Design for Electrical and Computer Engineers

Theory, Concepts, and Practice

Instructor's Solution Manual

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This document was prepared with LaTeX.

Contents

Preface: How to Use This Manual

This manual provides solutions to the problems found in Design for Electrical and Computer Engineers: Theory, Concepts, and Practice. For guidance to instructor's we identify problems as either: review, application, and project. Review-type problems usually ask the student to restate an important concept from the text, whereas application problems are those where the students are required to solve a more in-depth project that demonstrates an understanding of the concepts learned to a new scenario. Project problems are important steps in the completion of a senior capstone design project. Each particular problem is categorized in this solutions manual as to the type of problem it is by using the key [R], [A], and [P].

Furthermore, we also provide our guidance (identified in the manual as Notes), from experience teaching the material, with pointers on how we present the material and apply it to student projects. Selected project assignments are also supplied.

We also ask that instructor's keep this manual for instructor use only and do not post or otherwise distribute our solutions in any form. Unfortunately, it is becoming all too common for solutions to be copied and distributed over the Internet, thus hurting other instructors using the book.

Feedback

Feedback and suggestions concerning any aspect of this manual, that would likely benefit the overall presentation, would be much appreciated. Please send your comments via email to Ralph-Ford@psu.edu or coulston@mines.edu

Chapter 1

The Engineering Design Process

1.1 Problems

1. In your own words, describe the difference between prescriptive and descriptive design processes. Cite examples of each.

   [**R**] *Prescriptive design processes "prescribe" an exact sequence of steps and decisions for realizing a design. There are often decisions that must be made in prescriptive processes for determining whether to move from one stage to the next, or to move to the next phase. Descriptive processes describe the general steps needed to achieve a design, but do not explicitly layout the steps which should be followed to achieve the design.*

2. Describe the relationship between the Problem Identification, Research, and Requirements Specification phases of the design process.

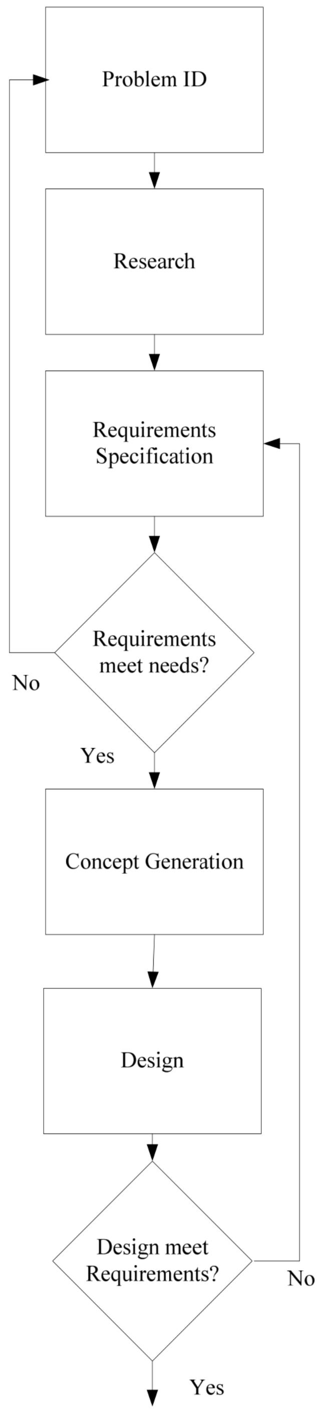
   [**R,A**] *Problem Identification, Research, and Requirements Specification are three early phases of the design process. The overall objective of these phases is to identify a problem, analyze it, and develop requirements for its solution. The Problem ID phase is where the end-user needs are determined, while further analysis occurs in the research phase. Both problem and research phases are used to develop a Requirements Specification that provides the requirements for those elements that must be satisfied in order for a successful design.*

3. Describe the relationship between the Concept Generation and Design phases of the design process.

   [**R,A**] *In Concept Generation, different technical options for solving the design are given – one is selected to pursue. In the Design Phase, the option selected from Concept Generation is further clarified and the design architecture is more clearly defined.*

4. Construct a prescriptive design process for the Problem Identification, Research, Specification, Concept, and Design phases of the design process. The result should be a flow chart that contains decision blocks and iteration as necessary.

   [**A**] *In the prescriptive design process, shown in the figure below, there are two decision points, one of which occurs after the requirements are determined. The objective in this decision is to determine whether the requirements satisfy the end-user needs. If not, the needs must be re-examined and the requirements must be updated as necessary, in order to meet the customer needs. The other decision occurs after the design is generated. Here, the objective is to determine if the design satisfies the requirements. If not, a new design*



concept must be generated.

5. Describe the main differences between the VLSI and embedded system design processes.

   [A] *VLSI and embedded systems design share similarities and contain differences. They are both similar in that they have phases for requirements specifications, system architecture design, and technical design. The difference between them lies in the technical* *design, where the steps depend upon the technology that is being developed. In the case of VLSI, steps are used to successively refine the design to meet develop a layout level circuit; however, embedded design requires that the technical design phase consists of software and hardware co-design.*

6. Using the library or Internet, conduct research on the spiral software design process.

   a) Outline the significant elements of the spiral software design process.

   b) Describe the advantages and disadvantages of this relative to the waterfall model?

   Cite all reference used.

   [A] *The spiral methodology reflects the relationship of tasks with rapid prototyping, increased parallelism, and concurrency in design and build activities*[1] *The spiral process recognizes that errors will occur in all stages of the production process and proceeds on this basis*[2]*. It is agreed that the development processes will have to be revisited multiple times as the design furthers completion; therefore, unlike the Waterfall model, this methodology incorporates an iteration cycle, which is continued until the design is fully complete. A Spiral Development Model diagram can be found at http://www.hyperthot.com/pm_sdm.htm as well at other sites on the Internet. Embedded in spiral design is the process of refactoring – changing software in such a way as to improve structure, but not affect the end result*[3]*. Overall, the spiral software design model is not as rigid, concrete, and strict as the Waterfall model; however, this method should still be planned methodically, with tasks and deliverables identified for each step within the spiral. The table below lists the advantages and disadvantages of the spiral design model in reference to the waterfall model.*

	Advantages		*Disadvantages*
1	*Increased time-to-market*	*1*	*Revisiting the same stages*
2	*Incremental & Iterative*	*2*	*Requirements are not fully identified*
3	*Promotes increase in documentation*	*3*	*Project goal is not initially established*
4	*No set structure or phase routine*		
5	*Non-idealistic*		
6	*Not as costly to revisit process steps*		
7	*Primitive to more intricate design*		
8	*Allows development to begin w/o full understanding*		

(1.) Chapman, James. "Spiral Methodology." Software Development Methodology. *2005. 20 May 2005 http://www.hyperthot.com/pm_sdm.htm*

(2.) Culwin, Fintan. "The Production Process." LAW – Learn Ada On the Web. *1998. 20 May 2005 http://www.scism.sbu.ac.uk/law/Section1/chap1/s1c1p3.html*

(3.) Hean, Daniel. "Design through to testing." Content & Document Management System. *2005. 20 May 2005. http://www.yedit.com/web-content-management-system/400-design-through-to-testing.html*

7. **Project Application.** In preparation for project and team selection, develop a personal inventory that includes a list of five favorite technologies or engineering subjects that you are interested in pursuing. Also, list the strengths and weaknesses that you bring to a project team.

[P] *Note: We find this exercise an important step in starting students on the path of team formation and project selection and usually assign it on the first day of class. We setup an electronic bulletin board for the students and have them post this information publicly for the whole class to see. Students are then encouraged to review this and identify potential team-mates. We have also done a variation where each student is required to determine this information and then make a short oral presentation (2 minute pitch) to the class, in which they describe what types of projects they are interested in and what strengths/skills they can bring to a team.*

Chapter 2

Project Selection and Needs Identification

2.1 Problems

1. In your own words, describe the differences between creative, variant, and routine designs.

   [R] *Creative designs are typically new and innovative design ideas – those that did not exist before. Variant designs are variations of existing designs, with the intent of improving some aspect of the existing system. Routine designs are concerned with fairly well-known artifacts for which there is a well-developed design knowledge base.*

2. List three guidelines that should be employed when selecting a project.

   [R] *(1) The project must be tied to the mission and vision of the organization; (2) The project must have payback; (3) The project should be selected with criterion; (4) The project objectives should be SMART (Specific, Measurable, Assignable, Realistic, and Time- Related).*

3. Assume a customer comes to you with the following request—*Design a mechanical arm to pick apples from a tree.* What are the assumptions in this statement? Rewrite the request to eliminate the assumptions. (This problem was originally posed by Edward DeBono [Deb70]).

   [A] *This statement contains a solution based on the assumption that a mechanical arm (by means of picking) is the best method for removing apples off of a tree. Therefore, the design space is immediately and needlessly limited. Also, we are unsure if there is a problem with current methods of removing apples. Here is a better statement:*

   "Design a device that can improve the current method of removing apples from a tree."

   This statement is rightly ambiguous in the sense of not specifying how, or from what, to build this device. This is the type of question and approach that should be sought for establishing a needs statement.

   > ***Note:*** *Including the word "mechanical" may be permissible, as it clearly defines a type of device, but does not specify further details or characteristics. This situation poses a fine line between problem and solution.*

4. Assume a customer comes to you with the following request—*Design an RS-232 networked personal computer measurement system to transmit voltage measurements from a remote location to a central server.* What are the assumptions this statement? Develop a list of questions that you might ask the customer to further clarify the problem statement.

   [A] *This statement, much like the one confronted in problem 3, is filled with numerous assumptions and solutions. The statement proves troublesome because both the problem (transmit voltages measurements from remote location to central server) and solution (RS- 232 networked personal computer) are given to together. Furthermore, you – as the Engineer – are unsure if the prescribed solutions are the best decisions for this particular problem. In order to dissect the statement and get to the actual problem, a list of questions must be asked.*

   Sample Questions

   - *What is the purpose of this transmission system?*
   - *Why are voltage measurements currently being sent? What do they represent?*
   - *How are the measurements currently being made?*

- *What are the problems with the current system?*
- *What do you like about the current system?*
- *What type of atmosphere will this device most likely be engaged in?*
- *Do you plan to implement multiple measurement systems?*
- *Why use RS-232?*
- *What is the purpose of the central server?*
- *What are the voltage measurements of?*

  Note: *The questions given here are variations on those presented in the book to ask the client when starting into a new project. The objective in asking this question is to get practice in asking these questions. Students are often hesitant to ask questions, particularly if they are working with an industrial sponsor. It help to give them practice in do this before they meet with their customer.*

5. Describe what is meant by a marketing requirement.

   [R] *A marketing requirement is a statement that describes a need in the language of the end-user or customer. It should describe what the system should do, not necessarily how it will be accomplished.*

6. What is the purpose of an objective tree and how is it developed?

   [R/A] *The objective tree is a graphical representation of the customer/end-user needs in a hierarchical layout. It is developed by determining the customer needs (through interviews, observations, etc.) and then translating the results of that into a set of specified needs. The needs are categorized into a hierarchy which is represented in the objective tree. The categorization is based upon functionality, not importance.*

7. The needs for a garage door opener have been determined to be: safety, speed, security, reliability, and noise. Create a pairwise comparison to determine the relative weights of the needs. Apply your judgment in making the relative comparisons.

   [A] ***DEVICE:*** *Garage Door Opener*
   NEEDS: *Safety, Speed, Security, Reliability, and Noise*

	Safety	*Speed*	*Security*	*Reliability*	*Noise*	*Total*
Safety	*X*	*1*	*1*	*0.5*	*1*	*3.5*
Speed	*0*	*X*	*1*	*0*	*0.5*	*1.5*
Security	*0*	*0*	*X*	*0.5*	*1*	*1.5*
Reliability	*0.5*	*1*	*0.5*	*X*	*1*	*3*
Noise	*0*	*0.5*	*0*	*0*	*X*	*0.5*

Most Important *Safety*
Reliability
Security
Speed
Least Important *Noise*

Note: *There is no single solution, and the results are somewhat subjective. However, safety should always be of the highest concern in such an application. The objective of this problem is to demonstrate that students can create a matrix, make it consistent, and compute the scores.*

8. Consider the design of an everyday consumer device such as computer printer, digital camera, electric screwdriver, or electric toothbrush. Determine the customer needs for the device selected. The deliverables should be: 1) marketing requirements, 2) an objective tree, and 3) a ranking of the customer needs using pairwise comparison.

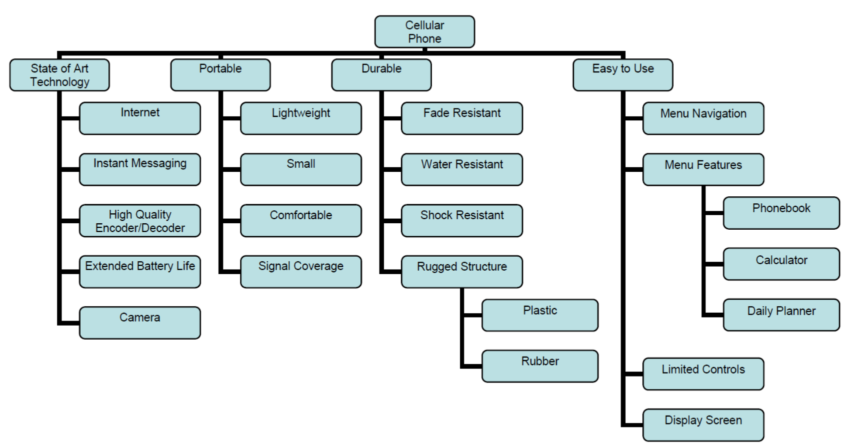
   [**A**] Note: *The objective of this question is to give the individual (or preferable a small-team) practice in identifying the needs. Fairly simple and common products should be used as a first step. This can be a very good exercise for the class. Each team could select its own product and then some teams can present the results to the class. Or several or all teams could work on the same project, with a reporting session, where a team presents their findings and the others critique them.*

   Consumer Device Selected: ***Cellular Phone***

   Need: *With today's high-paced world, immediate contacts are essential. Therefore, excellent cell phone design, implementation, and construction are a must.*

   a) ***Marketing Requirements***
   - *The system will be lightweight.*
   - *The system will withstand abusive treatment (dropping, running over, etc.).*
   - *The system will be comfortable and ergonomic.*
   - *The system will have high-quality audio encoding and decoding.*
   - *The system will not have to be frequently charged.*
   - *The system will have good signal pickup.*
   - *The system will survive from weathering (sun, rain, etc.).*
   - *The system will be easy-to-use.*
   - *The system will be able to connect to and browse the internet.*
   - *The system will contain as few buttons as possible.*

   b) ***Objective Tree***



   c) ***Ranking of Customer Needs***

   d) ***Ranking***

Table 2.1: Cell Phone Attributes

	Technology	Portable	Durable	Easy-to-Use	Total
Technology	X	0.5	0.5	0.5	1.5
Portable	0.5	X	0.5	0.5	1.5
Durable	0.5	0.5	X	0	1
Easy-to-use	0.5	0.5	1	X	2

Table 2.2: State of the art technology

	Internet	Text	Audio	Battery	Camera	Total
Internet	X	0.5	0	0	1	1.5
Text	0.5	X	0	0	0	0.5
Audio	1	1	X	0.5	1	3.5
Battery	1	1	0.5	X	1	3.5
Camera	0	1	0	0	X	1

Table 2.3: Portable

	Lightweight	Coverage	Small	Comfortable	Total
Lightweight	X	0	0.5	0.5	1
Coverage	1	X	1	1	3
Small	0.5	0	X	0	0.5
Comfortable	0.5	0	1	X	1.5

Table 2.4: Durable

	Fade Res.	Water Res.	Shock Res.	Rugged	Total
Fade Res.	X	0	0	0.5	0.5
Water Res.	1	X	0.5	1	2.5
Shock Res.	1	0.5	X	0.5	2
Rugged	0.5	0	0.5	X	1

Table 2.5: Easy To Use

	Navigation	Features	Lim. Ctrls.	Display	Total
Navigation	X	0.5	0.5	0	1
Features	0.5	X	0.5	0	1
Lim. Ctrl.	0.5	0.5	X	0	1
Display	1	1	1	X	3

Table 2.6: Menu Features

	Phonebook	Calculator	Planner	Total
Phonebook	X	1	1	2
Calculator	0	X	0	0
Planner	0	1	1	1

Table 2.7: Rugged Structure

	Plastic	Rubber	Total
Plastic	X	0.5	0.5
Rubber	0.5	X	0.5

Most Important	*Extended Battery Life and Audio Encoding/Decoding (3.5)*
	Signal Coverage and Display Screen (3)
	Water Resistant (2.5)
	Easy to Use, Shock Resistant, and Phone Book Feature (2)
	State of the Art Technology, Internet, Portable, and Comfortable (1.5)
	Durable, Camera, Lightweight, Rugged, Menu Navigation, Menu Features, Limited Controls, and Daily Planner (1)
	Instant Messaging, Small, Fade Resistant, Plastic, and Rubber (0.5)
Least Important	*Calculator (0)*

9. **Project Application.** Select criteria to be applied for selecting a project concept as shown in Example **??** then brainstorm and search to generate project concepts. Rank the top three to five concepts against the criteria as presented in Example **??**.

   [**P**] Note: *If the teams are being allowed to select the project, this is a good exercise to get them to focus on criteria for project selection. Conflict often develops between team members over which project to pursue, and this provides an opportunity to examine the merits of different projects. Criteria to consider are: cost, time to completion, team member skills, probability of success, interest in the project, etc.*

10. **Project Application.** Determine the needs for the project selected. The result should be list of marketing requirements, an objective tree, and a ranking of the needs.

    [**P**] Note: *The objective here is the same as question 8, with difference being that it is applied to the capstone design project. A difficulty here could be that the customer may not be as easily identifiable, an example being a design competition. If the team is developing a new and creative product idea, they should be able to do this. If they are working on an industry sponsored project, they should also be able to do this. In the case of design competition or another type does not lend itself as well, the team still should be able to develop an adequate objective tree based on the project rules and their knowledge of the subject. We have had teams be very creative in finding ways to identify the customer needs from conducting web-based surveys on bulletin boards and to conduct focus groups with other students on campus.*

11. **Project Application.** Conduct a research survey for your project using the guidance presented in Section **??**. The result should be a report summarizing the results of the survey.

    [**R**] *No Answer Provided.*

12. **Project Application.** Develop a Problem Statement for your project concept as outlined in Section **??**. Apply the processes presented in the chapter as appropriate.

    [**P**] ***Note:*** *We typically have the teams complete the simple Problem Statement similar to those in Examples 2.1-2.3 in the text. Along with this they submit a justification for the team they have selected (Team Proposal) that identifies who the members are and what objectives/skills they bring to the team. Once the basic Problem Statement and Team Proposal are completed and reviewed by the instructor, it is then followed by a more* *detailed submission of the Extended Problem Statement that is presented in the Project Application Section. This integrates all of the material from Chapter 2. In term of research, the goal here is to provoke the team to conduct research up-front and show they understand what is going on. In our experience, this is often overlooked, and teams regret it later. In our course, we typically get a 3-6 page report summarizing their findings. Our goal is to determine their level of understanding based upon that. All of this makes up part of the final design report submitted at the end of the project.*

Additional In-Class Exercise

The following exercise is one we use early on in the class to generate project ideas. The class is usually capable of generating at least one idea per minute, and we often get 40-50 ideas in a session.

As a class, the objectives are as follows:

- *Generate a minimum of 40 project ideas.*
- *Every single student in the class must offer at least on idea.*
- *If the two above criteria are met, then everyone in class gets a 10 point (100%) quiz grade. Otherwise, no grade recorded.*

Rules of Brainstorming

1. *No criticism or judgment of idea*
2. *Wild ideas are encouraged.*
3. *Quantity is stressed over quality.*
4. *Build upon and modify the ideas of others.*
5. *All ideas are recorded.*

Note: *Another option is to present a particular problem or application area and have the teams students generate ideas based upon them.*

CENBD/EE BD 480 - Engineering Design Concepts
Penn State Erie, The Behrend College

Background and Technology Survey Instructions

You should consult with your supervising faculty member when developing this section of the report. Each project is unique.

The objectives of this section are to:

- *Provide your audience (faculty, project sponsors, other students, etc) with sufficient background so that they understand the problem the team plans to solve.*
- *Demonstrate that the team has a sufficient understanding of the problem to proceed to the next stage of development.*
- *Demonstrate that the team has conducted research and understands the technology relevant to this project – namely, related solutions to the problem and their limitations.*
- *Depending on the project, you should also conduct searches on the US patent database for similar technologies.*

•To describe what is new/unique in the proposed design.
•To provide additional supporting information that for the Need and Objective statements.

Pointers:

•If it is an industry sponsored project, you will need to provide a clear overview of the problem and any related processes. You should also indicate why it is important to the organization – what benefit it will provide.
•You may provide more detail on the need for the project. For example, if this has market potential, indicate what the size of the market is. If you are preventing injuries – how many injuries are there per year? Supporting statistics are always great to demonstrate the need.
•If there are similar systems out there, describe limitations of current designs or technology. Benchmarking or strength/weaknesses analyses of existing technologies are powerful.
•Describe any basic theory to be described regarding the technology. For example, say you are designing a flywheel energy storage system – you should describe the basics of how flywheel energy systems work – what are the major systems, etc.
•Pictures always help - be sure to provide a description of diagrams.

On the writing itself:

•This is expected to be well-written prose.
•You ***must*** *provide a reference section. Reference all sources used – do not plagiarize. If you use a figure that is not yours, you must provide a clear reference as to where it came from – if not it is plagiarism (in which case you get a zero and reported for academic integrity hearings).*
•Follow the same format for references as used in the class textbook. Make sure that you reference web pages properly.
•All figures and tables must be labeled. Follow the same format used in the book for labeling and referring to figures and tables.
•This should be concise 3-4 pages in length. You cannot exceed 4 pages of 11 point with 1" margins.

Format for the report

Use 12 point Times New Roman bold for the headings of the section. 11 pt for text, 1.5 spacing between paragraphs.

Title

Team Members

1. Need
Text goes here – it should be 11 pt, Times- New Roman single spaced. Use 1.5 spacing between the paragraphs.

2. Objective
Text goes here – it should be 11 pt, Times- New Roman single spaced. Use 1.5 spacing between the paragraphs.

3. Background and Technology Survey

Text goes here – it should be 11 pt, Times- New Roman single spaced. Use 1.5 spacing between the paragraphs.

4. Marketing Requirements and Objective Tree

List the marketing requirements (numbered), Objective tree, and a summary of the ranked needs.

References

Appendix – Ranking of Needs

List the marketing requirements (numbered), Objective tree, and a summary of the ranked needs.

Chapter 3

The Requirements Specification

3.1 Problems

1. Briefly describe the four properties of an engineering requirement.

2. Identify the three levels of standards usage and what is meant by each one.

   [**R**] *The three levels of standards usage are user, implementation, and development. The **user level** simply incorporates the standard within the design without the need for technical knowledge concerning the standard. However, the **implementation level** requires an in-depth knowledge of the standard – developing hardware drivers and ensuring reliability requirements. As with the implementation level, the **development level** also requires knowledge of the standard in order to further develop and modify its predecessor.*

3. For each of the engineering requirements below, determine if it meets the properties of abstractness, unambiguous, verifiable, and realistic. If a requirement does not satisfy the properties, restate it so that it does:

   a) The TV remote control will be easy to use.
   [**A**] *Abstractness: **Yes** – doesn't give details on implementation*
   *Unambiguous: **Maybe** – there is not a clear definition of easy-to-use. It could be possible to develop some metrics for easy to use, such as size of buttons, number of buttons, etc.*
   *Verifiable: **Maybe -** this relates back to the ambiguity of easy-to-use. If the easy-to-use property is defined, then it could be verifiable.*

   b) The robot will identify objects in its path using ultrasonic sensors.
   [**A**] *Abstractness: **No** – provides a solution to the problem (ultrasonic sensors)*
   *Unambiguous: **No** – it will identify objects in its path, is somewhat clear. However, could be better defined if its path were defined, as well as the distance of detection*
   *Verifiable: **No** (Because it is not unambiguous.)*
   ***Restatement:** "The robot will identify objects in its forward path within 3 feet of the robot."*

   c) The car audio amplifier will be encased in aluminum and will operate in the automobile environment.
   [**A**] *Abstractness: **No** – provides a solution to the problem (aluminum case)*
   *Unambiguous: **No** – it will operate in an automobile is not quite clear. Where in the automobile and what size should it be?*
   *Verifiable: **No** − because it is not unambiguous.*
   ***Restatement:** "The car audio amplifier will operate in the automobile passgenger compartment and not have a size that exceeds 12"x4"6" "*

   d) The audio amplifier will have a total harmonic distortion that is less than 2%.
   [**A**] *Abstractness: **Yes** – doesn't give details on implementation*
   *Unambiguous: **Yes** – THD < 2%*
   *Verifiable: **Yes***

   e) The robot will be able to move at speed of 1 foot/sec in any direction.
   [**A**] *Abstractness: **Yes** – doesn't give details on implementation*
   *Unambiguous: **No** – provides two requirements in one statement*
   *Verifiable: **Yes***
   ***Restatement:** "The robot will be able to move at a speed of 1 foot/sec." or "The robot will be able to move in any direction."*

f) The system will employ smart power monitoring technology to achieve ultra-low power consumption.

[**A**] *Abstractness:* ***No*** *– provides a solution to the problem (smart power)*
Unambiguous: ***Yes*** *– it will achieve ultra-low power consumption*
Verifiable: ***No*** *– there is no exact target value on the power*
Restatement: *"The system will achieve power consumption below XX watts."*

g) The system shall be easy to use by a 12 year old.

[**A**] *Abstractness:* ***Yes*** *– doesn't give details on implementation*
Unambiguous: ***Maybe*** *– a 12 year old can use this device is clear, but as we saw in an earlier problem it is hard to determine ease of use without some sort of definition.*
Verifiable: ***Yes***

h) The robot must remain operational for 50 years.

[**A**] *Abstractness:* ***Yes*** *– doesn't give details on implementation*
Unambiguous: ***No*** *– Failure is a probability-based concept. A single robot always a non-zero chance of failure over an extended periodn of time.*
Verifiable: ***No*** *- As a practical matter, your design team would not be able to perform this test.*

4. Provide three example engineering requirements that are technically verifiable, but not realistic.

5. Describe the difference between *verification* and *validation*.

   [**R**] *Validation is the process of determining if the requirements meet the needs of the end-user. This answer the question – are we building the right product? Verification is the process of measuring or demonstrating that the requirements are met in the final realization. Verification answers the question – are we building the product right (does it meet the requirements).*

   Validation is typically harder to determine.

6. Explain how *validation* is performed for a Requirements Specification.

   [**R**] *Validation can be performed by being able to answer the following questions affirmatively:*

   - ***Is each requirement verifiable?*** *That is can it be measured or shown in the final system implementation.*
   - ***Is each requirement traceable to a user requirement?***
   - ***Is each requirement realistic and technically feasible?*** *This may be hard to determine. It can be determined based upon benchmarks or system prototypes.*
   - ***Is the property of orthogonality met for the Requirements Specification?*** *Are the requirements established with no redundancy?*
   - ***Is the property of completeness met?*** *Are all the needs of the end-user addressed in the Requirements Specification?*
   - ***Is the property of consistency met?*** *The Requirements Specification should not be self-contradictory.*

7. Provide an example of a project (real or fictitious) where verification is successful, but validation is unsuccessful.

8. Consider the design of a common device such as an audio CD player, an electric toothbrush, or a laptop computer (or another device that you select). Identify potential marketing and engineering requirements. Consider those categories presented in Section **??**, as well as any others that are applicable to the problem. You do not need to select the target values, but should identify the measures and units. Present the requirements in a table format as in Table **??**.

   [A] ***Marketing Requirements***

   - *Should be lightweight*
   - *Clean teeth well.*
   - *Have a long battery life.*
   - *Not shock the user (electric).*
   - *Be easy to hold*
   - *Be quiet.*
   - *Easy to clean.*
   - *Be lightweight.*
   - *Allow multiple users.*

Engineering Requirements	*Notes*
E1.Have ___ ft-lbs of torque (or translational force, depending upon design).	*This addresses how much force it can apply in cleaning the teeth. This requirement does require assuming part of the solution.*
E2.Should have a rotational/translational brush speed of ___ cycles/minute (Note some of the solution assumed here).	*This addresses how quickly it the toothbrush operated.*
E3.Must have a reliability of 95% at 5 years of service.	*Reliability – may be a good idea to place an estimate on this. This is a real guess, and one would have to do more work to determine this one.*
E4. Should emit < ___ dB of noise.	*User wanted it to be quiet*
E5. Must work in 100% humidity (could be submersed).	*Works in a wet environment. Could be submersed.*
E6.Must be able to withstand ___ drop from 6 feet and still operate motor (not brush head).	*User could drop it. 6 feet is typical person height.*
E7.Temperature range of ___ to ____ degrees Celsius.	
E8.Should have an operating lifetime of > ___ hours on a single battery (or charge).	*How long it will run for.*
E9.Toothbrush should weigh less than __ grams.	*Do not want it to be too heavy.*
E10. Should be ___ cm tall.	*Height should be specified. Should not be too long nor too short.*
E11. Should cost no more than $___ to produce.	*Cost is virtually always an issue.*

9. Develop a marketing-engineering tradeoff matrix for the device selected in Problem 8. **[A]**

		E1. Torque	*E2. Brush Speed*	*E3. Reliability*	*E4. Noise*	*E5. Humidity*	*E6. Shock Res.*	*E7. Temp.*	*E8. Battery Life*	*E9. Weight*	*E10. Size*	*E11. Cost*
		+	+	+	-	+	+	+	+	-	-	-
M1. Lightweight	-	$\downarrow$		$\downarrow$	$\downarrow$		$\uparrow$		$\downarrow$	$\uparrow$	$\uparrow$	$\downarrow$
M2. Cleans Well	+		$\uparrow$							$\downarrow$	$\downarrow$	
M3. Long Life	+		$\downarrow$	$\downarrow$			$\uparrow$	$\uparrow$	$\uparrow$	$\downarrow$		
M4. Electric shock	+					$\uparrow$						
M5. Easy to hold	+	$\downarrow$					$\downarrow$		$\downarrow$	$\uparrow$	$\uparrow$	$\downarrow$
M6. Quiet	+	$\downarrow$	$\downarrow$		$\uparrow$						$\downarrow$	$\downarrow$
M7. Durable	+			$\uparrow$		$\uparrow$	$\uparrow$	$\uparrow$				$\downarrow$

10. Develop an engineering tradeoff matrix for the device selected in Problem 8.

[**A**]

		E1. Torque	*E2. Brush Speed*	*E3. Reliability*	*E4. Noise Level*	*E5. Humidity*	*E6. Phys. Shock*	*E7. Temp.*	*E8. Battery Life*	*E9. Weight*	*E10. Size*	*E11. Cost*
		+	+	+	-	+	+	+	+	-	-	-
E1. Torque	+		↓						↓	↓	↓	↓
E2. Brush Speed	+				↓				↓			↓
E3. Reliability	+					↑	↑	↑		↓	↓	↓
E4. Noise Level	-									↓	↓	↓
E5. Humidity	+									↓		
E6. Phys. Shock	+									↓	↓	
E7. Temerature	+											↓
E8. Battery Life	+									↓	↓	↓
E9. Weight	-										↓	↓

11. Develop a list of potential standards that would apply to one of the devices proposed in Problem 8, and for each indicate how it would apply to the design.

[**A**] ***Standards for the Electric Toothbrush*** *Likely standards for this system include: UL (Underwriters Laboratory) and CE (Common European) safety standards. This is very common for consumer devices.*
ADA – American Dental Association. This would likely be a series of "standard" tests before branding ADA approval; therefore, showing that this system provides sufficient dental treatment.

12. **Project Application.** Develop a complete requirements document for your project as outlined in Section **??**. Make sure that the engineering requirements meet the five properties identified in the chapter. The team should complete the self-assessment checklist in Table **??**.

[**P**]

Note: *The Requirements Specification is an important document in the design. Remember that requirement specifications are "living" and evolving documents. Thus it is a good idea to provide design teams with the opportunity to resubmit and revise the document. We use a two-step submission process. The first submission is worth 30% of the specification grade. This is reviewed and resubmitted to the team, who resubmits, and the second submission constitutes the remaining 70%. Of course, if the team gets it right on the first submission, there is no need to resubmit.*

Constraints. *We have student teams identify at least five of eight constraints in their specification. They should be realistic. We don't require that they test each one in the final*

realization, but ensure that they are considered (this depends upon the complexity of the problem). However, the team should be able to that their system would meet some of the constraints.

Students may also make the counter argument for a constraint. For example, design team may consider a constraint category, and determine that it is not applicable. If a clear *rationale is given, the team could document that. If a project has virtually no constraints, then must question whether or not it is an acceptable project.*

Standards. *We have students identify standards that may apply to their project. Of course, they may not know all of the applicable standards until they get to the design phase. However, realistic decisions can be made on the standards that will apply to the project. Some of them may be very beneficial to the design team. For example, following design standards, such as the IEEE software design standards can be of great help to the teams.*

Checklist. *We expect our student teams to also complete the self-assessment checklist for requirements provided in Table 3.7.*

Oral Presentations. *After the students complete the Requirements Specification, we have them make a presentation to a faculty group. This presentation covers the Problem Statement material from Chapter 2, the Requirements, Constraints, and Standards. The idea is for the faculty to make accept/reject the project idea, or more likely, request changes/corrections.*

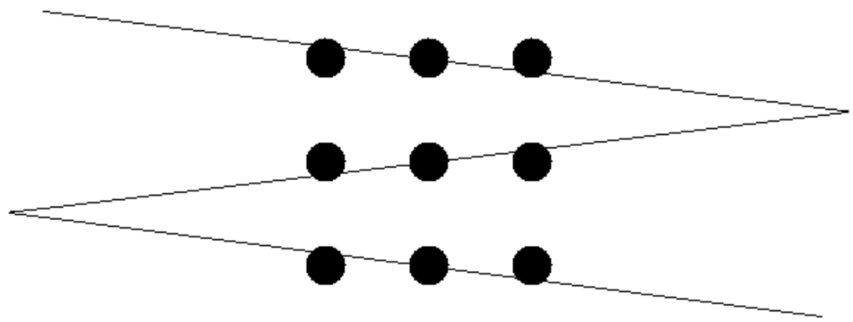
We also pick one or two teams to present theirs to the entire class prior to the faculty presentations. This way students can critique a presentation before hand.

Chapter 4

Concept Generation and Evaluation

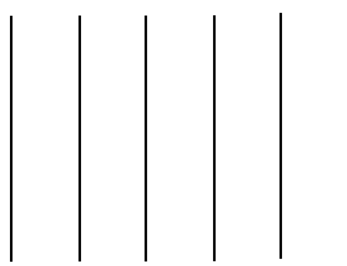
4.1 Problems

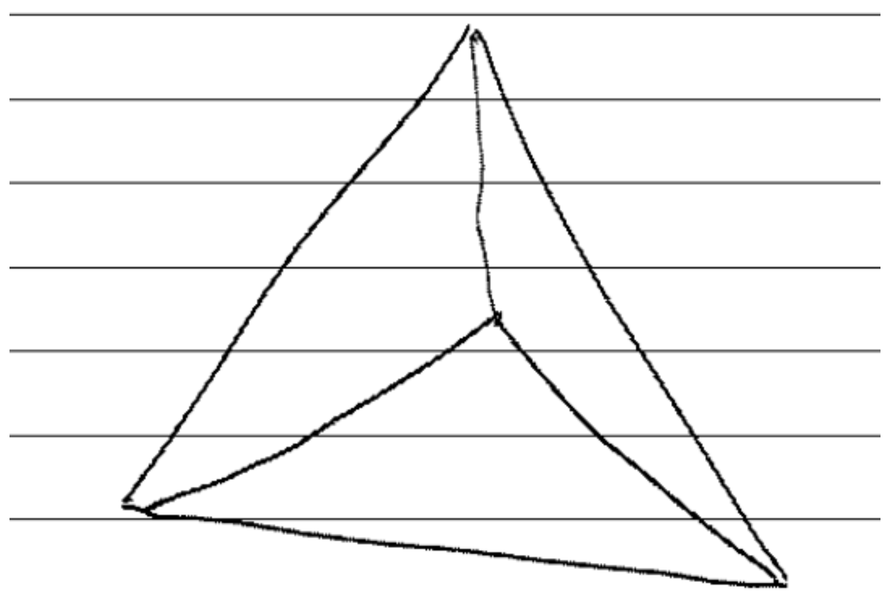
1. Consider the nine dot puzzle shown in Figure **??** (b). Draw **three** connected straight lines that pass through all nine dots.



[**A**]

2. Consider the six sticks shown below. Rearrange the sticks to produce four equilateral triangles (the sticks cannot be broken).

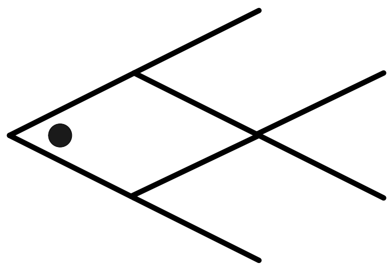


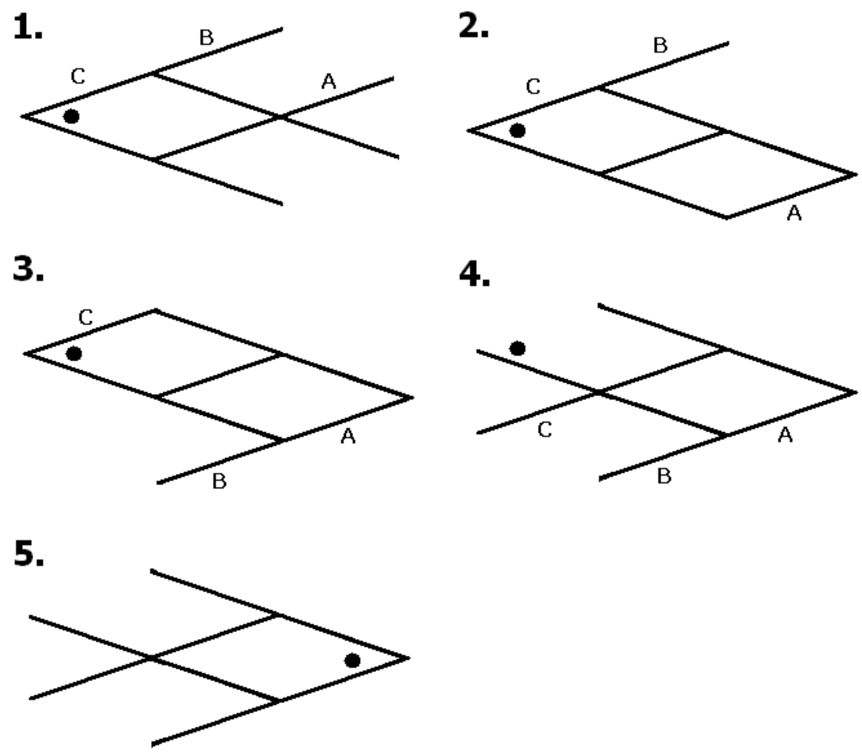


[**A**]

In this solutions, one has to go to 3 dimensions!

3. Consider the fish shown below made of eight sticks and a coin for the eye. The objective is to make the fish face the other direction by moving only the coin and three sticks.





[A]

4. For each of the following lateral thinking puzzles, develop a plausible solution (from Paul Sloane's Lateral Thinking Puzzles [http://dspace.dial.pipex.com/sloane]):

   - A man walks into a bar and asks the barman for a glass of water. The barman pulls out a gun and points it at the man. The man says 'Thank you' and walks out.

     [A] *The man had hiccups. The barman recognized this from his speech and drew the gun in order to give him a shock. It worked and cured the hiccups - so the man no longer needed the water.*

   - A woman had two sons who were born on the same hour of the same day of the same year. But they were not twins. How could this be so?

     [A] *The woman had triplets. They were two of the triple.*

	Accuracy	Cost	Size	Availability
Accuracy	1	1/3	2	$\frac{1}{2}$
Cost	3	1	5	1
Size	1/2	1/5	1	2
Availability	2	1	$\frac{1}{2}$	1

- Why is it better to have round manhole covers than square ones?

  [**A**] *While the square manhole sounds just as plausible as the round manhole cover, there is a major disadvantage. The round manhole cover will never be able to fall down the whole, because the diameter of the cover never changes. The square cover, if in the right position, would be able to be dropped down the hole.*

- A man went to a party and drank some of the punch. He then left early. Everyone else at the party who drank the punch subsequently died of poisoning. Why did the man not die?

  [**A**] *The punch, in its original state, was not poisoned. So, the man that had it early and left drank the punch without the poisoning. However, those that stuck around at the party continued drinking the same punch even after it was poisoned.*

5. Legislation was passed to allow handguns in the cockpits of passenger airliners to prevent hijacking. Brainstorm to develop concepts that prevent anyone other than the pilot from using the handgun.

   [**A**] Note: *This is a brainstorming exercise that we have used in our class a number of times with good results. Many interesting solutions will be developed, including those that involve biometric recognition of people to match them with the gun, mechanical solutions, and electronic solutions (i.e. proximity sensor of gun to pilot).*

6. Imagine if scientists and engineers were able to develop a technology that would allow people to be transported from any place on earth to another instantaneously. Brainstorm to determine the potential impact this would have on society.

   [**A**] *Brainstorming - no solution provided*

7. Student advising at many colleges and universities is seen as an area that can be improved. Brainstorm to develop ideas as to how student advising could be improved at your college or university.

   [**A**] *Brainstorming - no solution provided*

8. In your own words, describe what a concept table and a concept fan are.

   [**A**] *A concept table is a methodic method of investigating different combinations, arrangements, and substitutions of technologies for a given design. A concept fan is a hierarchical graphical representation of the design decisions, choices, and alternative solutions. A disadvantage of them is that they assume a form, or architecture, for the solution.*

9. Consider the problem solved in Section **??**. For this example assume that:

   - The following is the result of the paired comparison.
   - The parts costs are the following: resistors = \$0.05, bipolar transistors (BJTs) = \$0.10, op amps = \$0.35, and RTDs = \$0.25.

- The parts have an in-stock availability of 99%, 90%, 85%, and 70% of the time for the resistors, BJTs, RTDs, and op amps respectively.
- Everything else is the same as presented in Section **??**.

Compute the rankings of the design options using a weighted decision matrix of the type shown in Table **??**.

[**R**]

Step 1: Determine the Criteria In this example the comparison criteria of accuracy, cost, size and availability were given as a part of the problem.

Step 2: Select the Weighting Factors The weighting factors for the criteria are selected based upon the scores from the pair wise comparison. Normalizing the weighing factors as indicated in (2) produces $\omega_1 = 1/6 = 0.17$, $\omega_2 = 2.5/6 = 0.42$, $\omega_3 = 0/6 = 0$, $\omega_4 = 2.5/6 = 0.42$.

*Step 3: Select the Design Ratings Design ratings need to be made for each of the criterion. Accuracy. Since the objective is to minimize the deviation, the following rating is used ** figure ***

This produces the following design ratings for accuracy: $\alpha_{11} = 0.14$, $\alpha_{12} = 1.0$, *and* $\alpha_{13} = 0.68$; *and normalizing the row sum produces* $\alpha_{11} = 0.08$, $\alpha_{12} = 0.55$, *and* $\alpha_{13} = 0.37$.

Cost. Using the provided cost measure ($0.40 for design 1, $0.65 for design 2, and $0.50 for design 3) gives the following cost ratings for the three options respectively: $\alpha_{21} = 1.0$, $\alpha_{22} = 0.62$, *and* $\alpha_{23} = 0.8$. *Normalizing the row sum produces* α_{21} $\boldsymbol{= 0.41,}$ α_{22} $\boldsymbol{= 0.26,}$ ***and*** α_{23} $\boldsymbol{= 0.33.}$

Size. The objective is to minimize size. Using a measure analogous to the given space to manufacture each produces the following normalized decision ratings: $\alpha_{31} = 0.48$, $\alpha_{32} = 0.31$, *and* $\alpha_{33} = 0.21$.

Availability. A measure for the overall availability of parts to manufacture each design is required. One way to measure this is to compute the probability that a design will be able to be manufactured based upon the past history of part availability. This is found by multiplying the availability of all individual components needed for the design:

P(design 1 can be produced) = (0.99)(0.85)(0.90) = 0.76
P(design 2 can be produced) = (0.99)(0.85)(0.70) = 0.59
P(design 3 can be produced) = (0.99)(0.85)(0.90)(0.90) = 0.68

This produces the following normalized decision ratings for availability: $\alpha_{41} = 0.37$, $\alpha_{42} = 0.29$, *and* $\alpha_{43} = 0.33$.

*Step 4: Compute the Scores ** add table ***

Step 5: Review the Decision Remember that this is a semi-quantitative method. The final ranking indicates that design all design options are essentially equal in this case.

*** Add figures*

10. **Project Application.** Utilize the methods in this chapter to generate concepts for your particular design problem. Critically evaluate the concepts generated using one or more of the techniques presented in the chapter that is appropriate for the problem. Section **??** provides guidance on how to conduct this process and document the results.

    [**R**]

Note: *We usually combine this with the Design project application problem (5.7) in Chapter 5. What we are looking for is for each team to show that they have examined different potential solutions to the design problem and evaluated the alternatives. Thus they can document the results a variety of ways – such as concept fan/table or decision matrix. Highly quantitative decision tables are frankly difficult to develop, and the results may not be that valuable. We try to get them to demonstrate that they have put serious effort into examining the different solutions for a problem. Below is the text from the assignment that is provided to the students.*

The team must show that it has analyzed and evaluated different options/concepts for the design. This means that you should have examined different alternatives and be able to justify the choices the team made. The choices could be in terms of different design architectures and/or different decisions for elements of the overall system.

Apply the methods from Chapter 4 that are appropriate for the problem. The results can be presented in terms of a list of brainstormed ideas, Concept Tables/Fans and Decision matrices. If you do use decision matrices, you can use them to benchmark or compare different technical solutions considered. Only use the highly quantitative matrix (i.e. Example 4.1) if it realistic and applicable to the problem.

Chapter 5

System Design I: Functional Decomposition

5.1 Problems

1. Describe the differences between *bottom-up* and *top-down* design.

   [**R**] *In a bottom-up design, the designer begins with basic components and synthesizes them to create the overall system. However, the top-down designer has a vision of the overall functionality of the final system and partitions the problem into components, or subsystems. These components work together to achieve the overall goal. In essences, bottom-up designers are given parts and then they build the system, while top-down designers envision the system and then build the parts.*

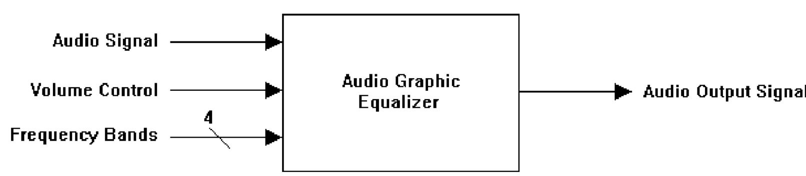
2. Develop a functional design for an audio graphic equalizer. A graphic equalizer decomposes an audio signal into component frequencies bands, allows the user to apply amplification to each individual band, and recombines the component signals. The design can employ either analog or digital processing. Be sure to clearly identify the design levels, functional requirements, and theory of operation for the different levels in the architecture.

   The system must

   - Accept an audio input signal source, with a source resistance of 1000Ω and a maximum input voltage of 1V peak-to-peak.
   - Have an adjustable volume control.
   - Deliver a maximum of 40W to an 8Ω speaker.
   - Have four frequency bands into which the audio is decomposed (you select the frequency ranges).
   - Operate from standard wall outlet power, 120V rms.

   [**R**] ***LEVEL 0***

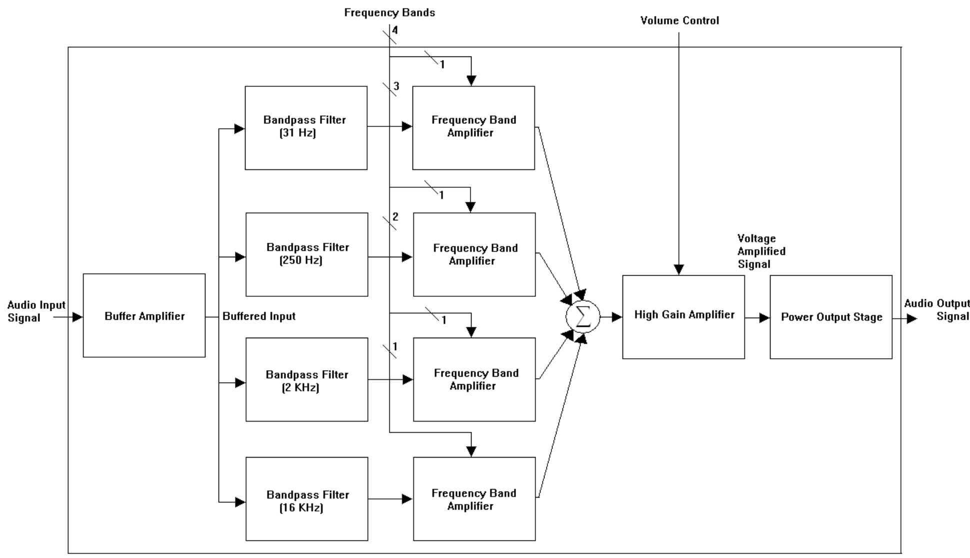
   The Level 0 functionality for the audio graphic equalizer, shown below, is fairly simple – the inputs are an audio signal, volume control, and four frequency band knobs, and the output is a reconstructed audio signal.



Module	*Audio Graphic Equalizer*
Inputs	• *Audio input signal: 1Vpp , 1000Ω* • *User volume control: variable control* • *Frequency band knobs: 4 bands (31Hz, 250Hz, 2KHz, 16KHz) , variable control.*
Outputs	• *Audio output signal: ?V peak value.*
Functionality	*Reconstructs the input audio signal by amplifying and/or deamplifying each of the 4 frequency bands to produce a 40W maximum output signal. The volume amplification and frequency knobs should have variable user control. level.*

Not all values can be known on the first pass through the design. However, knowing the maximum power allows the maximum output voltage to be computed as $V_{peak} = 8\Omega * 40W = 17.9V$.

Level 1



There are several unknowns at this time, and that will be apparent as we investigate the individual modules. The functional requirements for the Level 1 architecture are as detailed as possible, starting with the buffer amplifier.

Module	*Buffer Amplifier*
Inputs	• *Audio input signal: 1Vpp , 1000*Ω
Outputs	• *Audio output signal: 1Vpp , 1000*Ω
Functionality	*Buffer the input signal and provide unity voltage gain. it should have an input resistance of ¿ 100k*Ω *and an output resistance ¡ 100*Ω*.*

The input resistance is an educated guess, but is a realistically high value that will minimize any voltage losses with the source resistance. The output resistance is an educated guess, based on knowledge of what is achievable with the technology (bottom-up knowledge). These resistance values are later refined and adjusted, taking into account the input and output resistances for all stages.

Module	*Bandpass Filters (0-31Hz, 31-250Hz, 250-2KHz, 2kHz-16KHz)*
Inputs	• *Buffered input signal: 1Vpp , 1000*Ω
Outputs	• *Audio output signal: 17.9V peak value*
Functionality	*This filters out each of the desired frequency ranges so that they may be adjusted independently. It should have an input resistance of ¿ 1k*Ω *and an output resistance ¡ 100*Ω*.*

Module	*Frequency Band Amplifiers*
Inputs	• *Filtered audio signals: 1Vpp , 1000Ω* • *Frequency band knobs: 4 bands (31Hz, 250Hz, 2KHz, 16KHz) , variable control.*
Outputs	• *Audio output signal: 17.9V peak value*
Functionality	*Functionality Provide an adjustable voltage gain, between 1 and 35, for each of the 4 frequency bands, respectively. It should have an input resistance of ¿ 10kΩ and an output resistance ¡ 100Ω.*

Module	*Signal Summation*
Inputs	• *Audio input signals (31Hz, 250Hz, 2KHz, 16KHz): 1Vpp , 1000Ω*
Outputs	• *Audio output signal: 17.9V peak value*
Functionality	*Functionality This recombines each of the 4 frequencies that have be independently adjusted into one complete signal. It should have an input resistance of ¿ 1kΩ and an output resistance ¡ 100Ω.*

Module	*High Gain Amplifier*
Inputs	• *- Audio input signal: 1Vpp , 1000Ω* • *User volume control: variable control*
Outputs	• *Audio output signal: 17.9V peak value*
Functionality	*It should have an input resistance of ¿ 10kΩ and an output resistance ¡ 100Ω.*

Module	*Power Output Stage*
Inputs	• *- Audio input signal: : 17.9V peak*
Outputs	• *Audio output signal: 17.9V peak at up to ???A.*
Functionality	*Functionality Provide unity voltage gain with output current as required by a resistive load of up to ???A. It should have an input resistance of ¿ 1kΩ and an output resistance ¡ 100Ω.*

Note: there are other architectures that can work here as well. For example, the high gain amplifier and power output stage can be combined into a single amplifier. In addition, the filter and associated amplifiers might also be combined together, depending upon the filter topology used.

3. Develop a functional design for a system that measures and displays the speed of a bicycle. Be sure to clearly identify the design levels, functional requirements, and theory of operation for each level.
   The system must

   - Measure instantaneous velocities between zero and 75 miles per hour with an accuracy of 1% of full scale.
   - Display the velocity digitally and include one digit beyond the decimal point.
   - Operate with bicycle tires that have 19, 24, 26, and 27 inch diameters.

   [**R**] ***LEVEL 0***

   The overall goal is to convert a sensed speed to a digital speed reading (i.e. speedometer).

4. Draw a structure chart for the following C++ program:

```
void IncBy5(int \&a, int \&b);
int Multiply(int a, int b);
void Print(int a, int b);

main() {
    int x=y=z=0;
    IncBy5(x,y);
    z=Mult(x,y);
    Print(x,z);
}

void IncBy5(int \&a, int \&b) {
    a+=5;
    b+=5;
    Print(a,b);
}

int Multiply(int a, int b) {
    return (a*b);
}

void Print(int a, int b) {
    cout  << a << ‘‘, ‘‘ << b;
}
```

[**A**] *** add figure ***

Structural Chart of C++ Program

5. Develop a functional design for software that meets the following requirements. The system must

   - Read an array of floating point numbers from an ASCII file on disk.
   - Compute the average, median, and standard deviation of the numbers.
   - Store the average, median, and standard deviation values on disk.

   The design should have multiple modules and include the following elements: (a) a structure chart, and (b) a functional description of each module.

6. Describe in your own words what is meant by coupling in design. Describe the advantages of both loosely and tightly coupled designs.

   [**R**] *Coupling describes a particular individual module's dependence upon the interconnectivity of various modules for proper functionality. A module can be loosely coupled or tightly coupled. The advantages of these are as follows:*

   Loosley Coupled *(+) The maximum degree of impact one module can have is limited (+) May allow for continued functionality upon module failures (+) Maximizes the cohesion of a design (+) Allows for independent testing of modules*

Tightly Coupled *(+) Better performance (i.e. software) (+) Quicker solutions (not necessarily better)*

It should be noted that the number of advantages of a loosely coupled design usually outweigh that of a tightly coupled design.

7. **Project Application.** Develop a functional design for your project. Follow the presentation guidelines in Section 5.9 for communicating the results of the design.

   [**R**] Note: *this is a major deliverable that is due for the project. It is also tied closely in with Chapter 6 which also provides modern design techniques. The information that we use in our assignment is below.*