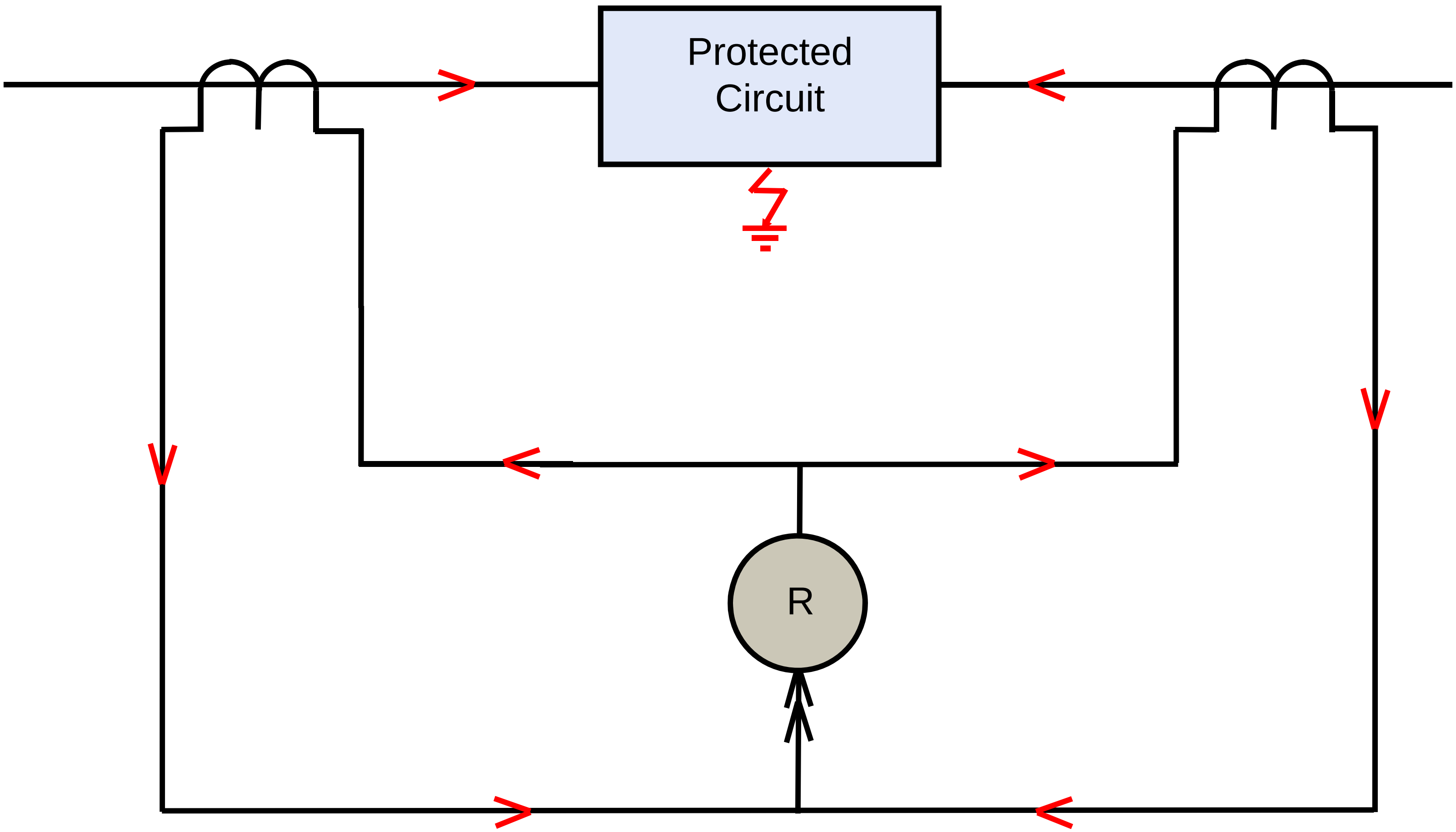
Fundamentals Of Differential Protection

Used where:

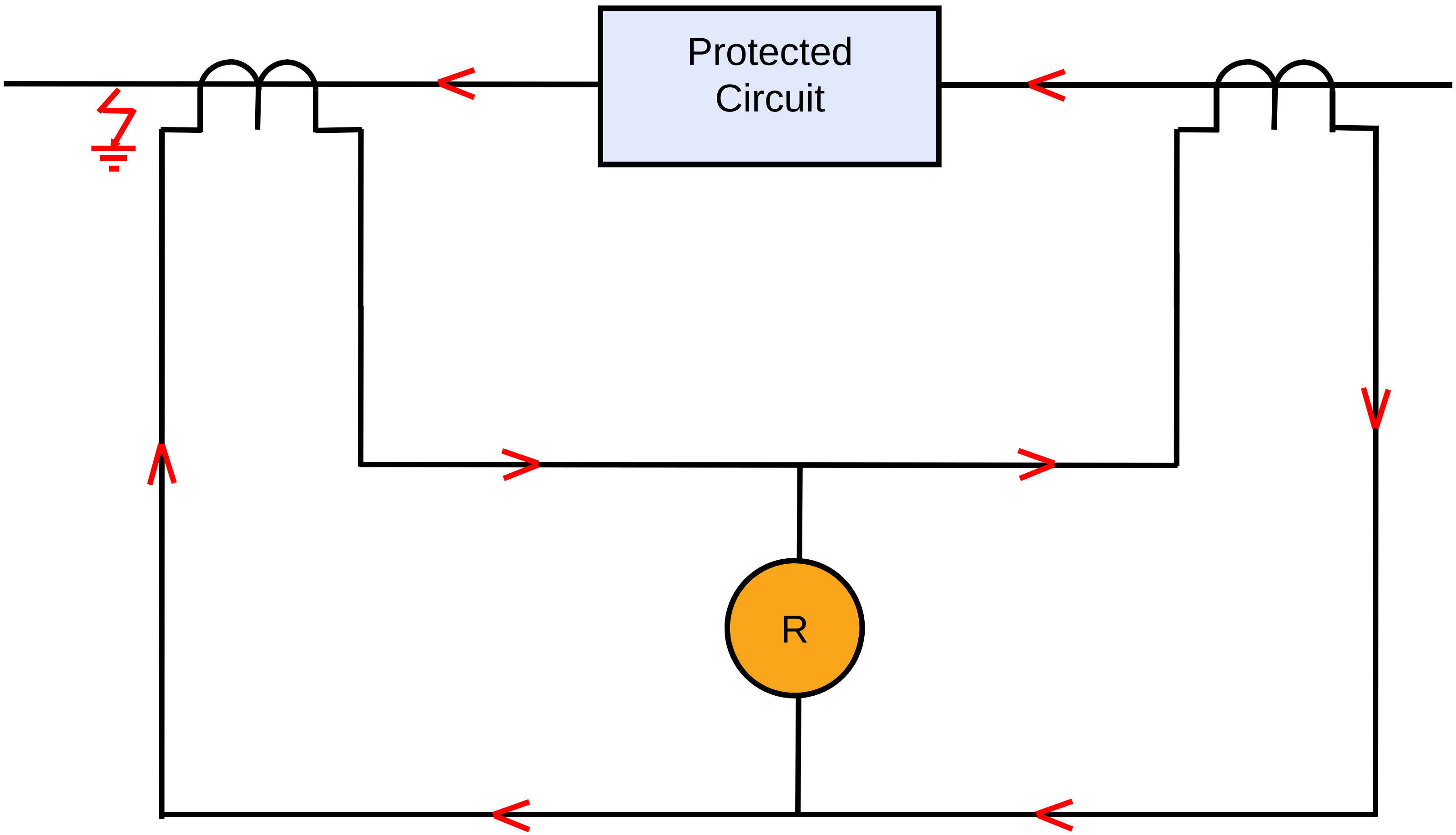
- Protection co-ordination is difficult / not possible using time delayed elements
- Fast fault clearance is critical

Can be used on all items of plant in one form or another (i.e. Generators, transformers, lines, cables, busbars, motors) to form a defined zone of protection dictated by current transformer location.

Differential Protection Principle (1)



Differential Protection Principle (2)



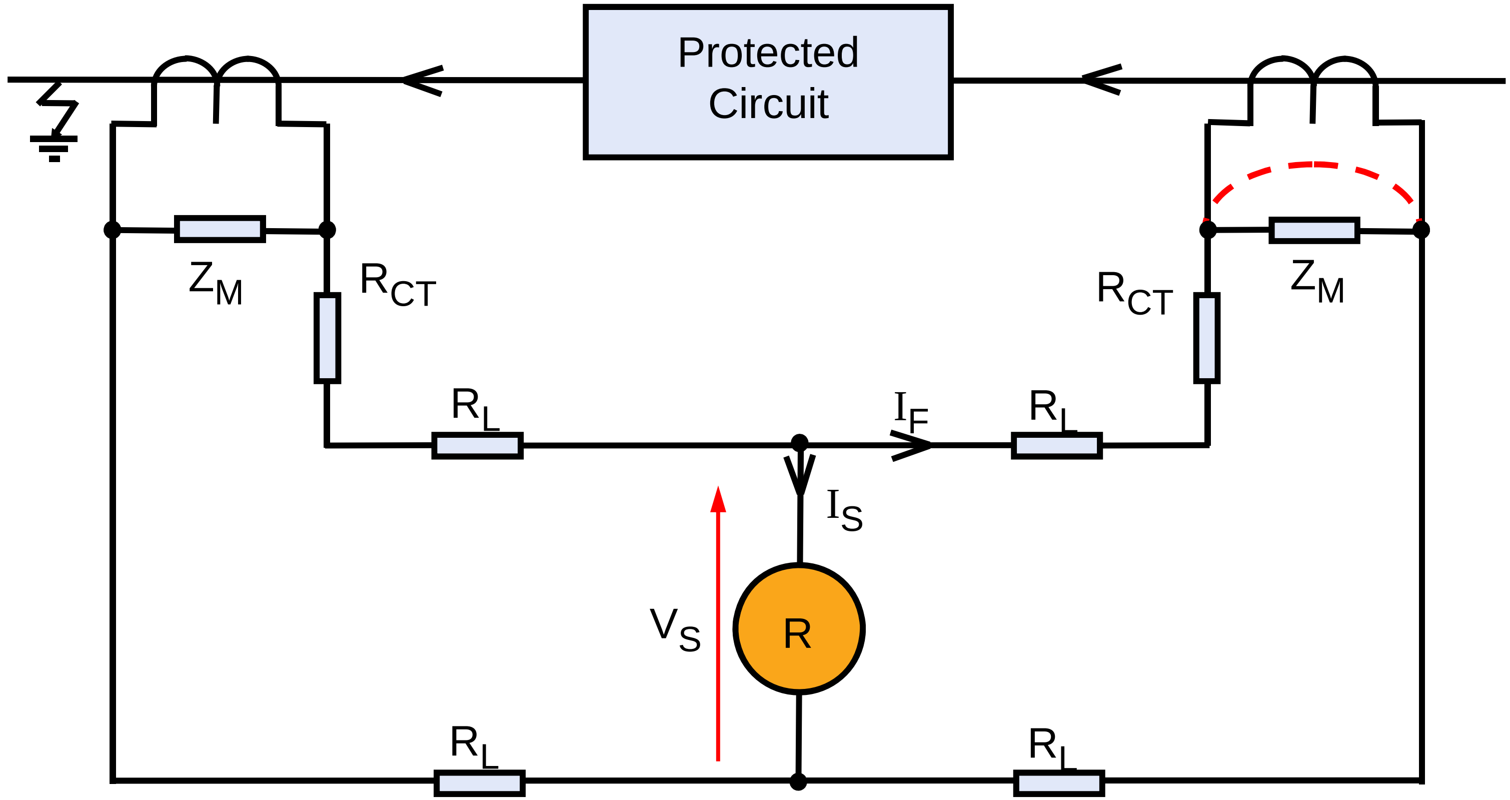
High Impedance Principle

High Impedance Principle (1)

Based on Merz-Price circulating current principle

- **Requires matched current transformers of low reactance design, typically class X or equivalent**
- **Equal CT ratios**
- **Typically current operated relay with an external stabilising resistor**
- **Non-linear resistor may be required to limit voltage across relay circuit during internal faults**
- **Suitable for zones up to 200 - 300 metres (typically)**

High Impedance Principle (2)



Maximum voltage across relay circuit, $V_s = I_f (R_{CT} + 2R_L)$

To limit current through relay to < Is the relay impedance $R_{relay} > V_s/I_s$

Stabilising Resistor

Use of stabilising resistor:

- Where relay impedance alone is too low to ensure stability then the relay circuit impedance can be increased through the addition of an external resistor connected in series with the relay
- Required circuit impedance > Vs/Is
- $R_{STAB} > (Vs/Is) - R_{relay}$

Current Transformer Output

Current transformer knee point requirements:

- **Current transformers must have sufficient output to ensure fast operation of relay during internal fault conditions**
- **Required Vk > 2 Vs (typically - depends on actual relay type)**

Non-Linear Resistors (Metrosils)

During internal faults the high impedance relay circuit constitutes an excessive burden to the CT's.

A very high voltage develops across the relay circuit and the CT's which can damage the insulation of CT's, secondary wiring and relay.

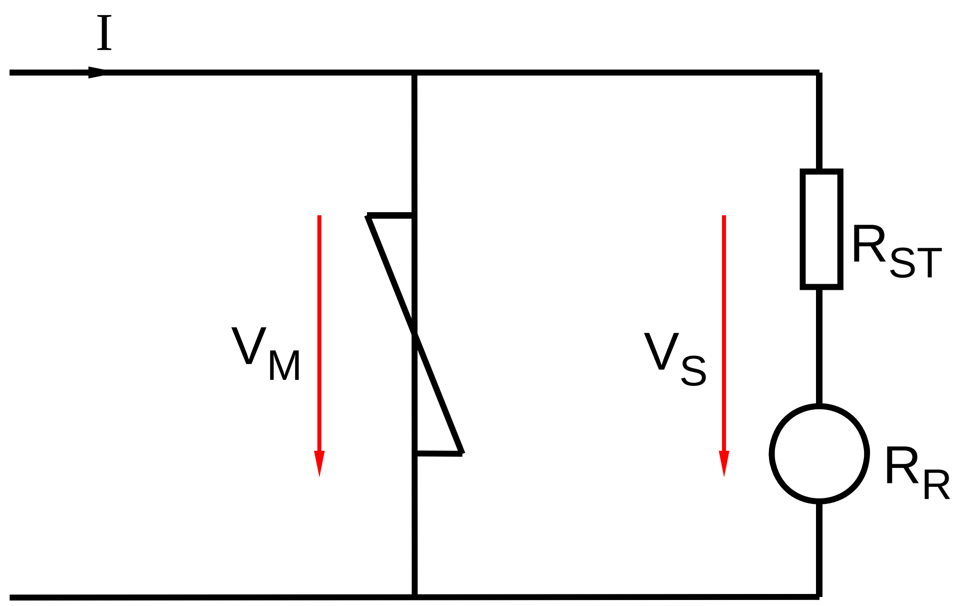
Magnitude of peak voltage VP is given by an approximate formula (based on experimental results)

$$V_P = 2\sqrt{2V_K (V_F - V_K)}$$

Where $V_F = If (R_{CT} + 2R_L + R_{STAB} + R_{relay})$

Metrosil required if $V_P > 3kV$

High Impedance Circuit Arrangement



Metrosil Characteristic

$$V = C\,I^{\beta}$$

Suitable values of C & β chosen based on :

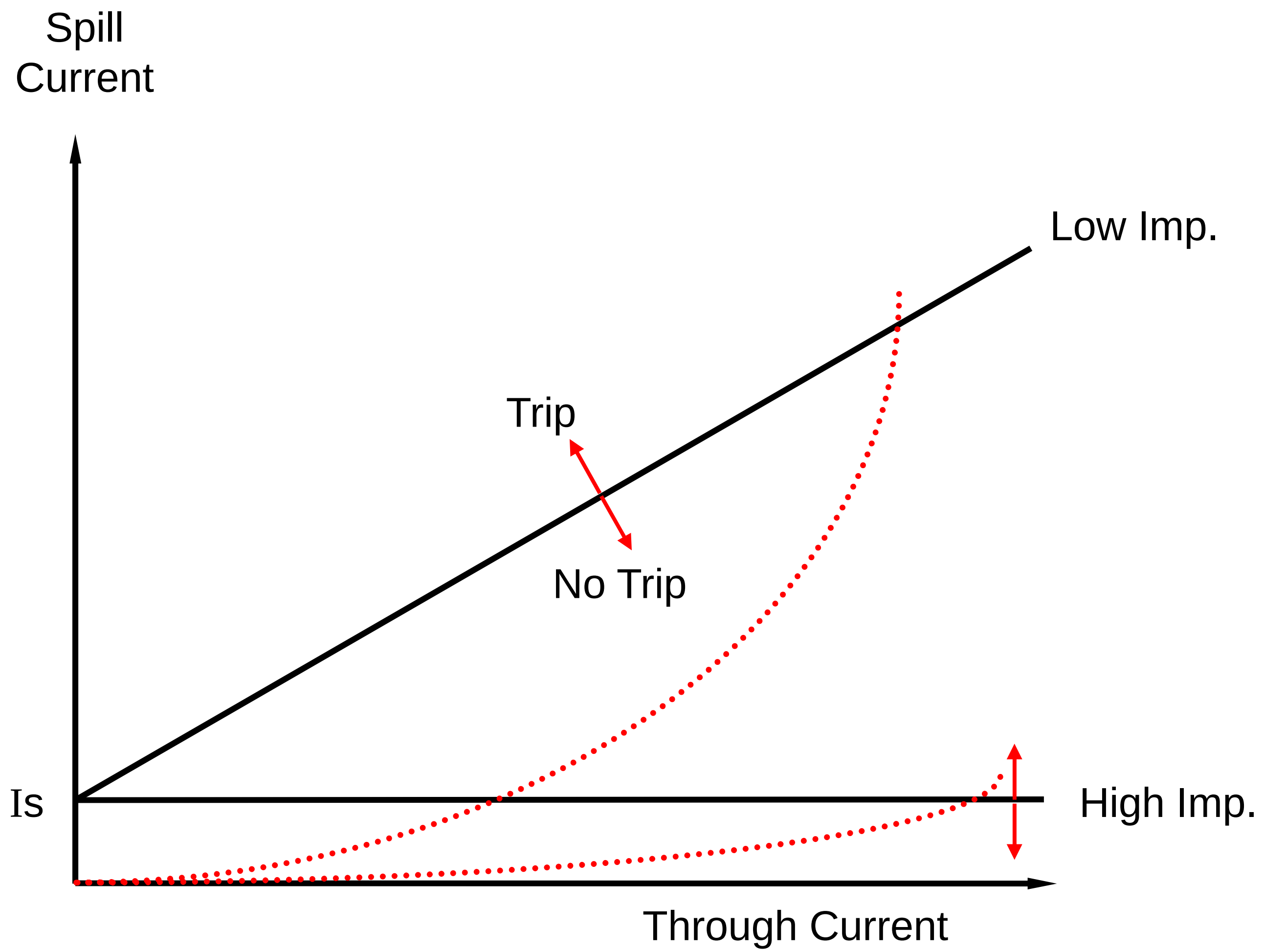
(1) Max secondary current under fault conditions
(2) Relay setting voltage

Low Impedance (Biased) Protection

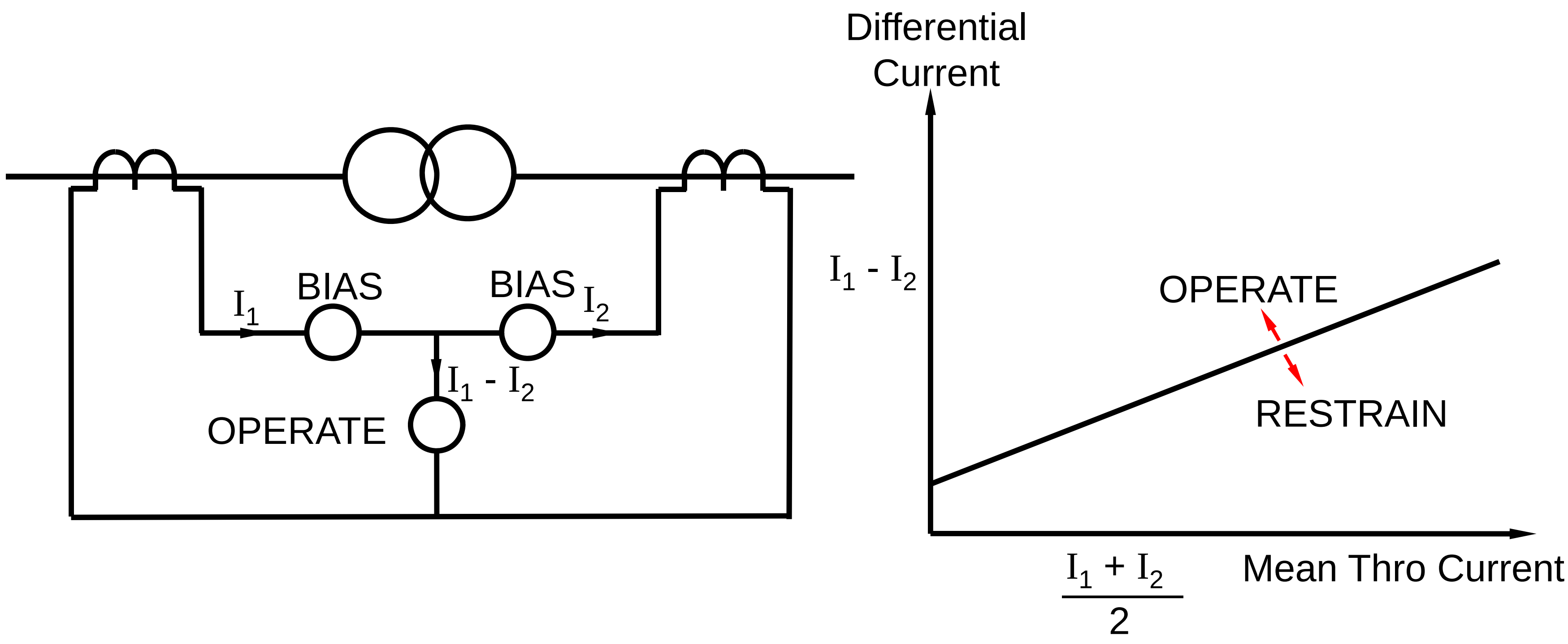
Low Impedance Principle

- High Impedance protection limits the spill current to a value less then relay setting
- Low Impedance principle provides no such limit on spill but instead artificially raises the setting of the relay
- The higher the through current, the higher the potential spill and hence the greater the increase in setting Required
- The increase in setting is therefore normally based on a percentage of the through current
- Protection is commonly referred to as percentage biased differential protection

Biased Differential Scheme (1)



Biased Differential Scheme (2)

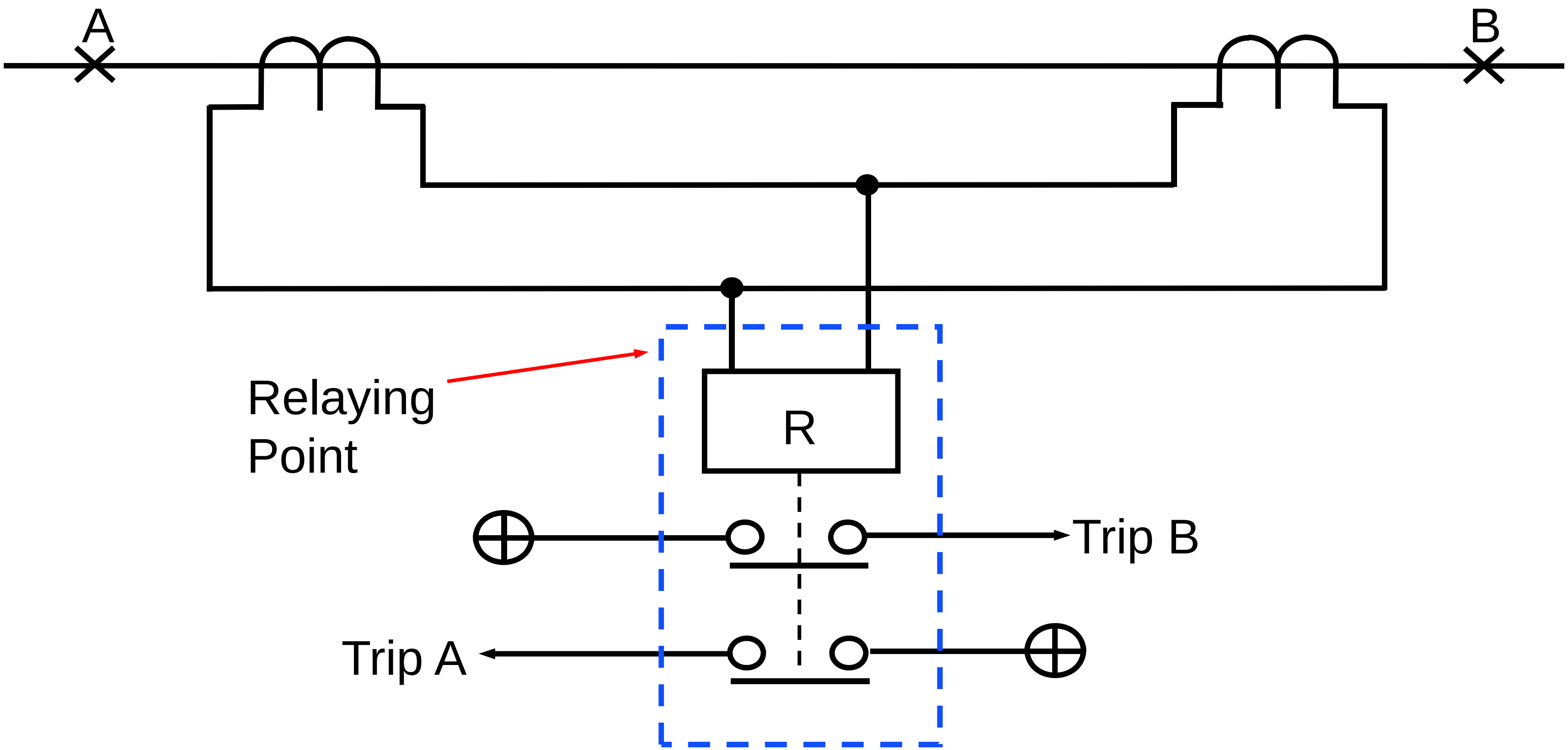


$$\textbf{Bias} = \frac{\textbf{Differential (or Spill) Current}}{\textbf{Mean Through Current}}$$

Low Impedance Principle

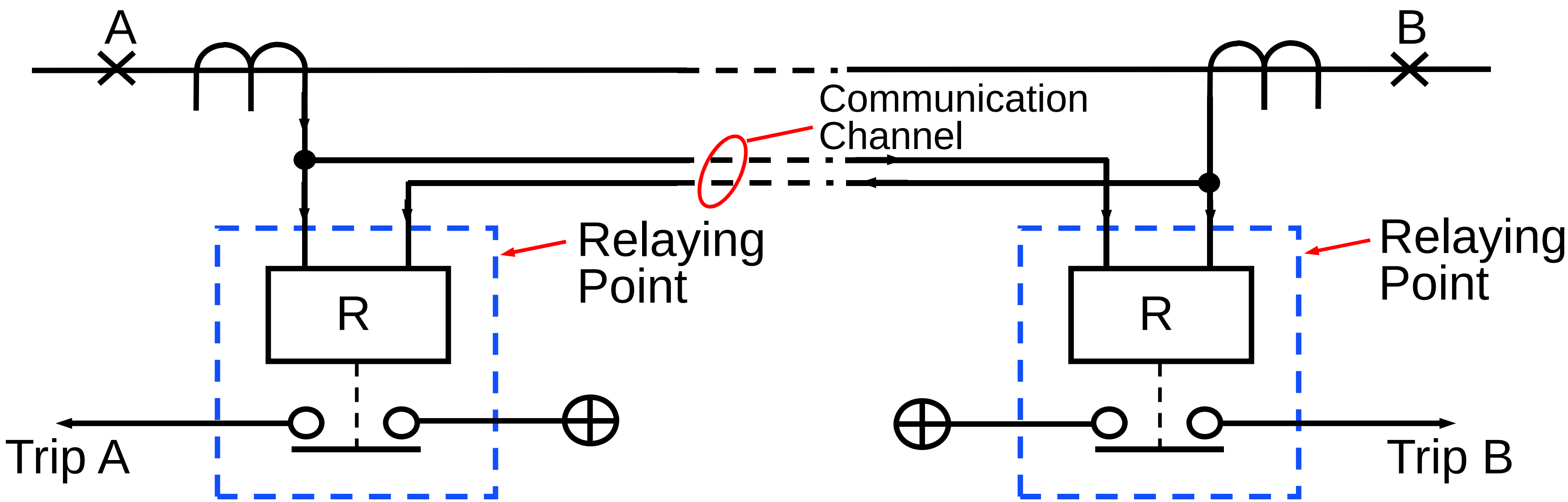
- **Does not rely on equal ratio CT's (ratio correction can be done via external interposing CT's or internally to the relay)**
- **Limit on allowable spill dictated by percentage of bias used - practical limit to give sufficient sensitivity to internal faults**
- **Amount of spill related to CT size - stability limits and CT requirements are therefore dependant on each other**

Unit Protection Involving Distance Between Circuit Breakers (1)



Simple Local Differential Protection

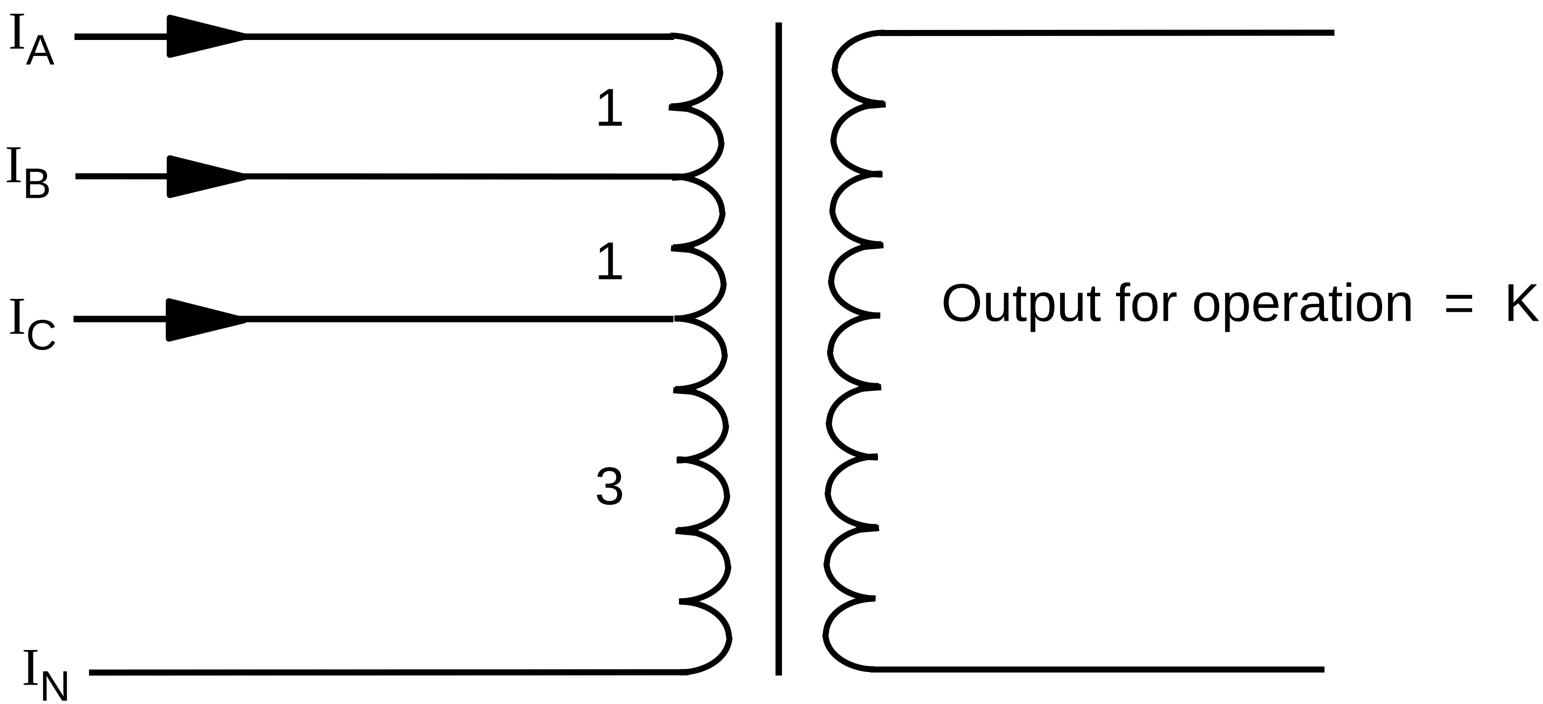
Unit Protection Involving Distance Between Circuit Breakers (2)



Unit Protection Involving Distance Between Circuits

Summation Transformers

Summation Transformer Sensitivity for Different Faults (1)



Let output for operation = K

(1) Consider A-E fault
for relay operation :

$I_A\,(1 + 1 + 3) > K$

$I_A > 1/5K$ or $20\%K$

Summation Transformer Sensitivity for Different Faults (2)

(2) B-E fault

for relay operation : $I_B (1 + 3) > K$

$I_B > 25\%K$

(3) C-E fault

for relay operation : $I_C \times (3) > K$

$I_C >$ **33**$^{1/3}$%K

(4) AB fault

for relay operation : $I_{AB} \times (1) > K$

$I_{AB} > 100\%K$

(5) BC fault

for relay operation : $I_{BC} \times (1) > K$

$I_{BC} > 100\%K$

(6) AC fault

for relay operation : $I_{AC} (1 + 1) > K$

$I_{AC} > 50\%K$

Line Charging Currents

Line charging currents flow in at one end of the feeder only and is therefore potentially capable of unbalancing a protective system.

Charging currents (or capacitance currents) of overhead lines generally low.

Charging current levels of underground cables however can be high enough to dictate minimum permissible operating level of the protection.

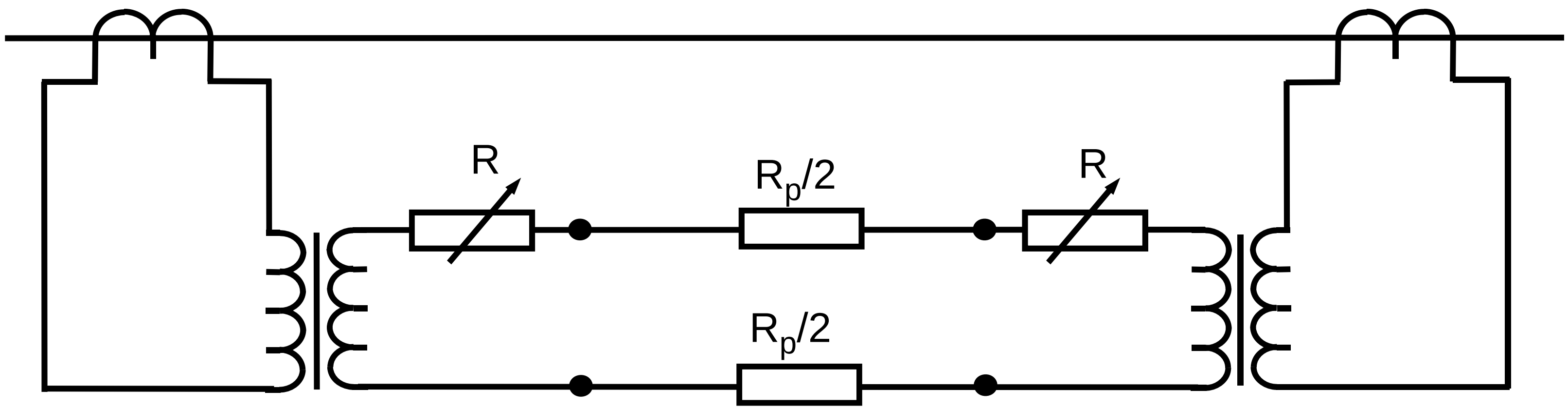
Pilot Characteristics

Resistance and shunt capacitance of pilots introduce magnitude and phase differences in pilot terminal currents.

Pilot Resistance

Attenuates the signal and affects effective minimum operating levels.

To maintain constant operating levels for wide range of pilot resistance, padding resistor used.



Padding resistance R set to ½ (1000 - R_p) ohms

Pilot Capacitance

Circulating current systems :

- **Pilot capacitance effectively in parallel with relay operating coil.**
- **Capacitance at centre of pilots has zero volts across them.**

Pilot Isolation

Electromagnetic Induction

Field of any adjacent conductor may induce a voltage in the pilot circuit.

Induced voltage can be severe when :

(1) Pilot wire laid in parallel to a power circuit.

(2) Pilot wire is long and in close proximity to power circuit.

(3) Fault Current is severe.

Induced voltage may amount to several thousand volts.

Danger to personnel

Danger to equipment

Difference in Station Earth Potentials

Can be a problem for applications above 33kV - even if feeder is short.

Formula for Induced Voltage

$$e = 0.232\, I\, L\ \mathrm{Log}_{10} D_e/S$$

where	I	=	primary line E/F current
	L	=	length of pilots in miles
	D_e	=	Equiv. Depth of earth return in metres = $655 \cdot \sqrt{e/f}$
	e	=	soil resistivity in Ω.m
	f	=	frequency
	s	=	separation between power line and pilot circuit in metres

Effect of screening is not considered in the formula.

If the pilot is enclosed in lead sheath earthed at each end, screening is provided by the current flowing in the sheath.

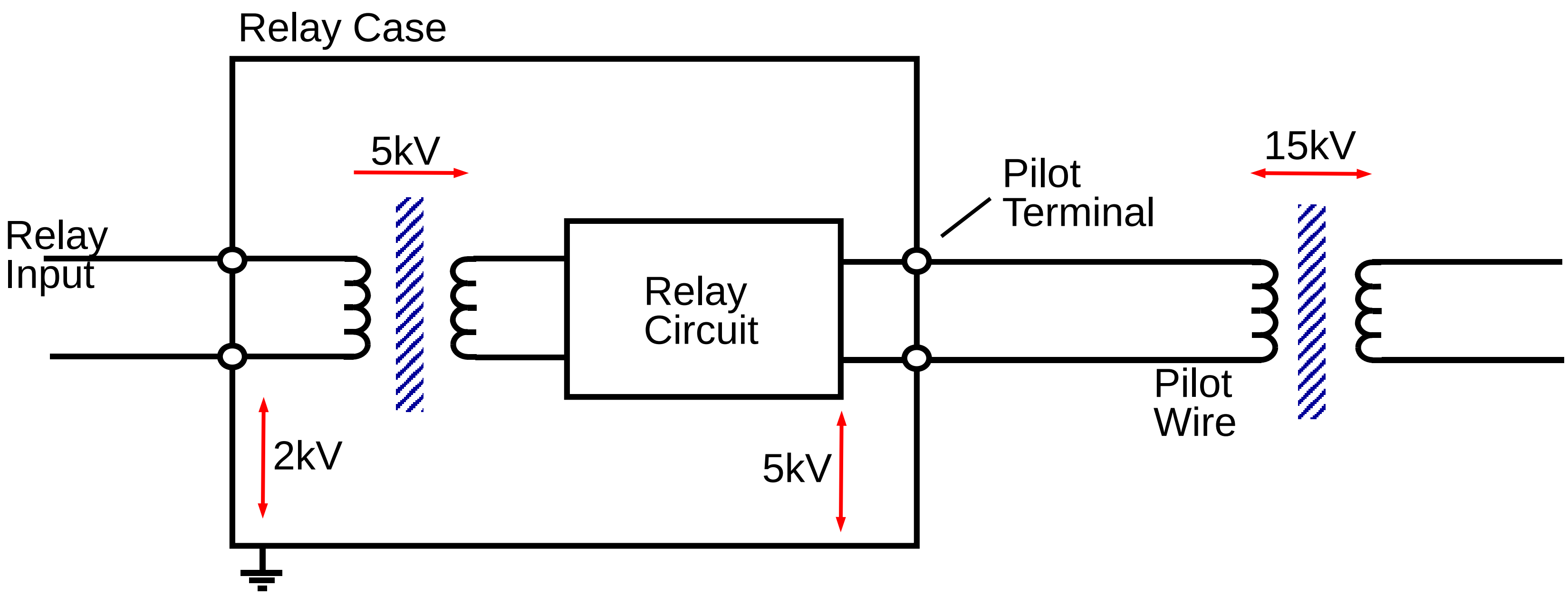
Sheath should be of low resistance.

0.3 V / A / Mile	Unscreened Pilots
0.1 V / A / Mile	Screened Pilots

Isolation Transformers

Pilot circuits and all directly connected equipment should be insulated to earth and other circuits to an adequate voltage level.

Two levels are recognised as standard : 5kV & 15kV



Supervision of Pilot Circuits

Pilot circuits are subject to a number of hazards, such as :

- **Manual Interference**
- **Acts of Nature (storms, subsidence, etc.)**
- **Mechanical Damage (excavators, impacts)**

Therefore supervision of the pilots is felt to be necessary.

Two types exist :

- **Signal injection type**
- **Wheatstone Bridge type**

Pilot Wire Supervision

	Circulating Current Schemes
Pilot Wire Open Circuited	Maloperate
Pilot Wire Short Circuited	Stable
Pilot Wire Crossed	Maloperate

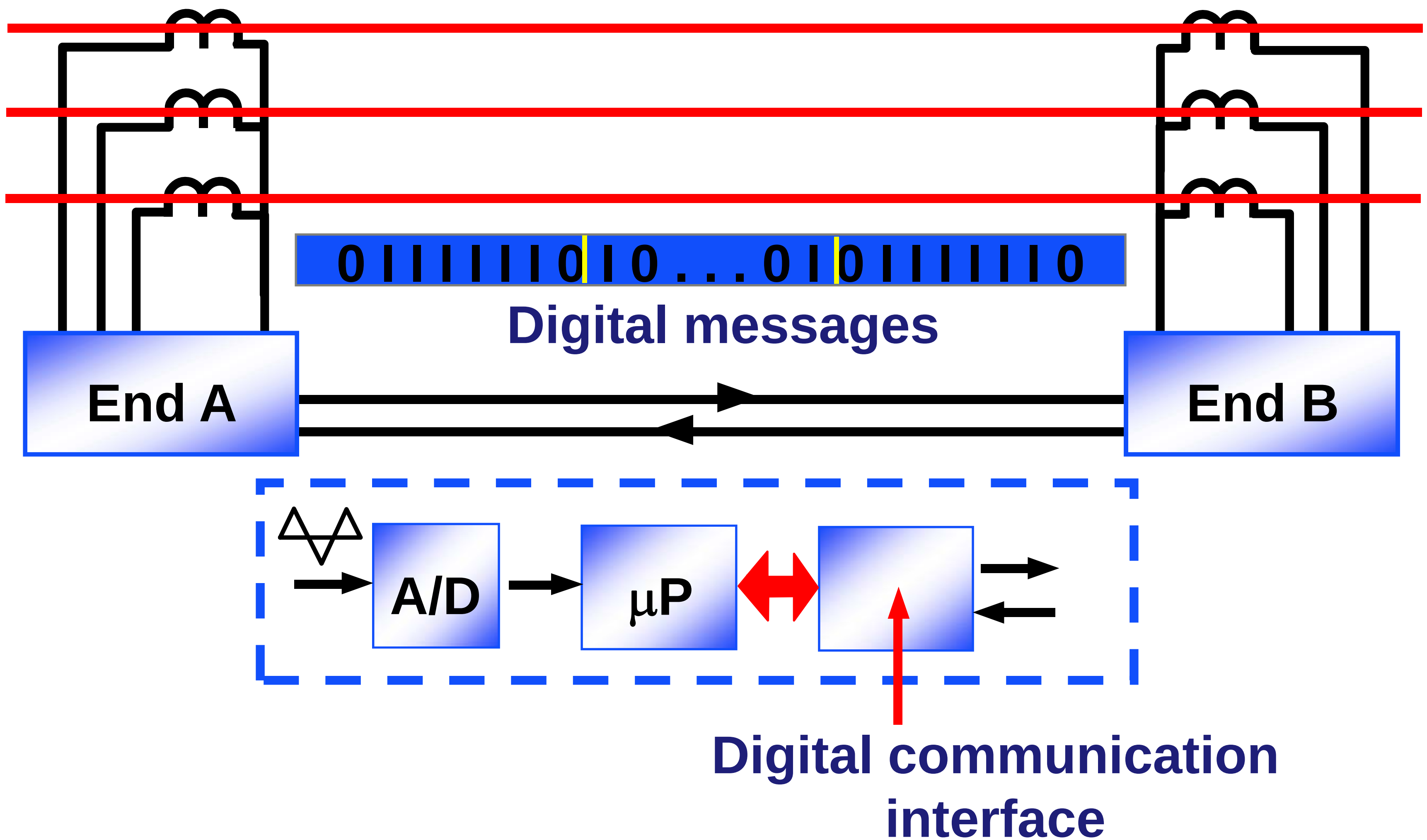
Maloperation occurs even under normal loading conditions if 3- phase setting < ILOAD.

Overcurrent check may be used to prevent maloperation.

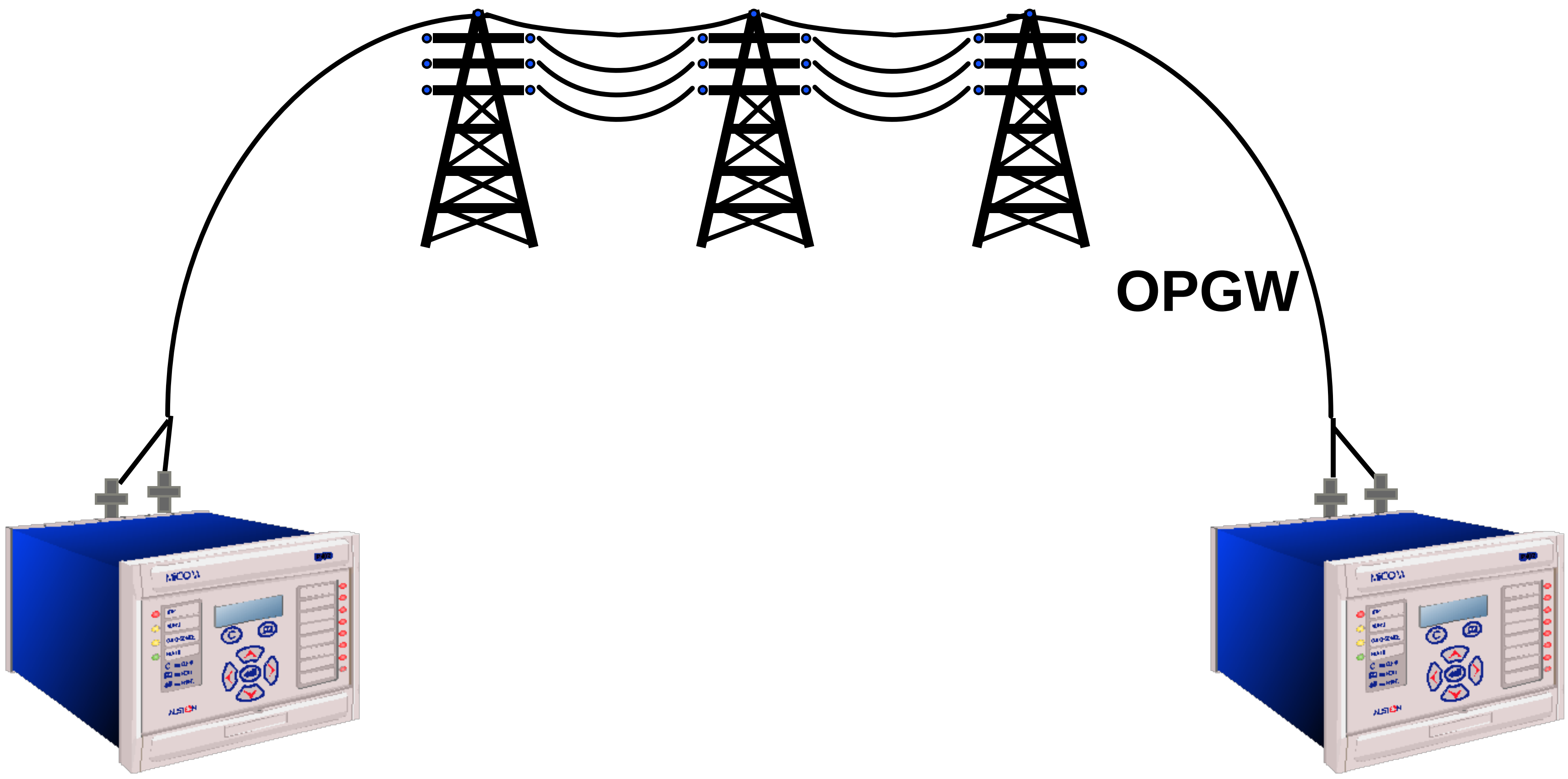
Overcurrent element set above maximum load current.

Numerical Feeder Differential Protection

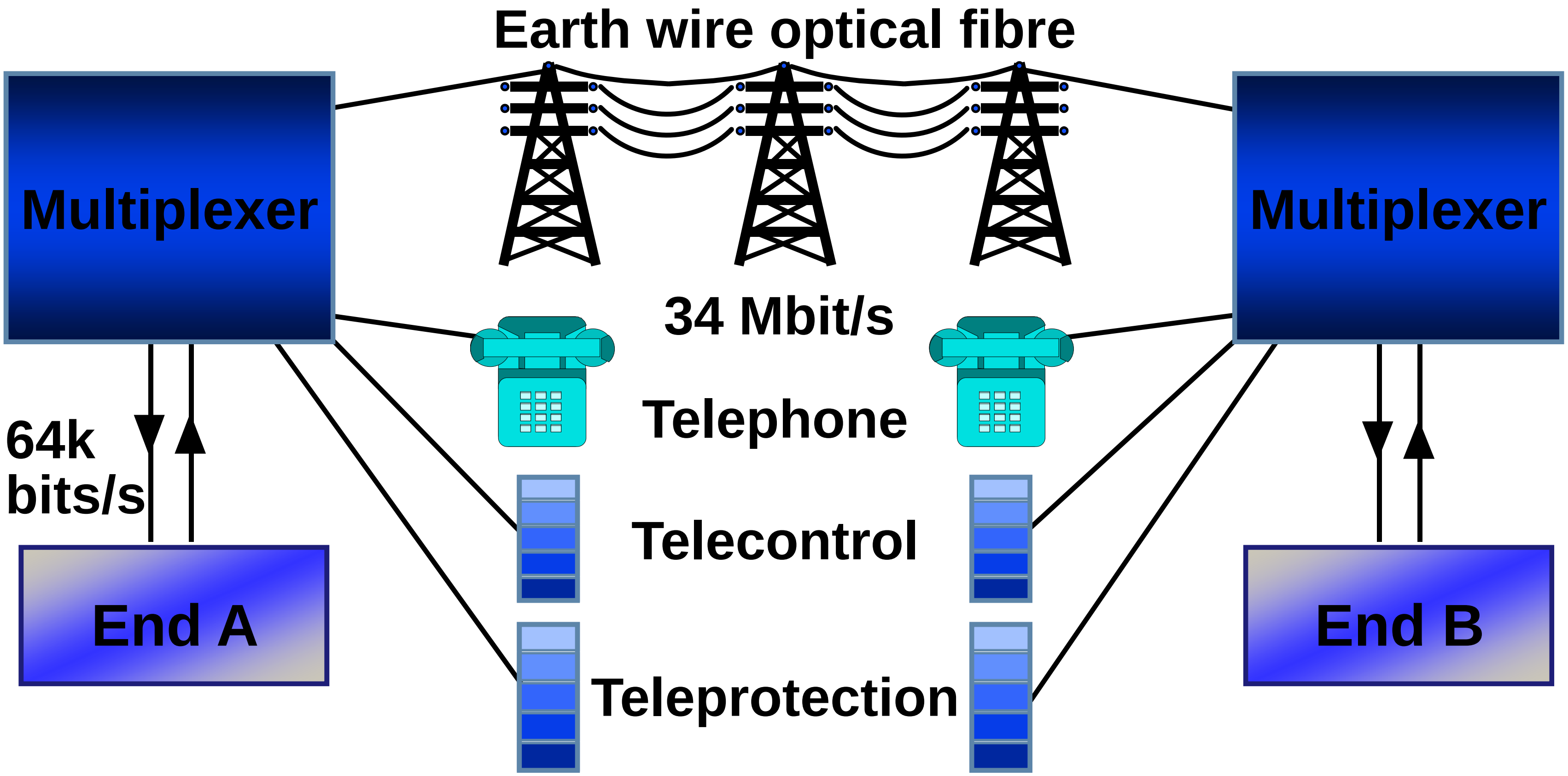
All Digital Design



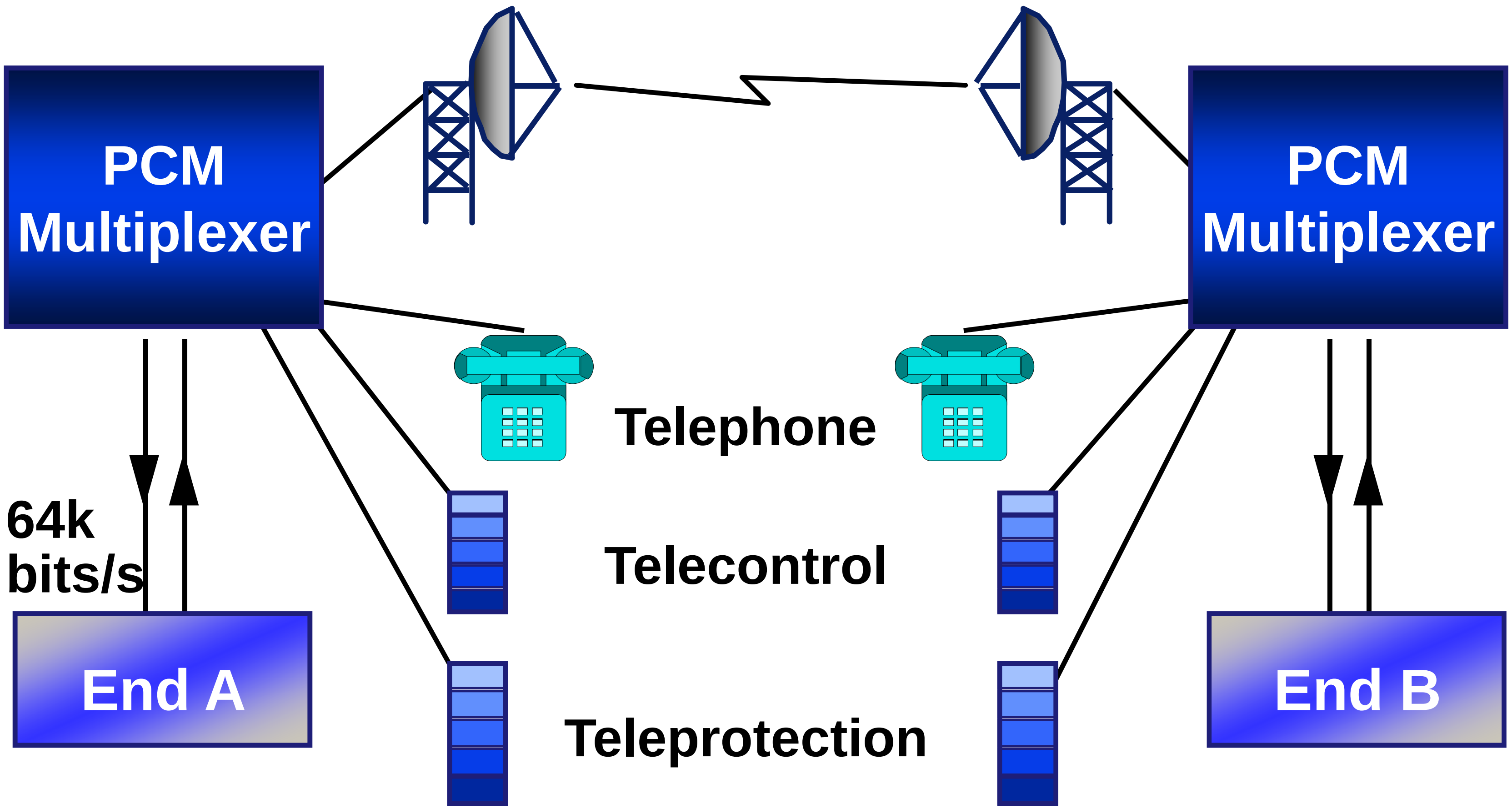
Direct Optical Fibre Link



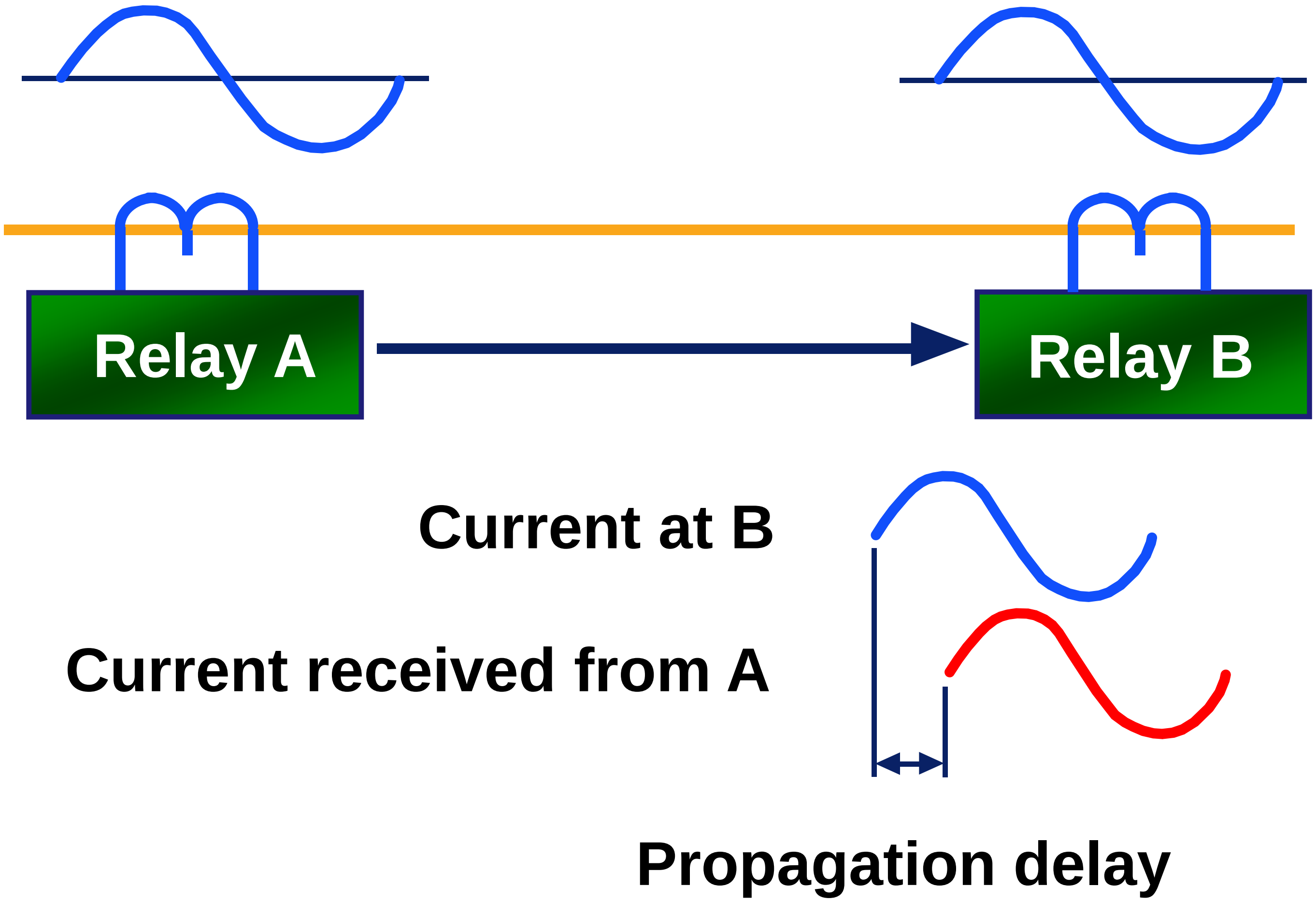
Multiplexed Optical Link



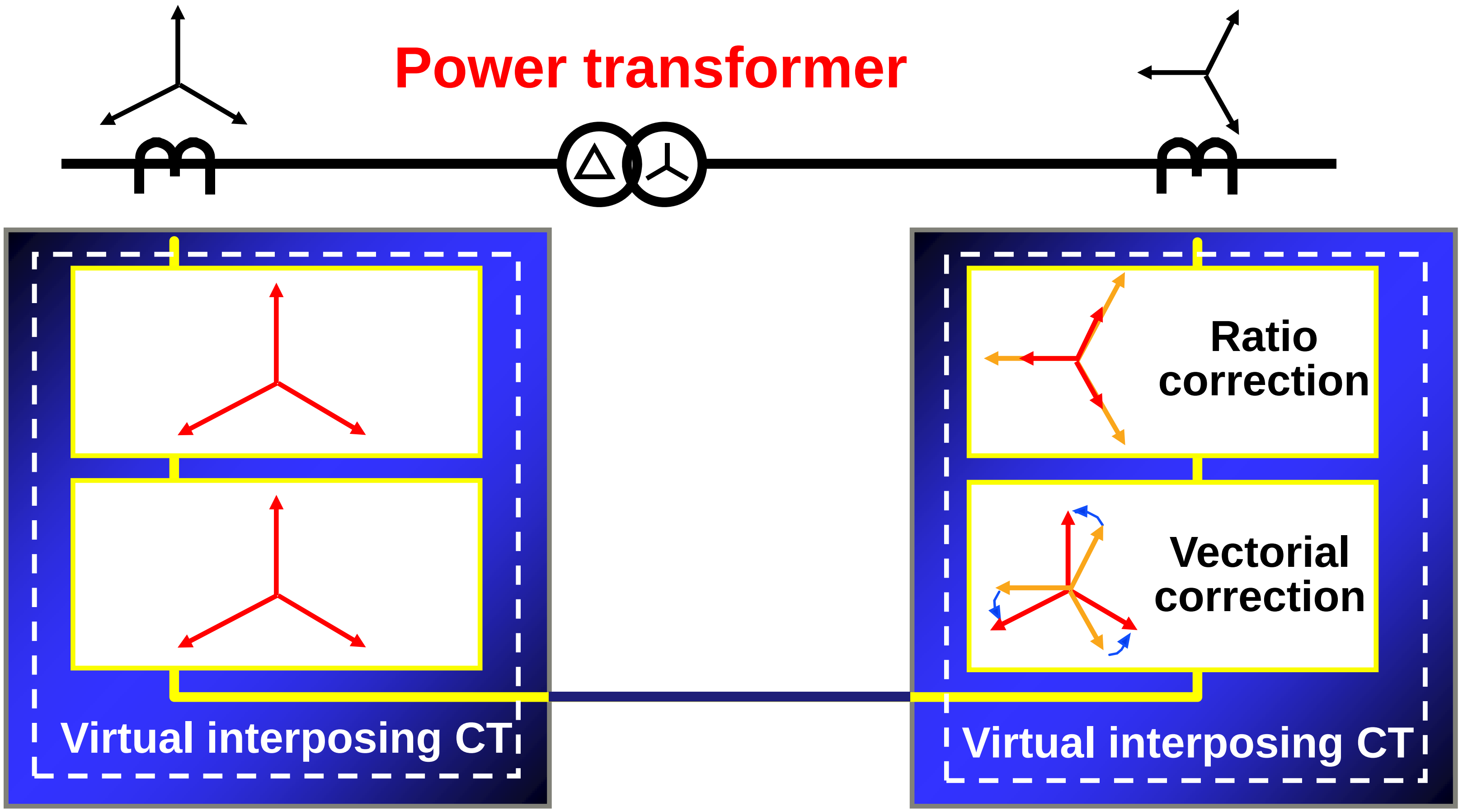
Multiplexed Microwave Link



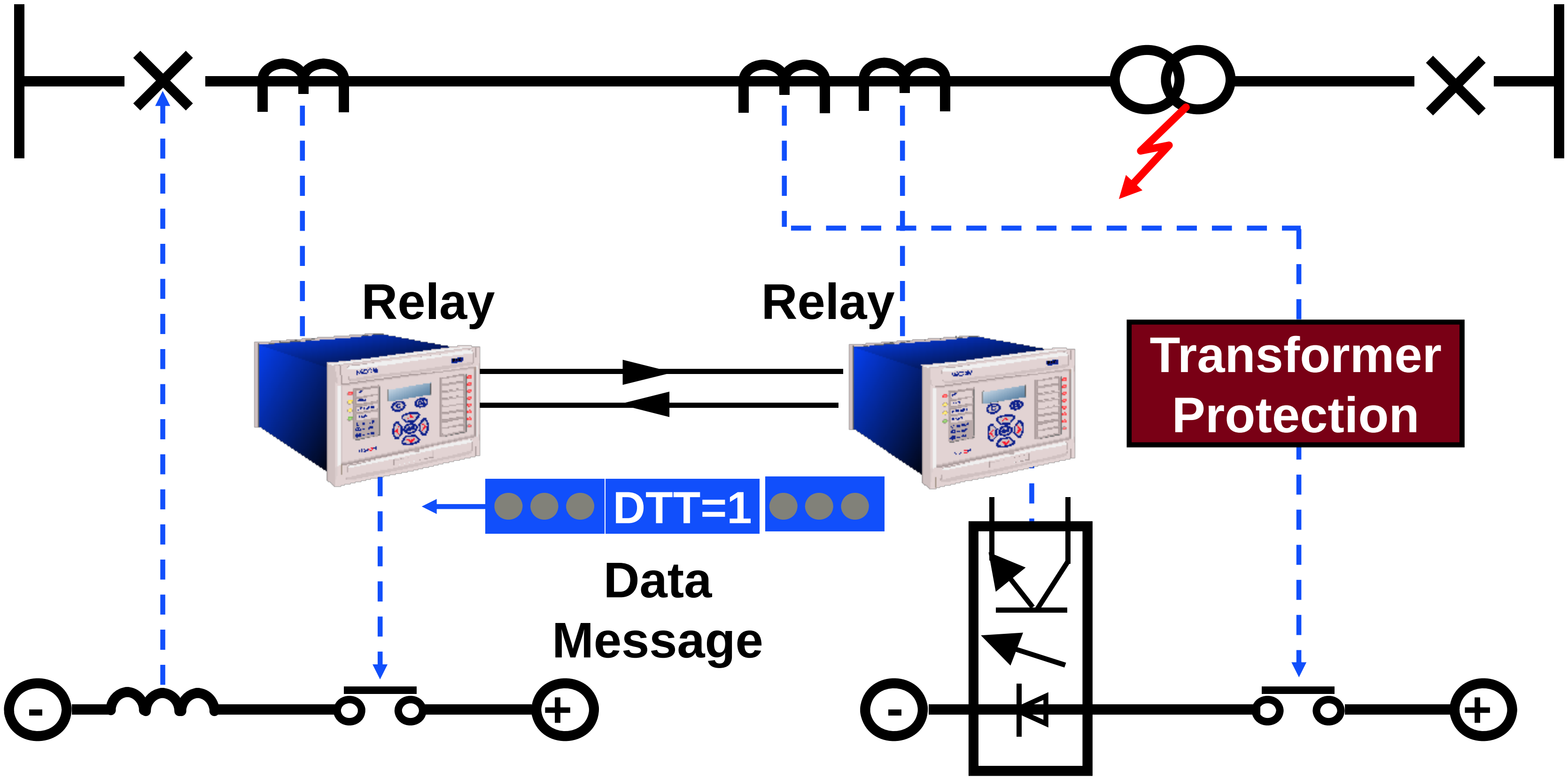
Propagation Delay Problem



Protection of Transformer Feeders



Direct Intertrip



- The channel could alternatively be used along with the distance elements and PSL to configure permissive or blocking distance aided schemes