



# **Pilot Protection of Transmission Lines**

# Outline

- Transmission line introduction
- Typical protection schemes
- Need for pilot aided schemes
- Various pilot schemes
- Redundancy considerations
- Desirable attributes of pilot relay



# Transmission Lines

- A Vital Part of the Power System:
- Provide path to transfer power between generation and load
- Operate at voltage levels from 69kV to 765kV
- Deregulated markets, economic, environmental requirements have pushed utilities to operate transmission lines close to their limits.



# Transmission Lines

- Classification of line length depends on:
  - ☐ Source-to-line Impedance Ratio (SIR), and
  - ☐ Nominal voltage
- Length considerations:
  - ☐ Short Lines:  $SIR > 4$
  - ☐ Medium Lines:  $0.5 < SIR < 4$
  - ☐ Long Lines:  $SIR < 0.5$

# Typical Protection Schemes

## Short Lines

- Current differential
- Phase comparison
- Permissive Overreach Transfer Trip (POTT)
- Directional Comparison Blocking (DCB)

# Typical Protection Schemes

## Medium Lines

- Phase comparison
- Directional Comparison Blocking (DCB)
- Permissive Underreach Transfer Trip (PUTT)
- Permissive Overreach Transfer Trip (POTT)
- Unblocking
- Step Distance
- Step or coordinated overcurrent
- Inverse time overcurrent
- Current Differential

# Typical Protection Schemes

## Long Lines

- Phase comparison
- Directional Comparison Blocking (DCB)
- Permissive Underreach Transfer Trip (PUTT)
- Permissive Overreach Transfer Trip (POTT)
- Unblocking
- Step Distance
- Step or coordinated overcurrent
- Current Differential

# Introduction

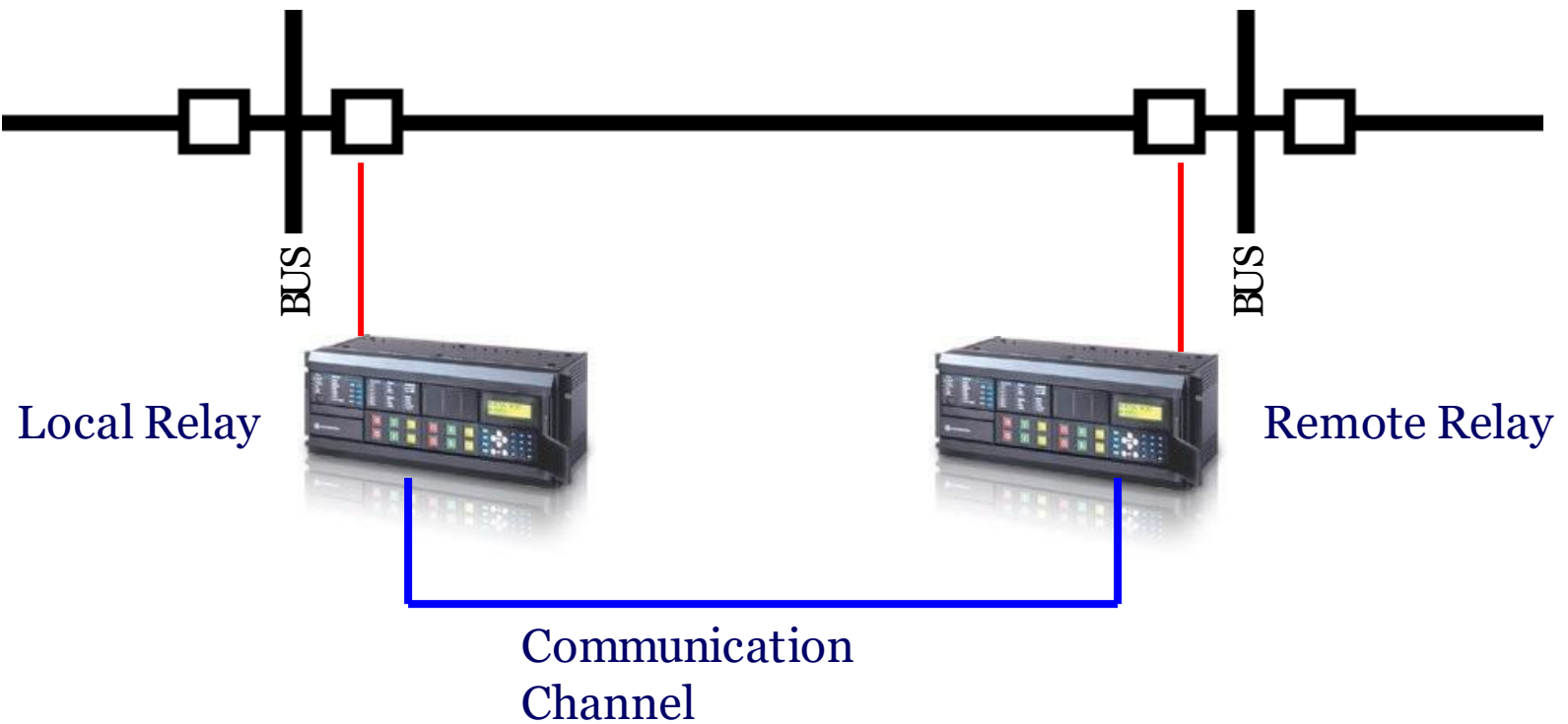
- Nonpilot protection using overcurrent and distance relays, contain a fundamental difficulty :

It is not possible to instantaneously clear a fault from both ends of a transmission line if the fault is near one end of the line.

- Pilot protection is an adaptation of the principles of differential relaying that avoids the use of control cable between terminals.
- The term 'pilot' refers to a communication channel between two or more ends of a transmission line to provide instantaneous clearing over 100% of the line.
- This form of protection is also known as 'teleprotection'.



# Need For Pilot Aided Schemes

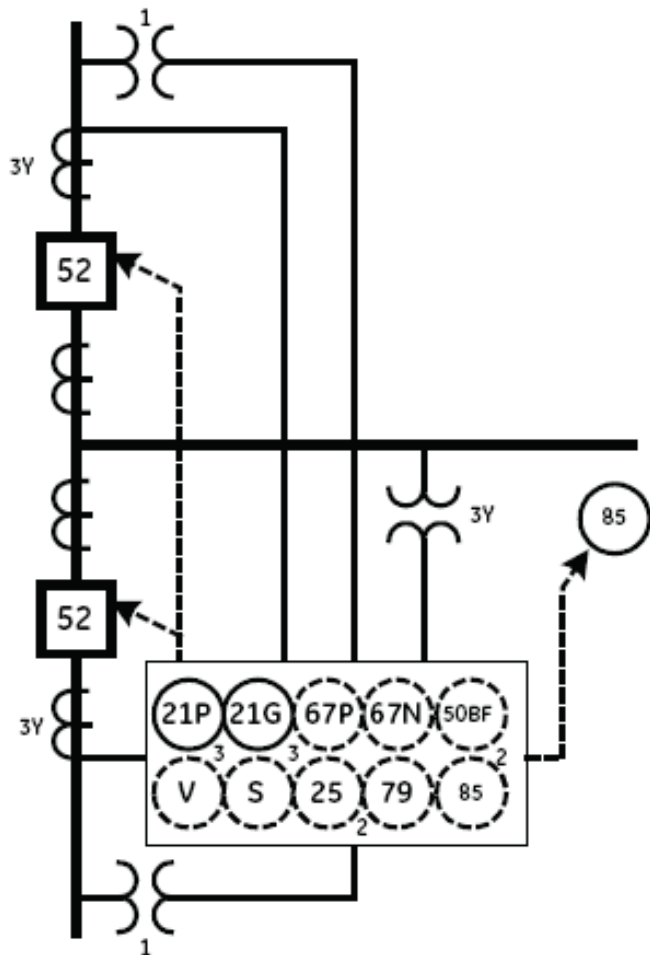


# Pilot Communications Channels

- Distance-based pilot schemes traditionally utilize simple on/off communications between relays, but can also utilize peer-to-peer communications and GOOSE messaging over digital channels
- Typical communications media include:
  - Pilot-wire (50Hz, 60Hz, AT)
  - Power line carrier
  - Microwave
  - Radio
  - Optic fiber (directly connected or multiplexed channels)

# Distance-based Pilot Protection

## Pilot Protection Schemes – Dual Breaker



### Typical Functions

- 21P Phase distance
- 21G Ground distance
- 85 Power line carrier / microwave transmitter & receiver

### Additional Functions

- 67P Phase directional overcurrent
- 67N Neutral directional overcurrent
- 50BF Breaker Failure
- 25 Synchrocheck
- 79 Reclosing
- V, S Voltage and Power metering

### Other Communications Options

- 85 Inter-Relay Communications
- 85 Sonet Multiplexer

### Synchrophasors

- Phasor Measurement Unit

# Pilot-Aided Distance-Based Schemes

☐ **DUTT** –Direct Under-reaching Transfer Trip

☐ **PUTT** –Permissive Under-reaching Transfer Trip

 ☐ **POTT** –Permissive Over-reaching Transfer Trip

☐ **Hybrid POTT** –Hybrid Permissive Over-reaching Transfer Trip

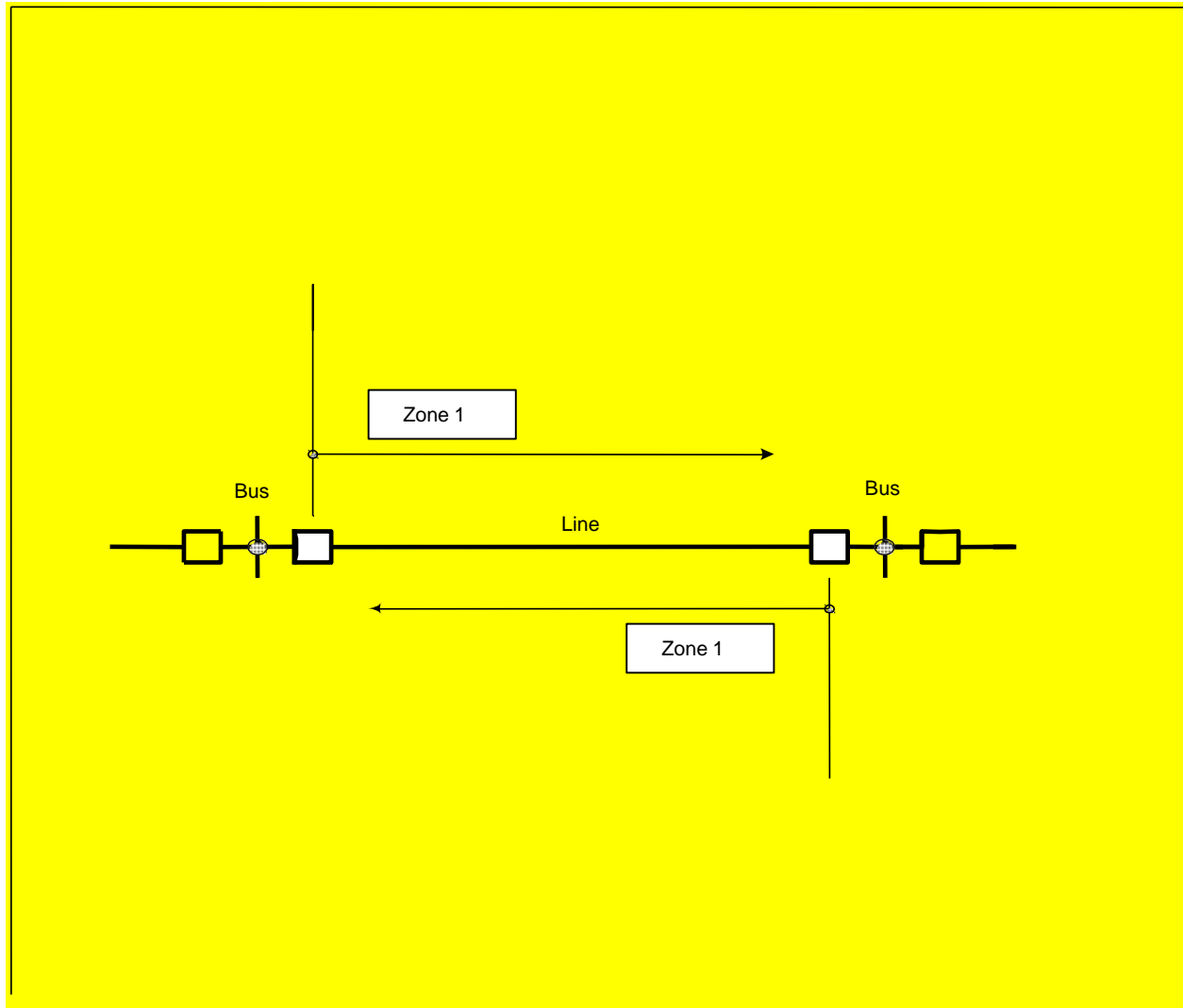
 ☐ **DCB** –Directional Comparison Blocking Scheme

☐ **DCUB** –Directional Comparison Unblocking Scheme

# Direct Underreaching Transfer Trip (DUTT)

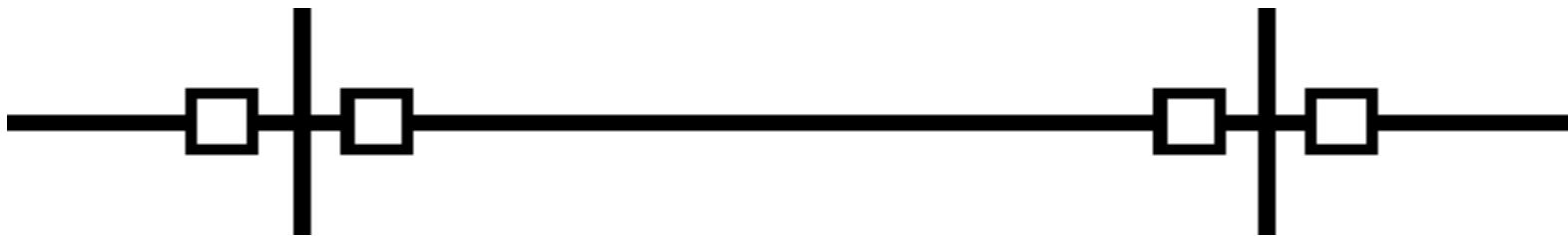
- Requires only underreaching (RU) functions which overlap in reach (Zone 1).
- Applied with FSKchannel
  - GUARD frequency transmitted during normal conditions
  - TRIP frequency when one RU function operates
- Scheme does not provide tripping for faults beyond RU reach if remote breaker is open or channel is inoperative.
- Dual pilot channels improve security

# DUTT Scheme



# Permissive Underreaching Transfer Trip (PUTT)

- Requires both under (RU) and overreaching (RO) functions
- Identical to DUTT, with pilot tripping signal supervised by RO(Zone 2)

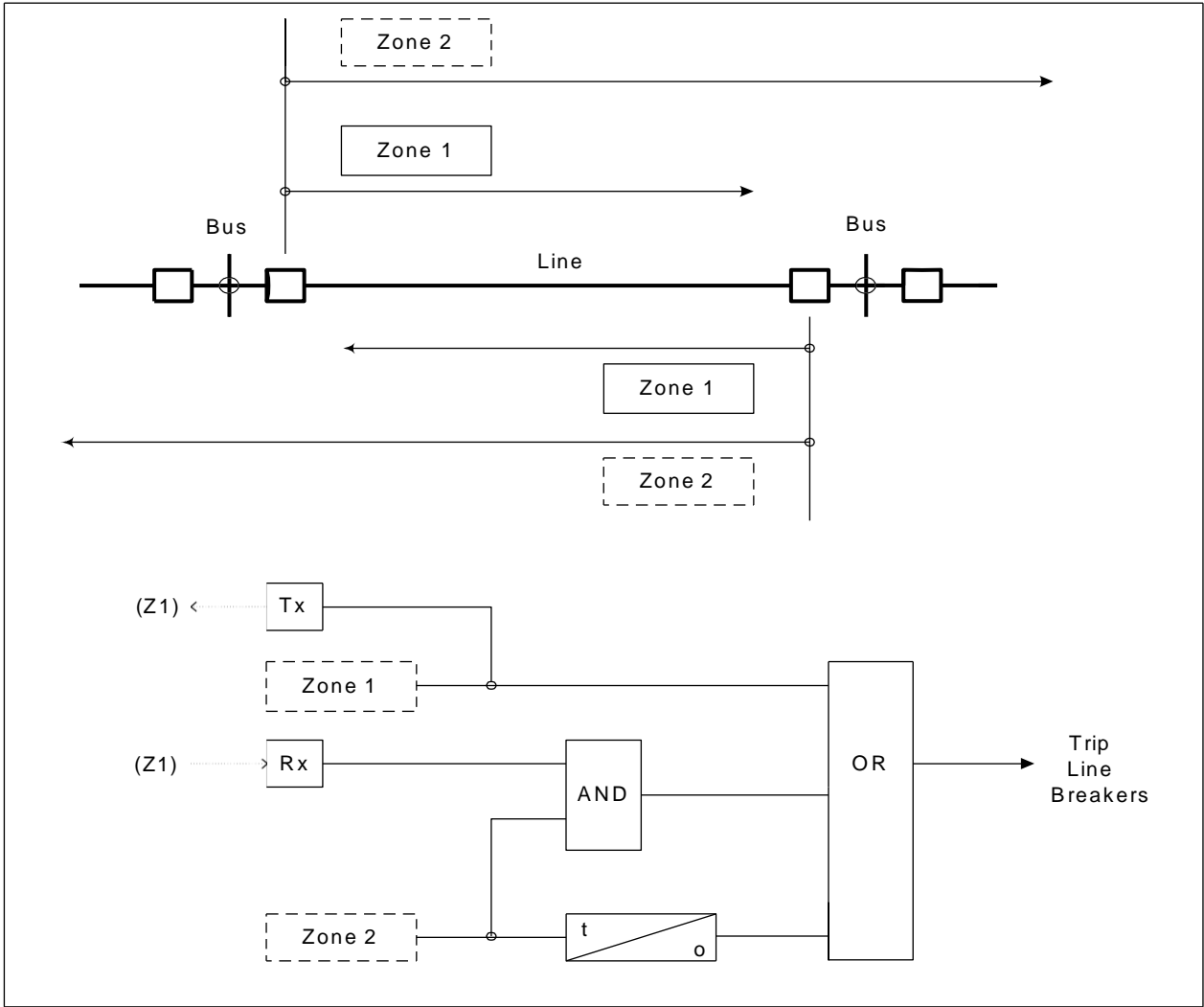




# Permissive Overreaching Transfer Trip (POTT)

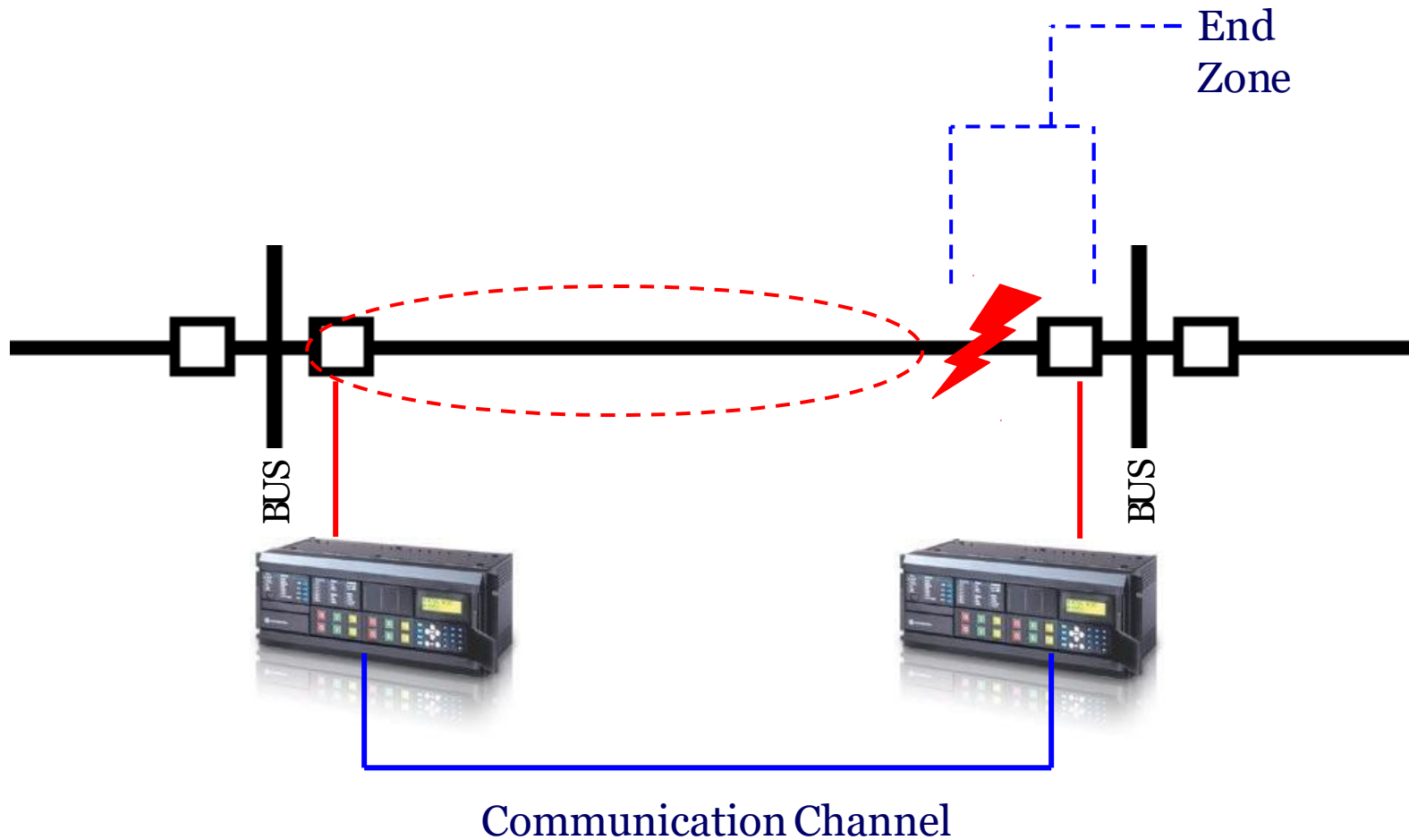
- Requires overreaching (RO) functions (Zone 2).
- Applied with FSKchannel:
  - GUARDfrequency sent in stand-by
  - TRIPfrequency when one ROfunction operates
- No trip for external faults if pilot channel is inoperative
- Time-delayed tripping can be provided

# POTT Scheme

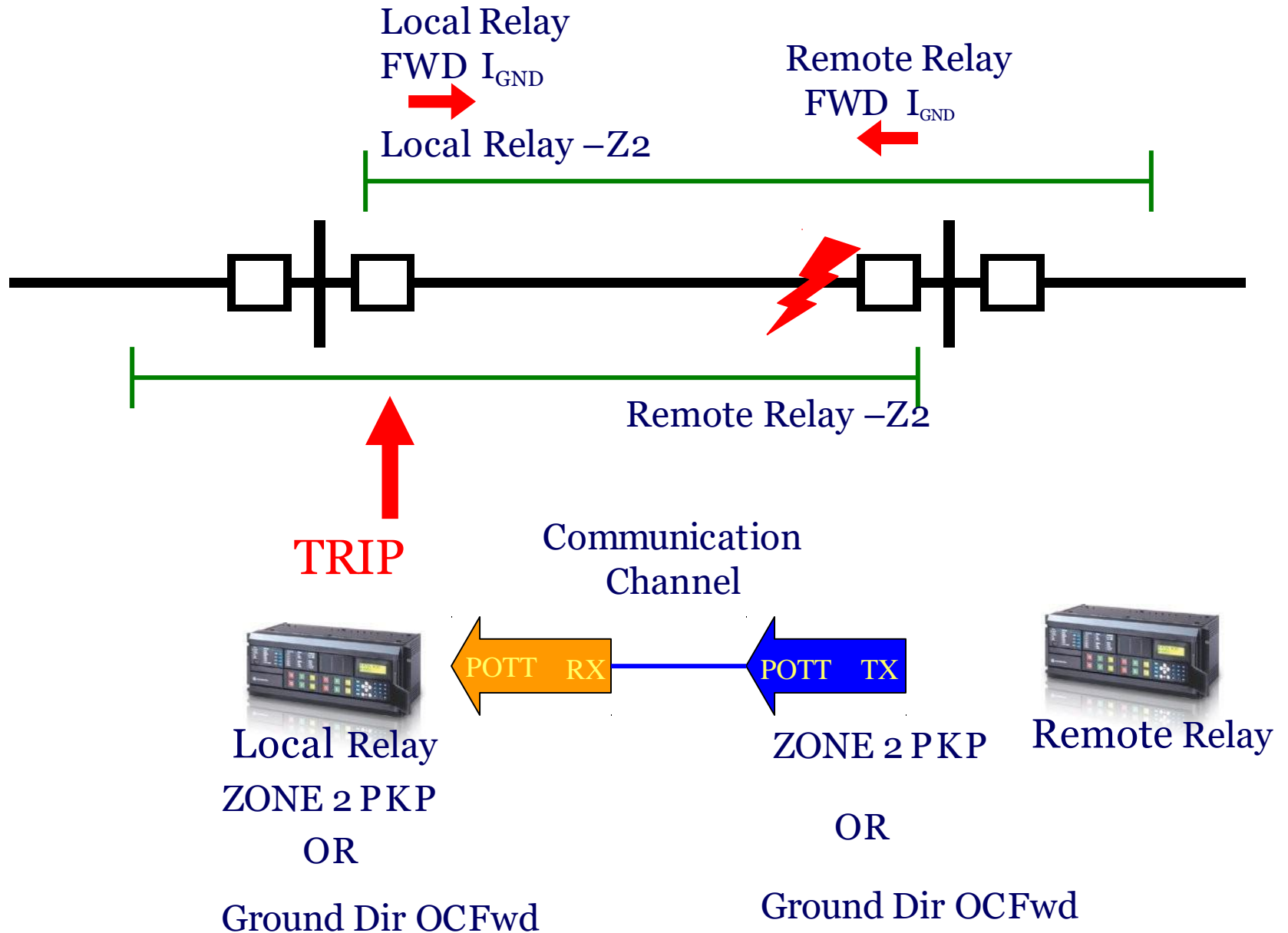


# POTT Scheme

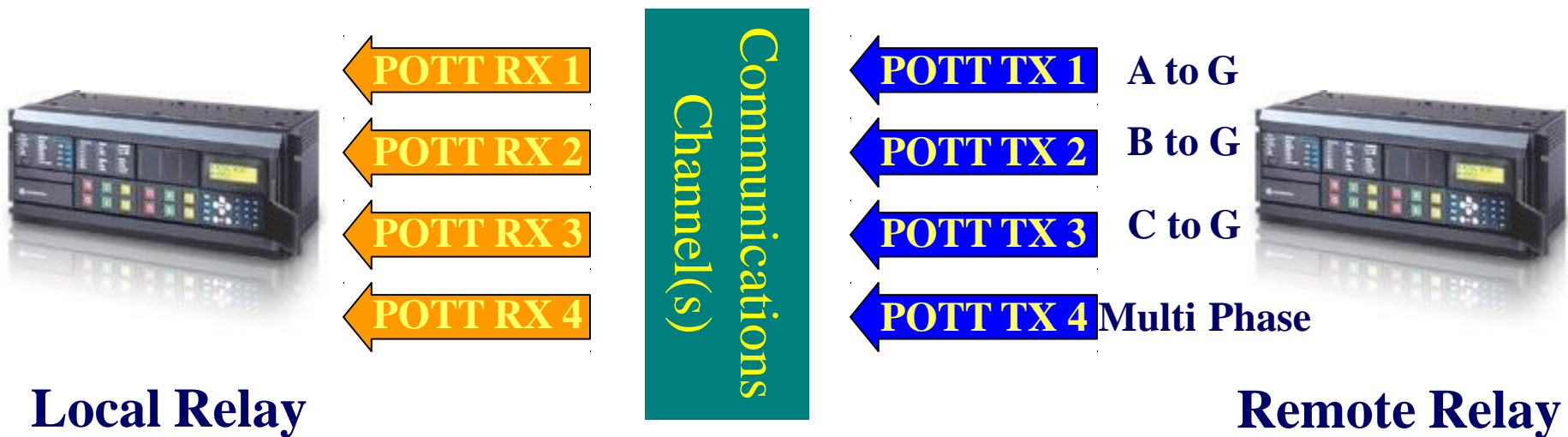
POTT – Permissive Over-reaching Transfer Trip



# POTT Scheme

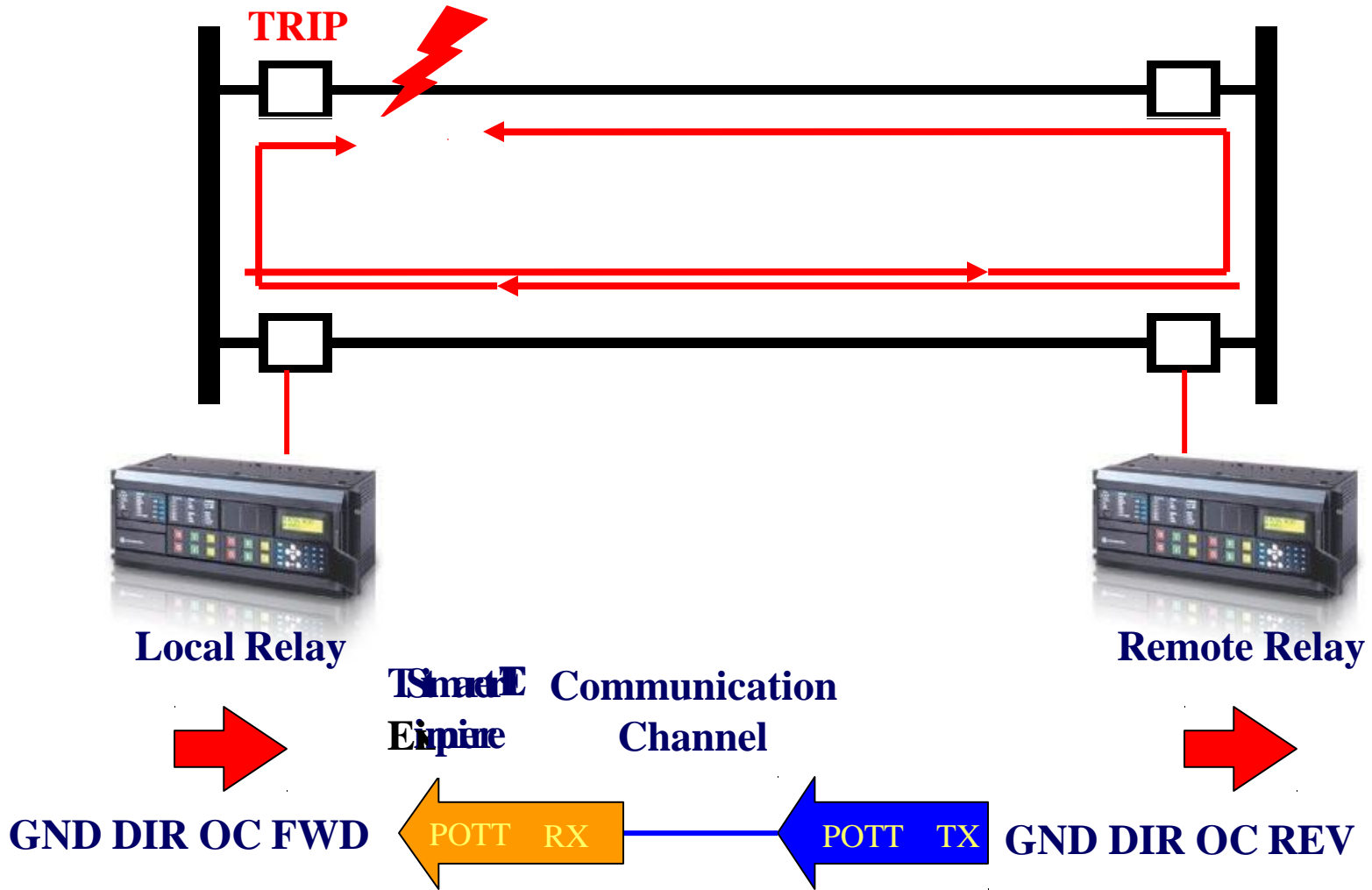


# POTT Scheme



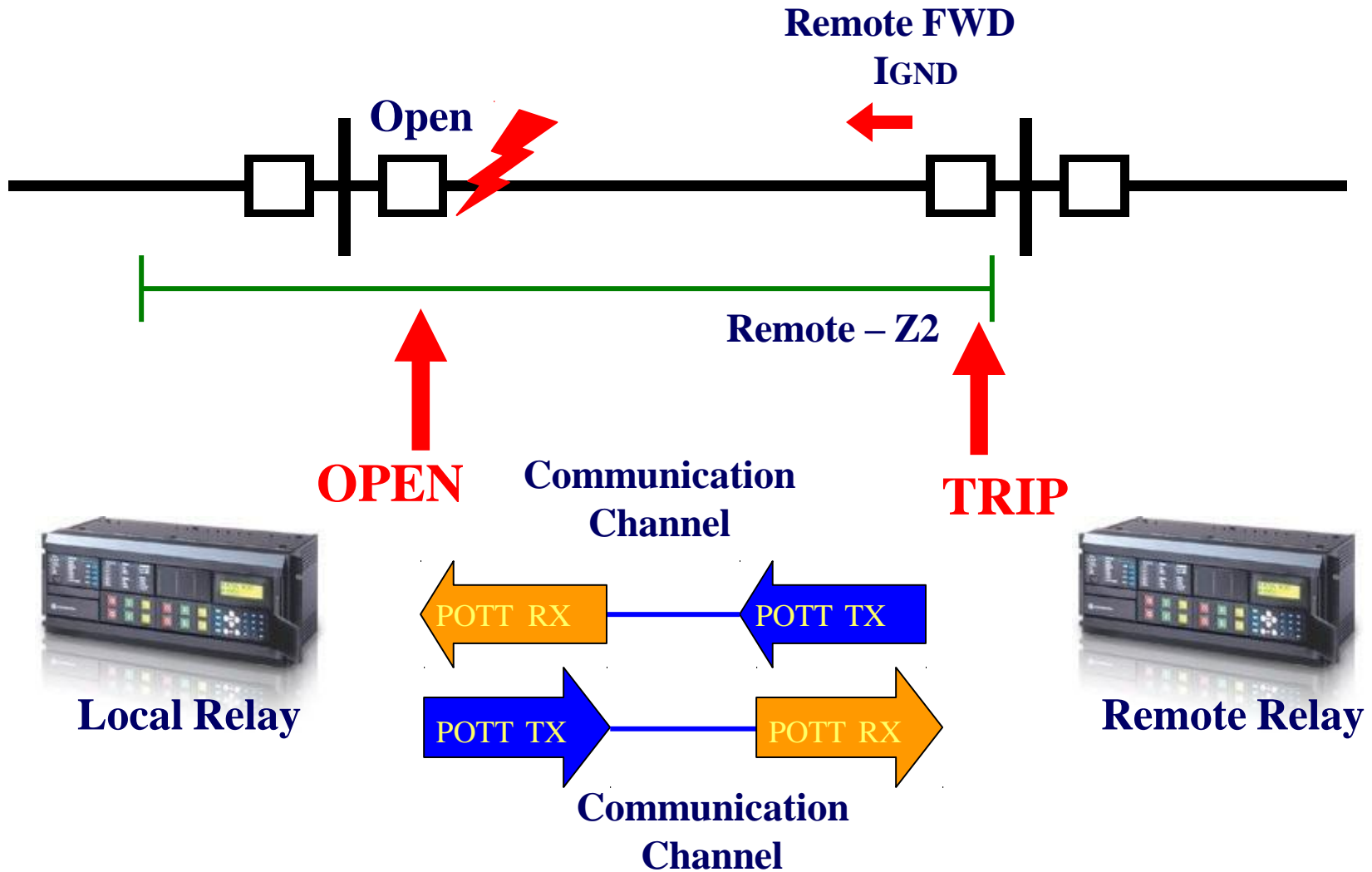
# POTT Scheme

Current reversal example



# POTT Scheme

## Echo example

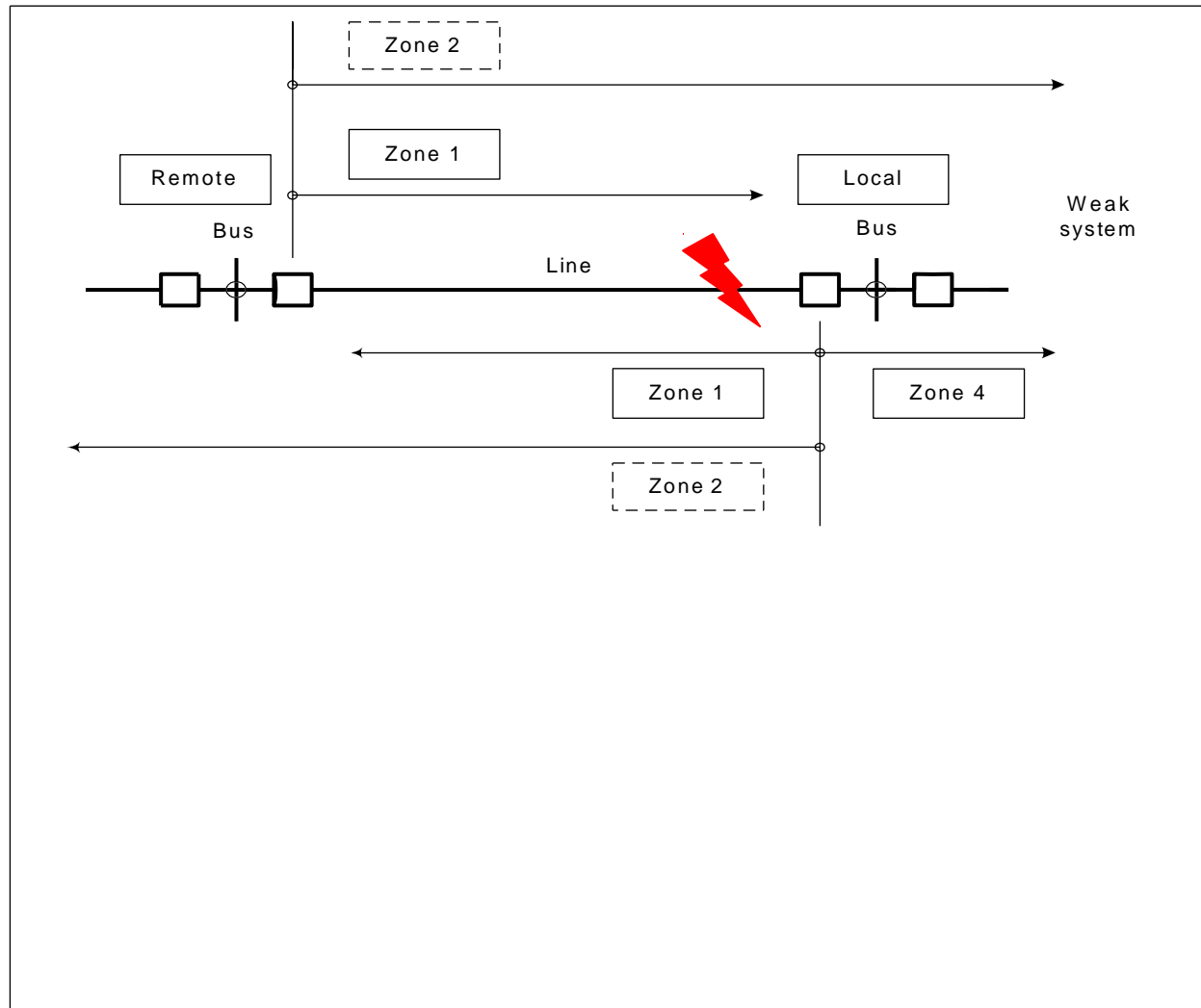


# Hybrid POTT

- Intended for three-terminal lines and weak infeed conditions
- Echo feature adds security during weak infeed conditions
- Reverse-looking distance and oc elements used to identify external faults



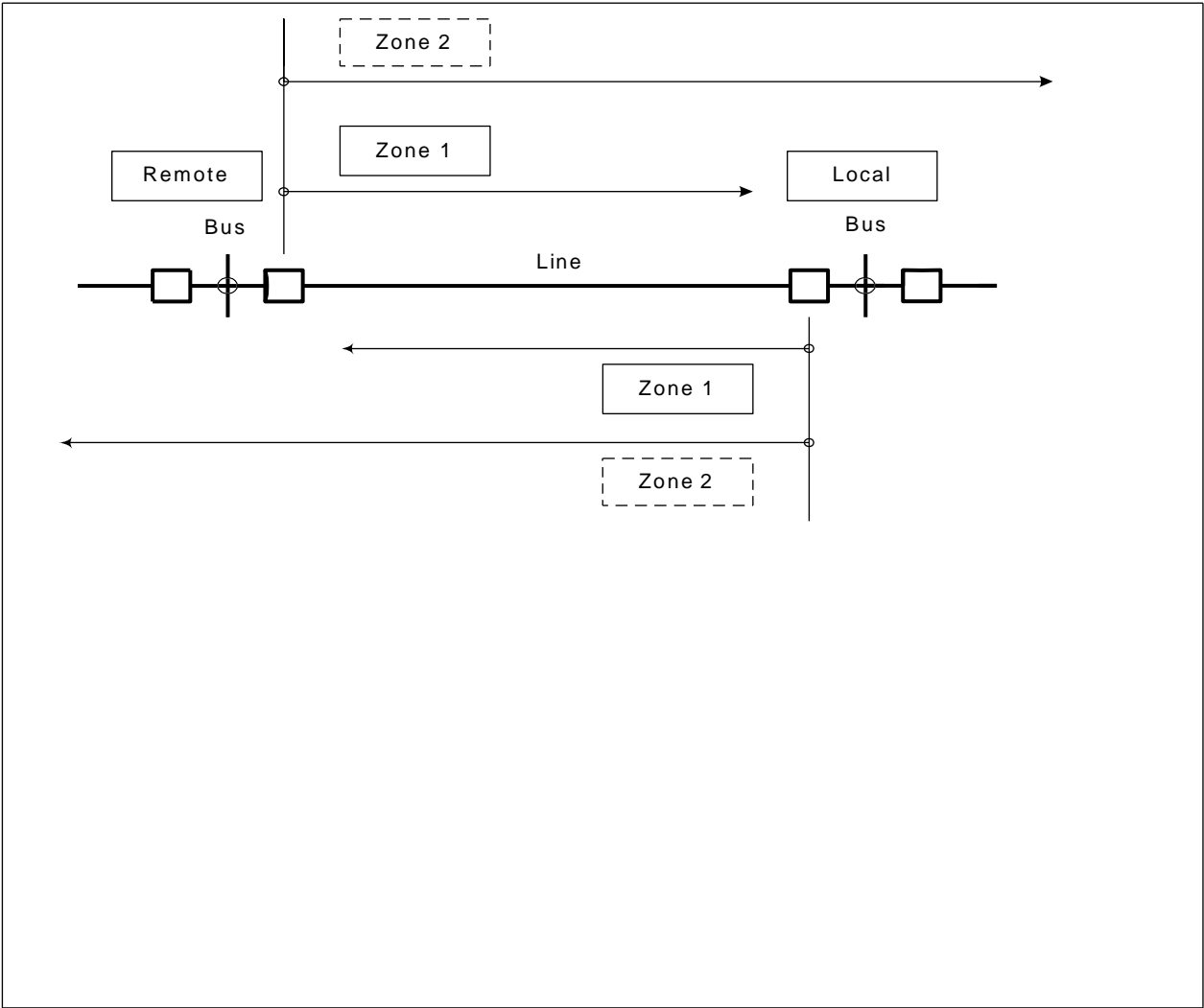
# Hybrid POTT



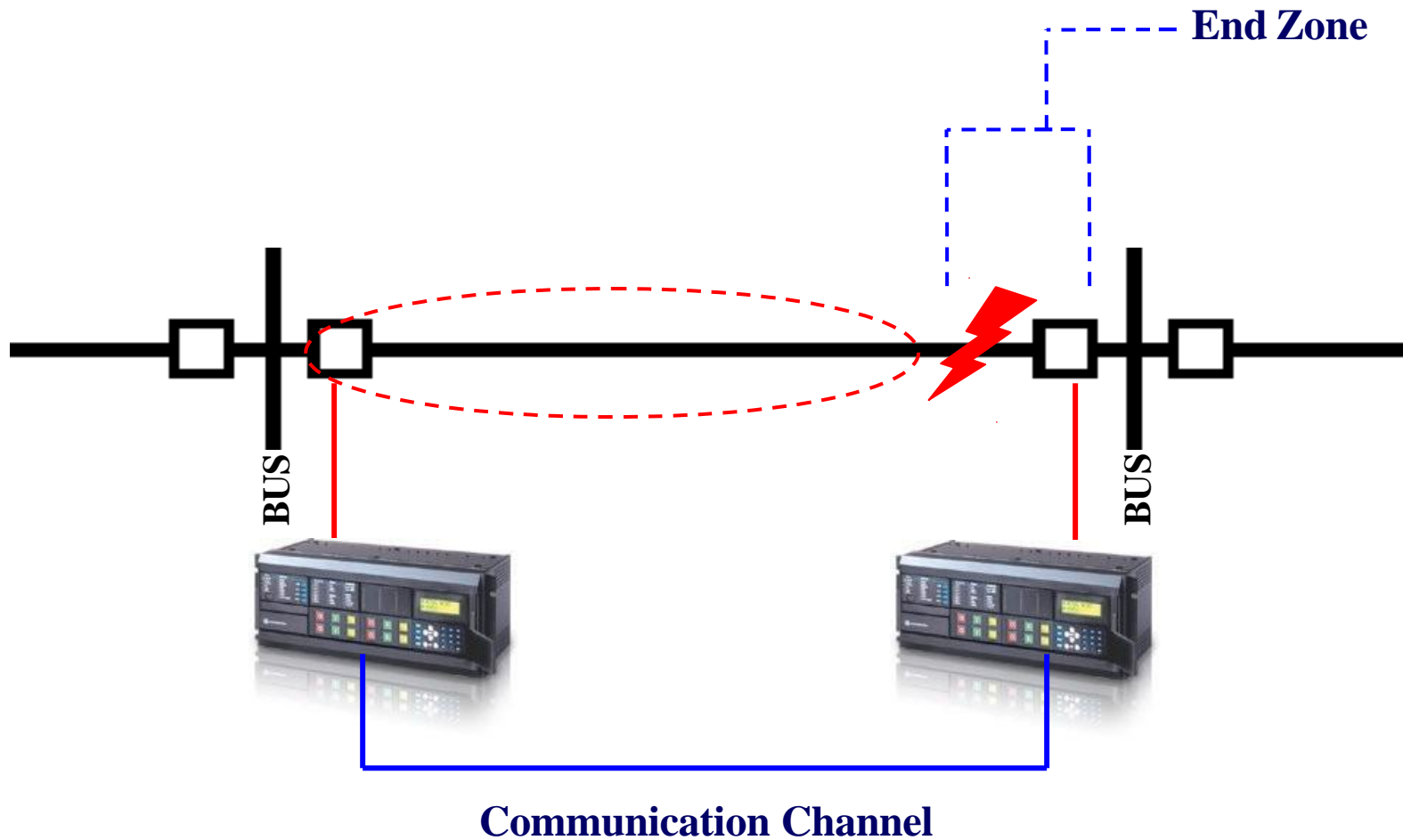
# Directional Comparison Blocking (DCB)

- Requires overreaching (RO) tripping and blocking (B) functions
- ON/OFF pilot channel typically used (i.e., PLC)
  - Transmitter is keyed to ON state when blocking function(s) operate
  - Receipt of signal from remote end blocks tripping relays
- Tripping function set with Zone 2 reach or greater
- Blocking functions include Zone 3 reverse and low-set ground overcurrent elements

# DCB Scheme

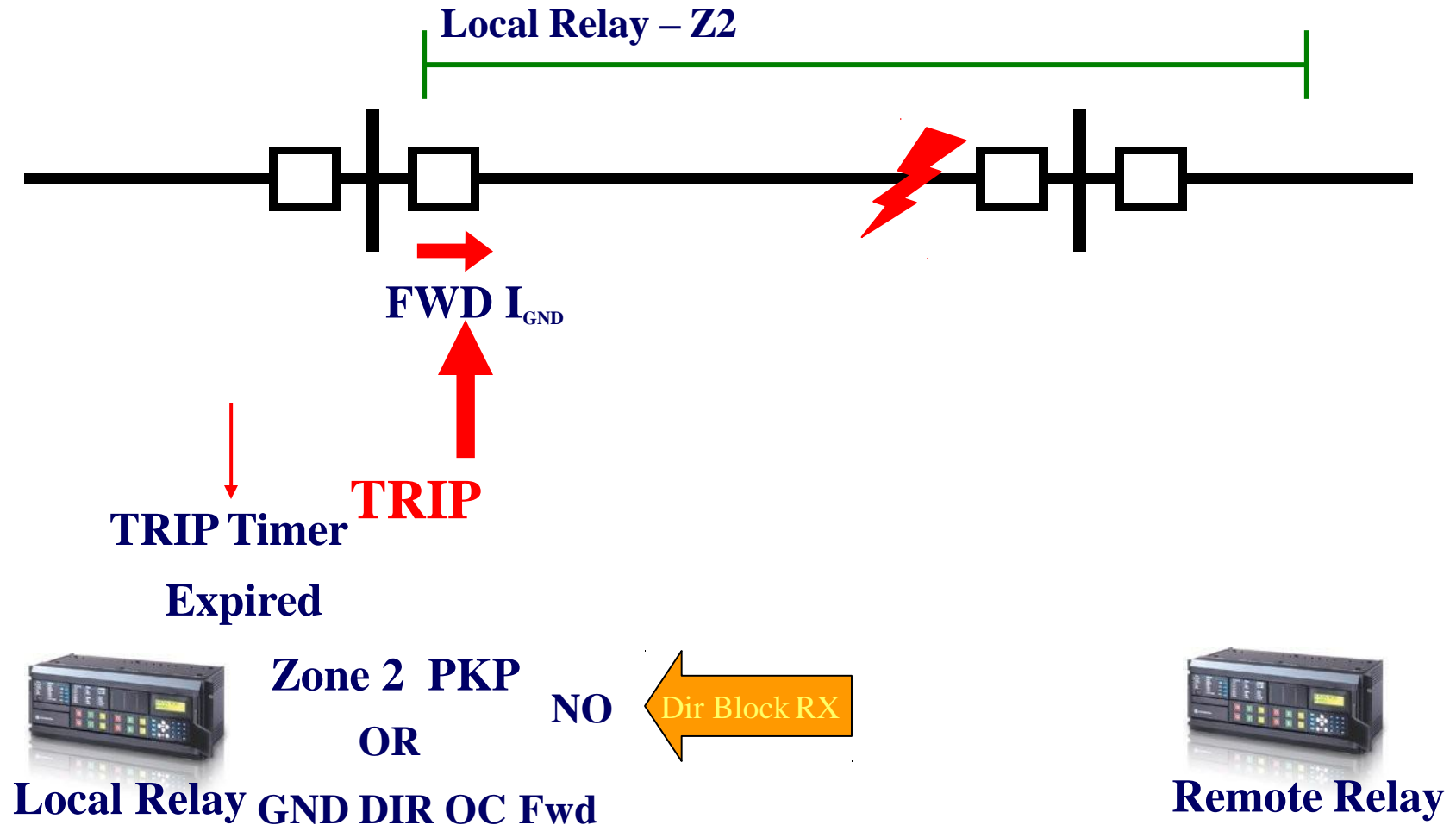


# Directional Comparison Blocking (DCB)



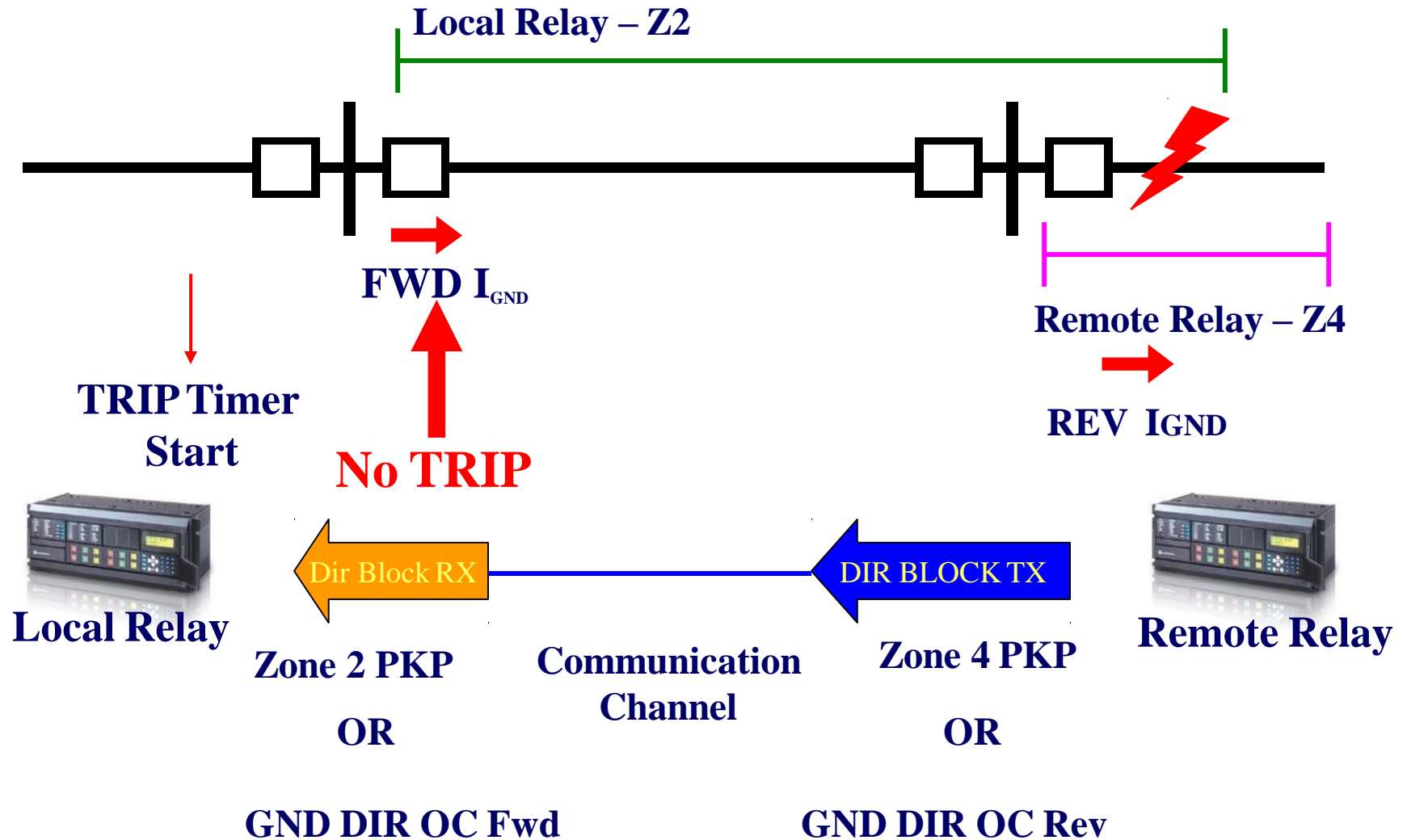
# Directional Comparison Blocking (DCB)

## Internal Faults



# Directional Comparison Blocking (DCB)

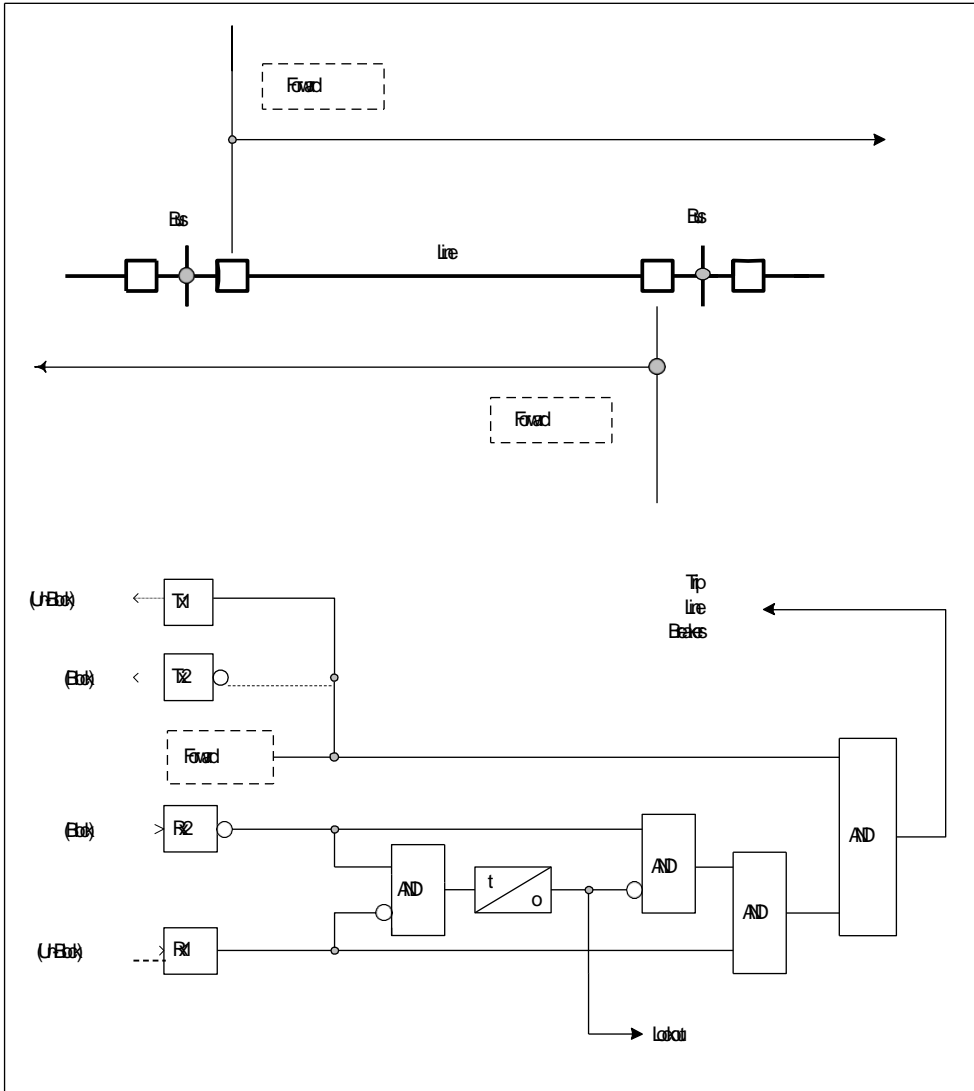
## External Faults



# Directional Comparison Unblocking (DCUB)

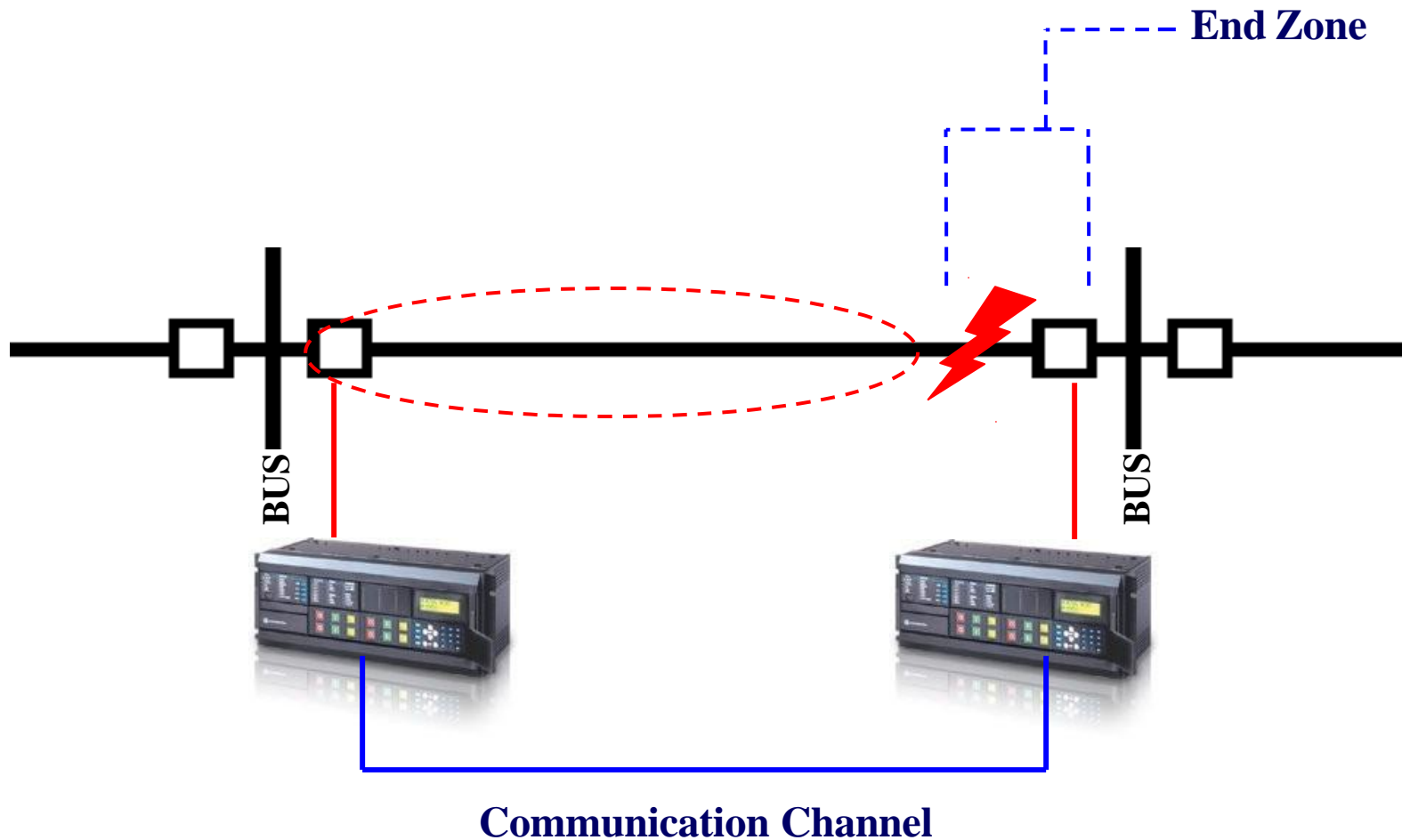
- Applied to Permissive Overreaching (POR) schemes to overcome the possibility of carrier signal attenuation or loss as a result of the fault
- Unblocking provided in the receiver when signal is lost:
  - If signal is lost due to fault, at least one permissive RO functions will be picked up
  - Unblocking logic produces short-duration TRIP signal (150-300 ms). If RO function not picked up, channel lockout occurs until GUARD signal returns

# DCUB Scheme



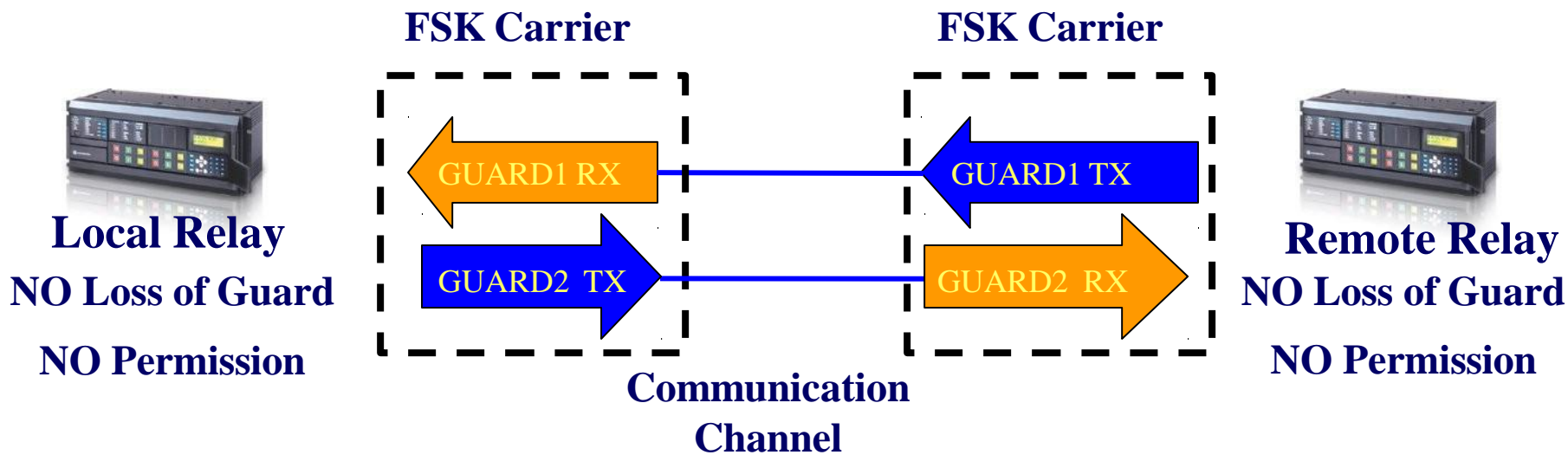


# Directional Comparison Unblocking (DCUB)



# Directional Comparison Unblocking (DCUB)

Normal conditions

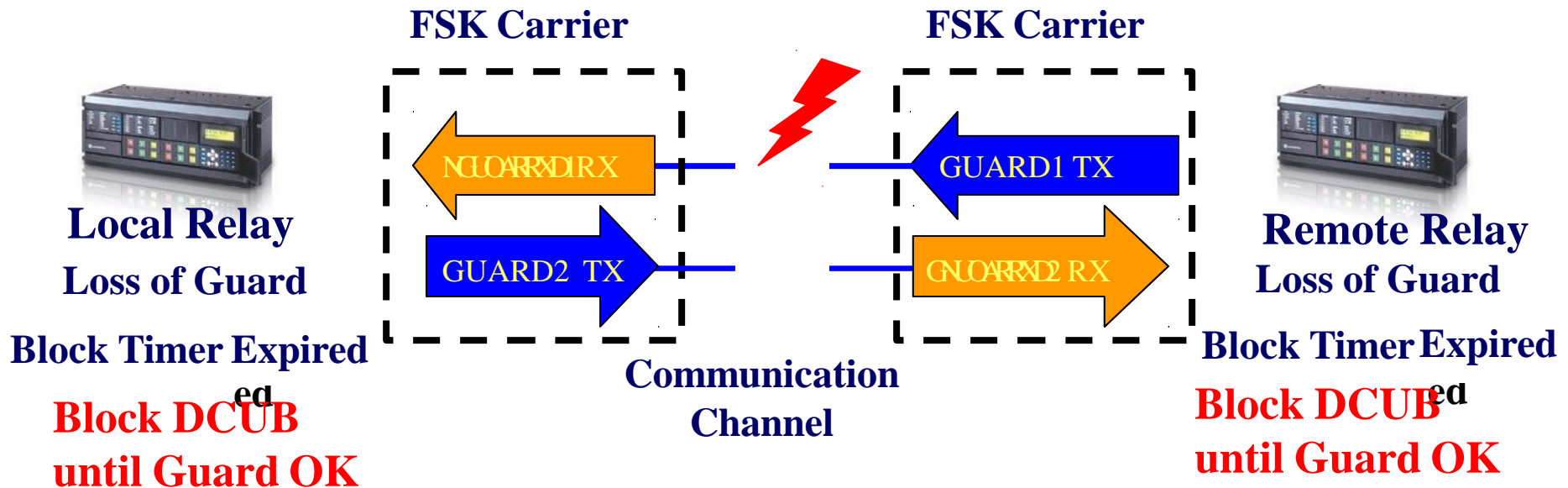


# Directional Comparison Unblocking (DCUB)

Normal conditions, channel failure

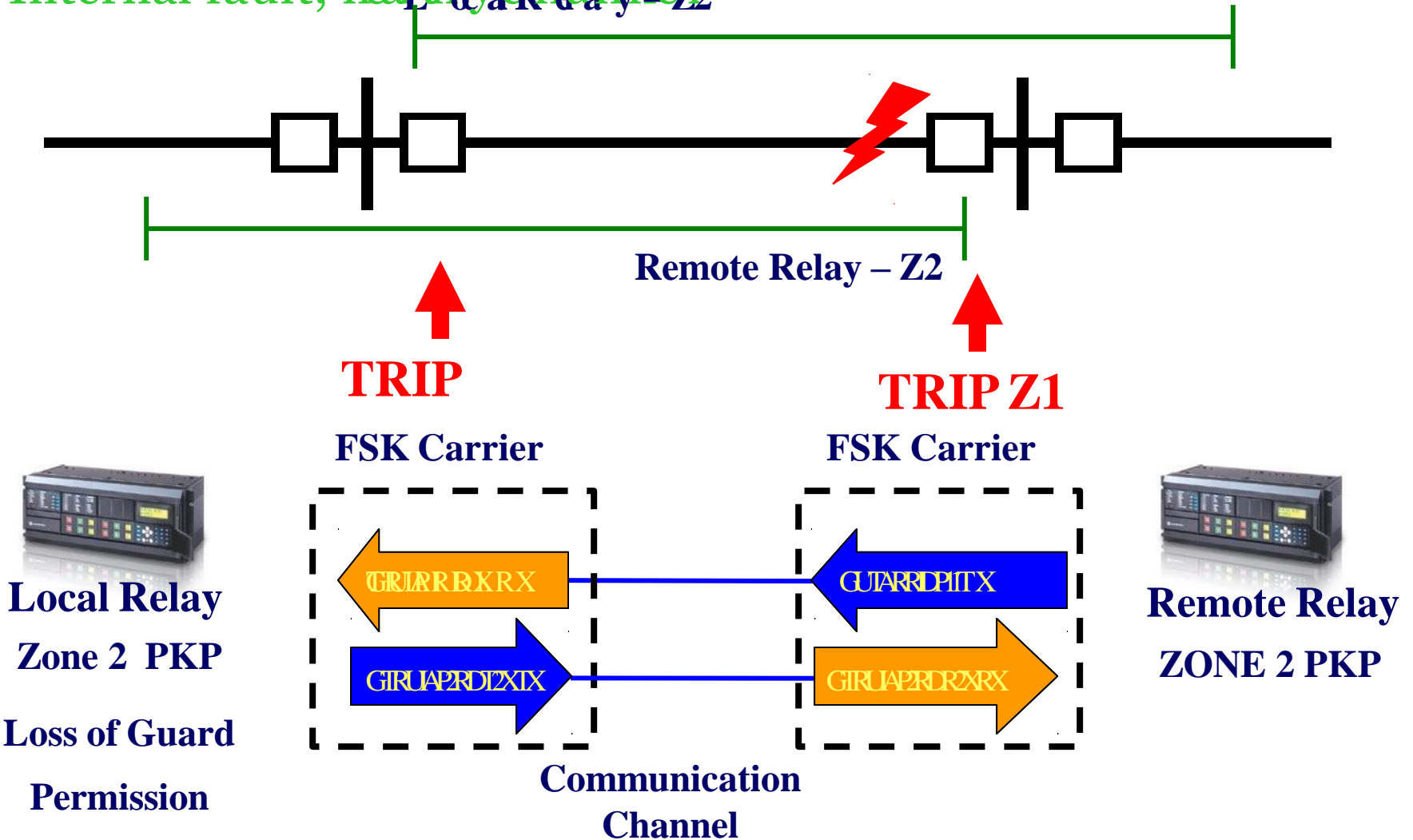


Loss of Channel



# Directional Comparison Unblocking (DCUB)

Internal fault, healthy channel

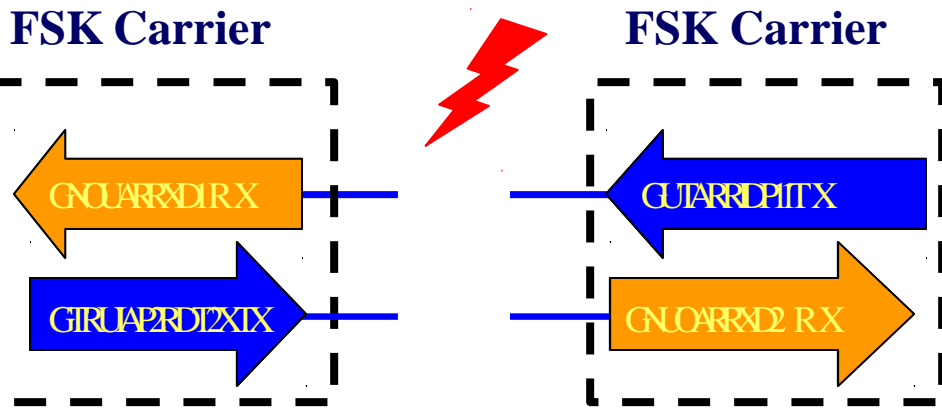


# Directional Comparison Unblocking (DCUB)

Internal fault, channel failure



**TRIP**      **Loss of Channel**      **TRIP Z1**



  
**Local Relay**  
**Zone 2 PKP**  
**Loss of Guard**  
**Block Timer Started**  
**Duration Timer Expired**  
**tarted**

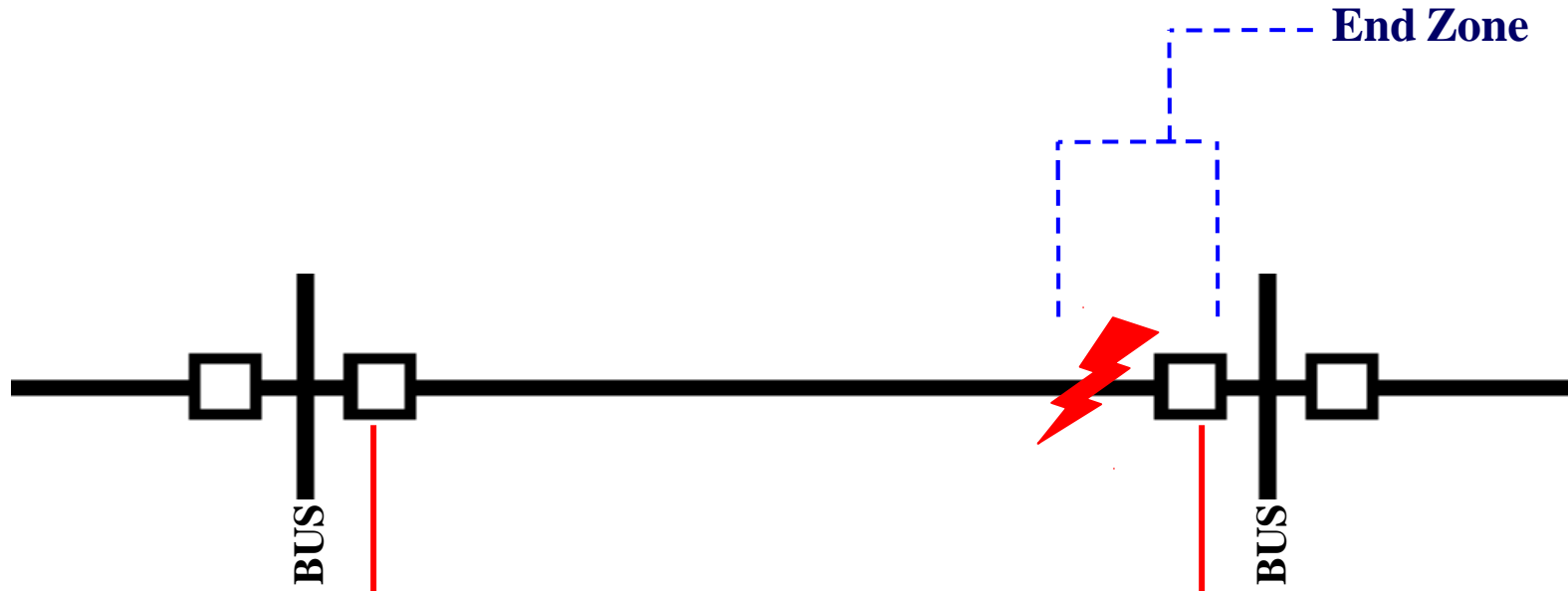
  
**Remote Relay**  
**ZONE 2 PKP**  
**Loss of Guard**

# Redundancy Considerations

- Redundant protection systems increase dependability of the system:
  - Multiple sets of protection using same protection principle and multiple pilot channels overcome individual element failure, *or*
  - Multiple sets of protection using different protection principles and multiple channels protects against failure of one of the protection methods.
- Security can be improved using “voting” schemes (i.e., 2-out-of-3), potentially at expense of dependability.
- Redundancy of instrument transformers, battery systems, trip coil circuits, etc. also need to be considered.

# Redundant Communications

End Zone



**AND Channels:**

POTT Less Reliable

DCB Less Secure

More Channel Security

**OR Channels:**

POTT More Reliable

DCB More Secure

More Channel Dependability

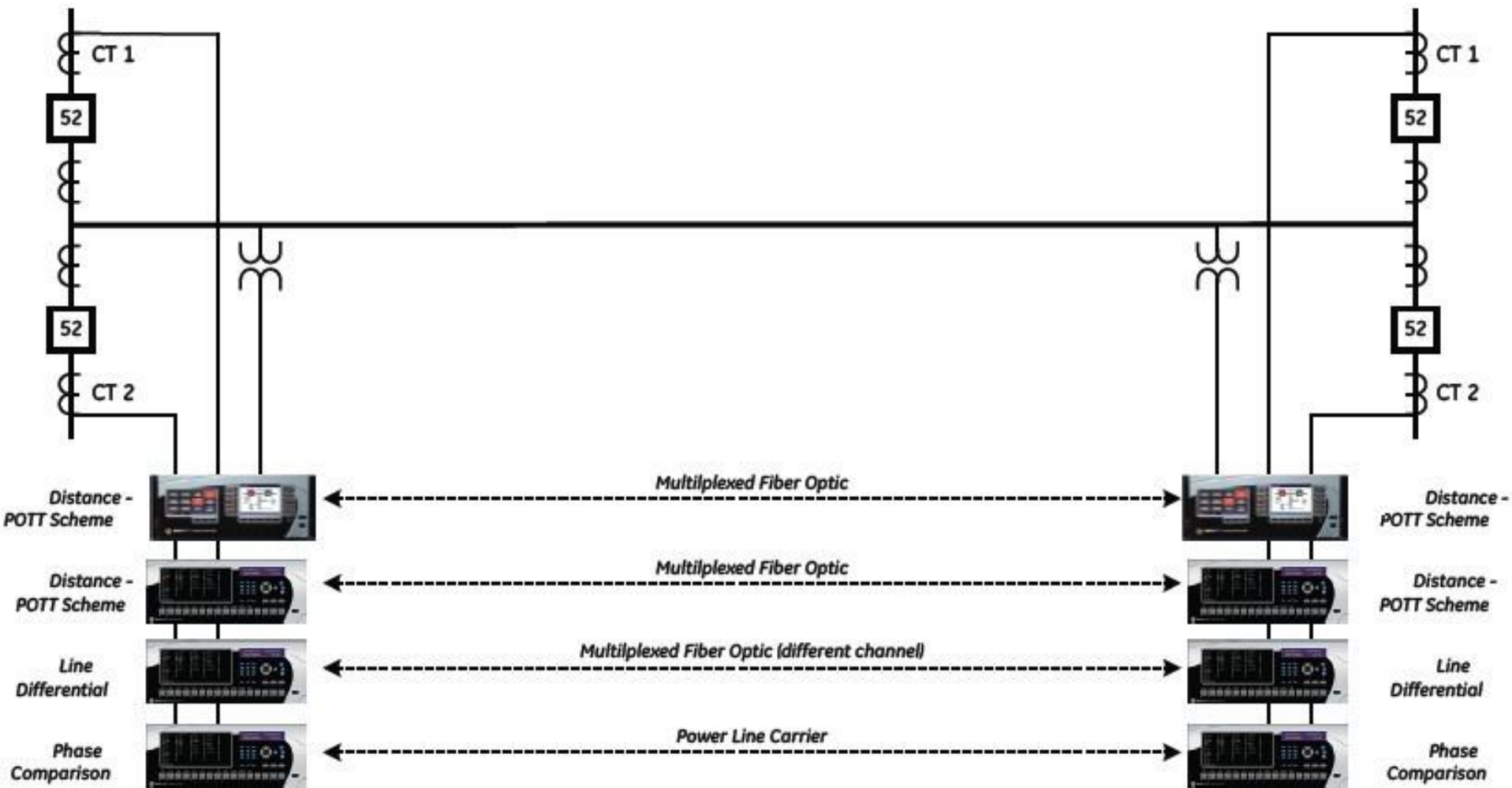
Communication Channel 1

Communication Channel 2

Loss of Channel 2



# Redundant Pilot Schemes





# Pilot Relay Desirable Attributes

- Integrated functions:
  - weak infeed
  - echo
  - line pick-up (SOTF)
- Basic protection elements used to key the communication:
  - distance elements
  - fast and sensitive ground (zero and negative sequence) directional IOCs with current, voltage, and/or dual polarization



**Questions?**

