The scientific method, engineering design process, and how the modern world was built

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The beginning: Why study engineering?

- I was good at math and physics.
  - Go study math and physics
- I want a job when I graduate.
  - Get a vocational degree
- My parents said to.
  - Yeah. That's nice
- I like tinkering.
  - Cool. Open a repair shop.
- I want to solve big problems.
  - Yes, you should study engineering

What is engineering?

- Engineering is defined by process
- Problem/Objective → Requirements/analysis → Verification/testing → Market
- Does not require science but is aided by science.
- Divergent- engineering leads to more engineering, invention to invention
- Has been around a long, long time

Not to be confused with science...

- Hypothesis → prediction → experiment → theory
- Aesthetics promote simpler theories or theories that explain more phenomena from fewer conjectures
- In principle, the more science is done, the less there is to do (not true in practice)
- Science is not really that old, maybe 400 years

GPS: engineering vs science

$$v_s = 3.9 km/s \rightarrow -7.3 \mu s / day$$

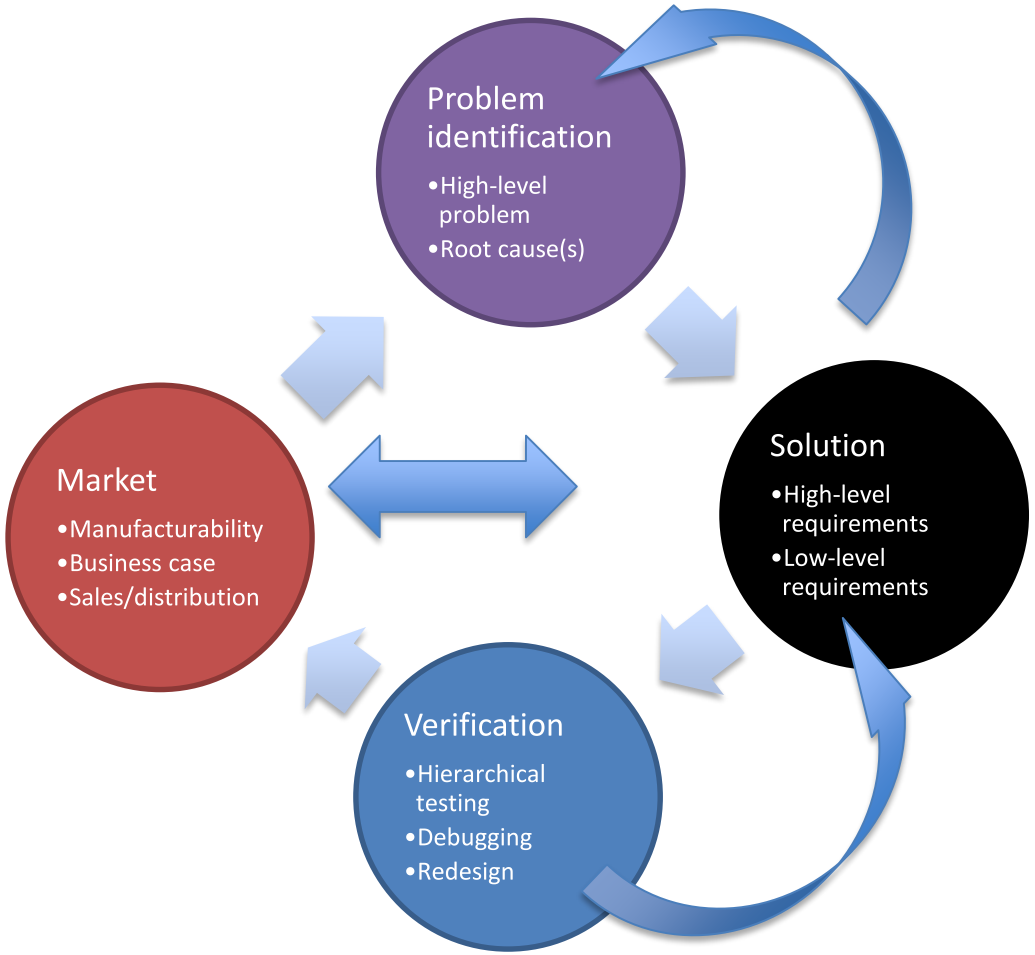
$$r_e = 6375 km, \qquad \frac{2GM}{r_e c^2} = \frac{r_s}{r_e} = \frac{8.9 mm}{6375 km} = 1.4 \times 10^{-9}$$

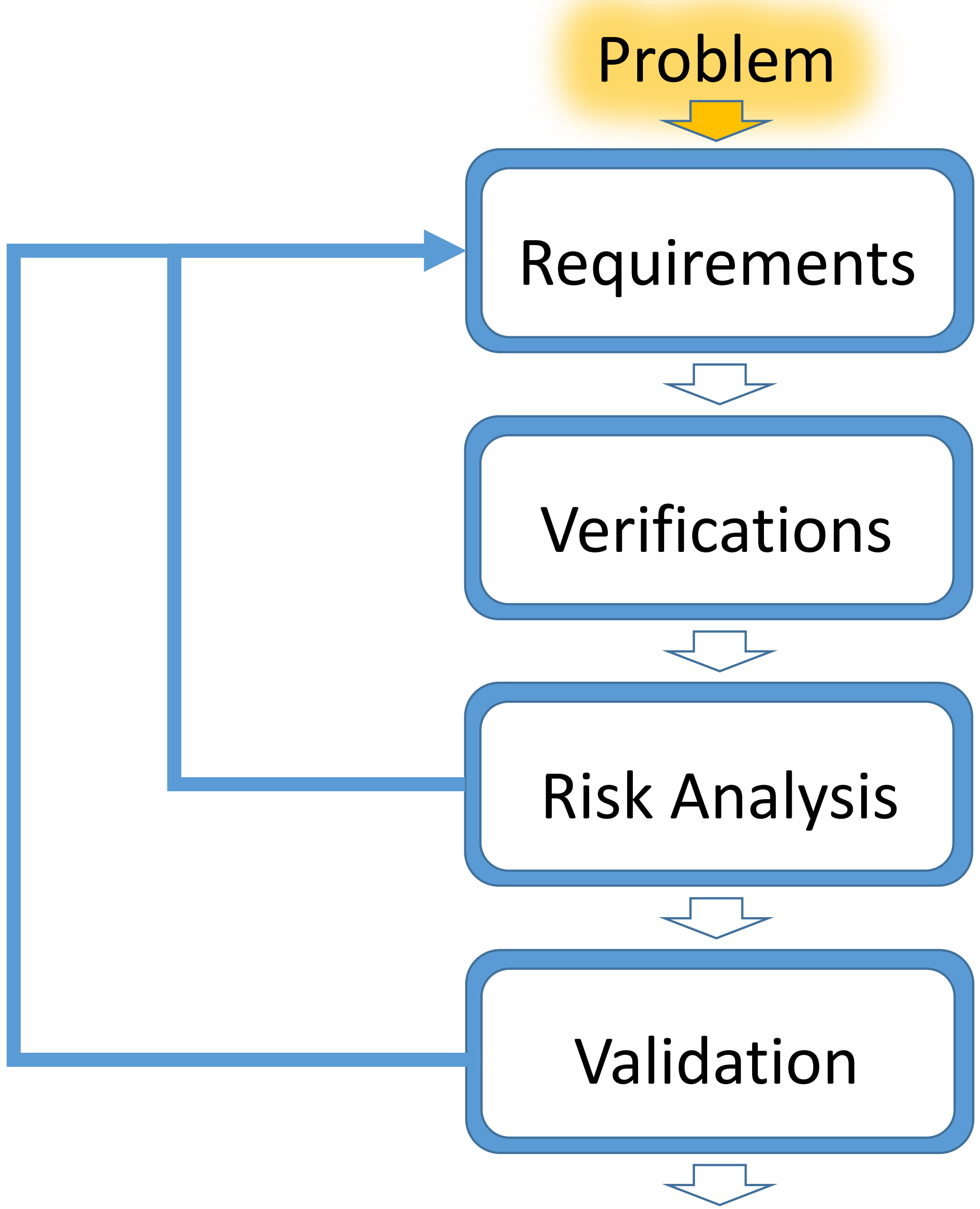
$$\rightarrow -60.5 \mu s / day$$

$$r_{sat} = 4 r_e \rightarrow -15 \mu s / day$$

$$net = 38.2 \mu s / day$$

Engineering in a graphic



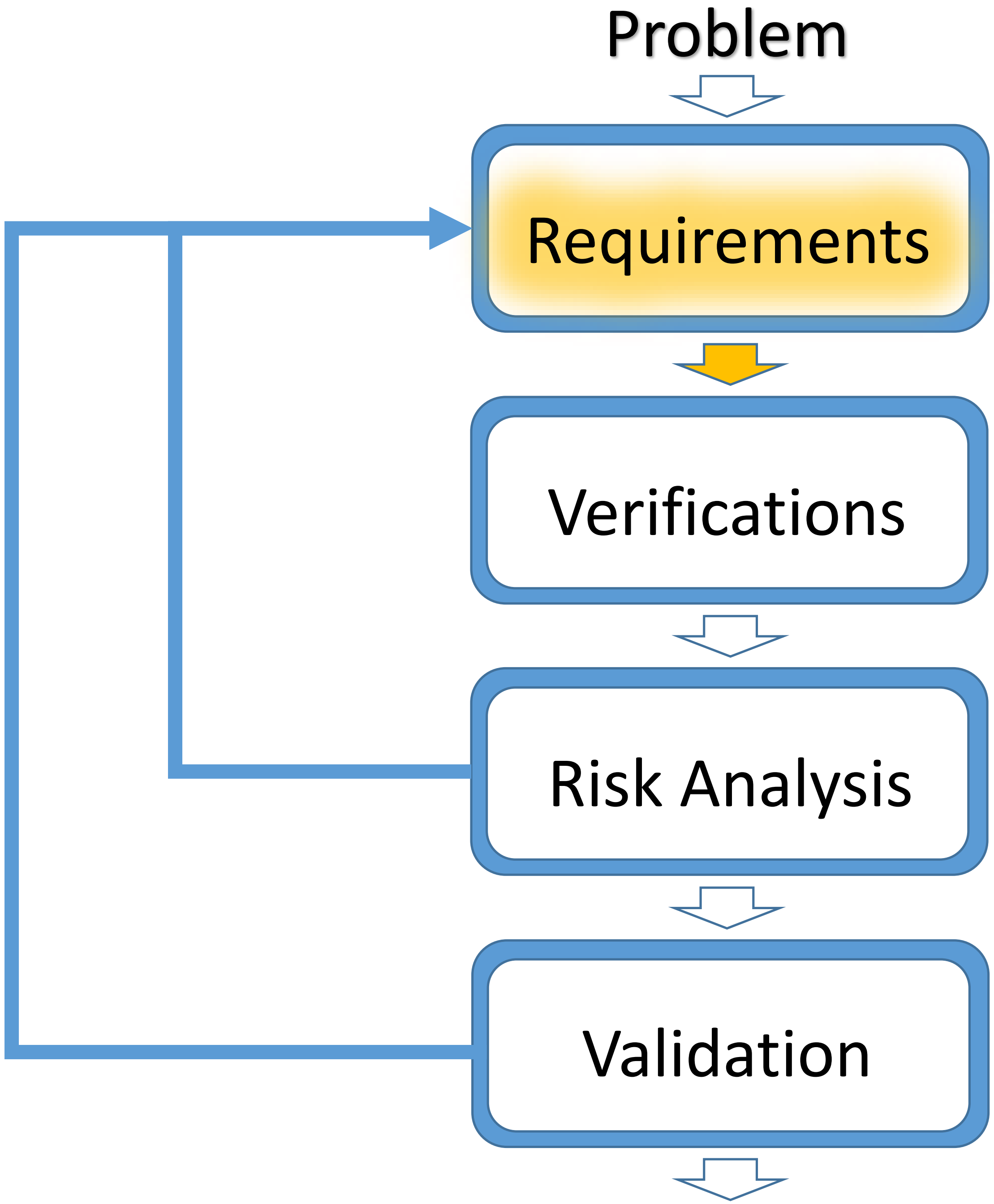


Problem Statement:

A description of what you are trying to solve and why.

A problem statement should be:

- Brief
- Clear
- Unambiguous

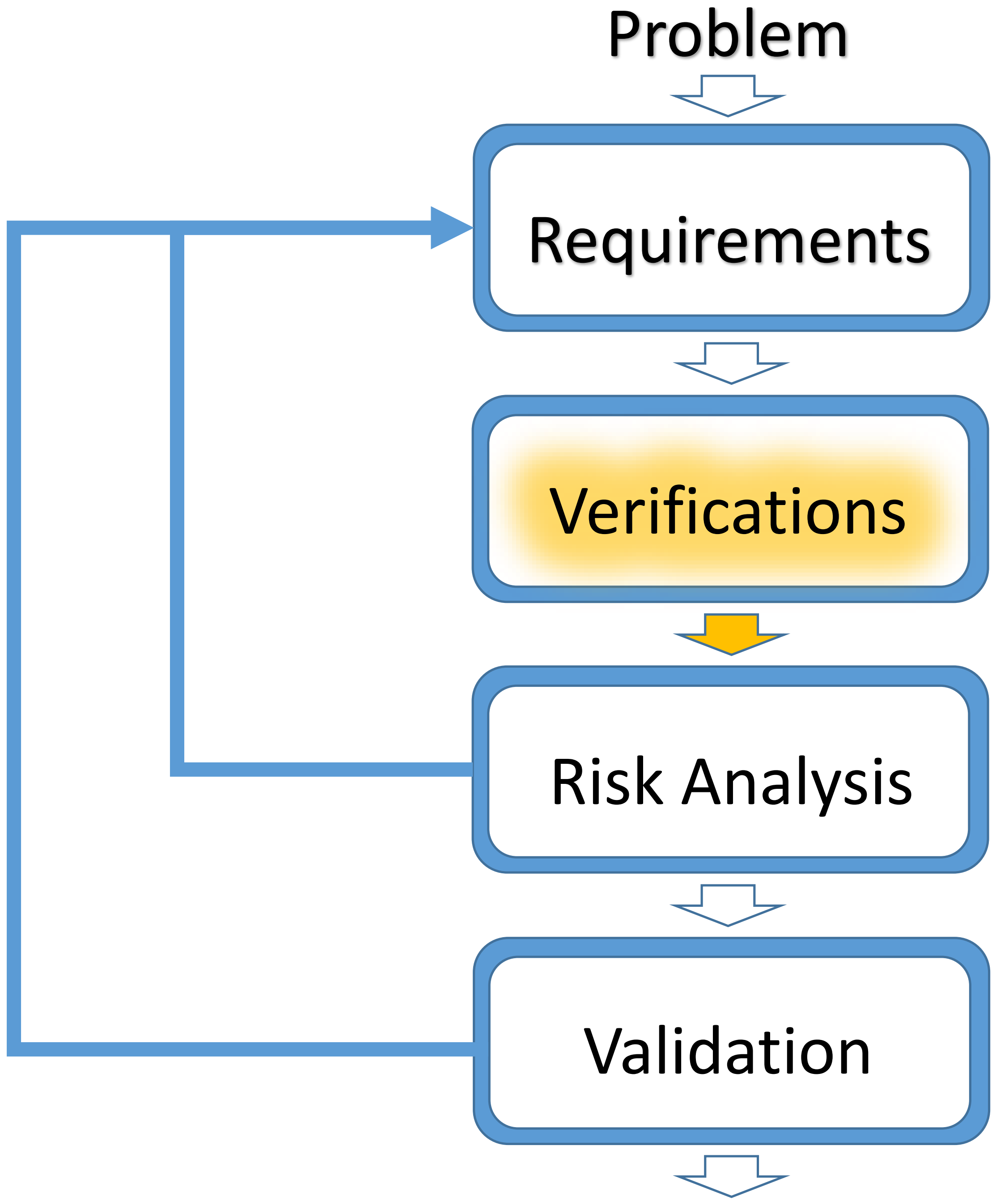


Requirements:

A set of statements that describe the attributes your system must have to solve your problem.

They should be:

- Quantifiable
- Relevant
- Detailed

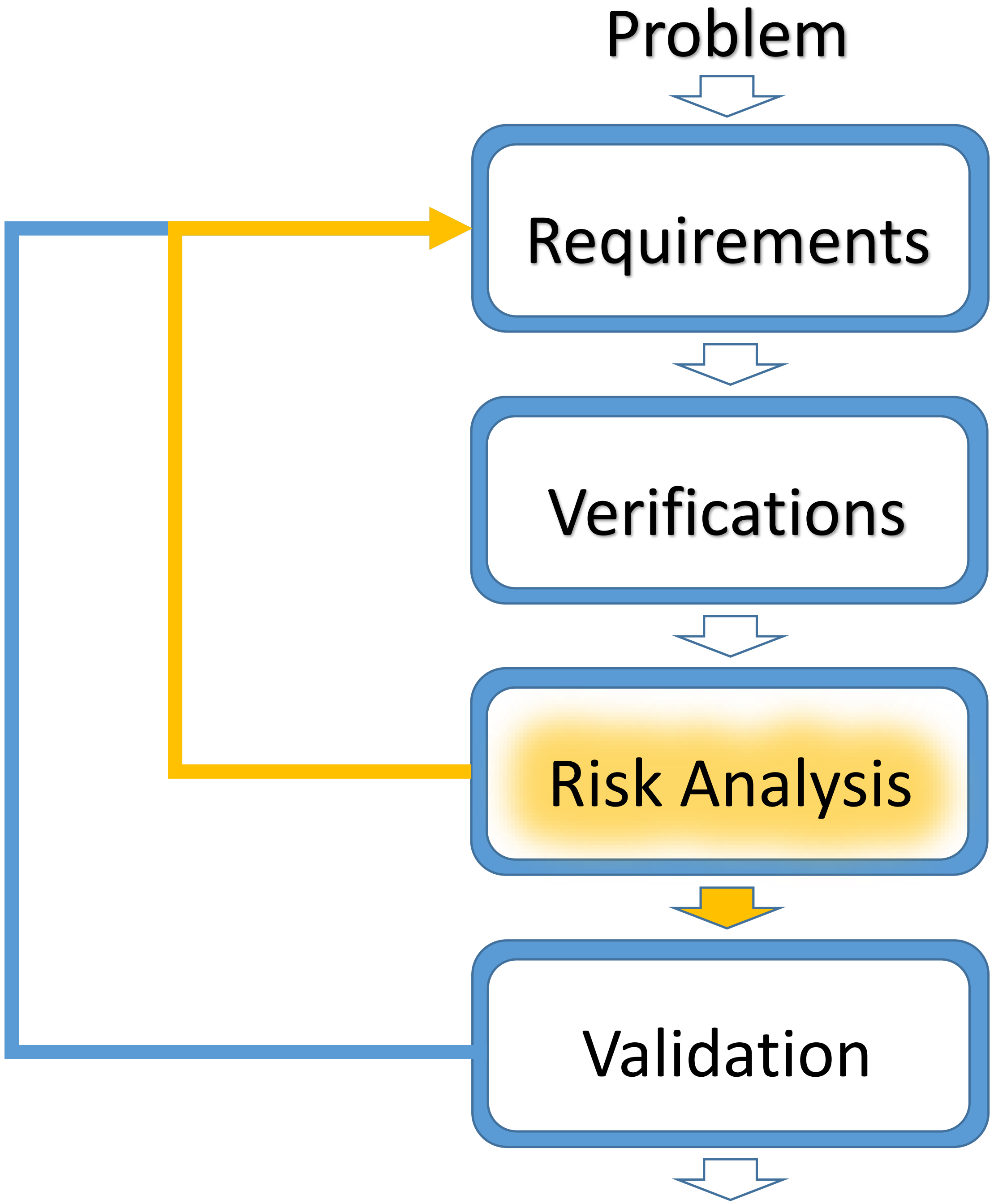


Verifications:

A set of statements that describe tests you will perform to make sure that your system meets the requirements.

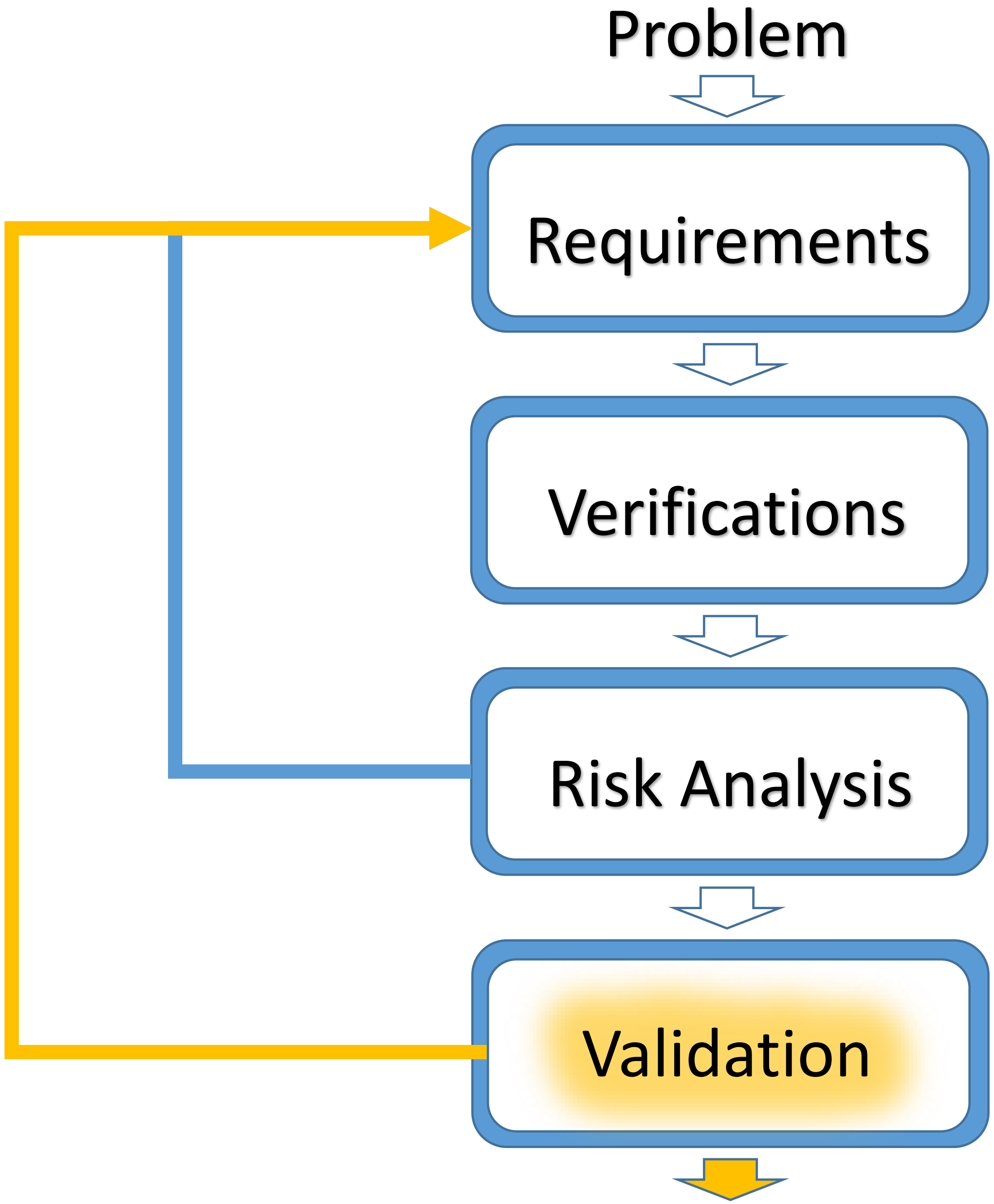
They should:

- Include measurement.
- Procedure for conducting measurement.
- Evidence that will be provided in report that requirement has been met.



Risk and Tolerance Analyses:

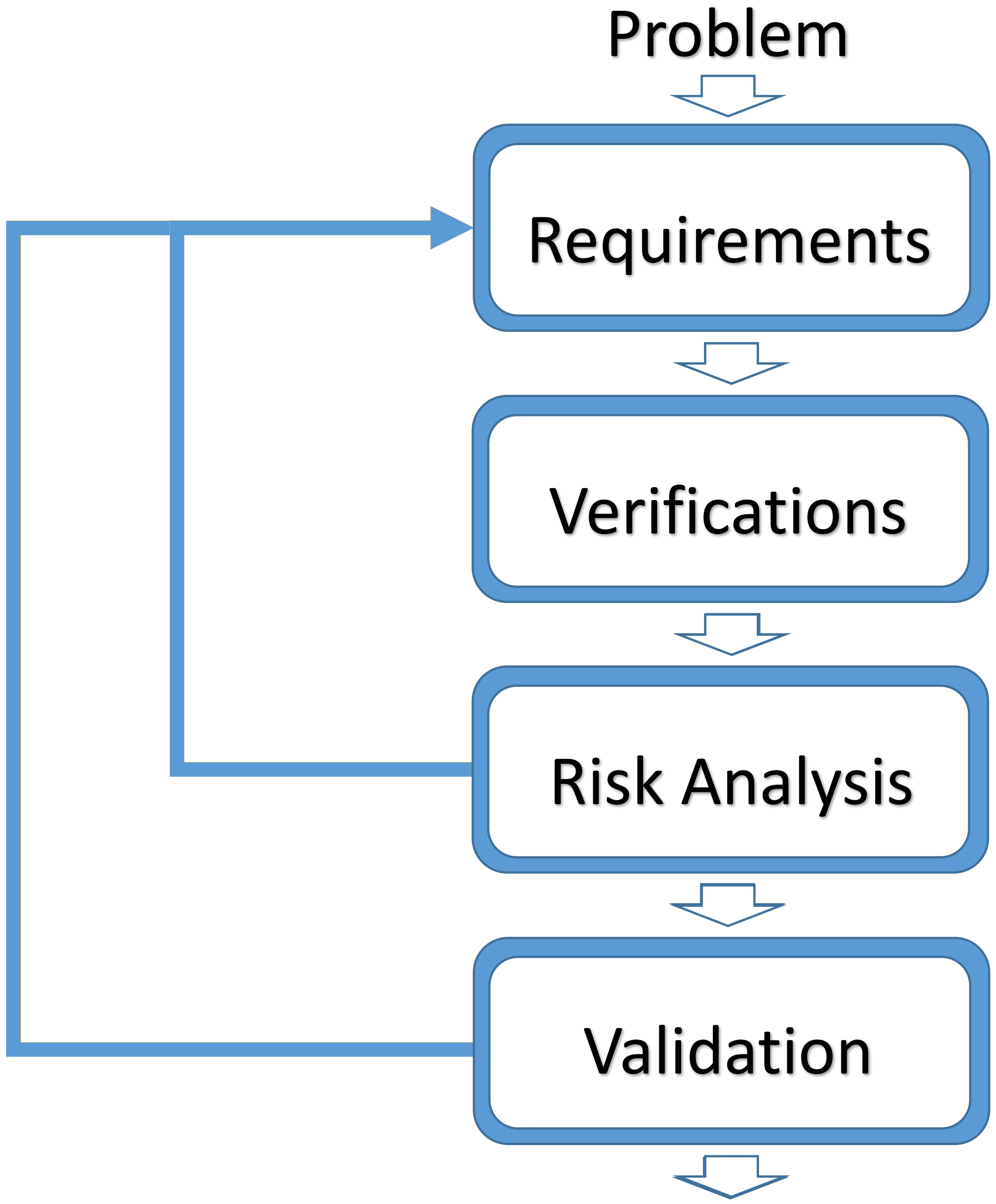
The risk of the failure of specific system component is dependent on two variables, the **consequence** of the loss and the **probability** that the loss will occur.



Validation:

Tests performed on prototype product to determine if they solve the problem of the user.

Often performed by an independent agency.



This process is iterative!!

Do not confuse your first set of requirements with your final set of requirements.

Feedback, testing and risk analysis

- GPS and relativity – how great engineering defeats bad science
- Medicine – engineering's closest relative
- Complexity and the inevitability of faults

So what does this process look like?

- ECE 445 UIUC
- ECE 398psc

Let's (re)invent something!

- Pick an every day problem or task
- Deconstruct the problem
- Write requirements for a solution
- How could you verify the solution?
- What are the biggest risks for failure?
- Is it manufacturable and marketable?

Design: Intellectual structure

<table>
<tr><th colspan="8">Problem</th></tr>
<tr><td colspan="3">Requirement 1</td><td colspan="2">Requirement 2</td><td colspan="3">Requirement 3</td></tr>
<tr><td>Req. 1.1</td><td>Req. 1.2</td><td>Req. 1.3</td><td>Req. 2.1</td><td>Req. 2.2</td><td>Req. 3.1</td><td>Req. 3.2</td><td>Req. 3.3</td></tr>
<tr><td colspan="8">Logical Integration</td></tr>
</table>

Design: Example

<table>
<tr><th colspan="8">Social-emotional agnosia
(inability to read facial expressions)</th></tr>
<tr><td colspan="3">Capture 90% of facial expressions from people user is talking with.</td><td colspan="2">Classify 5 basic emotions with 95% accuracy using facial expressions.</td><td colspan="3">Provide haptic feedback to user.</td></tr>
<tr><td>Record video at 12 frames per second or faster.</td><td>Activate camera when faces detected at distances of 0.3m to at least 2m with greater than 91% accuracy.</td><td>Transmit each image of each facial expression over Wi-Fi with 99% accuracy.</td><td>Classify five basic facial expressions and neutral with 95% accuracy.</td><td>Classify facial expressions in less than one second.</td><td>Provide between 0.25-0.5N force to user.</td><td>Provide feedback in less than 50ms of receiving label.</td><td>Require less than 50mA of current.</td></tr>
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Design: Example

Social-emotional agnosia (inability to read facial expressions)		
Capture 90% of facial expressions from people user is talking with.		
Record video at 12 frames per second or faster.	Activate camera when faces detected at distances of 0.3m to at least 2m with greater than 91% accuracy.	Transmit each image of each facial expression over Wi-Fi with 99% accuracy.
Logical Integration		

Design: Example

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<tr><td colspan="8">Solution</td></tr>
<tr><td colspan="3">Verification 1</td><td colspan="2">Verification 2</td><td colspan="3">Verification 3</td></tr>
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Design: Testing and verification

Build a facial expression prosthesis		
Build database of 20 conversations (vary gender, length, distance from camera). Manually label each facial expression. Play videos back to camera system. Compare number of expressions recorded by system to ground truth. Report accuracy.		
Record video of stopwatch with camera for 5 seconds. Does 5 second clip includes 60 frames? Repeat 100 times.	Create training data set of 1000 images. Half images with faces, half without. Vary gender and distance (0.1-3m) from camera. Record number of times camera is activated by face images. Report accuracy.	Transmit 1000 images over the Wi-Fi connection. Save transmitted images. Compare saved images to original images. Report percent of pixels that match.
Debugging		

Design: Correspondence to physical realization

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<tr><td colspan="8">Product</td></tr>
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Design: Example

A wearable facial expression recognition system		
Vision System		
Camera	Microprocessor	Wi-Fi
Physical Integration		

Risk Assessment

$$\boldsymbol{Risk = Loss \ * P(Loss)}$$

- The riskiest component is not simply the one that has the highest chance to fail.
- The riskiest component is the one with the highest **product** of chance of failure multiplied by the consequence of that failure.

Tolerance Analysis

In this class, perform tolerance analysis on the component with the highest risk.

Empirical verification of component as critical parameter is changed.

Example:
https://courses.engr.illinois.edu/ece445/documents/tolerance-analysis-guide.pdf

- Large construction projects frequently generate ground vibrations, which result from moving heavy equipment and driving piles.
- Our project is a tool for construction companies to monitor the level of vibrations which propagate off the construction site.
- We decide that the highest risk component is the anti-aliasing filter before A/D conversion. If aliased frequencies are allowed to pass, sensor may give inaccurate information (high Loss).

Tolerance Analysis: Example

There are two requirements for the filter:

1) The flatness of the passband from 0-100 Hz must be less than 1dB.
2) It must have an attenuation of at least 3 dB for frequencies at or above the Nyquist frequency.

To achieve the three requirements listed in the previous paragraph, a 10 kΩ resistor with 1% tolerance and a 62 nF capacitor with 6% tolerance were chosen. The sampling rate is 400Hz.

Tolerance Analysis: Hypothetical Example

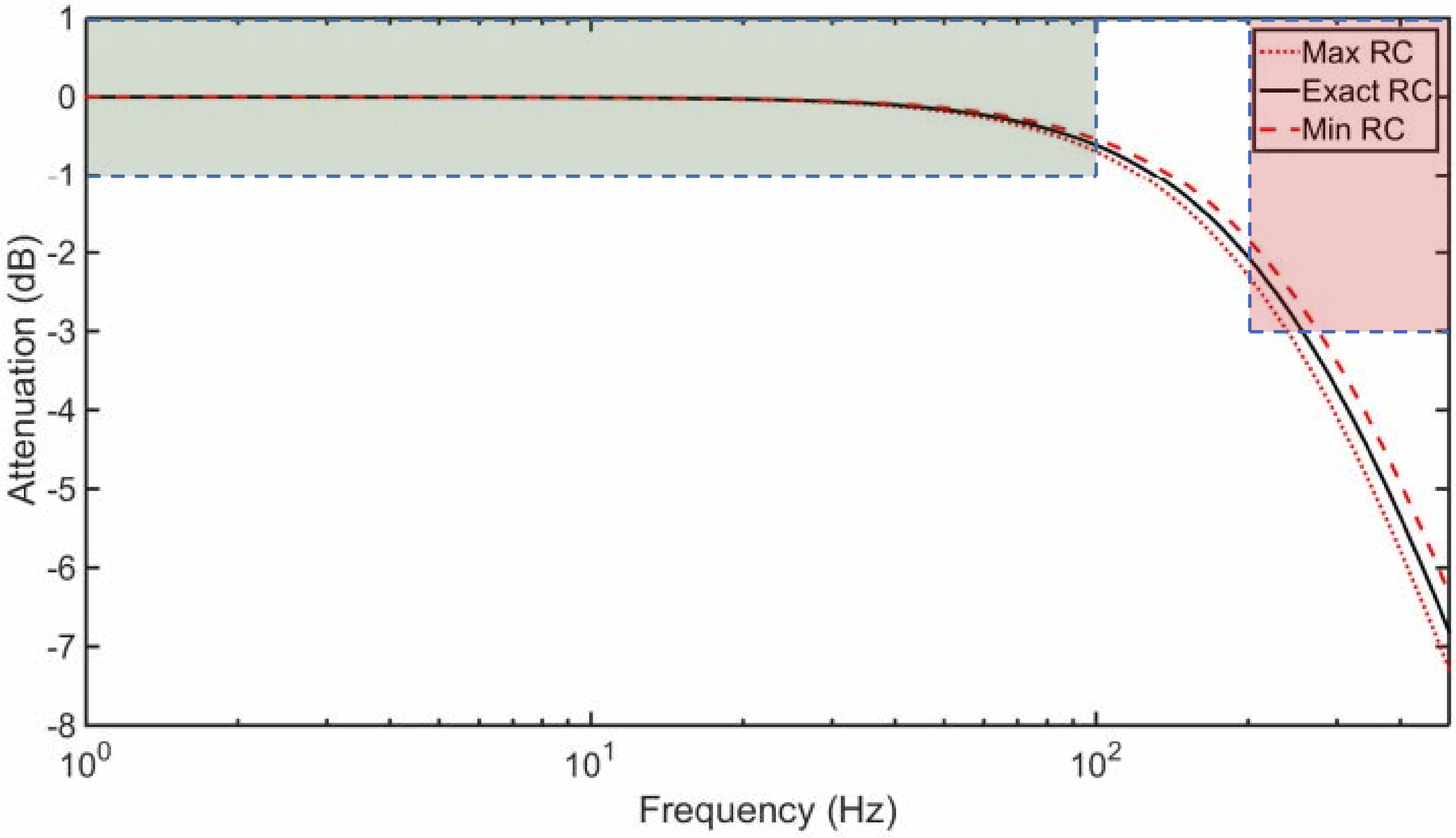
Plot our best, exact, and worst case RC products.

Requirement 1

- It can be seen that the flatness of the passband from 0-100Hz is less than 1db.

Requirement 2

- The attenuation at 200Hz (Nyquist frequency) is **less than** 3db.



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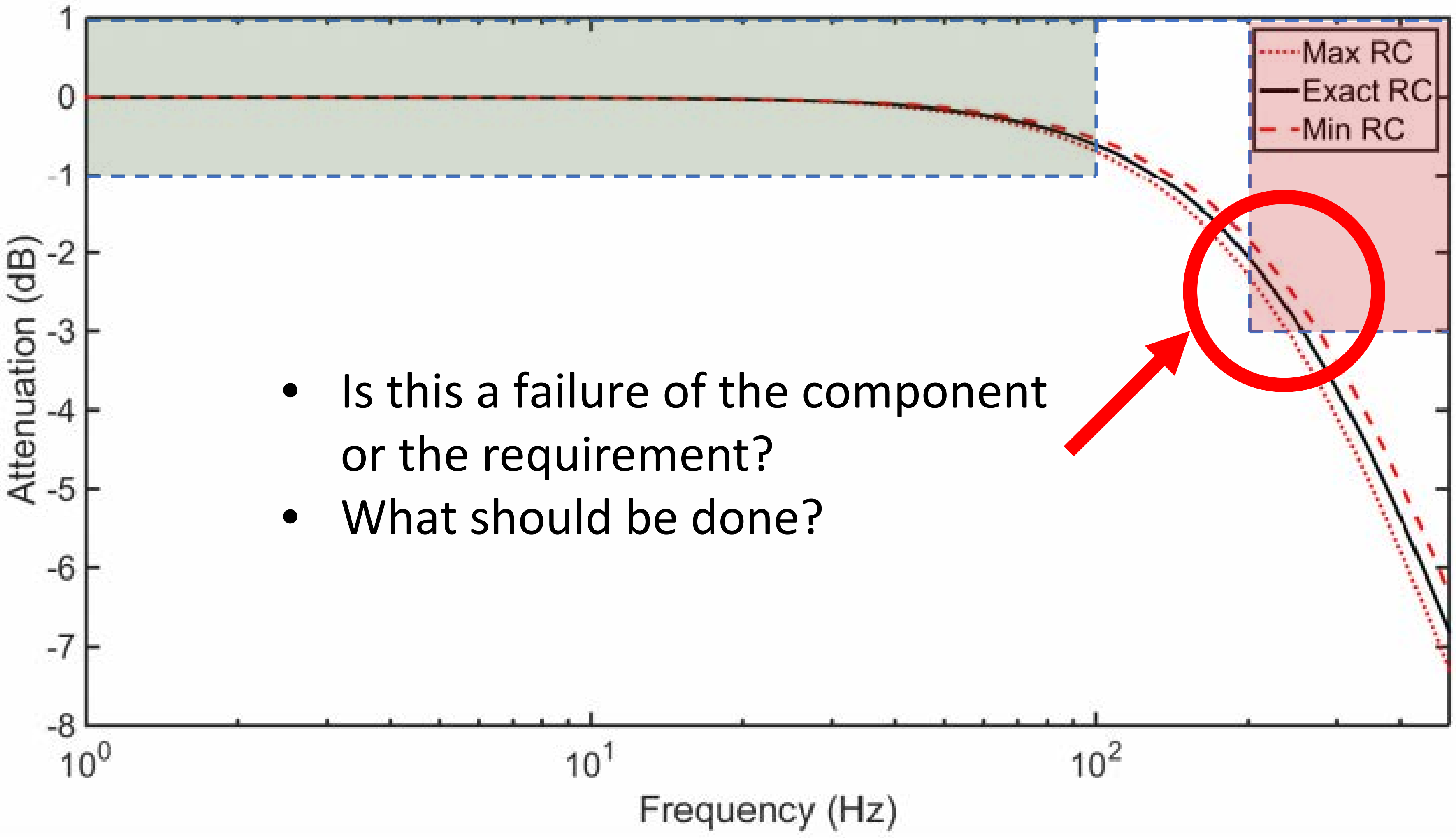

- Is this a failure of the component or the requirement?
- What should be done?

Requirements and Verification: Format

This is what you will produce for your project!

Block	Requirement	Verification	Points
Module 1: Video Recording	Records video at a minimum of 12fps	One minute of video footage will be recorded on the glasses camera and extracted The video will then be imported into a MATLAB program for analysis Using the VideoReader() function, the program checks if the number of frames are greater than 720 which means the video is shot with at least 12 fps	5 pts
	When a frontal face is within a meter of the Google Glass, a bounding box will be drawn on that face in 70% of the total video frames	Take 10 second video of 4 different people with Module 1. Using MATLABs VideoReader() function, determine the number of frames for which a face is detected for each video. If each video is taken at 12 fps, then if 336 of the total 480 frames have a face detected with a bounding box, 70% face detection is achieved.	10 pts
	Transmits video from Google Glass to PC at greater than 12fps.	Transmits video data to Module 2 over WiFi. Measure the time that it takes for the video to travel from the glass to the PC via MATLAB’s timing capability. If 720 frames are sent in a minute or less, then 12 fps transmission is achieved.	5 pts

R&V Exercise (25 minutes)

- Form groups of 3 with different people from lecture 1.
  Avoid friends, and say hi to someone new!

- Briefly pitch your quad chart ideas,
  and select 1 idea per group.

2 minutes

Requirements

- List requirements.
- Thoroughly Break down **modular** goals, e.g.,
  - portability → weight and size requirements,
  - safety → current limiting and protective enclosure requirements,
  - computation → sample rates and memory requirements,
  - power → hours of use and ripple requirements.
- Give **quantitative** measureable ranges, e.g.,
  - The power supply must provide a voltage in the range of $5V \pm 0.5V$ for a current load up to $100mA$.
- Design Requirements ≠ Purchase Requirements
  No points are awarded to purchased hardware that automatically satisfies requirements.

	R	
Module 1	Req. 1	
	Req. 2	
	Req. 3	
Module 2	Req. 4	
	Req. 5	
Module 3	Req. 6	
	Req. 7	
	Req. 8	
	Req. 9	

⋮
Etc.

7 minutes

Verification

- List verifications.

  Provide a detailed set of instructions describing how to verify the requirement has been satisfied.

- Be **Explicit**.

  Any qualified engineer should be able to follow these instructions without prior knowledge of the design.

- Describe experimental procedure, e.g.,
  - What instruments will be used?
  - How will the instruments be configured?
  - How will your design be interfaced?
  - How will the results be presented?

	R	V
	Req. 1	Ver. 1
Module 1	Req. 2	Ver. 2
	Req. 3	Ver. 3
Module 2	Req. 4	Ver. 4
	Req. 5	Ver. 5
	Req. 6	Ver. 6
Module 3	Req. 7	Ver. 7
	Req. 8	Ver. 8
	Req. 9	Ver. 9

⋮

Etc.

7 minutes

R&V Evaluation

- Find 2 other groups and form a circle of 9 people.
- Each group will present 1 module at a time.
- Provide constructive feedback:
  - Are the requirements too vague?
  - Are the instructions unclear?
  - Are the requirements satisfied by purchase or design?
  - Are the requirements relevant to the modular goals?
  - Could you determine if a designed system satisfies the R&V table?

9 minutes