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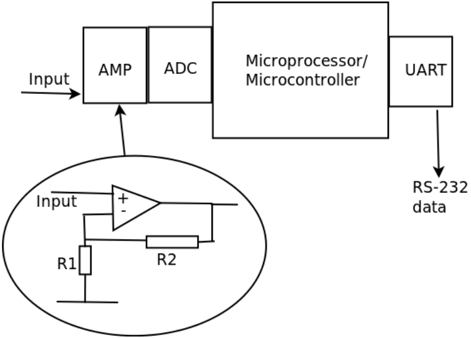
- **A - Analysis** Analyse how much impact this symptom will have on the environment/people/the system itsself

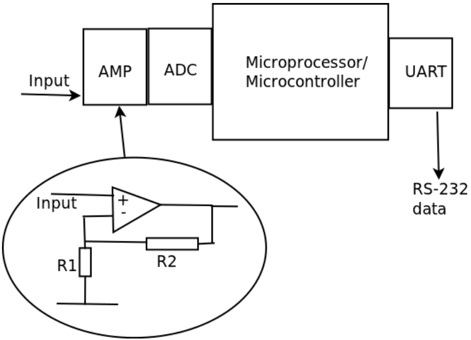
FMEA Example: Milli-volt reader

Example: Let us consider a system, in this case a milli-volt reader, consisting of instrumentation amplifiers connected to a micro-processor that reports its readings via RS-232.



FMEA Example: Milli-volt reader

Let us perform an FMEA and consider how one of its resistors failing could affect it. For the sake of example let us choose resistor R1 in the OP-AMP gain circuitry.



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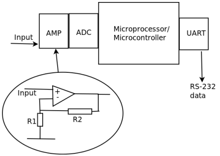

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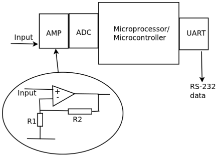

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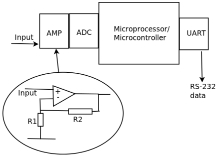

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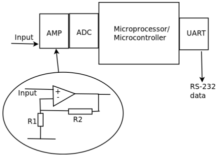

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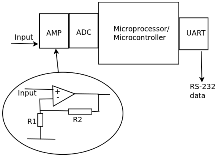

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- **M - Failure Mode** Consider the component failure mode SHORT
- **E - Effects** This will drive the minus input LOW causing a HIGH OUTPUT/READING
- **A - Analysis** The reading will be out of normal range, and we will have an erroneous milli-volt reading

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Rigorous Single Failure FMEA

Consider the analysis where we look at all the failure modes in a system, and then see how they can affect all other components within it.

Rigorous Single Failure FMEA

We need to look at a large number of failure scenarios to do this completely (all failure modes against all components). This is represented in the equation below. where N is the total number of components in the system, and f is the number of failure modes per component.

$$N.(N-1).f \tag{1}$$

Rigorous Single Failure FMEA

This would mean an order of N^2 number of checks to perform to undertake a 'rigorous FMEA'. Even small systems have typically 100 components, and they typically have 3 or more failure modes each. $100 * 99 * 3 = 29,700$.

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For looking at potential double failure scenarios (two components failing within a given time frame) and the order becomes N^3.

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The European Gas burner standard (EN298:2003), demands the checking of double failure scenarios (for burner lock-out scenarios).

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Table: FMEA Calculations

Failure Mode	P	Cost	Symptom	RPN
relay 1 n/c	$1 * 10^{-5}$	38.0	indicators fail	0.00038
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rear end crash ruptured f.tank	$14.4 * 10^{-6}$	267,700	fatal fire allow	3.855
rear end crash ruptured f.tank	1	11	recall fix tank	11.0

http://www.youtube.com/watch?v=rcNeorjXMrE

FMECA - Failure Modes Effects and Criticallity Analysis

Figure: A10 Thunderbolt

Emphasis on determining criticality of failure. Applies some Bayesian statistics (probabilities of component failures and those thereby causing given system level failures).

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Highest C_m values would be at the top of a 'to do' list for a project manager.

FMEDA - Failure Modes Effects and Diagnostic Analysis

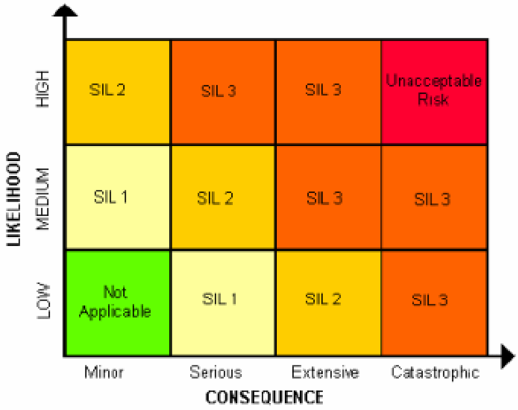

Figure: SIL requirements

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Diagnostic Coverage. The diagnostic coverage is simply the ratio of the dangerous detected probabilities against the probability of all dangerous failures, and is normally expressed as a percentage. $\Sigma\lambda_{DD}$ represents the percentage of dangerous detected base component failure modes, and $\Sigma\lambda_D$ the total number of dangerous base component failure modes.

$$DiagnosticCoverage = \Sigma\lambda_{DD}/\Sigma\lambda_D$$

FMEDA - Failure Modes Effects and Diagnostic Analysis

The **diagnostic coverage** for safe failures, where $\Sigma\lambda_{SD}$ represents the percentage of safe detected base component failure modes, and $\Sigma\lambda_S$ the total number of safe base component failure modes, is given as

$$SF = \frac{\Sigma\lambda_{SD}}{\Sigma\lambda_S}$$

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Safe Failure Fraction. A key concept in FMEDA is Safe Failure Fraction (SFF). This is the ratio of safe and dangerous detected failures against all safe and dangerous failure probabilities. Again this is usually expressed as a percentage.

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FMEDA - Failure Modes Effects and Diagnostic Analysis

Table: FMEA Calculations

SIL	**Low Demand** Prob of failing on demand	**Continuous Demand** Prob of failure per hour
4	10^{-5} to $< 10^{-4}$	10^{-9} to $< 10^{-8}$
3	10^{-4} to $< 10^{-3}$	10^{-8} to $< 10^{-7}$
2	10^{-3} to $< 10^{-2}$	10^{-7} to $< 10^{-6}$
1	10^{-2} to $< 10^{-1}$	10^{-6} to $< 10^{-5}$

Table adapted from EN61508-1:2001 [7.6.2.9 p33]

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Figure: FMEA Meeting

Static FMEA, Design FMEA, Approvals FMEA

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Figure: FMEA Meeting

Static FMEA, Design FMEA, Approvals FMEA
Experts from Approval House and Equipment Manufacturer discuss selected component failure modes judged to be in critical sections of the product.

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- In practise, failure scenarios for critical sections are contested, and either justified or extra safety measures implemented.
- Often Meeting notes or minutes only. Unusual for detailed arguments to be documented.

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- Reasoning Distance - component failure to system level symptom
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- Difficult to re-use previous analysis work
- Very Difficult to model simultaneous failures.

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- We can now use *derived components* as higher level components

FMMD - Failure Mode Modular De-Composition

- Analysis occurs in small stages, within *functional groups*
- Each *functional group* is analysed until we have a set of its symptoms of failure.
- A *derived component* is created with its failure modes being the symptoms from the *functional group*
- We can now use *derived components* as higher level components
- We can build a failure model hierarchy in this way

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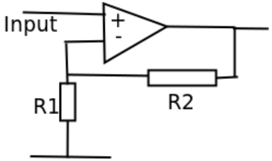
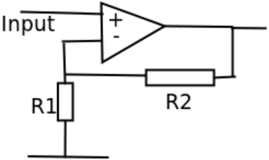
  $\bowtie (FunctionalGroup) \rightarrow DerivedComponent$

FMMD - Example - Milli Volt Amplifier



We return to the milli-volt amplifier as an example to analyse.

FMMD - Example - Milli Volt Amplifier



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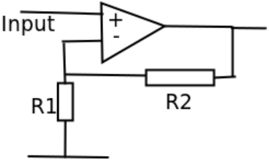

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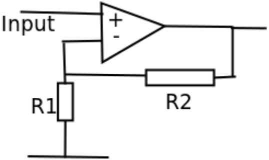
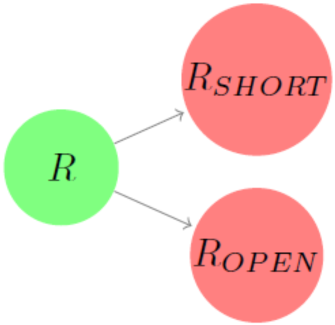


We return to the milli-volt amplifier as an example to analyse. We can begin by looking for functional groups.The resistors perform a fairly common function in electronics, that of the potential divider. So our first functional group is $\{R1, R2\}$.We can now take the failure modes for the resistors (OPEN and SHORT EN298) and see what effect each of these failures will have on the *functional group* (the potential divider).

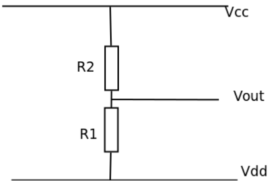
FMMD - Example - Resistor and failure modes

Resistor and its failure modes represented as a directed graph.

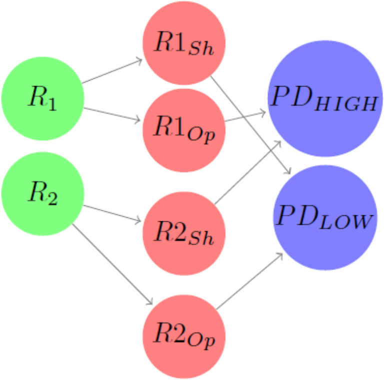


FMMD - Example - Failure mode analysis of Potential Divider

Failure Scenario / test case	**Pot Div Effect**	**Symptom**
FS1: R1 SHORT	*LOW*	*PDLow*
FS2: R1 OPEN	*HIGH*	*PDHigh*
FS3: R2 SHORT	*HIGH*	*PDHigh*
FS4: R2 OPEN	*LOW*	*PDLow*



FMMD - Example - Potential Divider as Derived Component



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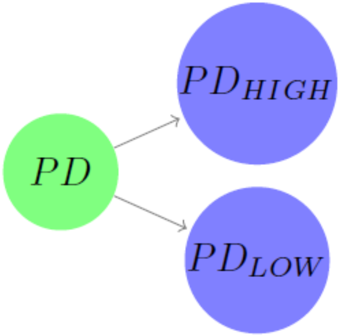
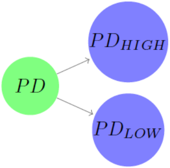
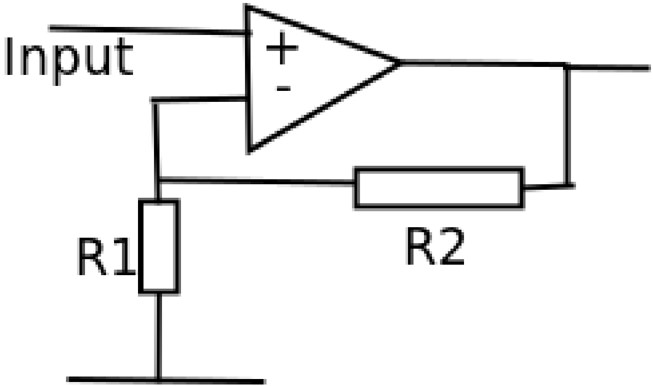


FMMD - Example - Potential Divider as Derived Component

We can now use this pre-analysed potential divider 'derived component' in a higher level design.



FMMD - Example - Non Inverting OP-AMP



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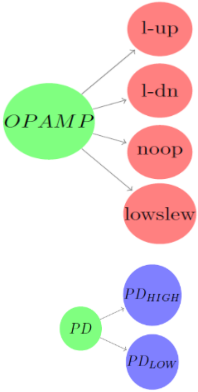

Failure Scenario	Circuit Effect	Symptom
l-up	Output High	N_INVAMP High
l-dn	Output Low	N_INVAMP Low
noop	Output Low	N_INVAMP Low
Low slew	Sluggish reactions	N_INV_LPASS
PD HIGH	Output Low	N_INVAMP Low
PD LOW	Output High	N_INVAMP High

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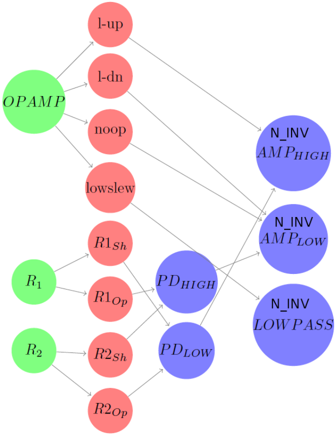

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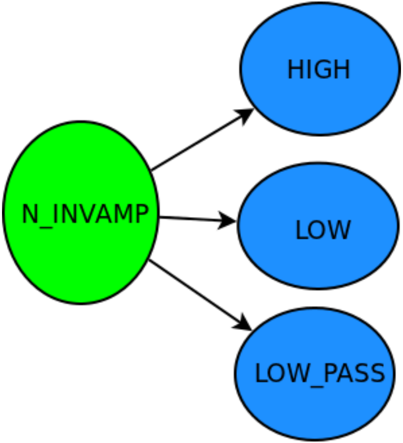

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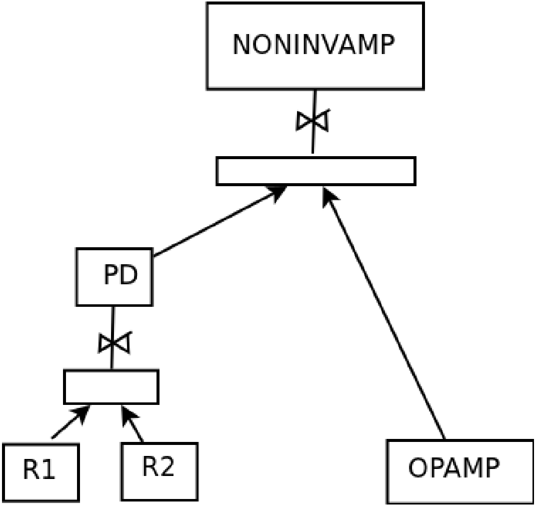

FMMD - Failure Mode Modular De-Composition

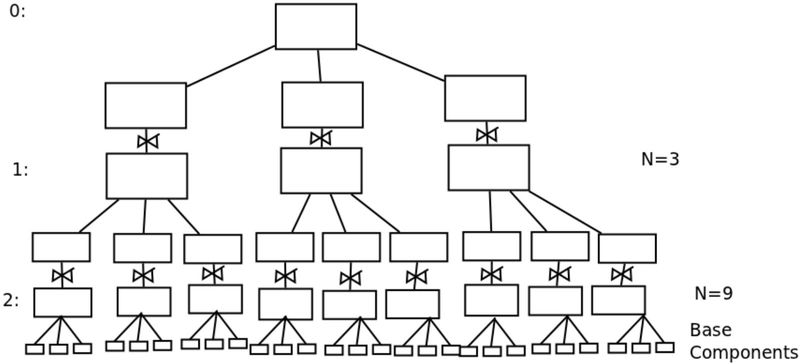

Figure: Functional Group Tree example

FMMD - Failure Mode Modular De-Composition

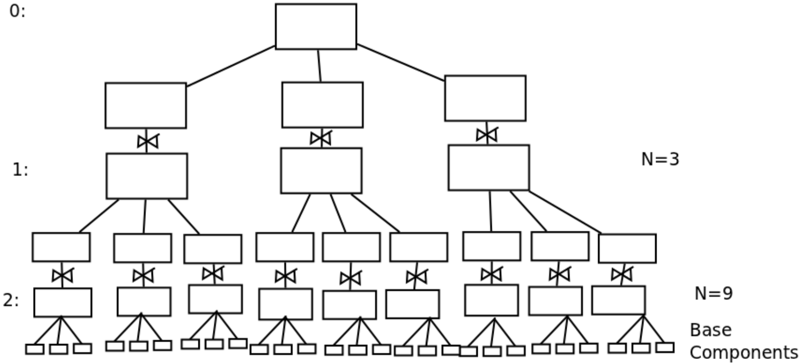

Figure: Functional Group Tree example

For the sake of example we consider each functional group to be

FMMD - Failure Mode Modular De-Composition

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The fact FMMD analyses small groups of components at a time, and organises them into a hierarchy addresses the state explosion problem.
For FMEA where we check every component failure mode rigorously against all the other components (we could call this **RFMEA**) Where N is the number of components, we can determine the order of complexity $O(N^2)$ thus.

$$N.(N-1).f \tag{4}$$

FMMD - comparing number of checks RFMEA . . . FMMD

If we consider c to be the number of components in a *functional group*, f is the number of failure modes per component, and L to be the number of levels in the hierarchy of FMMD analysis.
We can represent the number of failure scenarios to check in an FMMD hierarchy with equation 5.

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$$\sum_{n=0}^{L} c^n.c.f.(c-1) \qquad (5)$$

FMMD - Failure Mode Modular De-Composition

To see the effects of reducing 'state explosion' we can use an example. Let us take a system with 3 levels of FMMD analysis, with three components per functional group and three failure modes per component, and apply these formulae. Having 4 levels (in addition to the top zeroth level) will require 81 base level components.

$$81.(81-1).3 = 19440$$

$$\sum_{n=0}^{3} 3^n.3.3.(2) = 720$$

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- 19440 'checks' is not practical
- 720 checks is quite alot, but...
- Modules in FMMD can be re-used...

FMMD - Failure Mode Modular De-Composition

To determine all possible double simultaneous failures for rigorous FMEA the order $O(N^3)$.

$$N.(N-1).(N-2).f \tag{6}$$

Or express in terms of the level

$$c^{L+1}.(c^{L+1}-1).(c^{L+1}-2).f \tag{7}$$

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The FMMD case (equation 8), is cubic within the functional groups only, not all the components in the system.

$$\sum_{n=0}^{L} c^n.c.f.(c-1).(c-2) \tag{8}$$

FMMD - Failure Mode Modular De-Composition

Traceability Because each reasoning stage contains associations ($FailureMode \rightarrow Symptom$) we can trace the 'reasoning' from base level component failure mode to top level/system failure, by traversing the tree/hierarchy. This is in effect providing a 'framework' of the reasoning.

FMMD - Failure Mode Modular De-Composition

Re-usability Electronic Systems use commonly re-used functional groups (such as potential dividers, amplifier configurations etc) Once a derived component is determined, it can generally be used in other projects.

FMMD - Failure Mode Modular De-Composition

Total coverage With FMMD we can ensure that all component failure modes have been represented as a symptom in the derived components created from them. We can thus apply automated checking to ensure that no failure modes, from base or derived components have been missed in an analysis.

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Conclusion: FMMD

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Conclusion: FMMD

- Addresses State Explosion
- Addresses total coverage of all components and their failure modes
- Provides traceable reasoning
- derived components are re-use-able

FMMD - Failure Mode Modular De-Composition

Questions?