Reliability Block Diagram (RBD)

A **Reliability Block Diagram (RBD)** performs the system reliability and availability analyses on large and complex systems using block diagrams to show network relationships. The structure of the reliability block diagram defines the logical interaction of failures within a system that are required to sustain system operation.

The rational course of a RBD stems from an input node located at the left side of the diagram. The input node flows to arrangements of series or parallel blocks that conclude to the output node at the right side of the diagram. A diagram should only contain one input and one output node.

The RBD system is connected by a **parallel** or **series** configuration.

A **parallel** connection is used to show redundancy and is joined by multiple links or paths from the Start Node to the End Node.
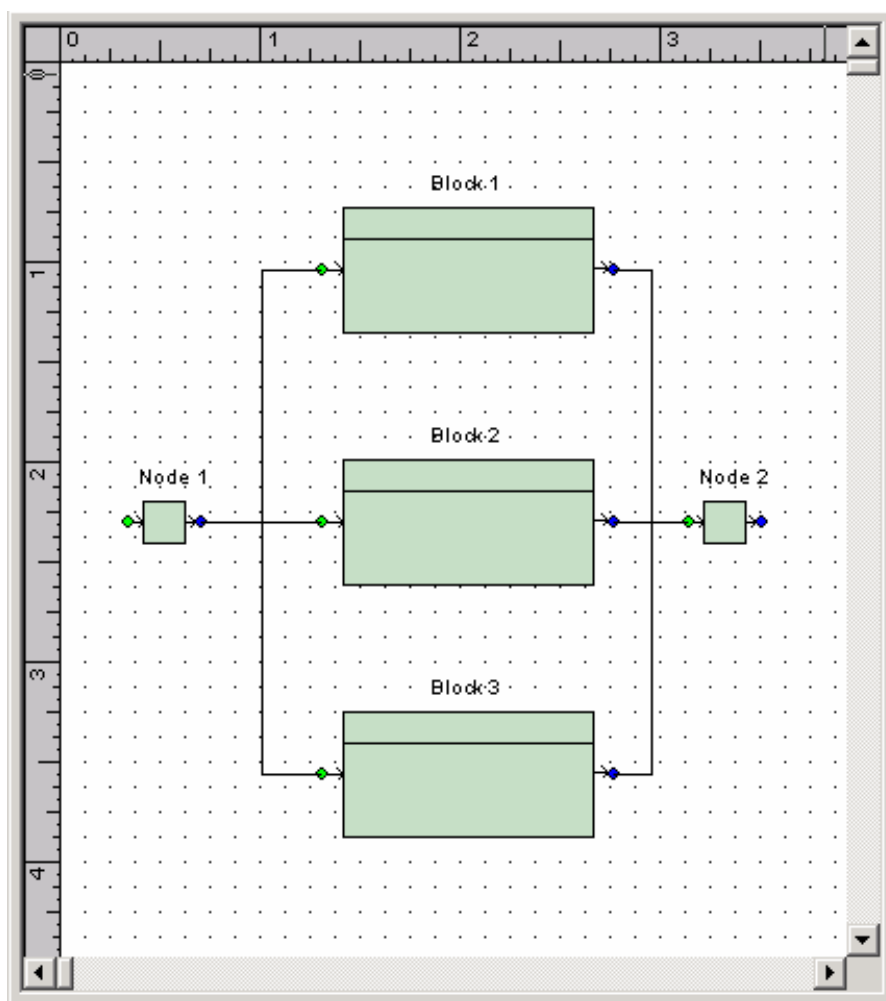
A **series** connection is joined by one continuous link from the Start Node to the End Node.
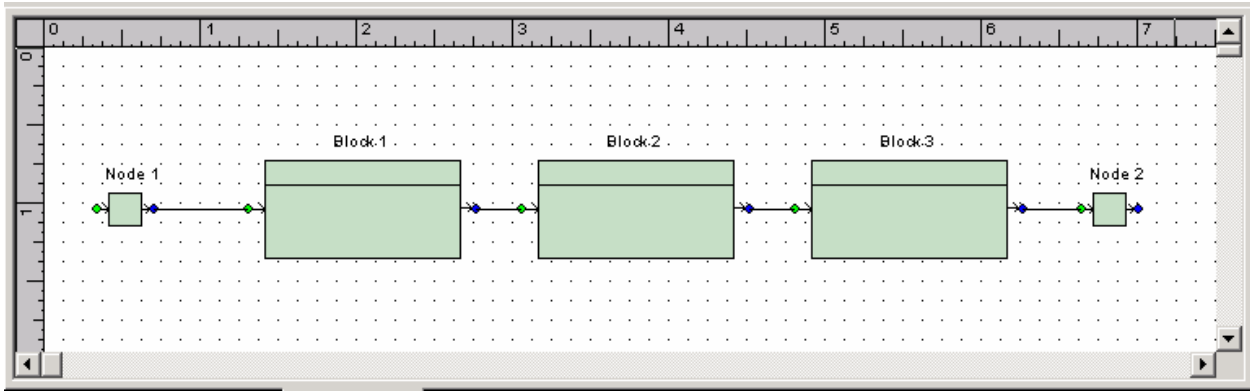
A system can contain a series, parallel, or combination of series and parallel connections to make up the network.
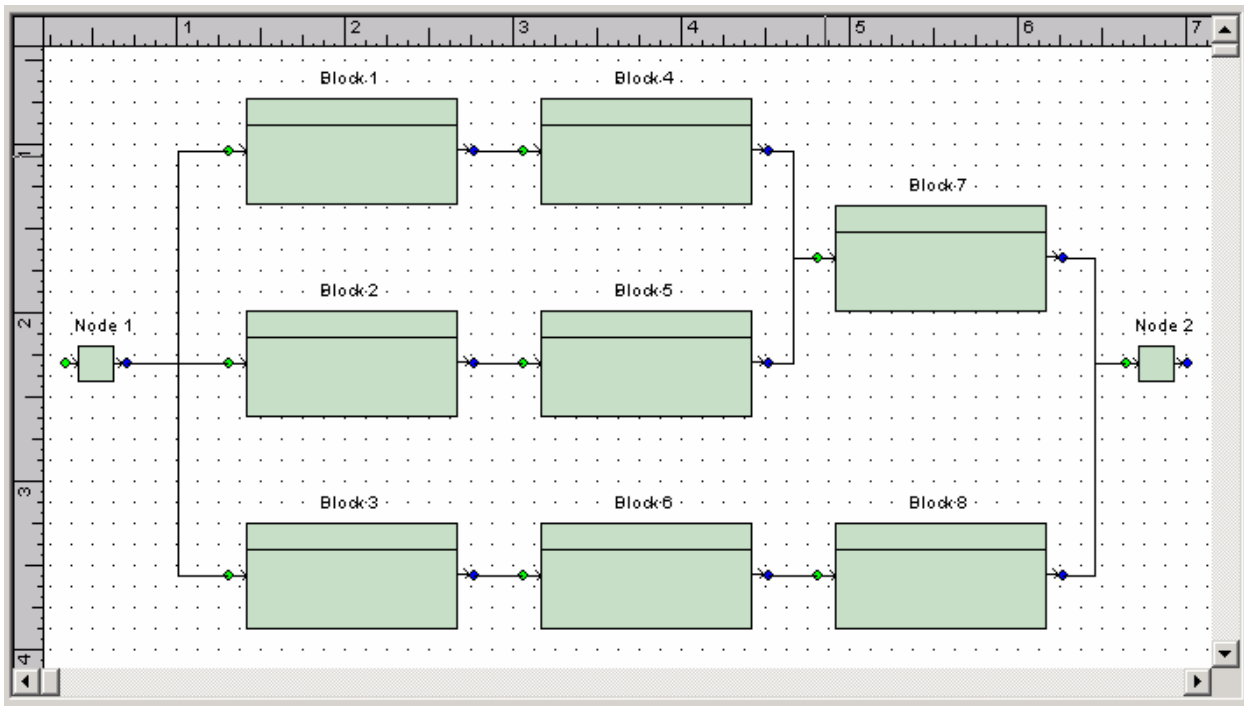
Successful operational systems require at least one maintained path between the system input and the system output. Boolean algebra expressions are used to describe the minimum combination of failures required to cause a system failure. Minimal cut sets represent the minimal number of failures that can cause the system to fail.

A reliability block diagram (RBD) is a drawing and calculation tool used to model complex systems. An RBD is a series of images (blocks) representing portions of a system. Once the images (blocks) are configured properly and image data is provided, the failure rate, MTBF, reliability, and availability of the system can be calculated. As the configuration of the diagram changes, the calculation results also change.

Reliability block diagrams often correspond to the physical arrangement of components in the system. However, in certain cases, this may not apply. For instance, when two resistors are in

parallel, the system fails if one fails short. The reliability block diagram for such a system for the "fail short" mode of failure would be composed of two series blocks. However, for other modes of failure, such as an "open" failure mode, the reliability block diagram is composed of two parallel blocks.

The logical flow of a network diagram originates from an input node at the left hand side of the diagram to an output node at the right hand side of the diagram. Blocks are arranged in series and parallel arrangements between the system input and output nodes. It is important to note that in the RBD module, the connection between blocks is directed. Keep this in mind if you normally create undirected connection representations of RBD.

2. How RBD is Quantified

2.1 CFI System Conditional Failure Intensity

$$\lambda_s(t) = \frac{\omega(t)}{1 - Q(t)}$$

Where:

$\lambda_s(t) =$ System Conditional Failure Intensity at time t:

"The probability that the component fails per unit time at time t, given that it was as good as new at time zero and is normal at time t".

$\omega(t) =$ Failure Frequency at time t.

$Q(t) =$ Unavailability at time t.

Note: A large value of $\lambda_s(t) =$ means that the system is about to fail.

Reference: Kumamoto & Henley Pages 282, 287, 364

2.2 Expected Number of Failures

This gives the expected number of failures of the system in lifetime t.

$$W(t_1, t_2) = \int_{t1}^{t2} \omega(t)dt$$

Where:

$W(t_1, t_2) =$ Expected Number of Failures over interval $[t_1, t_2)$ given that the component was as good as new at time zero.

$\omega(t) =$ Failure Frequency at time t (Unconditional Failure Intensity), Or System Failure Frequency

Note: The $W(0, t)$ of a non repairable component is equal to F(t) (Unreliability) and approaches unity as t gets larger. The $W(0, t)$ of a repairable component goes to infinity as t becomes infinite.

Reference: Kumamoto & Henley Pages 283

2.3 Failure Frequency of a Cut Set

Failure frequency unlike failure rate is the probability of failure per unit time at life time t, independent of whether the failure has occurred before time t. Failure rate on the other hand is the conditional failure rate that the failure has not occurred before time t.

$$\omega_{CutSet} = \sum_{j=1}^{\eta} \omega_j \prod_{\substack{i=1 \\ i \neq j}}^{\eta} Q_i$$

Where:

ω_{CutSet} = Failure frequency of the cut set

ω_j = Failure frequency of the jth event in the cut set

Q_i = Unavailability of the ith event in the cut set

n = Events in the cut set

2.4 System Failure Rate

Assuming a constant rate model, the system failure rate is given by,

$$\lambda(t) = \frac{\omega(t)}{1 - Q(t)} = \frac{1}{MTBF}$$

Where:

$\lambda(t) =$ Failure Rate at time t

$\omega(t) =$ Failure Frequency at time t (Unconditional Failure Intensity).

2.5 MTBF System Mean Time Between Failures

$$MTBF = \frac{t}{W(0,t)} = MTTF + MTTR$$

Where:

$MTBF =$ mean time between failures: The expected value of the time between two consecutive failures.

$W(0,t) =$ Expected Number of Failures over interval $[0,t)$ given that the component was as good as new at time zero.

Reference: Kumamoto & Henley Pages 284

2.5 MTTF System Mean Time To Failures

$$MTTF = \int_0^{\infty} t f(t) dt$$

Where:

$MTTF =$ Mean time to failure

$f(t)dt =$ Probability that the TTF is around t.

Alternative:

$$MTBF = MTTF + MTTR$$
$$MTTF = MTBF - MTTR$$

Where:

$MTBF$ = Mean time between failure
$MTTF$ = Mean time to failure
$MTTR$ = Mean time to repair

Reference: Kumamoto & Henley Pages 277, 285

2.6 MTTR System Mean Time To Repair

$$MTTR = \frac{TDT}{W(0,t)} = MTBF - MTTF$$

Where:

$MTTR =$ Mean time to repair
$TDT =$ Total Down Time
$W(0,t) =$ Expected Number of Failures over interval $[0,t)$ given that the component was as good as new at time zero.
$MTBF =$ mean time between failures: The expected value of the time between two consecutive failures.

2.7 System Unavailability

If Quantification Method is set to Esary-Proschan, system Failure Frequency is obtained by applying:

$$\omega_{sys} = \sum_{i=1}^{n} \omega_{CutSet_i} \prod_{\substack{j=1 \\ j \neq i}}^{n} (1 - Q_{CutSet_j})$$

Where:

ω_{sys} = System failure frequency

ω_{CutSet_i} = Failure frequency of cut set i

Q_{CutSet_j} = Unavailability of cut set j

n = Number of cut sets

If Quantification Method is set to Rare, system Failure Frequency is obtained by applying:

$$\omega_{sys} = \sum_{i=1}^{n} \omega_{CutSet_i}$$

Where:

ω_{sys} = System failure frequency

ω_{CutSet_i} = Failure frequency of cut set i

n = Number of cut sets

2.8 System Unreliability

Unreliability is the probability of one or more failures to age t.

$$F(t) = 1 - e^{-(1-Q(t))}$$

Where:

$F(t)$ = Unreliability at time t

$Q(t)$ = Unavailability at time t

3. RBD Importance

3.1 Fussell-Vesely Importance

$$IMP_{FV} = \frac{\sum Q_{ofcutsetscontainingBlock/Event}}{\sum Q_{ofallcutsets}}$$

The Fussell-Vesely importance measure indicates a block's / event's contribution to the system unavailability. Change in unavailability of blocks / events with high importance values will have the most significant effect on system unavailability.

3.2 Birnbaum Importance

$$IMP_{BB} = \frac{\sum Q_{ofcutsetscontainingBlock/Event}}{Q_{ofBlock/Event}}$$

The Birnbaum importance represents the sensitivity of system unavailability with respect to changes in the block's / Event's unavailability.

3.3 Barlow-Proschan Importance

In effect the probability that the system fails because a critical cut set containing the block / event fails, with the block / event failing last.

$$IMP_{BP} = \frac{\omega_{ofBlock} * \sum Q_{ofcutsetscontainingBlock/Event}}{Q_{ofBlock/Event} * Numberof \exp ectedsystemfailures}$$

$\omega_{ofBlock/Event} = Block/EventFailureFrequency$

$QofBlock/Event = Block/EventUnavailability$