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## Design Project Information and Guidelines

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### Overview of Electronic Circuit Design

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**Introduction** Design is what engineers do for a living. This is what all of the physical and mathematical theory, software tools, and laboratory experience lead up to. Yet in addition is required the key element of creativity, without which no new designs can be born. Creativity is more of an innate skill, one which cannot be easily taught, but still one which is the trademark of gifted engineers whose designs show a sense of poignance, freshness, and elegance which makes them immediately successful in the commercial or industrial marketplace.

**Goals** Quite simply, the goal of design is to solve a problem. Unlike many “textbook” design problems in which one simply runs an analysis problem backwards to find the value of a component or two to give a circuit a given behavior, real design involves much more open-ended questions. Unlike “textbook” design problems in which there often exists a unique solution to those few, specific, unknown component values, real design problems are most often characterized by an infinity of possible solutions.

The job of the engineer is then not only one of finding *a* solution, it is a job of finding *the best* solution, subject to other practical constraints. These practical constraints typically involve the size, weight, power consumption, temperature range, sensitivity, reliability, or cost of the final design. The relative importance of these practical constraints will often have more impact on the route the design takes than any of the more technically microscopic specifications themselves.

Yet there may still be many possible ways to solve a given problem, even while still satisfying the practical constraints. This feature is why most engineers have chosen the profession that they have. In short, this infinity of possible solutions to any given problem allows an engineer the flexibility to express his or her own creativity. The satisfaction gained by the creative design process is what addicts most engineers to their careers. Thus, the goal of engineering is to solve problems, but to do so in a creative and self-satisfying manner.

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**Standards** Another practical constraint on any design is that of standardization. While one may calculate that a certain value of component is needed for some location in a circuit, if that value cannot be purchased from a supplier, then the problem has still not been solved. Much of the rapid progress that electronics has made can be attributed to the availability of applicable standards. These include standard values for commonly used components, standard physical sizes of parts and case dimensions, standard mounting hardware and casework, standard connector sizes and configurations, standard integrated circuit types, and standard protocols, routines, and interfaces for communications, control, and power flow.

As a result of these standards, one does not need to design everything from scratch. Instead one may simply rely upon some “catalog engineering” to solve the more mundane tasks within an overall design. For example, in designing a new PC board for a computer, one does not want to spend time re-designing how a single resistor is made. Instead, one simply chooses the best resistor from those available, relying upon the manufacturers' specifications to help select the “best” part. Hence, the specification sheet (or “spec sheet” for short) becomes one of the engineer's most important tools. As one progresses from school into their career, textbooks are quickly overtaken and replaced by data books and specification sheets, in which component manufacturers list the specifications of their wares. Much of the experience one acquires in a field includes a knowledge of what components and subassemblies are currently available, and what one may typically expect from them in performance specifications. This is often termed “understanding the technology.”

**Spec Sheets** In many ways data books and spec sheets are the input to a given design, since these describe the parts which will be used in the construction of the final system. However, randomly sticking parts together is not a goal of any design process, even if the final mess happens to be functional. For a design to be reliable, maintainable, safe, easily used, easily upgraded, and generally understandable to others, it must be painstakingly documented. So while an engineer uses spec sheets for building his or her design, he or she also constructs a spec sheet which is used to describe the design to other engineers who may wish to employ it. Specification sheets are thus the input *and* output of the design process.

*Design Project Guidelines*

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Class Project	In the remaining three weeks of laboratory time, one “mini” design project will be assigned. This project will vary from quarter to quarter, and the desired specifications for the design project will be distributed around the middle of the quarter.
Requirements	In addition to the specifications that will be handed out, the design must be prototyped in the laboratory and checked out by one of the teaching assistants. In addition, proper documentation for the design must be handed in as a short report. Only one prototyped circuit and one set of design documents is required for each laboratory group. The features of this design report are detailed later on in this handbook.
Constraints	In addition to merely satisfying the specifications required, the design will also be subject to the practical constraint of minimum cost. The cost of the design will only include those parts which are used on the solderless breadboard, and the prices for those parts will be assigned based upon the current E.E. Stockroom catalog prices. The TAs will verify the parts used and the prices assigned to them as part of the laboratory check-out of the prototype circuit. Note that if a CD4001 quad 2-input CMOS NOR gate is used, and if only one of the four gates is used in the prototype circuit, the price of the entire integrated circuit must be used in the cost calculation. (This is the way it would work in real life, afterall.) However, the cost of the design does not include any parts that you may have bought, but not used or perhaps destroyed. It is standard practice to tabulate the parts cost of the design in a bill of materials (BOM), usually constructed as a spreadsheet.
Grading	A single grade for the design project will be given to each member of the laboratory group. This grade will be comprised of 50 percent from the laboratory check-out of the prototype (functionality), and 50 percent from the submitted design report (documentation).
Deadlines	The design prototype must be checked out in the laboratory by the T.A. no later than the end of the last scheduled laboratory period (the last week of class). The design report, which must include all of the requested items, must be handed in to the T.A. by Friday of the last week of class. Design projects will not extend over into finals week. Thus, it is in your best interest to do most of the paper design work outside of the regularly scheduled laboratory time, and reserve the scheduled laboratory time period for actually building, testing, and tweaking your prototype circuit.

## Design Project Documentation

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Contents      A typical electronic circuit design will include the documentation listed below. Depending upon the actual project, some of the items may not be necessary. For the class design projects, you will be told by the instructor which of the following documentation parts are to be included with your design submission.

### 1. Title Page

This should contain the title of the project, the organization producing the finished device, the designers names, the design group division to whom the designers belong, the project number, and the date that the design was submitted.

### 2. Purpose, Features, and Ratings

The purpose of the design should be given first in very abbreviated form, and may be only an expanded description of the design's name. A list of principal (usually desirable) features should appear next, followed by a list of ratings which detail the operating conditions under which the design was intended to operate.

### 3. Block Diagrams

A block diagram should be introduced next which breaks the overall design into functional units and gives some idea of signal, power, and control flow paths. Each block should be given a specific name which indicates its function and identifies it uniquely for other documents.

### 4. Key Design Equations or Relations

A page or two should summarize the most essential calculations or engineering tradeoffs that are associated with the given choice of circuit topology or component values or ratings.

### 5. Performance Simulation or Predictions

Based upon the previous design equations, some prediction, either by sample calculation, tabulated numbers, simulation software (e.g. SPICE), or math software (e.g. Mathcad, Matlab, or Mathematica), should be given which illustrates the design choices.

### 6. Test Results

The results of laboratory tests on the prototype design should be given here. It is also common to include performance tests on the design which indicate how the system behaves under differing loads or environments. These would normally provide the potential user with information on what to expect from the system. These test results would typically include any variations in performance with temperature, input power supply, or output load current.

### 7. Complete Schematics

A complete set of schematics must be included, and is often the single most important component of the design documentation package. The schematics may be a

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single sheet, or multiple sheets which connect in either a flat design, or in a simple or complex hierarchy. The schematics should be uniquely numbered and referred to in such a way that their interconnection is clear. All signals entering or leaving a sheet must be given names and indicated clearly. Every part on each schematic must have both a unique part identifier (or reference ID) name and either a part value or a part number.

Standard schematic symbols should be used whenever possible. Do not indicate devices by drawings of their packages! For example, an operational amplifier should be indicated by the standard triangular opamp symbol; not by a rectangular box indicating the actual 8-pin package. Standard SSI logic gates should also use the standard logic symbols for NAND, NOR, XOR, etc. Integrated circuits which contain several functional blocks, such as a quad opamp or a quad NAND gate, should never be drawn as one box containing all of the functional blocks. Instead, just indicate the functional blocks where (and if) they are needed in the circuit by their standard symbols. Spare functional blocks may be accumulated in one of the un-used corners of the schematic, if desired.

On integrated circuits and other devices with many mechanically identical pins, indicate the pin numbers beside the terminals of the symbol. It is conventional to place the pin number directly above each pin. Assembly and troubleshooting of the circuit is virtually impossible without this information. A rectangular block may be used for complicated and special purpose integrated circuits where no other standard symbol exists. For digital parts which have many terminals constituting an input or output bus, separate the conductors at each connection to the IC, but lump the conductors into a bus (single, thick line) to route it across the schematic. Where the bus is condensed into a single line, draw a slash through the line and write down the number of conductors that are represented by the line.

### 8. *Bill of Materials and Cost Estimate*

From the schematics a bill of materials should be constructed which lists each type of part, the identifiers which use it, and the part value or part number. This is conventionally done on a spreadsheet so that item costs and subtotals can be computed and summed to give a cost for each module of the design. This is usually the best way to get a handle on where the construction costs are going, and it also forms an initial materials schedule for production of the design. Many schematic capture applications can automatically generate a bill of materials from the entered schematic.

From the bill of materials, an initial cost estimate of the design should be produced which includes all necessary hardware parts in addition to the electrical parts. The cost estimate usually is made for only the functional subassembly, that is, the working parts of the design which does not include final exterior enclosures or ergonomic features.

### 9. *Printed Circuit Board Layout*

If a given design is going to involve many integrated circuits or discrete devices, it is usually best to construct the final circuit on a printed circuit board or PCB. A well designed PCB will improve the reliability and reduce the cost of a design from any other type of assembly method, except for complete integration of the entire design into a single IC. PCB design involves both mechanical and electrical issues and is usually a

rather complex process, involving many choices for optimum component layout and interconnection. Any design may succeed brilliantly or fail miserably, depending upon the quality of the PCB work. Because only the circuit designer really understands all of the issues pertaining to a given project, it is becoming increasingly common for the circuit designer to also do the PCB layout. In the past, when electrical and mechanical design issues were less interwoven, it was common for circuit designers to send their schematics to artwork specialists who then did the PCB layout. Today, circuit designers do this themselves.

PCB layout is organized into a system of stacked layers, each of which contains certain objects of the layout. The simplest PCB involves only a single layer of patterned copper foil to interconnect the component pads. More typical PCB's involve at least a component side (usually the top) and a solder side (usually the bottom) copper foil, possibly several buried internal copper foil layers on more expensive boards, and layers for adhesive bonding, solderpaste application, soldermask template, and silkscreen lettering, each on possibly either or both sides of the board. On each of these layers may occur the usual objects for PCB layout which include: component pads, network interconnections (also called nets or traces), vias (which connect one copper layer to another), test points, layer markers, alignment targets, mechanical dimensions, text, part outlines, copper fill zones, and drill holes.

A complete PCB layout will specify the occurrence, location, and orientation of all of the above objects. The layout process is necessarily one of numerous details, but this is what takes a conceptual schematic or breadboard into a fully functional and manufacturable product. In reality, it is impossible to even estimate the size of a design without trying to do a PCB layout to see how big it really is.

It is unlikely that a full PCB design will be required for the "mini" class project, but it is a good idea to keep this aspect in mind in the development of the design.

#### 10. Subassemblies and Bench Adjustments

Laying out the PCB's for a design only partly gets it ready for production. In addition, a design engineer must also perform the important task of explaining how certain subassemblies or modules are to be assembled, and also how they are to be adjusted to bring them into proper working order. In many cases, PCB assembly can be automated with automatic insert or pick-and-place of components and wave or reflow soldering processes. However, there are often some unusual parts which must be put in by hand, and in general, most boards are tested and adjusted by a human operator who needs to know how to perform the task. Some limited run boards may be completely hand assembled. This section should give the detailed procedures for putting the board together, and how the board is to be tested and adjusted.

#### 11. Chassis Layout, Casework Assembly, Control Panels, and Installation Notes

This section should specify how the previous subassemblies are to be put together to form the overall functioning unit. In this case, the designer will need to specify any and all of the sheet metal and/or plastic parts that are needed to mount and enclose the functional subassemblies. This would normally include any chassis or casework that is necessary to accommodate specialized components, such as motor mounts, vibration

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dampers, and cooling hardware. While the designer may not need to specify the color of the box enclosing the parts, he or she does have a keen interest in making sure that the unit can be operated properly. As such the designer should also specify any user interfaces such as control panels, front panel displays or optoelectronics, and user controls. Control panel layout should not be a random placement of knobs and switches, but rather a well-thought-out design in itself which suggests proper usage of the instrument and maximum information transfer between the instrument and its user. Similarly, if a design is destined to be a replacement or upgrade to an existing system, it should be well-thought-out in its installation procedures. Such procedures should likewise be documented in this section.

### 12. *Operational Hazards and Precautions*

Any possible hazards and precautions for avoiding them should be stated here. This includes possible conditions which could damage the design or result in a situation which could harm the operator or technician working with it.

### 13. *References and Acknowledgements*

Any references used in completing the design should be stated here for future reference. These include published articles from magazines, manufacturer's data books and application notes, copies of applicable standards (EIA, IEEE, ASME, etc.), and any compliance certifications from regulatory agencies (FCC or UL certifications). Any other sources of design or devine inspiration may also be included here.

### 13. *Design History of Project*

This section forms an addendum to the other design documents which is not contributed to until after the first design submission. This section keeps a running log of discovered problems, solutions, upgrades, and revisions to the design. It is customary to record changes in part numbers and their date of effect in this section. (This is the part where “the manufacturer reserves the right to change the specifications at any time.”)