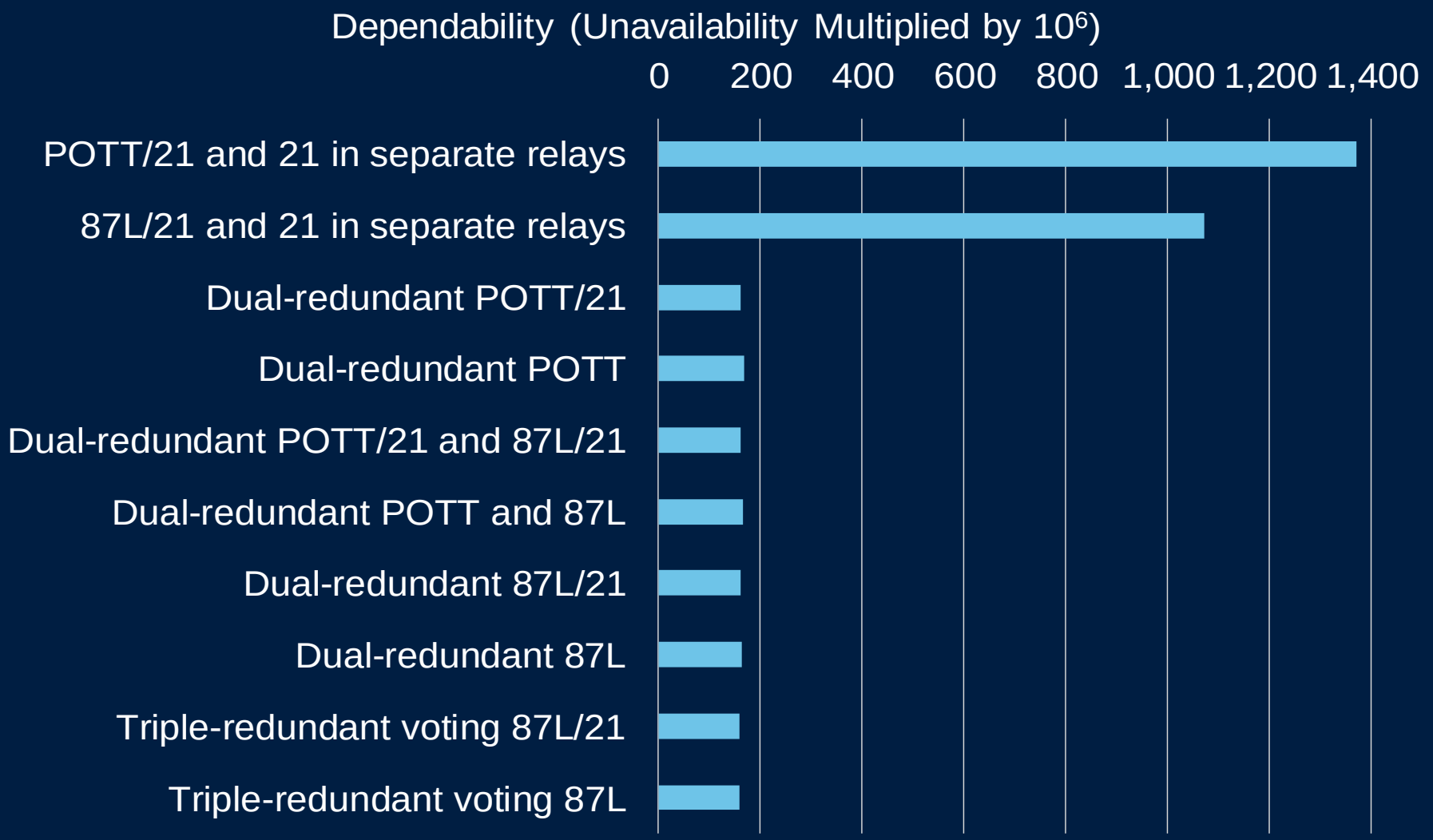


Security FT for Triple 87L/21

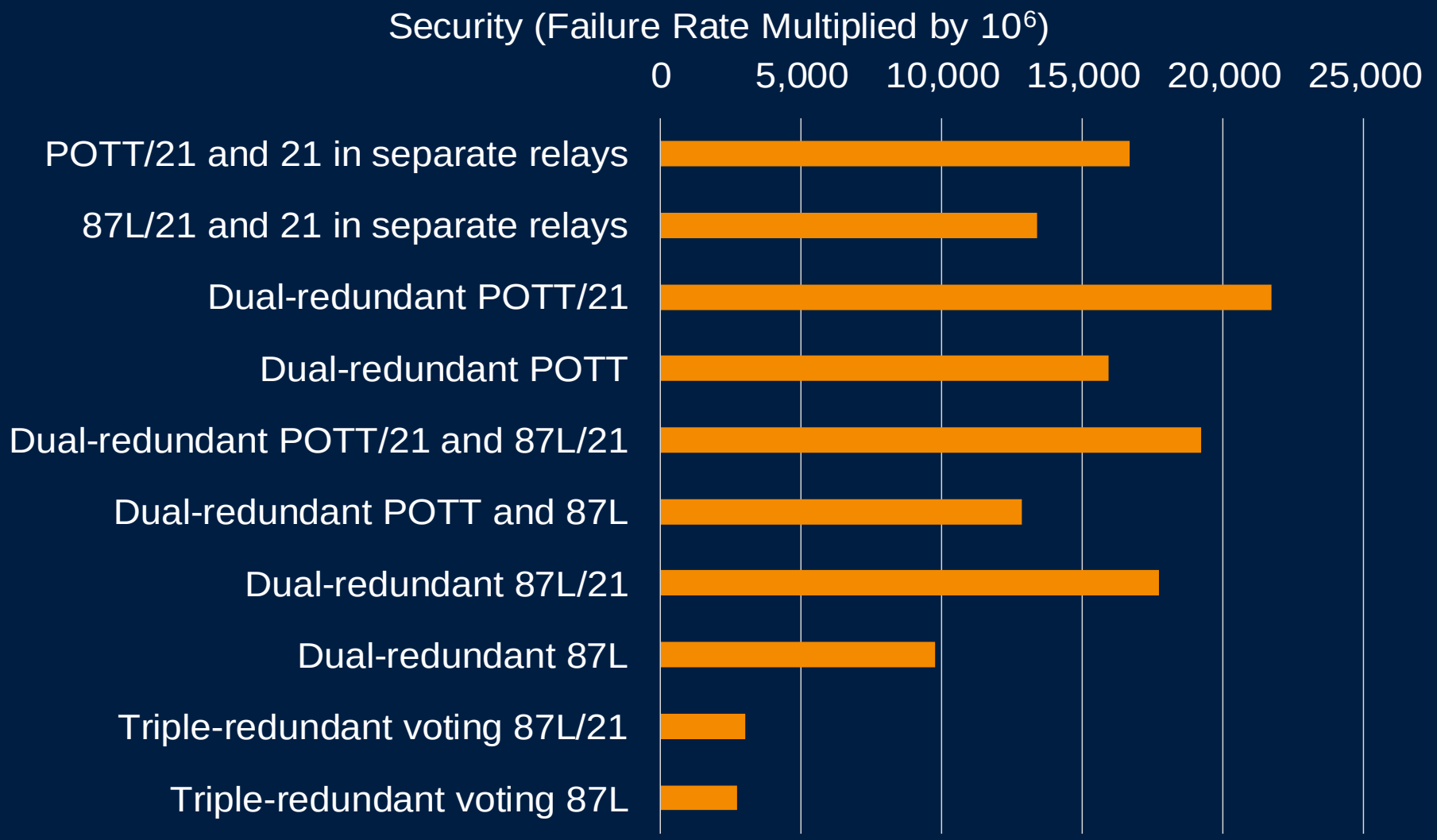
Note: Numbers shown are failure rates multiplied by 10^6



Line Protection Dependability Comparison



Line Protection Security Comparison



87L Is Best Solution for Complex Line Protection Applications

- Series compensation
- Mutual coupling
- Single-pole tripping
- Multiterminal and tapped lines
- Short lines

Conclusions

- Filtering delays phasor-based element operation
- Schemes with high-speed elements and fast channels trip in less than 1.2 cycles
- Time-domain principles substantially reduce relay operating times
- 67N is more sensitive than 21N
- 87L provides best combination of speed and sensitivity

Conclusions

- 87L schemes are more dependable and secure than POTT schemes
- Dual pilot schemes are more dependable and less secure than pilot and 21 schemes
- Triple redundancy with voting enhances security without impairing dependability
- Zone 1 removal enhances security and reduces speed of redundant schemes


Questions?