AN INTEGRATED DESIGN ENVIRONMENT FOR SMALL SATELLITES

SUNIL GAVINI

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JNT University, India

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This thesis has been approved

for the Department of Electrical and Computer Engineering

and the College of Graduate Studies by

_____

Thesis Committee Chairperson, Dan Simon

_____

Department/Date

_____

Yongjian Fu

_____

Department/Date

_____

Wenbing Zhao

_____

Department/Date

To my family and friends

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ABSTRACT

Small satellites are generally spacecraft weighing around few hundred kilograms that are confined mostly to low Earth orbit where they perform specific tasks such as remote sensing, conduct science operations, and serve as technology test beds and communication relays. This ultimately results in a multibillion industry. Hence the design of these small satellites plays an important role in developing a satellite. The following thesis discusses an Integrated Design Environment for satellite design that integrates the software required for the satellite design onto a single platform.

Software that is used for project management, requirements management and electrical/power simulations are integrated using Visual Basic.Net. This allows the developer to access the software from a single interface, reducing access time and providing file sharing over the network.

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CHAPTER I

INTRODUCTION

Small satellites have existed since the dawn of the Space Age, but the success of these satellites was overshadowed by large satellites which dominated the space industry. A new approach to satellite design utilizing modern small satellites arose in the late 1980s and opened up a new class of space applications. Today major advances in microelectronics, in particular microprocessors, have made smaller satellites a viable alternative. They provide cost-effective solutions to traditional problems at a time when space budgets are decreasing. Interest in small satellites is growing rapidly, a fact which is evident by the initiation of satellite programs by businesses, governments, universities and other organizations around the world with applications in military, science, technology, remote sensing, and communications.

Examples of the increased interest in small satellites are NASA's Small Explorer (SMEX) Program, NASA's Earth Science System Pathfinder (ESSP) satellite [1], NASA's Space Technology 5 program, the Nanosat Constellation Trailblazer satellite, the Air Force Research Laboratory's Technology Satellite of the 21st Century (TechSat 21) and the MightySat programs. Further advances in small satellite capabilities are being

driven by research into new technologies such as microelectromechanical systems (MEMS), microelectronics, software, and lightweight components.

The increase in the number of small satellite launches over the past two decades and the planned inclusion of small satellites in many future programs indicate that there is a need for system engineering tools which will aid in the conceptual studies for these programs and which are appropriate to small spacecraft and the new technologies from which they are derived. Systems engineering is concerned with the improvement of the overall performance of the satellite, such as the reduction of mass, power consumption, and cost.

Spacecraft design is an established discipline, but the characteristics of small satellites are different from those of traditional large satellites with respect to mass, surface area, solar panel technology, and electromechanical devices. Hence, there is a need to design tools to support the requirements of small satellites. The overall process used to design small satellites and large satellites may be the same, but the tools vary significantly. In this paper, a new design tool for small satellites, in the form of an Integrated Design Environment (IDE), is proposed and constructed.

In this Chapter, Section 1.1 discusses the literature review done for this thesis while Section 1.2 discusses the satellite design procedures in use today. The Integrated Design Environment for small satellites as well as the motivation for implementing new techniques in satellite design procedures is discussed in Section 1.3. Section 1.4 deals with the space mission life cycle, and Section 1.5 explains the procedure used in this IDE, namely, a six-step process which includes all the phases of satellite design: concept,

definition, design, development, operation and disposal. Section 1.6 gives an overview of the thesis organization.

1.1 Literature Review

Todd J. Mosher et al. [1] applied a platform approach to five generic design reference missions for small satellites to yield cost effective and flexible small satellite architecture. They also addressed the process of determining platform architecture for small satellites and a survey of small satellite industry in done to know the uses of small satellites and emerging trends in mission requirements.

Allan I. McInnes et al. [2] discusses the Aerospace Corporation"s small satellite systems engineering tool, used for concurrent engineering methodology applied during the design process. The approach underlying the tool, overview of the implementation, relationships between various subsystems along with the flow of information are discussed.

Robert H. Klenke et al. [3] developed an integrated design environment which supports the design and analysis of the digital systems from initial phase to final implementation. They developed a tool called ADEPT (Advanced Design Environment Prototype Tool) to implement the interface. The tool is based on IEEE 1076 VHDL and uses a schematic capturing as a front end via an EDIF interface.

James R. Wertz et al. [4] in their "Space Mission Analysis and Design" book, described the preliminary mission design with all system aspects such as design of

spacecraft, orbital design, mission geometry, payload, ground segment and operations. It also describes the design of small spacecraft with defining mission parameters and requirements refining and the process of reducing cost.

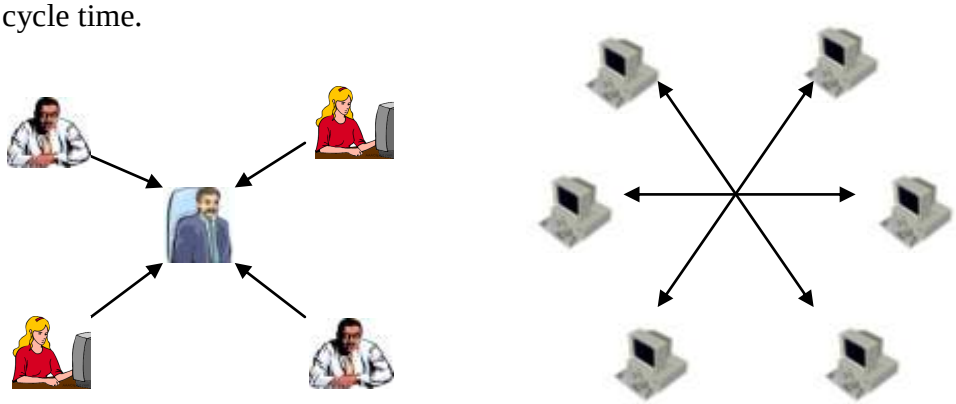
Todd Mosher et al. [5] discusses the Aerospace Corporation's small satellite cost model (SSCM) and small satellite design model (SSDM), used extensively by the systems engineers to understand conceptual spacecraft designs. The SSCM is used for cost estimation using a spreadsheet by gathering information from the developer on the specific components used and purpose for which the satellite will be used. The SSDM is a general purpose spreadsheet model used by spacecraft systems engineers to explore a variety of design solutions and identify critical subsystems.

1.2 Small Satellite Design Procedures

Traditional small satellite design methods use sequential and multidisciplinary processes which have several disadvantages. For example, the design of one subsystem may be dependent on that of another subsystem, so the design of the first subsystem cannot proceed until the design of the second has been completed. The result is that the time required for the overall design of the satellite design is substantially increased. In addition the communication of design data from the personnel responsible for one subsystem to the personnel responsible for another can be a complex and time-consuming task. Apart from the sequential design process there are two more processes that are recognized by the Aerospace Corporation [2].

1.2.1 Centralized Design/Analysis

To improve satellite design using the traditional sequential process, the Aerospace Corporation developed a centralized design process (Figure 1 (a)) based on concurrent design methodology. In this design process, a systems engineer works with a subsystem specialist to construct simple subsystem designs that have good overall performance. In this case all of the subsystem requirements are considered simultaneously, and this has the advantage of using more options in a given design cycle as well as decreasing the design cycle time.



(a) Centralized Design/Analysis (b) Distributed Design Analysis

Figure 1: Centralized and Distributed Design/Analysis [2]

1.2.2 Decentralized Design/Analysis

A concurrent engineering approach to spacecraft design can also be used in a distributed mode as shown in Figure 1 (b). In this process the individuals work on a single subsystem and the results are linked via a network to other specialists designing other subsystems. This process has an advantage over the Centralized Design process,

because the subsystem specialist is part of the network during the design process iteration, and therefore can design the subsystem using more complex algorithms [2].

1.3 Integrated Design Environment for Small Satellites

In general, tools or software available for the design of the satellite subsystem are not linked within the design environment. This disconnection leads to the system model being of little use to the design team as a starting place for their implementation. At worst, the system model developed using these types of tools can be completely inaccurate because of assumptions and abstractions that cannot be verified until the design is almost complete, at which point redesign is too time consuming and expensive. Even those design environments which employ the system level model often use different terminology for different parts of the model and require the user to develop complex, ad hoc interfaces between components modeled at different levels of abstraction. Using different modeling paradigms for each type of analysis that is to be performed causes a lack of coordination among various design teams [3].

Major changes are required to this traditional satellite design process because of the growth of technology with onboard processing capability and the continuing emphasis on low-cost missions. In this thesis a new method for the design and analysis of small satellites is proposed. With this Integrated Design Environment (IDE), satellite analysis and design is an evolving process. The IDE is a single software package that can

be used for design, integration, testing, launch and orbital operations support (some operations are yet to be included).

This IDE unifies the main software involved in each phase of the small satellite development. The IDE will not only allow users to design and build small satellites, but also allows for ready retrieval of information. This is a type of "knowledge capture" with which satellite design expertise can be leveraged for future satellite design projects. The IDE, when installed on a network, allows developers to enter any satellite design phase that they desire, and they can work on more than one phase simultaneously. Also, the simulation results or design procedures of one subsystem can be shared over the existing network facilitating sharing and the usage of the same design paradigms within the design group. But with this procedure, sharing the design process may require a database server for accuracy in using the relevant files of each project. For example if a subsystem specialist SS1 wishes to work on power system design for satellite A and subsystem specialist SS2 for satellite B, the correct power system design files corresponding to satellite A must be accessible by SS1 and of satellite B by SS2. This is possible only with a background database server which maintains all the subsystem files under the corresponding satellite or project titles.

This IDE is being implemented in Visual Basic.NET (VB.NET), a development tool that is used to develop Windows-based applications. It is an object oriented (OO) programming language which can be viewed as Visual Basic implemented on Microsoft .NET Framework. It supports rich user interface tools that are available in the Windows operating system. All of the rapid application development (RAD) tools that developers have come to expect from Microsoft are found in Visual Basic .NET, including drag-and-

drop design and combined with the ability to write code for forms. Visual Basic .NET supports the extensive use of external applications and dynamic object creation through the Component Object Model[1] (COM) in which reference objects can be created dynamically for the external objects and used for programming. The IDE for small satellite design includes several design and simulation software packages, including tools for electronics simulation, orbit analysis, structural dynamics, and power distribution.

1.4 The Space Mission Life Cycle

The life cycle of a satellite space mission generally progresses through four main stages [4].

1.4.1 Concept Exploration

The first is the Concept Exploration stage during which three basic activities occur: *Requirements Generation* (by Users and Operators), *Acquisition Management* (by Developers) and *Planning* (by Sponsors).

Users and Operators develop and coordinate a set of broad needs and performance objectives. At the same time, developers modify and expand the concepts developed by the user and operating community. The sponsors develop an overall program structure and estimate budgets to meet the needs of users, operators and developers. The main goal

[1] Microsoft Visual Basic .NET, Microsoft Visual Basic and COM are trademarks of Microsoft Corporation

during this stage is to assess the need for the space mission and develop alternatives that meet the requirements of the user.

1.4.2 Detailed Development

During the Detailed Development stage, the Project Manager and the System Development Manager work closely to develop detailed data and process models, refine system and functional requirements, and refine high level architecture and logical design. There are three key reviews during this stage: the *Detailed Level Requirements Review*, the *Logical Design Review*, and the *Technical Design Review*.

1.4.3 Production and Deployment

The Production and Deployment stage commences as the third step and encompasses Operations and Support. During the Production and Deployment stage, the system should achieve the operational capability that satisfies mission needs.

There are primarily two tasks in the production stage: *Low-Rate Initial Production* and *Full-Rate Production*. The Low-Rate Initial Production stage should result in the completion of manufacturing development. The systems engineering effort in the Full-Rate Production and Deployment stage delivers the fully-funded quantity of systems and supporting material and services for the program. During this stage, the system attains Initial Operational Capability.

As the combined components develop into a system, test and evaluation processes reveal issues that require improvements or redesign. The initial manufacturing process may also reveal issues that were not anticipated.

1.4.4 Operations and Support

The objective of this stage is the execution of a program that meets operational support performance requirements and sustains the system in the most cost-effective manner over its total life cycle. When the system reaches the end of its useful life, it must be disposed in a safe manner. These two work efforts, Sustainment and Disposal, comprise the Operations and Support Stage [6].

1.5 The Six-Step Process

The life cycle of the space mission is distributed over six phases in this IDE which are extracted from the ideas of the general space mission life cycle discussed in Section 1.4. Each stage from the actual satellite design life cycle may be covered in one or more of these six phases. Each phase in turn may be used for the design or operation of one or more subsystems. In general, these six phases exist for every project that is created using the IDE. Also the design concepts of a particular subsystem of one satellite can be used in the design of another satellite"s subsystem. These six phases are discussed as below in Sections 1.5.1 through 1.5.6.

1.5.1 Concept

Requirements from the users, developers and the sponsors are usually gathered in the Concept phase. Primary issues such as mission statement, cost factors, required resources, and time-schedules are usually organized using Microsoft Project 2003[2] during this phase.

1.5.2 Definition

The primary data that is collected in the Concept phase is reviewed by the subsystem specialists from the point of view of the optimization requirements necessary for efficient operation of the satellite, including cost effectiveness, as well as user requirements. In this phase

a. The technical and business baselines for the spacecraft project are defined;
b. Design processes for the subsystems are reviewed as stated in the mission statement;
c. The state charts for the system are drawn, elaborating the complete satellite system including all subsystems;
d. The requirements are modified depending on the design techniques that are feasible;
e. The project time-line is designed and resources are allocated to each subsystem.

[2] Microsoft Project 2003 is a trademark of Microsoft Corporation.

Cradle[3] requirement analysis software is used to meet the needs of the Definition phase.

1.5.3 Design

In this phase the various subsystems involved in the design of a satellite are designed and simulated in software. Though simulations are not as accurate as the real system, they generally give an idea of how the real system will behave under various conditions such as a change in temperature or a change in pressure. They also provide the means to test the subsystems under various conditions and design enhancements when possible. The subsystems that are to be considered in the satellite design are:

a. Command and Control (Electrical)
b. Communication Subsystem
c. Payload Subsystem
d. Mechanisms and Deployment Subsystem
e. Power Subsystem
f. Thermal Management Subsystem
g. Propulsion and Orbit Maintenance
h. Structure (Mechanical)

Simplorer v7.0[4] is used to design the electrical and power subsystems. Currently, only these two subsystems have been implemented. The rest of the subsystems will be implemented in the future.

[3] Cradle is a trademark of ThreeSL.
[4] Simplorer v 7.0 is a trademark of Ansoft Corporation.

1.5.4 Development

In this phase, assembly, test and launch (ATLO) operations take place. After the subsystem units have been assembled, the following system level tests are performed:

a. Thermal testing, simulating the conditions in space.

b. Mission simulations.

c. Acoustics, simulating the environment required.

These and other specifications must be met depending on the type of the satellite being developed. The satellite is to be developed in a laboratory that has met all of the specifications required for a safe operation.

1.5.5 Operations

This phase includes the operations performed on the satellite after its deployment. The commands are sent from the ground stations and are received by the command and data handling module on the satellite. This module coordinates the activities between various subsystems on the satellite ensuring the safe operation of the satellite.

a. This phase starts immediately after the launch of the spacecraft.

b. The mission operations include the control and command of the spacecraft.

c. Depending on the complexity of the spacecraft and the mission, the mission operations team is defined.

The IDE communicates with the satellite from the ground station using Visual Basic software.

1.5.6 Disposal

This phase is useful in design of the techniques required for the safe disposal of the spacecraft.

The six phase life cycle of the IDE can be seen as shown in Figure 2.

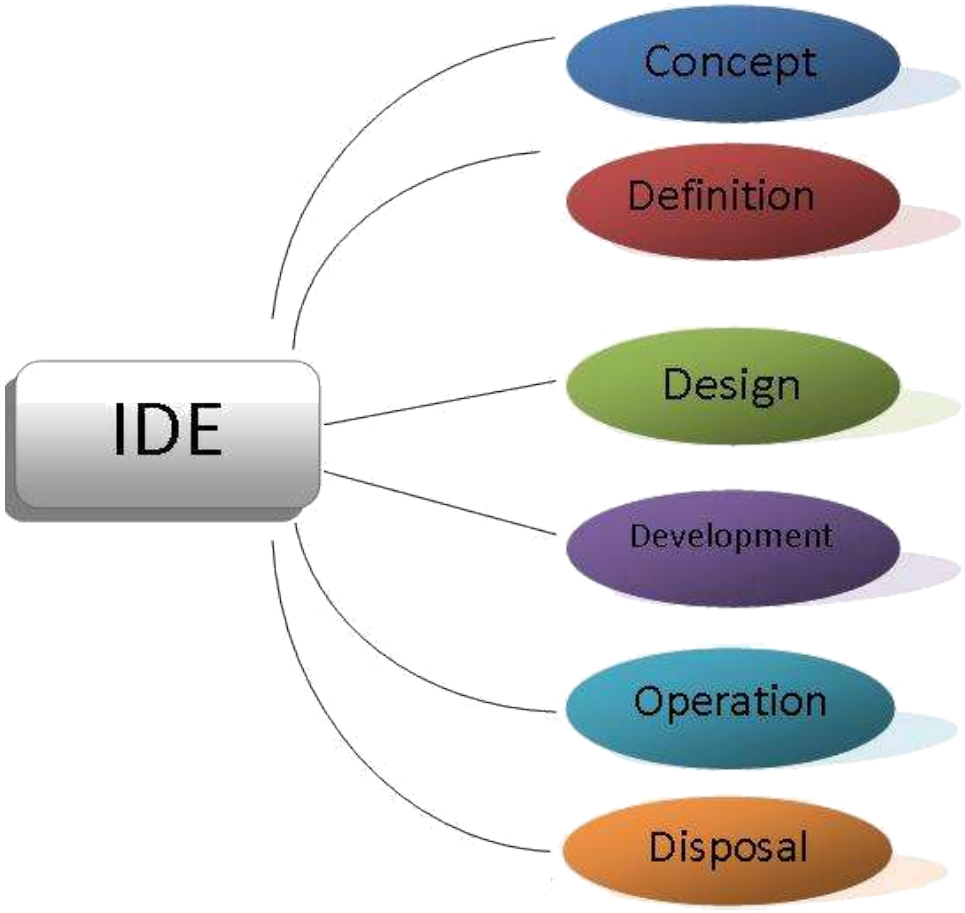


Figure 2: High level diagram of the IDE[5]

[5] Drawn in Microsoft Word with an idea from the architecture of the IDE.

1.6 Thesis Organization

Chapter 2 of the thesis deals with the Concept phase, in which the Project Management procedures are discussed with a template created in Microsoft Project 2003. Chapter 3 discusses the Definition phase in which Cradle software is used to illustrate how the requirements are refined and shows how to draw system diagrams such as Dataflow diagrams, State charts etc.

In Chapter 4, the electrical subsystem design is discussed using the Simplorer software. Each of Chapters 2, 3 and 4 discuss an example which gives a better idea of using the respective software. Chapter 5 gives an overview of the implementation procedures in this IDE. Conclusions and possible future work are discussed in Chapter 6.

CHAPTER II

PROJECT MANAGEMENT

A project can be defined as a unique undertaking that has clearly defined start and finish dates and requires the management of time, resources, cost and quality to create a unique product or service. Project management is the discipline of organizing and managing resources so that the project is completed within the defined scope, available man-power, materials, time and cost constraints [7].

The main task of project management is to ensure that a project is delivered within the defined constraints. The other tasks are optimized allocation and integration of the inputs required to meet the pre-defined objectives. Project management usually follows the major phases termed as the feasibility study, project planning, implementation, evaluation and support or maintenance. These phases include developing a project plan, defining project goals and objectives, specifying tasks or how goals will be achieved, what resources are needed and associating budgets and timelines for completion [7]. It also includes implementing the project, along with careful controls to stay on the "critical path", i.e., to ensure the plan is being managed according to the strategy.

The discipline of *Network Analysis* began in the early 1950s, where in Europe the development of such techniques as the *Critical Path Method (CPM)* and *Project Network Techniques* began. With the development of the Polaris missile system in the USA, the technique called *Program Evaluation and Review Technique* or *PERT* evolved. These simple analysis techniques allow a project manager to define a series of tasks that are essential to be undertaken to achieve the product, to link the tasks in a logical pattern to form a network, and analyze individual task timings to calculate a critical path to achieve an end date. Thus Network Analysis is the core technique of all modern project management practices [7].

These techniques are good in concept, but their practical application requires substantial calculations more suited to a computer which allows a project manager to produce a plan quickly and, more importantly, to revise that plan as time progresses. Project managers can assign resources to tasks and distribute their workloads with appropriate cost assignments. Today there are many software packages available for project management such as Active Project, Leading Project, and Microsoft Project, which differ in features among which are project tracking, resource management, task management, and web services. Therefore, it is important to understand the principles of project planning before applying them to a project management software package like Microsoft Project which is used in this IDE.

In this chapter, Section 2.1 gives a brief introduction to Microsoft Project and Section 2.2 gives an overview of Microsoft Project Server. Section 2.3 lists all the tasks that are used for the template of the IDE. Section 2.4 explains briefly the features such as

the Gantt chart, Calendar, Network Diagram, and the PERT Analysis Technique provided by the Microsoft Project.

2.1 Microsoft Project

*Microsoft Project (*or *MSP)* is a project management software program developed by Microsoft, designed to assist project managers in developing plans, assigning resources to tasks, tracking progress, managing budgets, preparing reports and analyzing workloads. The first version of Microsoft Project for Windows v1.0 was released in 1987 on a contract to a small external company. In 1988 the company was taken over by Microsoft, releasing the developed project as part of Microsoft Windows 3.0. The Macintosh version of Microsoft Project was released in July 1991. From then until 2003 six versions were released for both Windows and Macintosh [8], and the Project 2007 version is under development and is planned to be released in 2007.

Microsoft Project is a scheduling and planning tool for project managers, providing easy-to-use tools for preparing a project schedule and assigning responsibilities. It is a flexible software application for creating schedule graphics, estimating resource requirements, analyzing task dependencies, and tracking project progress. It can also be used to provide a graphical presentation for a project schedule, where the tasks are listed and assigned with task durations, resources, dates, costs and, etc [9]. In many project environments, managing scarce staff resources and dealing with

difficult schedules are the major obstacles to achieve project success. Microsoft Project is a planning tool which assists the project manager in performing the following tasks:

a. Organize the project plan and facilitate tuning it with time and budget constraints.
b. Schedule tasks in the appropriate sequence and with deadlines that must be met.
c. Assign resources and costs to tasks, schedule tasks around the availability of resources, and provide links between elements of the project (tasks, resources, and assignments) and related project management documents in other applications.
d. Collaborate with other project stakeholders by reviewing the schedule and by notifying resources of their assignments.
e. Prepare professional-looking reports to explain the project to stakeholders such as owners, top management, supervisors, workers, subcontractors, and the public.
f. Publish the project on a server for other project managers to access and for stakeholders to review via Internet browsers.
g. Track all the information gathered about the work, duration, costs, and resource requirements for the project.
h. Exchange project information with other Microsoft Office System applications such as Access, Excel, PowerPoint, and Word.

Microsoft Project also supports communication between the team members. When work begins on the project, Microsoft Project can be used to do the following:

a. Track progress and analyze the evolving real schedule to see if it will finish on time and within budget.

b. Notify resources of changes in their assignments and get progress reports on work that has been accomplished and that is yet to be done.
c. Revise the schedule to accommodate changes and unforeseen circumstances.
d. Post automatically updated progress reports on the Project Server, or on an Internet Web site or a company intranet.
e. Produce final reports on the success of the project and evaluate problem areas for consideration in future projects.

Microsoft Project creates critical path schedules, which can be resource leveled, and chains or links can be visualized in a Gantt chart. It also facilitates different user access levels to projects, views, and other project related data. Custom objects such as calendars, views, tables, filters and fields can be stored in a project server, so that all users can share them over the network.

2.2 Microsoft Office Project Server

Microsoft extends the capabilities of Microsoft Project with Project Server and Web Access. Project Server stores the project information in a central database, protected from unauthorized access and corruption. A project administrator can control security, defining users and access rights for a particular project [10].

The Project Center supports reporting across an organization at the project level. The Project manager can communicate project plans and distribute task assignments to team members. Assignment of tasks can be distributed to team member home pages in

Web Access, who in turn need to communicate their status and changes to keep the project manager up to date. Project Server supports electronic communication over the web via Web Access. The options that are available in Microsoft Project for communication with the Project Server (or Project Center) are as shown in Figure 3.

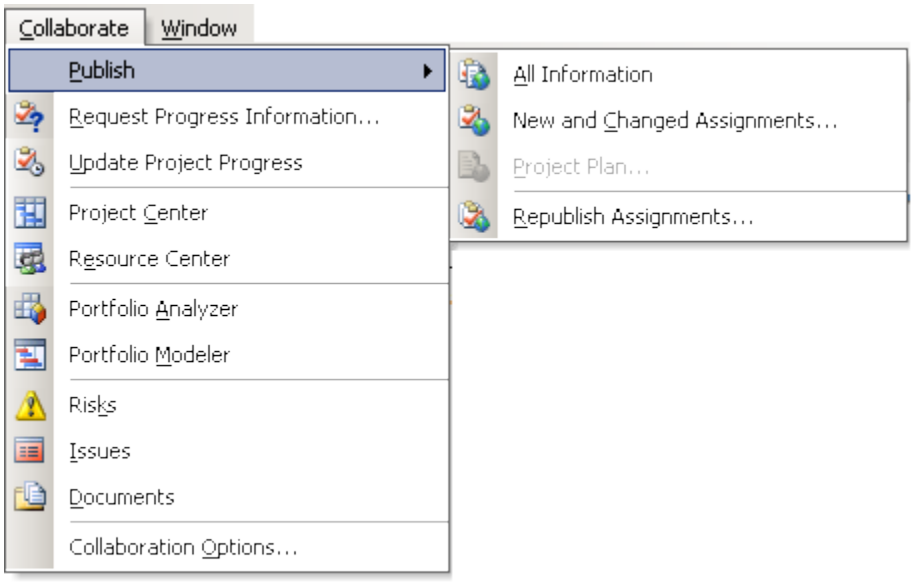


Figure 3: Project Server options in Microsoft Project

Resource workloads can be analyzed by Project Center and resources with Resource Center, allowing organizations to forecast future resource requirements and make more efficient use of resources. View definitions are easier to understand and more robust with Web Access than with Microsoft Project. Views can be protected to assist standardization. Project Server stores custom calendars, views, tables, filters, and fields in an Enterprise global location where users have access to the latest version every time Microsoft Project is restarted.

2.3 Microsoft Project in the IDE

A template has been created for using Microsoft Project in this IDE. This template consists of the tasks that are assumed to be common to most of the satellite design projects [4]. The six-step satellite design process discussed in Section 1.5 of Chapter I is implemented in the template with each stage being the main task with one or more sub-tasks included in it. Milestones (important events) such as reviewing the process at various levels have also been included as tasks. All the tasks along with their corresponding total duration in days, start date, finish date, percentage work completed (% Finish) and the predecessors have been listed in the form of a table as in Table I.

TABLE I: TASKS LISTED IN THE MICROSOFT PROJECT TEMPLATE

WBS	Task Name	No. of Days	Start Date	Finish Date	% Finish	Predecessor
1	Project Name: **Test Document**	198?	5/2/06	1/31/07	42%	
2	**Phase A :Preliminary Analysis**	**38**	**5/4/06**	**6/26/06**	**100%**	
2.1	Mission Needs/ Requirements	17	5/4/06	5/26/06	100%	
2.1.1	Functional Needs/ Requirements	12	5/4/06	5/19/06	100%	
2.1.1.1	Performance	3	5/4/06	5/8/06	100%	
2.1.1.1.1	Primary Objective	3	5/4/06	5/8/06	100%	
2.1.1.1.2	Payload	3	5/4/06	5/8/06	100%	
2.1.1.1.3	Size	3	5/4/06	5/8/06	100%	
2.1.1.2	Coverage	4	5/8/06	5/11/06	100%	
2.1.1.2.1	Orbit	4	5/8/06	5/11/06	100%	
2.1.1.2.2	Swath width	4	5/8/06	5/11/06	100%	
2.1.1.3	Responsiveness	10	5/8/06	5/19/06	100%	
2.1.1.3.1	Communications architecture	5	5/8/06	5/12/06	100%	
2.1.1.3.2	Processing delays	5	5/15/06	5/19/06	100%	14
2.1.2	Operational Needs/Requirements	6	5/8/06	5/15/06	100%	
2.1.2.1	Duration	6	5/8/06	5/15/06	100%	
2.1.2.2	Availability	6	5/8/06	5/15/06	100%	
2.1.2.3	Survivability	6	5/8/06	5/15/06	100%	
2.1.2.4	Data Distribution	6	5/8/06	5/15/06	100%	
2.1.3	Constraints	7	5/18/06	5/26/06	100%	
2.1.3.1	Cost	7	5/18/06	5/26/06	100%	

2.1.3.2	Schedule	7	5/18/06	5/26/06	100%	
2.1.3.3	Regulations	7	5/18/06	5/26/06	100%	
2.1.3.4	Sponsor	7	5/18/06	5/26/06	100%	
2.1.3.5	Environment	7	5/18/06	5/26/06	100%	
2.1.3.6	Interfaces	7	5/18/06	5/26/06	100%	
2.1.3.7	Development Constraints	7	5/18/06	5/26/06	100%	
2.2	Mission Characteristics	23	5/25/06	6/26/06	100%	
2.2.1	Data Delivery	5	5/25/06	5/31/06	100%	
2.2.1.1	Space vs. Ground	5	5/25/06	5/31/06	100%	
2.2.2	Communications Architecture	10	5/29/06	6/9/06	100%	
2.2.2.1	Data rates bandwidth	10	5/29/06	6/9/06	100%	
2.2.2.2	Ground System	10	5/29/06	6/9/06	100%	
2.2.3	Scheduling and Control	6	6/12/06	6/19/06	100%	
2.2.3.1	Level of anatomy	5	6/12/06	6/16/06	100%	
2.2.3.2	Central vs. Distributed	6	6/12/06	6/19/06	100%	
2.2.4	Mission Timeline	5	6/13/06	6/19/06	100%	
2.2.4.1	Level of timeline flexibility	5	6/13/06	6/19/06	100%	
2.2.5	Identify system drivers for each	6	6/19/06	6/26/06	100%	
2.2.5.1	Size	6	6/19/06	6/26/06	100%	
2.2.5.2	On-Orbit weight	6	6/19/06	6/26/06	100%	
2.2.5.3	Power	6	6/19/06	6/26/06	100%	
2.2.5.4	Data Rate	6	6/19/06	6/26/06	100%	
2.2.5.5	Communications	6	6/19/06	6/26/06	100%	
2.2.5.6	Pointing	6	6/19/06	6/26/06	100%	
2.2.5.7	Altitude	6	6/19/06	6/26/06	100%	
2.2.5.8	Coverage	6	6/19/06	6/26/06	100%	
2.2.5.9	Scheduling	6	6/19/06	6/26/06	100%	
2.2.5.10	Operations	6	6/19/06	6/26/06	100%	
3	**Mission Definition Document**	**8**	**6/27/06**	**7/6/06**	**100%**	**3**
4	**Mission Definition Review (MDR)**	**3**	**7/7/06**	**7/10/06**	**100%**	**51**
5	**Phase B: Definition/ System Requirements**	**15**	**7/11/06**	**7/28/06**	**100%**	**52**
5.1	Draft System Requirements	5	7/11/06	7/17/06	100%	52
5.2	System Requirements Review	2	7/19/06	7/20/06	100%	54
5.3	Allocate requirements to subsystems	3	7/20/06	7/22/06	100%	52
5.4	Develop Budgets	5	7/24/06	7/28/06	100%	56
6	**Preliminary Design Review (PDR)**	**1**	**7/28/06**	**7/28/06**	**100%**	**53**
7	**Phase C: Design and Analysis**	**81?**	**7/31/06**	**11/15/06**	**76%**	**58**
7.1	Propulsion	8	7/31/06	8/9/06	100%	58
7.2	Attitude Determination and Control	14	7/31/06	8/17/06	100%	58
7.3	Communication	21	8/3/06	8/29/06	100%	61
7.4	Command and Data Handling	16	8/14/06	8/31/06	100%	61,62
7.5	Payload	13?	9/11/06	10/11/06	80%	65

7.6	Structure and Mechanisms	10?	9/25/06	10/6/06	85%	60,61
7.7	Power	30?	9/18/06	10/31/06	43%	63,65
7.8	Thermal	24?	10/9/06	11/15/06	50%	65,66
8	**Critical Design Review (CDR)**	**2?**	**11/16/06**	**11/18/06**	**30%**	**59**
9	**Phase D: Integration and Verification**	**31?**	**11/20/06**	**12/29/06**	**0%**	**68**
9.1	System Acceptance Review (SAR)	4?	11/20/06	11/23/06	0%	68
9.2	Fabrication	25?	11/27/06	12/29/06	0%	70
10	**Flight Readiness Review (FRR)**	**2?**	**1/1/07**	**1/2/07**	**0%**	**69**
11	**Operational Readiness Review**	**5?**	**1/3/07**	**1/9/07**	**0%**	**72**
12	**Phase E: Operations**	**9?**	**1/10/07**	**1/22/07**	**0%**	**73**
13	**Phase F: Disposal**	**7?**	**1/23/07**	**1/31/07**	**0%**	**74,3**

A finished task (100%) will have the exact number of working days unlike unfinished tasks or tasks that have not yet begun. These latter two kinds of tasks will have an estimated duration which is indicated by the „?" symbol after the numerically estimated days. The last column shows the predecessors for a particular task, i.e., information from that predecessors is used for completing the current task. As the number of tasks and predecessors increases, it sometimes happens that the process becomes so complex that the tasks can form a recursive loop, or proceed along an unexpected path. Hence, to ensure feasibility and that the process follows a critical path, it should be scheduled or prepared to be as simple as possible while including all of the important details.

2.4 Features of Microsoft Project

Microsoft Project provides many views such as Calendar, Gantt chart, Network diagram, Tracking Gantt, Task Usage, Resource Graph, Resource Chart, Resource Usage

and many other views as desired by the user. A resource sheet where all the resources can be managed is also available. It can also generate user-friendly reports which vary from project summary to individual task status, and these are customizable to meet requirements. A feature which exports the project to Microsoft Excel is useful for further analysis of the simple PERT analysis technique. These and many other features aid the project manager in maintaining the project at various levels. Some of these features are discussed in Sections 2.4.1 through 2.4.8 [7].

2.4.1 Gantt chart

A *Gantt chart* is a graphical representation of the duration of tasks over time. This is a project planning tool that can be used to represent the timing of tasks required to complete a project. Since Gantt charts are simple to understand and easy to construct, they are used by most project managers. A variety of Gantt charts are available such as the Basic Gantt, Milestone Gantt, Bar Gantt, Baseline Gantt, Timeline Gantt, Summary Gantt, and Spotlight Gantt.

In a Gantt chart, each task occupies one row, and dates run along the top in increments of days, weeks or months, depending on the total length of the project. The expected time for each task is represented by a horizontal bar. Tasks may run sequentially, in parallel or overlapping. As the project progresses, the chart is updated by filling in the bars to a length proportional to the fraction of work that has been accomplished on the task. When resources are added to individual tasks, each bar corresponding to a task in the Gantt chart shows the resource information beside the bar.

Gantt charts are generally good for projects that have a small number of tasks. More complex projects require subordinate charts which detail the timing of all the subtasks that make up one main task. The important events in the project are called "milestone" events, marked with a special symbol of an upside-down triangle „ ‟ called *nabla*.

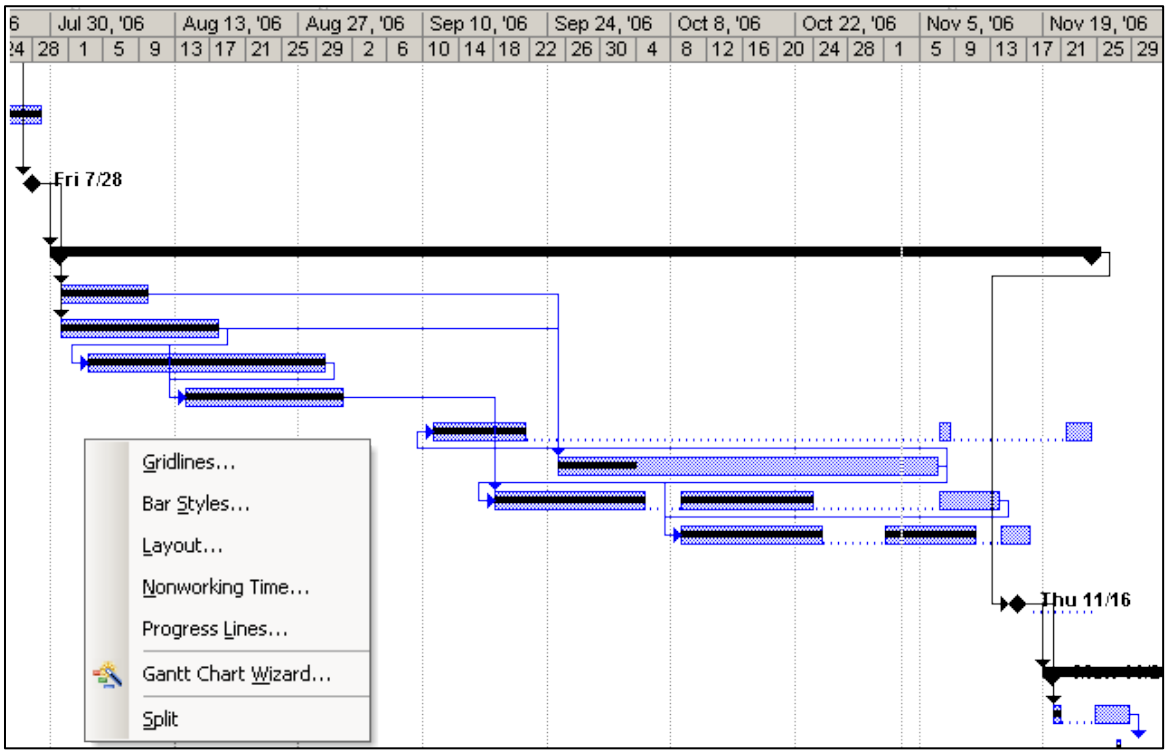


Figure 4: Gantt Chart View from IDE Template

These charts illustrate the start and finish dates of the terminal elements and summary elements of a project. Terminal elements and summary elements comprise the work breakdown structure (WBS) of the project. Gantt charts can also show the dependency of relationships between activities (i.e., the precedence network), which can

be seen as lines between the activities as in Figure 4. Also shown are the options provided for custom viewing.

2.4.2 Calendar View

The *Calendar* view shows the Gantt bars on a desktop calendar. Tasks can be created, edited, and linked, and resources can be assigned in the same way as in the Gantt View. The view can be refined using filters to select a particular resource or type of activity. The calendar can be viewed by selecting **View>Calendar** or by clicking on the **Calendar** icon on the *View Bar*. A screen shot of a particular week of activities in the template created for this IDE is shown in Figure 5.

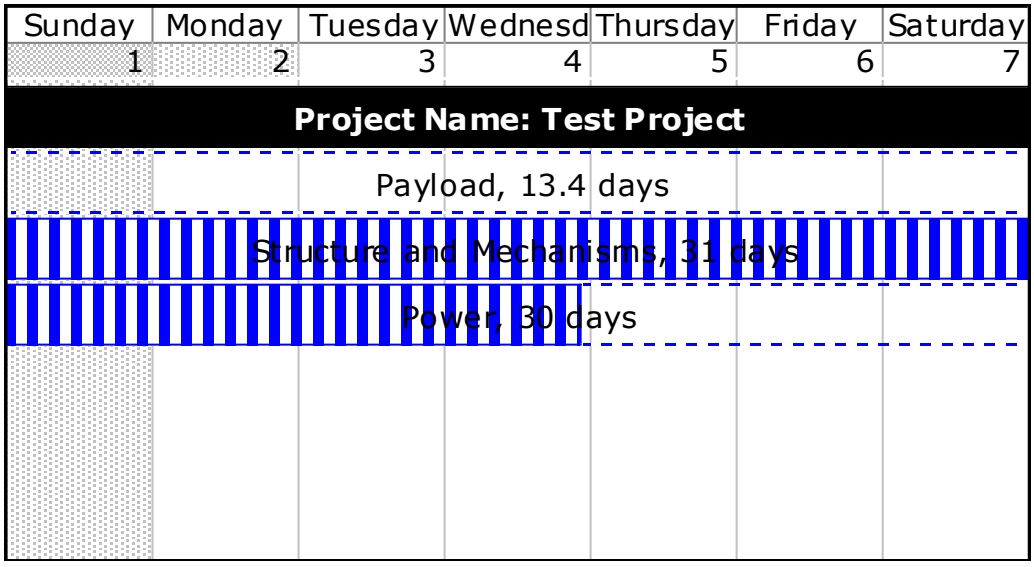


Figure 5: Calendar View from IDE Template

2.4.3 Network Diagram

The *Network Diagram* is a logic chart showing all of the tasks and the task dependencies which are the logical relationship between tasks. This view is used to create and fine-tune the schedule in a flowchart format. Tasks can be created, edited, and linked, and resources can be assigned in the same way as in the Gantt View. Select **View>Network Diagram** or click the **Network Diagram** icon on the *View* bar. Figure 6 shows a part of the network diagram in the template created for this IDE.

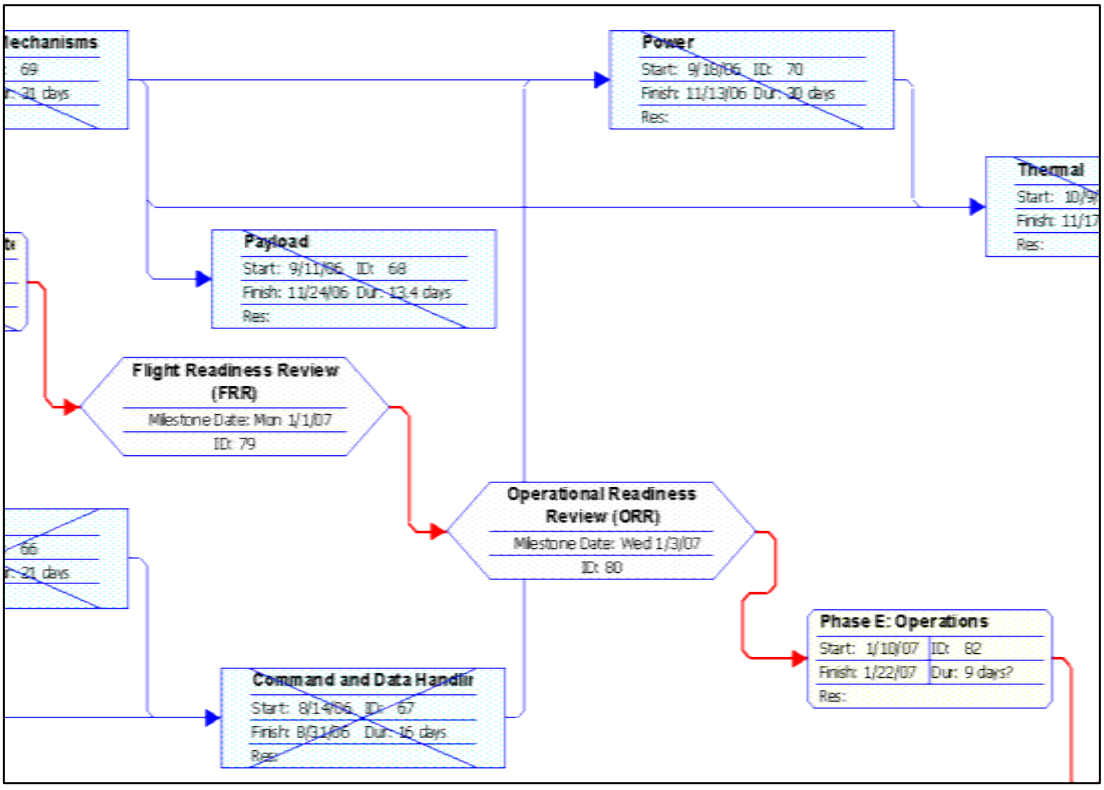


Figure 6: Network Diagram from IDE Template

Each rectangular box in the Network Diagram corresponds to a task and a hexagonal box represents a milestone. Tasks which are one hundred percent completed

are marked with a cross on the box. Tasks that have begun but partially finished are marked with a single line across the box and those that not begun yet will be plain.

2.4.4 Program Evaluation and Review Technique Analysis in Microsoft Project

Microsoft Project implements a quantitative risk analysis technique called PERT (Program Evaluation and Review Technique). The PERT model was developed in the 1950s to address uncertainty in the estimation of project parameters. According to classic PERT, expected task duration is calculated as the weighted average of the most optimistic, the most pessimistic, and the most likely time estimates. Using PERT in Microsoft Project is very easy using the *PERT Toolbar*. To enable the PERT toolbar (shown in Figure 7), on the View menu, from the Toolbars menu choose PERT Analysis.

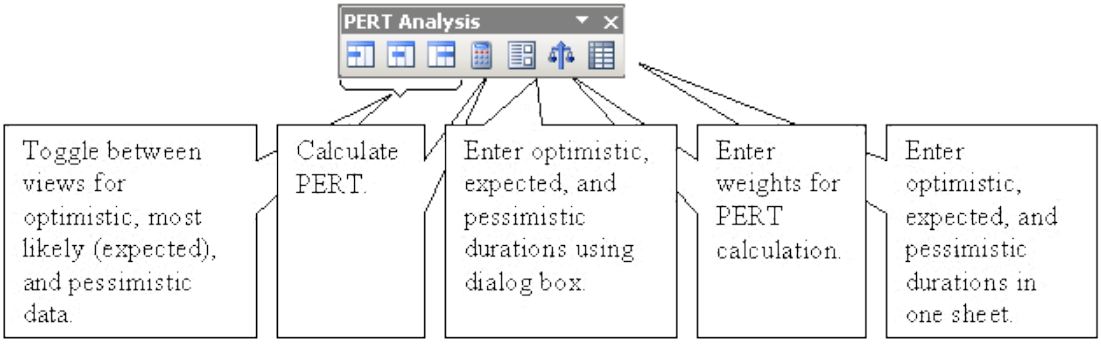


Figure 7: PERT Analysis Toolbar

Microsoft Project has four views that aid in entering data for PERT analysis: views for the optimistic, expected, and pessimistic duration, as well as a PERT entry sheet. The most powerful is the PERT entry sheet which allows the user to enter and see all durations together. The Calculate PERT button on the toolbar shows the results of

calculations performed on optimistic, expected and pessimistic durations in the form of a Gantt chart.

The classic PERT methodology has a number of limitations. The main problem is associated with accurately estimating the optimistic, most likely, and the pessimistic durations of the task.

2.4.5 Resource Rates

Microsoft Project creates budgets based on assigned work and resource rates. As resources are assigned to tasks and assignment work estimated, the program calculates the cost (the work times the resource rate), which rolls up to the task level and then to any summary tasks and to the project level. Resource definitions (people, equipment and materials) can be shared between projects using a shared resource pool. Each resource can be assigned to multiple tasks in multiple plans, and each task can be assigned multiple resources. The application then schedules tasks based on resource availability as defined in the resource calendars.

2.4.6 Resource Sheet

A *Resource Sheet* is a list of resources and their related information. The resource sheet view is used to review, add, or edit data about resources and to copy or paste information from one resource to another. Different tables can be applied to view resource information from different perspectives, or a filter can be applied to display only

the required information. A typical resource sheet taken from the template is as shown in Figure 8.

Resource Name	Type	Material Label	Initials	Group	Max. Units	Std. Rate	Ovt. Rate	Cost/Use	Accrue At	Base Calendar
Resource 1	Work		R	A	100%	$30.00/hr	$35.00/hr	$25.00	Start	Standard
Resource 2	Material	M007	M	B		$10.00		$10.00	Prorated	

Figure 8: Resource Sheet from the Template of the IDE

2.4.7 Reports

Reports are a series of built in layouts that can be edited and customized for building new reports. The user can select any of the options available as shown in Figure 9. The Custom selection offers the user a variety of reports related to Cost, Project Summary, Resources and Tasks. These can be further customized to meet user requirements by selecting which columns the user wishes to print.

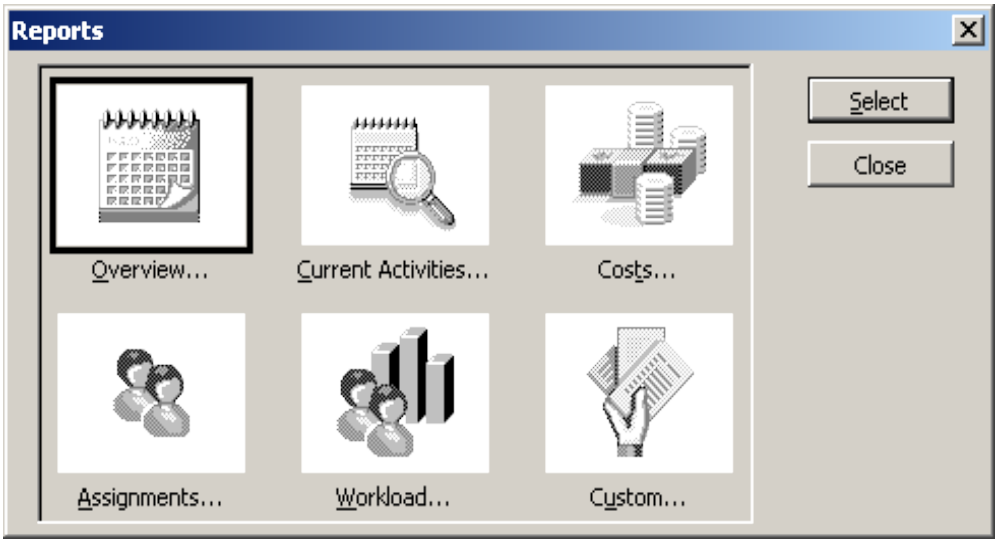


Figure 9: Reports menu from Microsoft Project

2.4.8 Tracking Gantt

Tracking Gantt is similar to the normal Gantt chart view, although the bars are thinner. This view is useful for viewing the Baseline, which is a snapshot of the main elements of the project before the start of project. A sample Tracking Gantt view is shown in Figure 10 in which the base lines are compared against the actual work progress. The baselines are the grey lines with dashed lines on them. This view is helpful in reports when displaying the current status of the project.

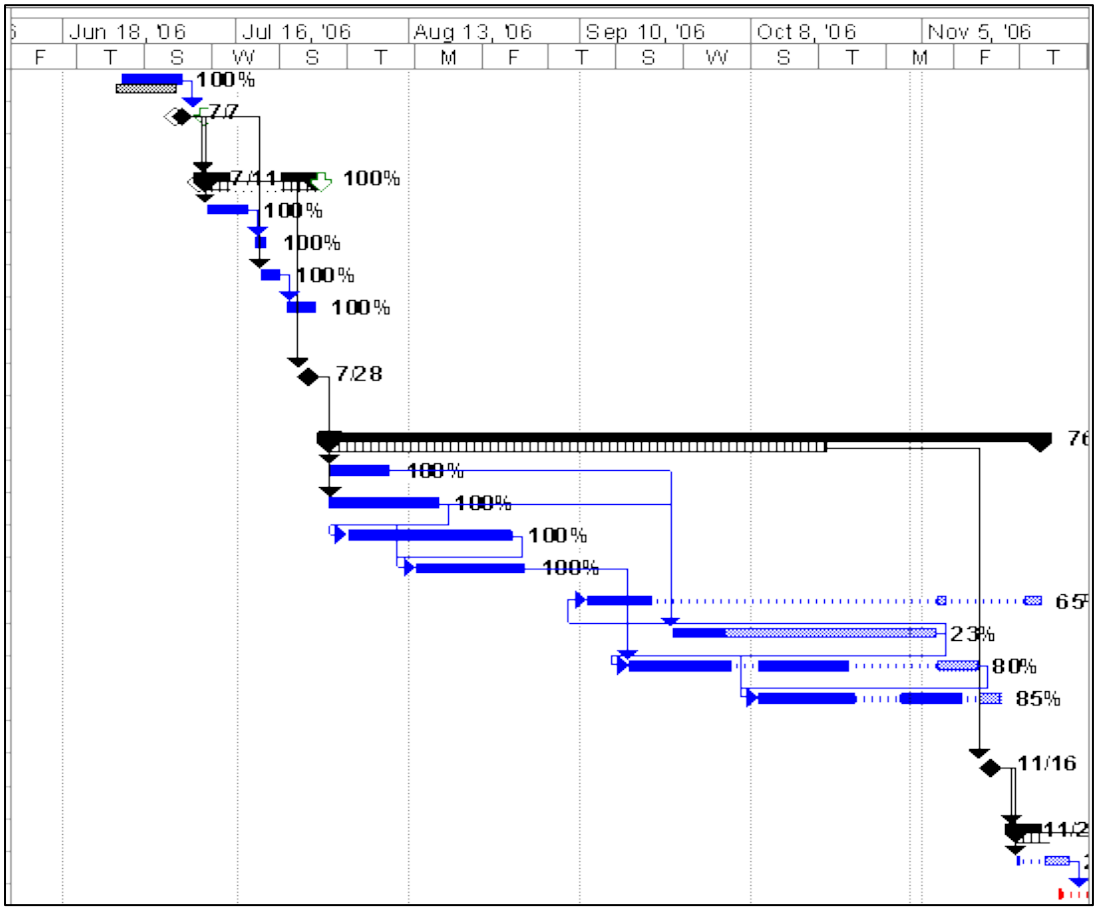


Figure 10: Tracking Gantt View for the IDE Template

CHAPTER III

REQUIREMENTS MANAGEMENT

A *requirement* is a specification given about an individual system function. Requirements that must be supported by the system are specified in detail and should be achievable and testable. They are designed taking information from a variety of sources, such as the customer/user, regulations/codes, and the corporate entity.

Defining requirements is a complex process which uses performance analysis, trade studies, constraint evaluation and cost benefit analysis. These requirements are framed by the business analysts or requirements engineers, who discuss the requirements with the user along with the other stakeholders (people involved in the project). Then they formulate the feasible requirements and transfer them to the developers in the form of a technical document. Developers generally follow the requirements provided to them and develop a system that is expected to meet the user requirements. It can be stated that these business analysts or requirements engineers form a bridge of communication between users and developers. Hence, the communication must be done precisely, so that there will be a minimal difference between the user requirements and the final system at the end of the project [11].

Section 3.1 of this chapter describes the procedures used in requirements analysis. Section 3.2 gives an introduction to the Cradle software, Section 3.3 describes the Cradle Modules, and Section 3.4 describes the Cradle Components. Cradle functionalities are discussed in Section 3.5, which will show why Cradle is used in this IDE. Section 3.6 explains model-based systems engineering, which uses diagrams to illustrate the requirements in Cradle Software.

3.1. Requirements Engineering

Requirements are the foundation of a system and form the basis for the design, manufacture, test and operation of a system. As each requirement has a cost impact on the overall system, it is necessary that an optimum set of requirements be specified before development. Modifying requirements later in the development cycle has a significant cost impact on the system, and hence care must be taken when defining them. A survey by the Standish Group[6] shows the importance of requirements engineering. The analysis of more than 352 companies reporting on more than 8,000 software projects showed that [12]:

a. Of all software projects, about 31 percent are canceled even before they were completed accounting for a waste of $81 billion.
b. About 53 percent of the projects were about 189 percent of their original estimate cost.

[6] The Standish Group is an Information Technology leader in project and value performance, formed in 1985 to collect case information on real IT failures and environments.

c. In large companies, only about 9 percent of the projects were completed on time and within budget.

d. In small companies, only about 16 percent of the projects were completed on time and within budget.

In systems engineering and software engineering, requirements engineering encompasses all of the tasks that go into the initiation, scoping and definition of a new or altered system. Conceptually, requirements engineering includes three types of activities:

a. *Requirements elicitation* is the task of communication with customers and users to determine what their requirements are.

b. *Requirements analysis* determines whether the stated requirements are unclear, incomplete, ambiguous or contradictory and resolves these issues.

c. *Requirement recording* is documenting the requirements in various forms such as use cases, process specifications, and natural-language documents.

During the elicitation period, performed in an iterative fashion, new requirements may be added or the existing modified. This is especially necessary in developing or changing an existing system because the requirements can clarify the important issues between the stakeholders and developers and because:

a. End users may not know exactly what they want.

b. Users may insist on new requirements after the cost and schedule have been fixed.

c. Technical personnel and end users may use different terminology which may lead to problems when final product is delivered.

Requirements analysis helps to create the environment and relations between stakeholders and can be a long and arduous process. The process may include holding interviews or focus groups and thereby developing prototypes and use cases. *Requirements analysis* is also called requirements engineering, requirements specification, system analysis, or operational concept documenting.

Today there are many software tools on the market to manage these requirements. Of these, Analyst Pro, AxiomSys, ClearSpecs Composer, Cradle, IBM Rational Rose are just a few. In this IDE, Cradle Version 5.3 is being used because of the features it provides, which will be discussed in the following sections.

3.2. Cradle

ThreeSL's Cradle is a multi-user, multi-project, systems engineering environment, and it can span the entire systems and software development lifecycle. It "provides a set of tools that can integrate all project phases, activities and deliverables within a single, configuration managed, access controlled framework" [13]. Cradle can also be used as a web portal for project information in an integrated systems engineering environment.

All project activities can be defined within a project schema. Cradle's multi-user, high capacity database can manage huge volumes of data, which allows requirements (and other item types) to contain text, tables, graphics etc. Database items can also be linked to external data objects such as URLs and data in other databases.

Cradle facilitates requirements to be linked to a wide variety of Unified Modeling Language (UML), use case, functional, behavioral, dynamic and architectural models. They can also be allocated to business processes and operational sequences, which in turn can be allocated to functions, classes, etc. Estimation of performance and budget aggregation, along with allocation within and across these architectures, is fully supported by Cradle. It also provides resources to develop the models for hardware and software, along with the generation and reverse engineering of source code.

The requirements for designing a small satellite must include its objectives, specifications, physical description, functional requirements, power management and distribution, command and data handling, attitude determination and control, environmental performance, and testing.

The payload accommodation requirements may include details of mass, geometry, thermal interfaces, power, and electromagnetic interference limits along with other important data. The mission architecture adds further requirements such as on-board data processing, communication links, batteries, propulsion, and reliability. These and other requirements should specify the details of every system that is related to the satellite that is being developed. These requirements give the subsystem specialist an idea of what and how a particular subsystem needs to be implemented.

These requirements should be made available to the whole team including the customer and other stakeholders. This is necessary so that during common reviews, such as a *Preliminary Design Review* (PDR) or a *Critical Design Review* (CDR), the team can take corrective actions, if needed, decide on elements which need to be included, or

decide on the modification of existing elements. These reviews also give an idea of the progress of the project and aid in amending future timelines accordingly.

3.3. Cradle Modules

Cradle modules are various interfaces that are used for communicating with the Cradle Server, and each module has its own features. For example, modules such as the Project Data Module or the Workbench provide an interface for managing the whole project with a user management feature and a requirements management feature. The Requirements Management module can capture the requirements from Word or Excel. This Section gives a brief overview of all the modules that are available in Cradle, and Figure 11 shows various modules that are available.

a. **PDM** (Project Data Module) provides the main project framework which provides user management, an extensible project schema, alerts, and viewing requirements.

b. **REQ** (Requirements Management) is a tool to capture requirements and manage them from multi-version source documents, with support for Microsoft Word, Excel and PDF.

c. **MET** (Metrics) “provides a tool to gather and analyze project statistics from live project data” [14].

d. **SYS** (Systems Modeling) provides an analysis and design modeling environment.

e. **PERF** (Performance Modeling) “provides pre-simulation predictive performance assessment, budget allotment and data [grouping]” [14].

Figure 11: Cradle modules [14]

f. **SWE** (Software Engineering) is a tool for code generation and the reverse engineering process.

g. **DOC** (Document Generator) is a tool for document generation.

h. **WEBP** (Web Publishing) is for publishing project data for sharing details among users and other stakeholders.

i. **WEBA** (Web Access) provides restricted access to project data through web browsers and the Cradle Web Server.

j. **WRK** (WorkBench) allows customizable access to project data to create specialized environments for stakeholders.

3.4. Cradle Components

Cradle supports the full development lifecycle through the use of different interfaces. Each of these components may support many Cradle modules. These components are discussed in this section.

3.4.1. Toolset

Toolset is a UNIX based interface which comprises most modules provided by Cradle and is the backbone of Cradle [14]. Most features of Cradle are available with the Toolset and it is an example for Project Data Module or **PDM**. It is used for project administration, requirements management, systems modeling, systems engineering, etc.

3.4.2. WorkBench

WorkBench is a Windows based interface and supports many of the modules that Toolset supports and presents them in a clear and user friendly interface. This component is designed for team managers and project managers to use as it provides an easy-to-use interface.

3.4.3. WEBA (Web Access)

The WEBA module is a component that is also a Cradle module. The web access component allows distributed teams to work together on the same project at the same time using a web browser. Web publishing to HTML, XML and SVG[7] is provided [13].

[7] SVG or Scalable Vector Graphics is for describing 2D graphics and graphical applications in XML.

3.4.4. Document Publisher

Document Publisher is a component used to generate complex documents which may include tables, matrices, diagrams, images, and nested information, from the data stored in the Cradle Database. It can quickly generate the complete document by outputting data from Cradle to Microsoft Word.

Toolset, WorkBench and Web Access can all perform administration tasks, manage, create, amend, delete and manage relationships between items of data and output that data in a variety of ways.

3.5. Cradle Functionality

Cradle supports a full development lifecycle, can be distributed across a full team, and licenses can be utilized whenever required. Sections 3.5.1 through 3.5.6 discuss various functions Cradle provides to the user.

3.5.1. Requirements Capture and Management

The requirements capture process involves gathering documents received from external or internal sources and producing an initial set of requirements. Each document formally received for a project is termed a *source document*, whose content has to be analyzed. Each statement will be satisfied by, and cross referenced to, one or more

formal requirements. Other forms of data can be captured into Cradle as items called *Frames* which can contain data in the form of text, images, documents, and video [14].

Cradle is fully integrated with Microsoft Word, Microsoft Excel, and Adobe PDF. With the interface shown in Figure 12, it provides a requirements capture facility, which scans customer statements, extracts requirements and assumptions, and creates cross references to the original document. The user can login into a particular project and select all items, sections, and tables that need to be captured and exported.

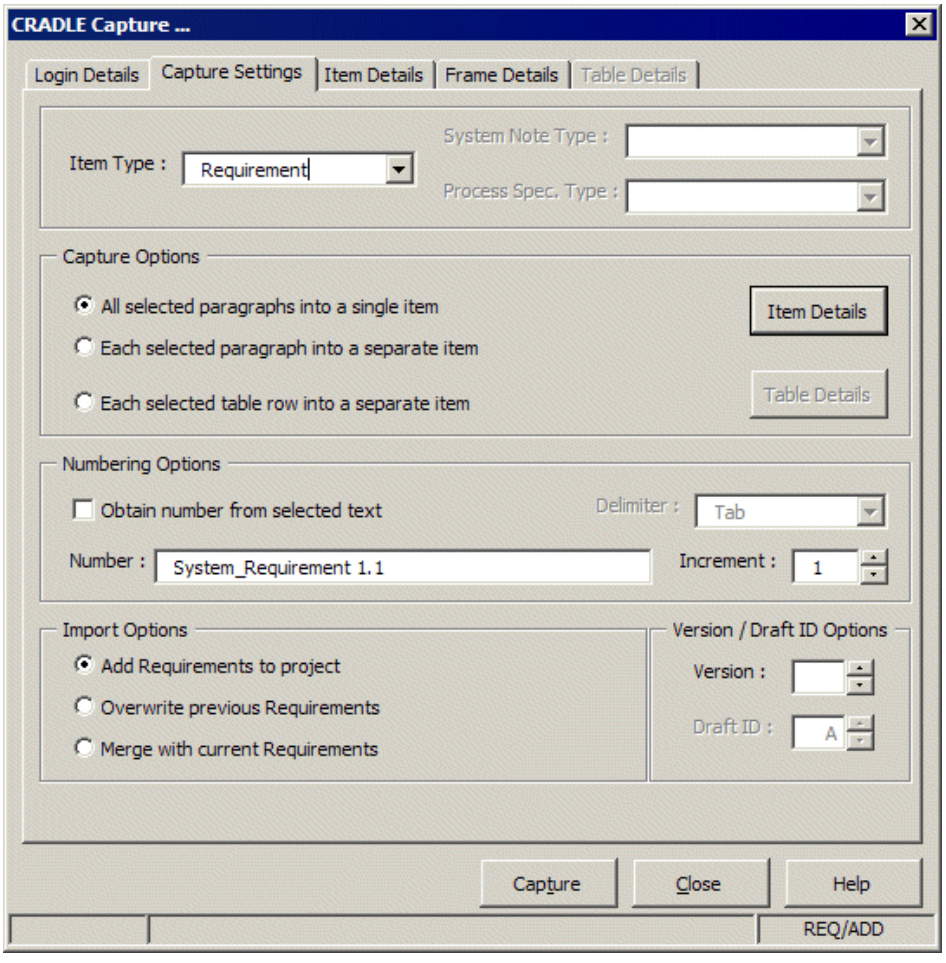


Figure 12: Cradle Capture Interface in Microsoft Word

The requirements capture process essentially creates and maintains a set of cross references between carefully identified statements within source documents and requirements derived from them. These requirements are further engineered to produce the set of formal requirements which form the basis for the development of the system.

In order to attain a consistent level of detail between requirements sets, a sequence of operations called focus and split operations are performed on the original captured requirements, transforming them into improved requirements set for the system. Splitting requirements is an approach often used to split large requirements sets, in which the requirement is subdivided into lower-level, more detailed parts. In a focus operation, several requirements are combined together into a single requirement.

3.5.2. Analysis

Different models are considered for the requested system, which can be developed using a wide range of recognized modeling methodologies. Each diagram has specifications and Data Definition entries, which can be linked to the initial requirements. This allows each aspect of any model to be traced to one or more requirements at any stage of the development process. Examples of modeling methodologies are discussed in Section 3.6.

3.5.3. Systems Design

The model is developed based on the requirements, and the lead teams track the process. Any changes that are made which may impact another part of the system will automatically raise an alert, so that other stakeholders will be notified of that change.

3.5.4. Testing

Testing can be done by linking the initial requirements to specific functions, to specific architecture, to specific tests, and to test results. This records, in a definable and traceable manner, how every requirement is satisfied.

3.5.5. Implementation

Requirements can be tracked in Cradle from the initial capture stage, and all models and proposed solutions can be regularly checked against them. This insures that the implementation will work well, since changes made to the requirements can be managed, and any impact upon the system can be viewed by the alert system.

3.5.6. Formal Delivery

With the help of Document Publisher, the final documentation for the system can be produced, showing how every requirement agreed to in the contract has been satisfied, implemented and tested.

3.6. Model-Based Systems Engineering

Model-based systems engineering is a multi-faceted discipline that utilizes diagrams as a means of interpreting and communicating functional and behavioral aspects of models. Many diagram types, such as an Activity diagram, a Behavior Diagram, a Class Diagram, a Data Flow diagram, a Process Flow diagram, a State Chart diagram, and a Use Case diagram, can be used for both analysis and implementation in Cradle. Some of these are discussed in this section [14].

3.6.1. Class Diagram

A Class Diagram is the basis of Object Oriented (OO) analysis and design. A Class Diagram consists of the classes of the system, their interrelationships, and the operations and attributes of the classes (defined by Process Specifications, PSpec). The PSpec for a class is mandatory, because Cradle stores the set of class attributes and operations not within the Class Diagrams, but within frames of the PSpecs. Each instance of a class on a Class Diagram may have a different symbolic representation. A class is said to be defined in the package that contains it, but may be declared within any other package that the designer requires.

Classes exhibit relationships with other classes. These relationships range from a simple association, through a part-of-aggregation or composition relationships, to inheritance relationships. These relations are associated with a connection symbol, which can be 0, 1, an integer or * (many). Navigation can be added to the relationships by

symbols that include arrowheads. The navigation for a relationship indicates the direction in which it can be queried. By default, relationships are bidirectional. Figure 13 shows a sample class diagram for the Users class.

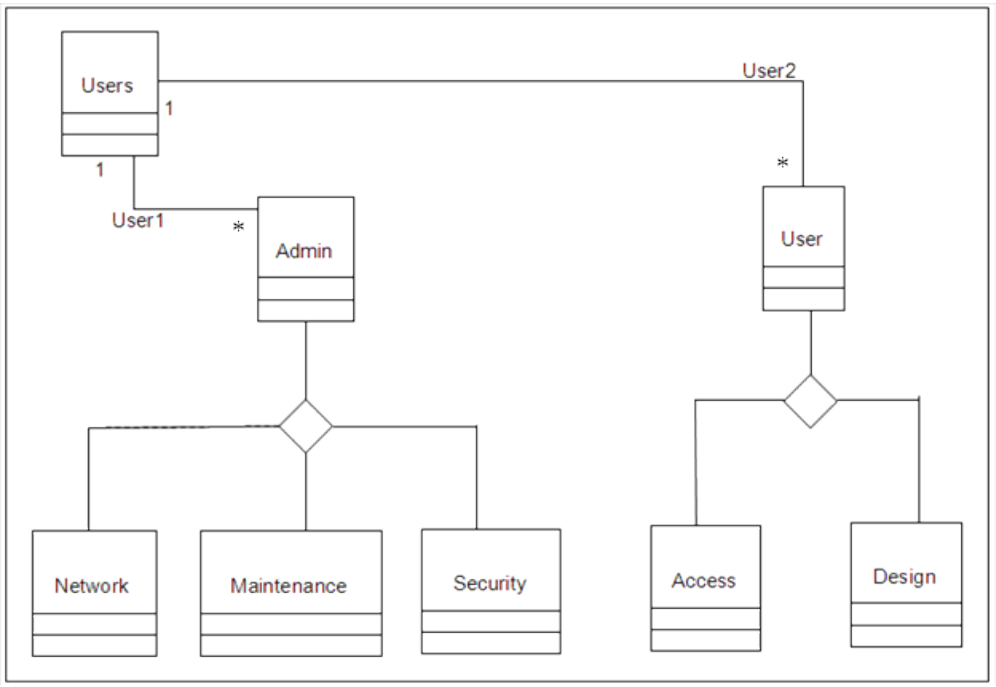


Figure 13: Class Diagram of the Users Class

3.6.2. Activity Diagram

In an Object Oriented (OO) Unified Modeling Language (UML) model, the static representation of the system is a set of Class Diagrams. Each class may have an associated Activity Diagram to show the internal behavior and/or algorithm for the class. The Class Activity Diagram shows one or more parallel sequences of possible behaviors distributed along a timeline, which in turn may have branches and optional synchronization.

An Activity Diagram represents a set of component activities that are required to describe the behavior of a class. The Activity Diagram shows these component activities along a vertical timeline, which may be split into branches and associated synchronization points to show concurrency as in Figure 14. Activity diagrams contain a time-sequenced representation of the functionality of a class, and are related to the class"s associated State Chart diagram.

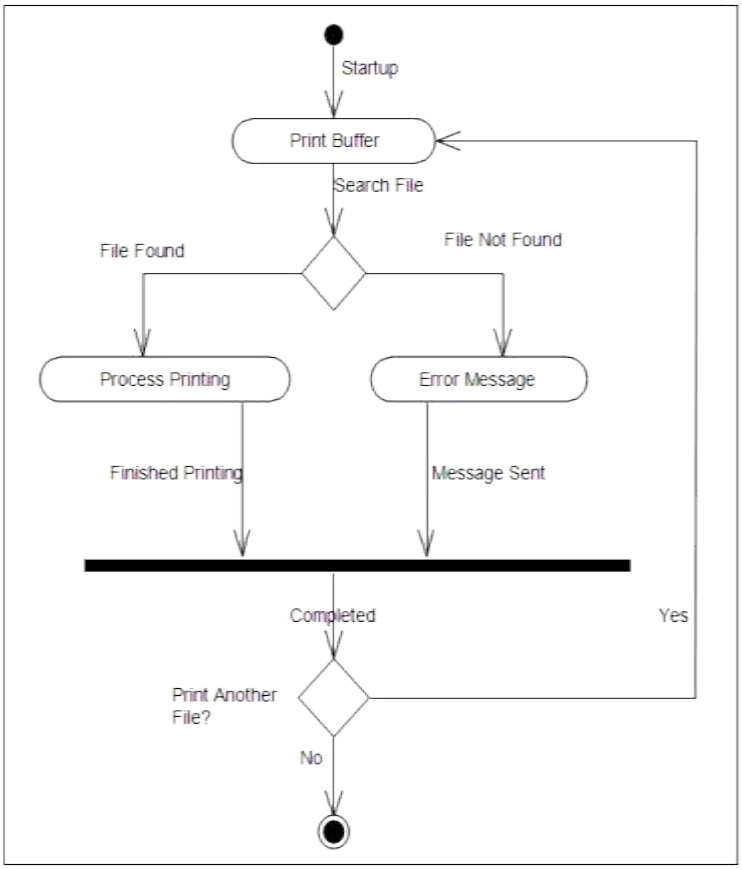


Figure 14: Activity Diagram for a Print Class

3.6.3. State Chart Diagram

Classes that exhibit different external behavior in different circumstances can be augmented by a State Chart Diagram. A State Chart Diagram depicts a finite-state-machine that describes how the class responds to different external stimuli. These stimuli are messages received by instances of the class, in the form of calls to the class's operations. An example for a State Chart diagram is shown in Figure 15.

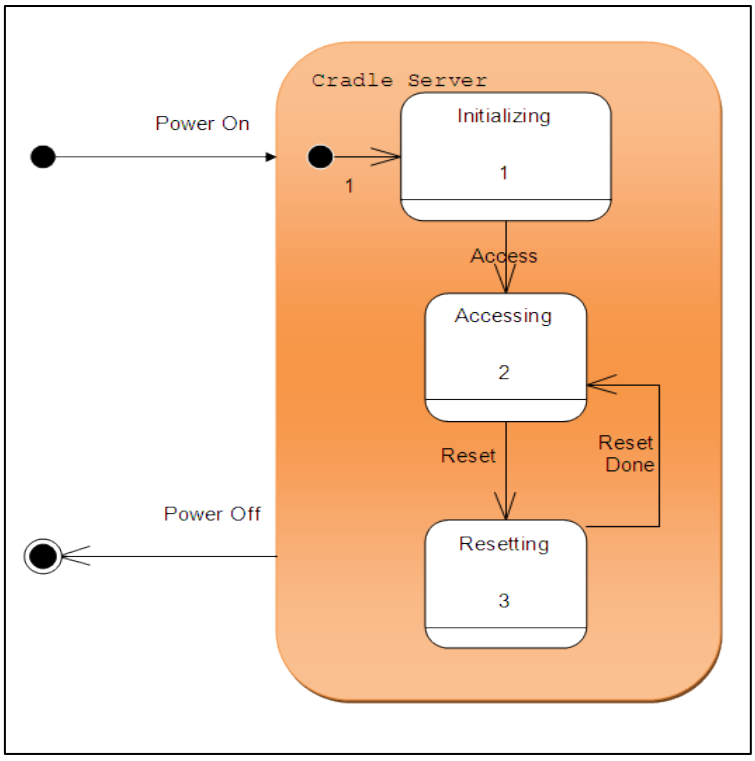


Figure 15: State Chart Diagram for a Cradle Server

A State Chart Diagram has one initial state and one or more final states. A transition may be to a superstate, in which case the flow of control begins at the initial state symbol nested within the superstate.

A superstate may contain more than one set of nested states and transitions. Each set can be separate from all other sets having their own initial state and final state symbols. These sets are considered to be running concurrently. A transition from a superstate is considered to come from any or all of the states within it. A superstate may have superstates nested within it, of which each may contain states and transitions, and other superstates [14].

3.6.4. Use Case Diagram

Use Case Diagrams are used to describe the interaction between a system and its environment and are used extensively in object oriented programming. Each use case shows how the system interacts with the users and other systems to achieve a particular goal. An object oriented model is begun by examining the interaction between the system under study and its environment.

A Use Case diagram represents the environment as a set of external actors who participate in classes of interaction with the system. Each class of interactions is called a use case. Each use case contains one or more possible sequences or flows of events between the system and the environment. These flows can be a normal sequence or those related to alternate cases or error-handling situations. A scenario is a particular route through the normal, alternate, or error use case flows, and is normally chosen to emphasize a particular alternate sequence or a particular exceptional case. Common behavior among use cases may be shown in a shareable use case marked with a border. A sample Use Case scenario for the IDE is shown in Figure 16.

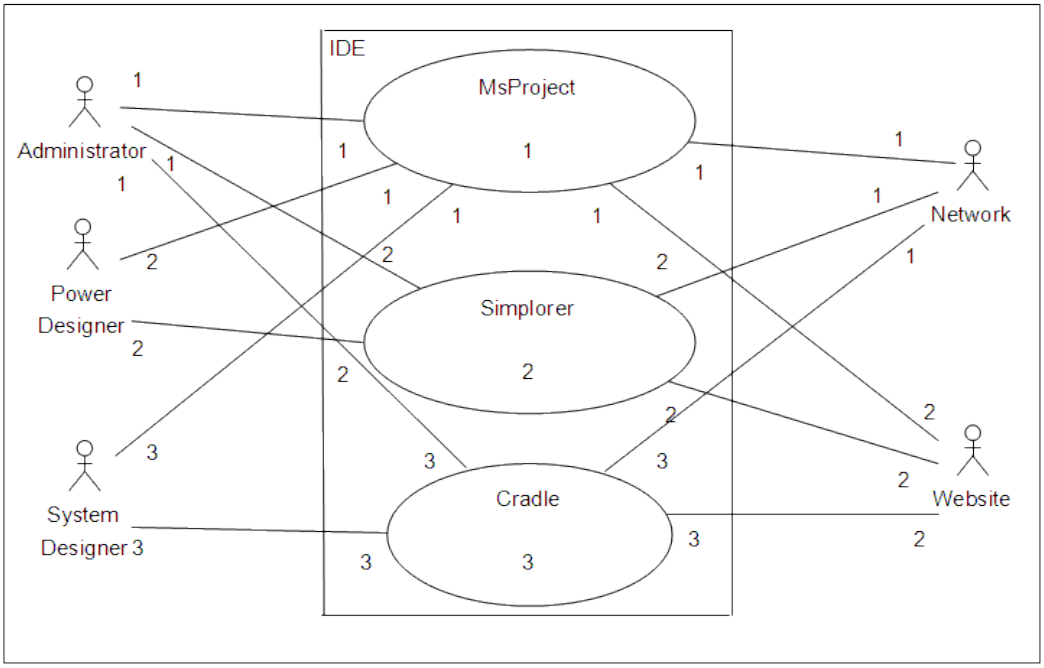


Figure 16: Use Case Diagram for IDE

Cradle allows hierarchies of Use Case diagrams, in which a use case can be expanded into a lower-level diagram, either to show more detail or to show alternate scenarios within the use case.

CHAPTER IV

DESIGN SIMULATIONS

A *simulation* may be defined as a replica or a model of a real system, which, when passes certain simulated tests, demonstrates that the real product can be built. Simulations aid the designer in understanding basic research principles and analytical techniques, and aid researchers in exploring new analytical techniques applied to a problem. These simulations can serve as a tool for teachers, evaluators and methodologists, to address complex analysis, theories and assumptions. The analyst designs the simulation based on a known model, and analyzes its performance when various changes have been introduced. This is possible because the simulations facilitate direct manipulation of the model to see how the results change and the analysis is affected [15].

Simulations are easier to analyze than analyzing real data, because the analyst never perfectly knows the real-world process that caused the particular measured values to occur. In a simulation, the analyst can control factors making up the data and manipulate them to see their affect on the analysis. Simulations can also be more advantageous than abstract theory for research topics because they enable the analyst to interact directly with the model, change assumptions, and develop a good system.

Section 4.1 of this chapter presents an overview of the advantages of using simulations. Section 4.2 gives an introduction to Ansoft Simplorer software, while Section 4.3 discusses some of the features provided by Simplorer software. Section 4.4 discusses an example of a PID speed control for a DC motor with a three phase rectifier, and an example of an analog-to-digital converter design.

4.1 Advantages of Simulations

The main advantage of simulations is that they provide practical feedback for real systems. This allows the user to explore alternative designs for a system without actually building the system, and hence eliminates the alternatives that do not improve performance or service quality. Studying a range of alternatives also helps in identifying various properties of the system.

Another benefit of simulations is that they permit users to study a system at different levels of abstraction. Because of this, the user can understand the details and interaction between the high level components of the system. This permits the user to study the overall system without becoming overwhelmed by the complexity of the system that accrues as the lower-level details are added. The entire system can then be built upon the "top-down" technique. Working at a higher level of abstraction also facilitates *rapid prototyping*, in which preliminary systems are designed quickly for the purpose of studying the feasibility and practicality of the high-level design.

Simulation modeling tools allow more agility and rapid results as compared to load testing on a test bed. It permits testing and analysis to proceed without constructing the actual system. The model can be modified in less time, and new results can be obtained quickly [16].

Simulations can also be used as an effective means for teaching or demonstrating concepts to students. Simulations which can dynamically show the behavior and relationship of all the system components provide the student with a meaningful understanding of the system's nature.

Simulation modeling makes possible the exploration of many options quickly, leading to better understanding and decision making. In summary, the benefits of simulation modeling are:

a. Easy exploration of a wide range of alternative approaches.
b. A test bed is not required to run the load tests.
c. Flexibility to apply new alternatives and also results can be obtained more rapidly.
d. Cost effectiveness, since there are no costs to buy parts to build a system.

Simulations also have the advantage of allowing large number of tests of a problem with minimal cost. Also the models and simulations results are easily accessible over a network and are portable. Software available today allows the user to simulate various systems in various domains. Software to simulate aerospace, electromechanical, and physical systems, 3D models, and many other types of systems are available. These

software provide features such as exporting and recording results. In this IDE Ansoft Simplorer v 7.0 is used for electrical circuit simulations and satellite design.

4.2 Ansoft Simplorer

Ansoft is a developer of electronic design automation (EDA) software which designs state-of-the-art products, such as electromechanical components and systems, power electronics, wireless products, ICs and printed circuit boards (PCBs). Simplorer® is a simulation package from Ansoft for electrical circuit simulations. It is used for the simulation of large-scale, multi-domain systems commonly found in the automotive, aerospace/defense and industrial automation industries. The wide range of modeling techniques, statistical analysis capability, and adherence to IEEE standards, facilitate the reduction of modeling time and increase engineering efficiency when designing electrical, mechanical, power-electronic, and electromechanical systems using Simplorer. The software features powerful model-generation tools, model libraries, co-simulation capability, and VHDL-AMS modeling techniques.

"Simplorer's unique simulator coupling and co-simulation technologies utilize a data exchange backbone, which auto-interactively selects optimum simulators with numerical algorithms specifically tuned for the multi-domain nature of electromechanical systems" [17]. These technologies allow users to create models in various domains, at different levels of abstraction, and simulate complex electromechanical systems quickly and easily.

4.3 Features of Simplorer

Simplorer supports linear, non-linear, and continuous signal systems with various analysis types such as DC, AC and transient analysis. It can also interact with other Ansoft software such as Maxwell, Q3D Extractor, and RMxprt, along with third party software such as MATLAB, Simulink, MathCAD, and C/C++.

Simplorer also features statistical analysis and optimization tools such as Monte Carlo, 3D graphic, and Genetic Algorithm. It also supports scripting in Visual Basic, Java and Tcl/Tk. It has a fast and numerically stable circuit simulator, and a block-diagram system simulator for signal analysis and control design. Simplorer also incorporates VHDL-AMS, the IEEE industry-standard modeling language for analog, digital, mixed-signal, and multi-domain systems [17].

With a wide range of modeling techniques, statistical analysis capability and adherence to IEEE standards, Simplorer significantly reduces modeling time, the number of physical prototyping iterations and increases engineering efficiency when designing automotive, aerospace, electrical, power electronics, and electromechanical systems. Sections 4.3.1 through Section 4.3.5 explain some of the features provided by Simplorer.

4.3.1 Creating New Library Elements

Simplorer allows user to add new elements to the existing library and save them for later use. To create new libraries in Simplorer the following steps must be followed.

a. Choose **File>New Library** in the Model Agent, or **New Library** on the shortcut menu of a tab in the Model Agent, Schematic, or Symbol Editor.
b. Define the library name and location and click **Save**.
c. Click **New** in the **Resource Tables** area and select a language for model text strings and click **OK**. A new set of entries appears in the list.
d. Repeat step c to add more than one language.
e. Click **New** in the **Simulation Tables** area and select **SML20** for the simulation description used in version 7.0 and click **OK**. A new set of entries appears in the list. Repeat this to add another modeling language.
f. Click **OK** to create the new model library.

The model library will be inserted into the model tree without a model. Models can be inserted via **Element>New** or by dragging and dropping from other libraries. The name for the model library and language resources can be modified later. An example illustrating how to create an analog to digital converter (ADC) as a new library element is given in Section 4.4.3.

4.3.2 Equation block

The equation function provides for the use of mathematical expressions in all Simplorer modules. The formula interpreter manages general mathematical and logical expressions, which consist of a number of operands and operators. Variables are allowed as operands (for example voltages or currents from the circuit components). Also variables from other expressions can also be used in an expression. The name of a variable can be defined by the user, but some conventions must be followed. An equation block cannot be applied to the signals from conservative nodes such as voltage and current because of the non-conservative nature of the parameters or the variables used in the equation block. As a result the equation block cannot be used for some domains [17].

4.3.3 Creating macros from .vhd file

Macros can be created using the VHDL language. The following steps are to be followed in order to create macros from a .vhd file [17]

a. Create a **.vhd** file with a macro definition using VHDL-AMS files from models on a Schematic sheet using **Simulation>Description** and using the .vhd filter.
b. Open the Model Agent in the SSC Commander and select a library for the new model.
c. Choose **Elements>Insert>Macro(s)** from VHDL-AMS File in the Model Agent. This will be available only if the VHDL-AMS resource is already installed.

d. Select the VHDL-AMS file with macro description. The dialog displays all available macro definitions in the VHDL-AMS file.

e. Define the title and language for the macro identified by the function, and click **Insert** and repeat the steps if more than one macro is contained in the source code.

f. The model completed and integrated in the selected library can be changed at any time until it is locked.

4.3.4 VHDL-AMS

The VHDL-AMS Basic Library has been developed to support the user with the basic functionality, circuit components and blocks. The models have been developed according to the IEEE 1076.1 (VHDL Analog and Mixed Signal Extensions Standard) [17].

The functionality of all VHDL-AMS models is a subset of that available with the equivalent SML models. Also, the VHDL-AMS and VHDL models do not use wizards to parameterize the models. Advantages of VHDL-AMS are the model exchangeability between the simulation tools, multi-level modeling, multi-domain modeling and mixed-signal modeling which supports analog and digital and multiple modeling styles such as behavioral and dataflow.

VHDL-AMS models may be used in parallel with SIMPLORER models. All VHDL-AMS models are simulated by the analog simulator and the digital solver. It is possible to view the inputs and outputs of the VHDL-AMS model using the appropriate

analog or digital display element. Also the internal values used within the architecture of a model can be viewed in the display graphs and shared as variables between models. If the VHDL-AMS design needs to be exported to other simulators, then the internal values of the model should not be used outside the model.

4.3.5 Symbol Editor

Every component in a model library has a symbol which is displayed when the component is placed on the Schematic sheet. Component symbols are language dependent, and each language can provide its specific symbol. With the Symbol Editor, modification of existing component symbols is possible.

Along with the graphic properties, optional features can be defined, such as switch areas and conditions for symbol changes during a simulation process. The Symbol editor can be used for creating/modifying the parts of an element symbol, modifying symbols, editing pins, creating animated symbols, creating interactive symbols, and modifying representations and displays.

Simplorer provides many other programs depending on the requirement. Programs that are available with Simplorer are Schematic, Editor, Day-post processor, Model Agent, Symbol Editor, Experiment Tool, Analytical FA, C Model Wizard, Report Manager, and an Excel plug-in [17]. Simplorer Schematic is used to draw a schematic of a model. This is discussed with an example of a PID speed control for a DC motor with a three phase rectifier in Section 4.4.1 and Section 4.4.2. Another example of how to add a new element is given in Section 4.4.3.

4.4 Simplorer Examples

A three phase full wave converter operating with a DC motor is given as an example to illustrate how to use a Schematic sheet. The speed control for this DC motor is done with a PID controller and is discussed in Section 4.4.2. To demonstrate how to add a new element to the library of elements already provided by Simplorer, another example of an Analog-to-Digital converter is given in Section 4.4.3.

4.4.1. Three Phase Full Converter with DC Motor

Rectification is the process of converting an alternating current or voltage into a direct current or voltage. This conversion is achieved using a variety of circuits based on switching devices such as diodes, thyristors, power transistors, etc. These rectifiers can be classified into three categories: uncontrolled, full-controlled and half-controlled.

The control of the rectification can be done by Phase Angle Control in which switching devices such as thyristors can be controlled to switch on and off periodically with a certain phase, by setting a firing angle. The firing angle determines the continuous or discontinuous operation of the rectifier.

Three phase rectifiers are commonly used in large power applications, using step-up and step-down transformers. As an example, a three phase full converter with a DC motor developed in this IDE is shown in Figure 17. The load, a DC motor in this case, is fed via a three phase half-wave connection, and the return path via the other half of the supply (with no need for a neutral). The upper group of the diodes is called the positive

half group as they operate during the positive half of the supply, and the other set is called the negative half group [18].

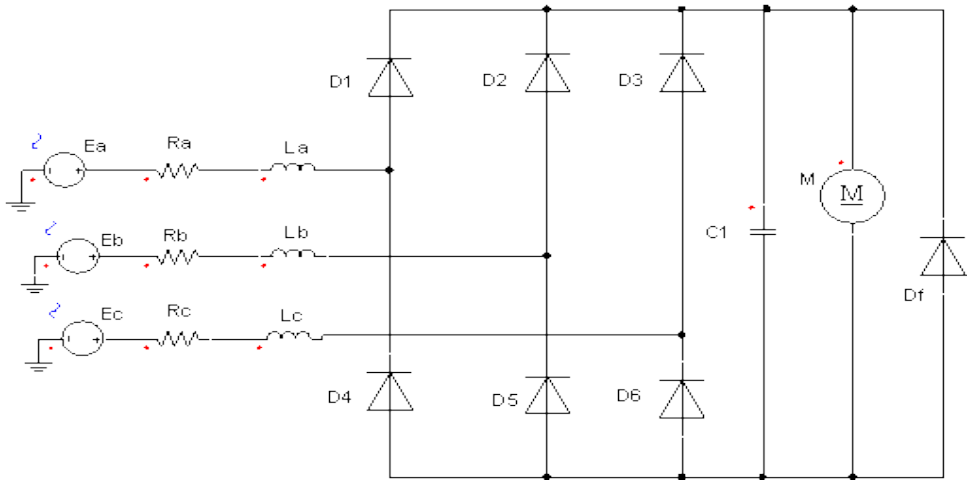


Figure 17: Three Phase Full Converter with DC Motor

The diode D_f is called a *freewheeling diode*, which transfers load current away from the rectifier whenever the load voltage goes into a reverse state. This diode also prevents a reversal of the load voltage (except for small voltage drop across the diode). The capacitor C_1 is used for power factor (PF) correction at the load terminals. The values of the various parameters used are as given below.

a. Voltage Sources E_a, E_b, E_c = 240 V, 50 Hz with each 120° phase difference.

b. Rectifier Diodes D_1, D_2, D_3, D_4, D_5, D_6, freewheeling diode D_f and switch BJT_1 values are:

   i. Forward Voltage = 0.8 V

   ii. Reverse Resistance = 100 KΩ

   iii. Bulk Resistance = 1 mΩ

c. DC Motor Armature (M) values are

i. Resistance= 1.2 ohm

ii. Inductance= 6.5 mH

iii. Rotor Flux=1 Wb

iv. Moment of Inertia=0.001 Kg-m

v. Initial Arm Current=0 Amp

vi. Initial Rotor Speed= 0 rpm

vii. Initial Rotor Position =0 deg

d. Supply resistances R_a, R_b, R_c = 1 Ohm

e. Supply inductance L_a, L_b, L_c = 1 mH

f. Capacitor C_1 = 100 pF

The motor voltage and current waveforms are as shown in Figure 18 along with source voltages.

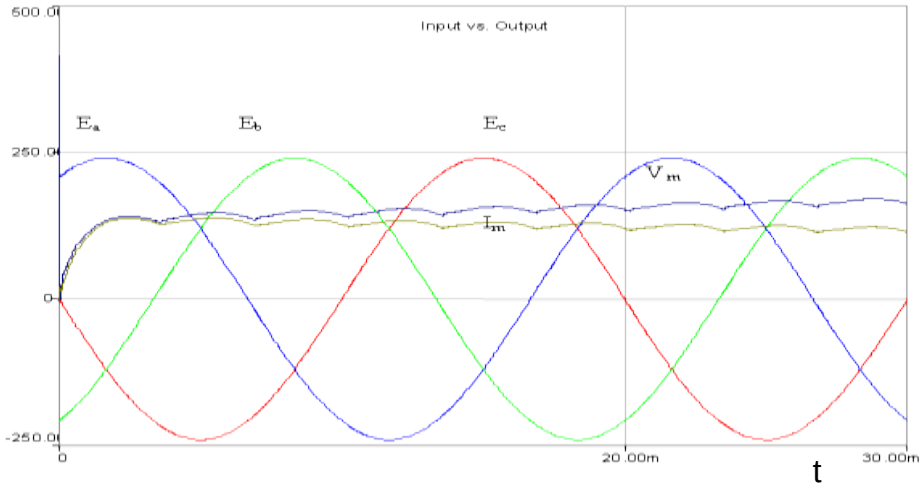


Figure 18: Motor Current and Voltage with Source Voltages

4.4.2. Proportional-Integral-Differential (PID) Controller

PID feedback controllers are widely used controllers. To control the rotational speed of the system in this example a PID controller is used. The three parameters available for the tuning of the PID are proportional gain K_p, integral gain K_i and derivative gain K_d. These parameters are chosen on a trial and error basis so as to achieve the desired response of the system.

$$G_C(s) = \mathrm{K_p} + \frac{\mathrm{K_i}}{s} + K_d s \tag{1}$$

The error signal, which is the difference between a set value of the speed and the measured, is sent to the PID controller. The controller is used to reduce the error to zero. The controller computes both the derivative and the integral of this error signal. The controller output will be equal to the sum of proportional gain (K_p) times the error, integral gain (K_i) times the integral of the error, and the derivative gain (K_d) times the derivative of the error as shown in the above equation (1). The output of the controller is then fed back to the system directly or through a switch.

The values of K_p, K_i and K_d are adjusted manually on a trial-and-error basis to obtain an error of zero. Figure 19 shows the circuit diagram for the speed control of the DC motor discussed in Section 4.4.1.

The values used for the PID controller parameters in order to obtain good performance are:

a. Proportional gain $K_p = 60$,

b. Integral Gain $K_i = 1$, and

c. Derivative gain $K_d = 0.2$

Good performance was determined by considering the overshoot, settling time, amplitude and linearity of the response.

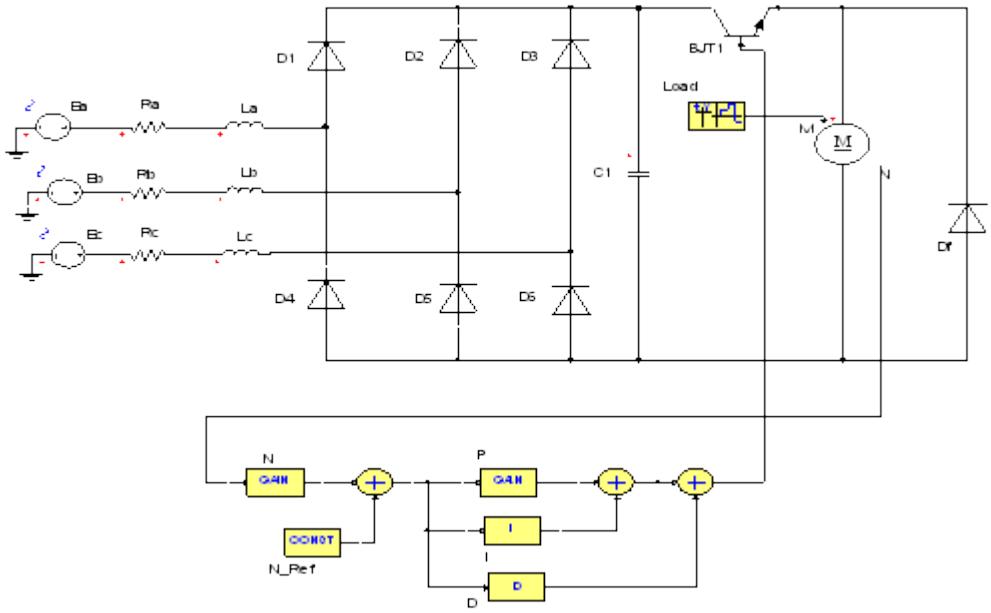


Figure 19: DC Motor Speed Control Using a PID Controller

The applied load values are:

TABLE II: DATA PAIRS OF EXTERNAL LOAD (N)

No	x-axis:	y-axis:
1	0	0
2	0.075	50
3	0.1	50

i. Period = 0.1s

ii. Phase = 0 deg

iii. Periodic = YES

It can be seen from Figure 20, the speed and voltage of the DC motor are suddenly dropped whenever a load is applied at regular intervals. The current of the DC motor increases so as to meet the load whenever is applied.

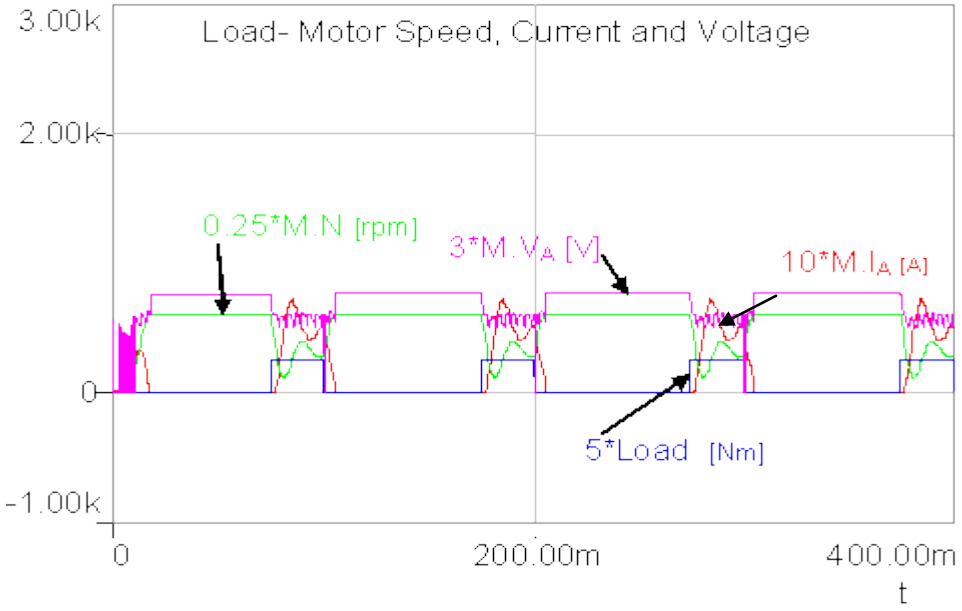


Figure 20: Motor Speed, Current and Voltage waveforms with Load

4.4.3. Analog-to-digital Converter

The Analog-to-Digital (A/D) Converter module in a PIC microcontroller has five inputs for the 28-pin microcontrollers and eight for the 40-pin microcontrollers. In general the analog input charges a sample and hold capacitor, whose output is the input into the ADC converter. The converter then generates a digital result of this analog level using successive approximation. The A/D conversion of the analog input signal magnitude, at a particular instant of time, results in a corresponding 10-bit digital number. The A/D module has high and low voltage reference input. For the A/D

converter to meet its specified accuracy, the charge holding capacitor must be allowed to fully charge to the input channel voltage level [19].

Mathematically the digital equivalent of an analog input is calculated by the repeated division of the analog input value with „2" or 10 (in binary), until a remainder of zero is obtained. Then the digital (binary) equivalent of the analog input is obtained by the combination of all the remainders with the last remainder as the most significant bit.

Using the symbol editor, the symbol for the PIC is drawn and is shown in Figure 21. After the element has been designed and locked for deployment, the user cannot change the symbol or the behavior of the element. Therefore user-defined elements also represent the same accessibility of the libraries, restricting the ability of the user to change the behavior of the user-defined libraries.

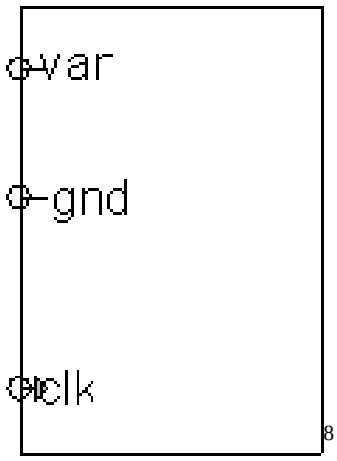


Figure 21: PIC symbol after editing using Symbol Editor

Using the properties of the PIC_ADC block, the user can specify the pins to use. Also the type of each pin can be specified as a bit, real, or electrical which indicates the

[8] All output pins that are available for the PIC_ADC block are not shown in the figure. They can be viewed by setting specific pins to be visible in the properties page of the element.

type of signal that the pin can handle. The code for the PIC_ADC block is written in VHDL and is integrated into the Simplorer Schematic library under **Basics>PIC** menu, as discussed in Section 4.3.1. The VHDL code for the analog-to-digital conversion process is given in Appendix B.

A simple circuit is drawn in the Schematic sheet using the PIC_ADC block from the **Basics** library under PIC models as shown in Figure 22.

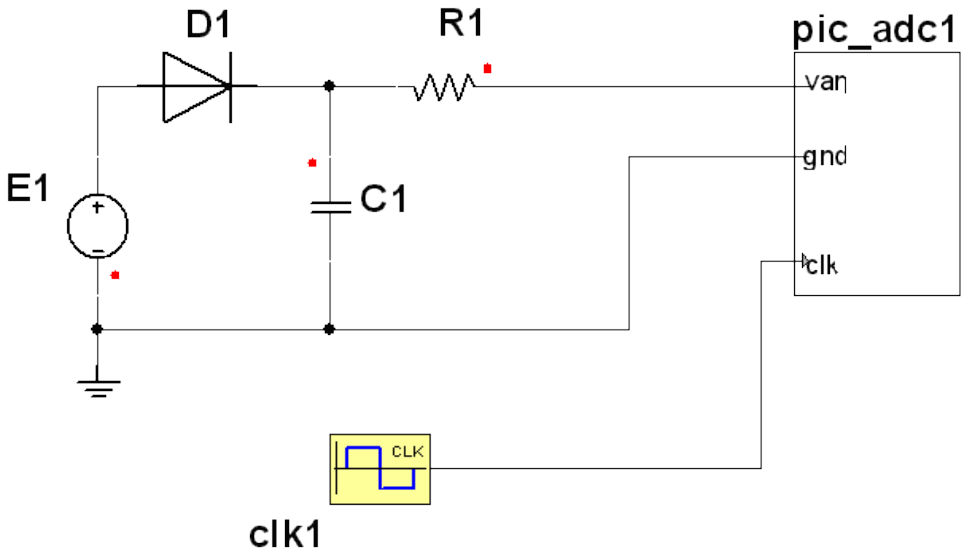


Figure 22: Simple circuit diagram using the PIC_ADC Block

The parameters that are used in the circuit are

a. E_1: the analog input voltage that can be varied from 0 to the MAX value. The PIC_ADC can accept any type of signal for E_1, such as a direct EMF value, or a sine, pulse, or triangular signal.

b. „RES": the value of the bit-resolution, i.e., the number of bits in the output. This value decides the data size that can be accepted by the PIC_ADC block.

c. Clock input: the value can be varied from 1 KHz (1ms)-50 KHz (20µs)

The voltage at the pin V_{an} referenced to ground is measured and the ADC calculates the equivalent digital value.

Outputs viewed in 2D Digital Graph[9] (selected from displays of Schematic library) are as shown in Figure 23 through Figure 26 with varying values of MAX, Input and Clock.

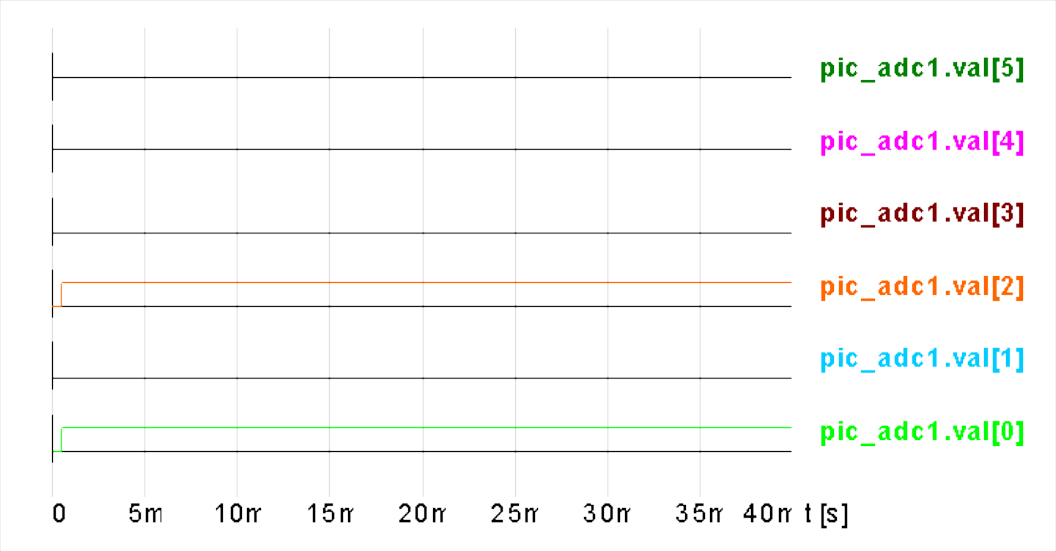


Figure 23: With MAX=8 RES=8 and Input=5 V (EMF value), Clock=1 ms

[9] The 2D Digital graph can display the output in digital scale for each parameter selected.

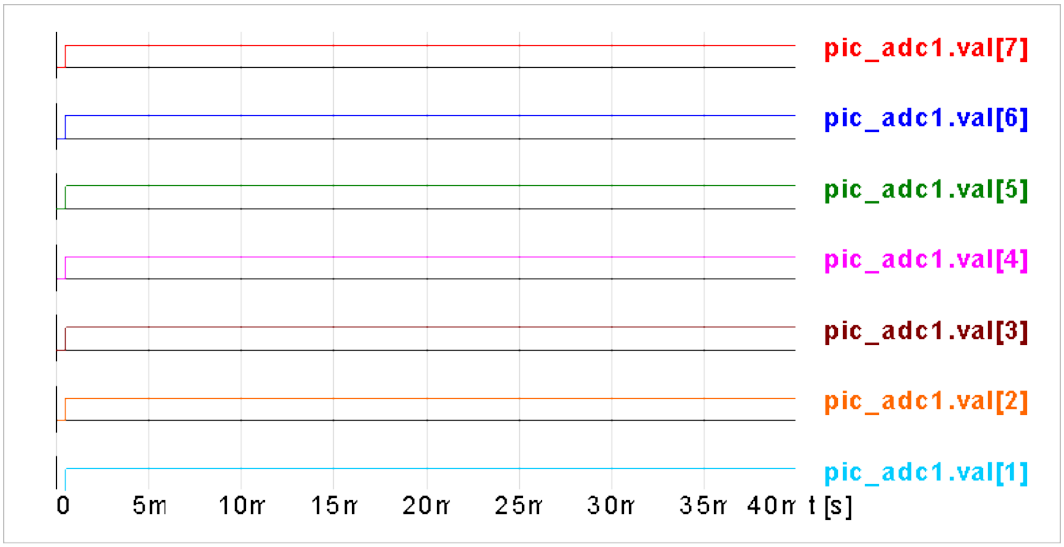


Figure 24: With MAX=255 RES=8 and Input=255 V (EMF value), Clock=1 ms

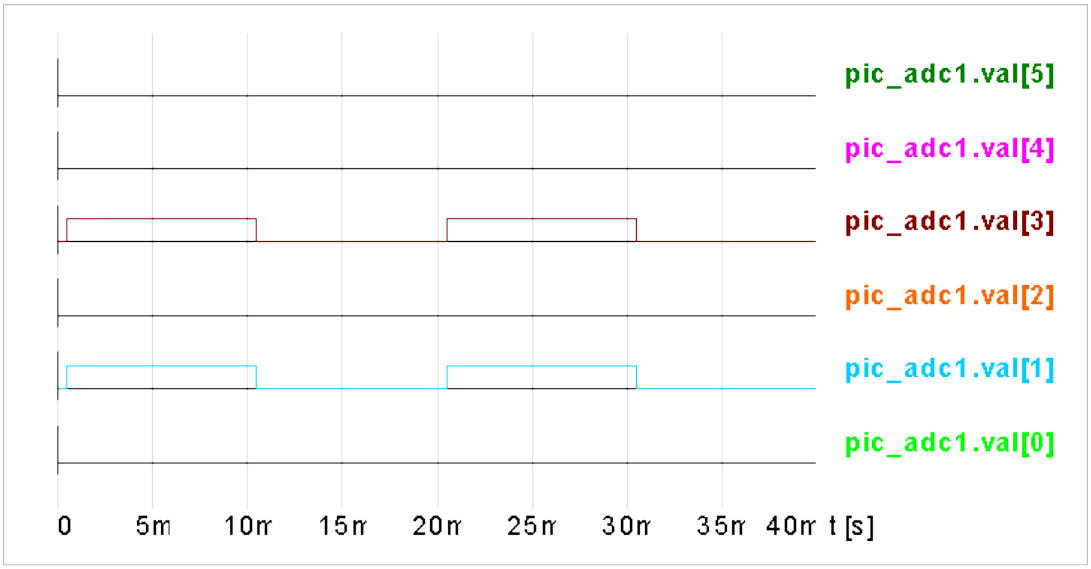


Figure 25: With MAX=255 RES=8 and Input=10 V (Pulse input), Clock=1 ms

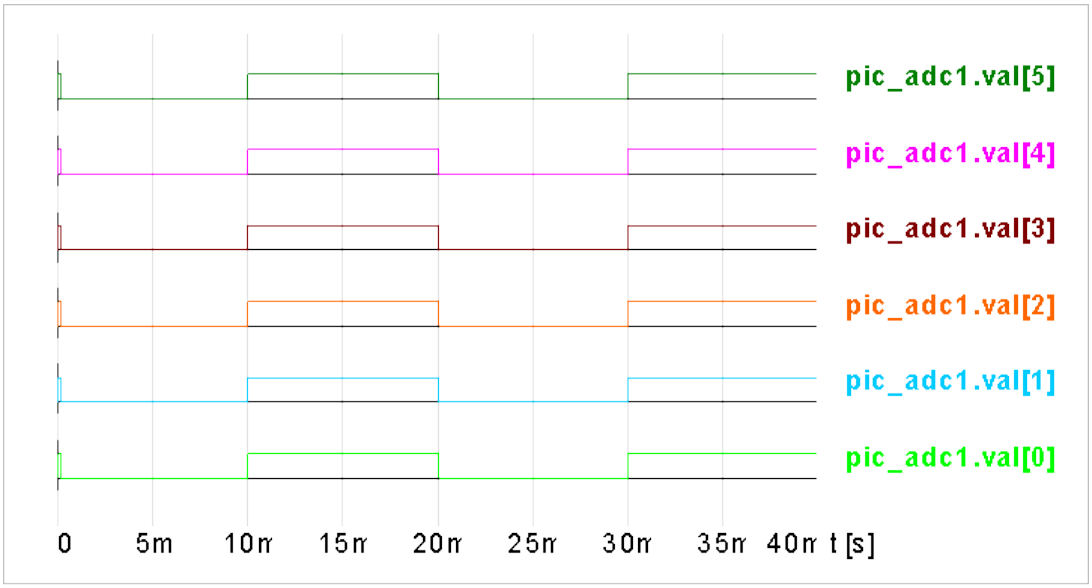


Figure 26: With MAX=255 RES=8 and Input=255 V (Pulse input), Clock=20 us

Thus, Ansoft Simplorer is used to simulate electrical circuits in this IDE. For mechanical, orbital, thermal, and stress simulations, other software such as Ansoft Maxwell and Satellite Tool Kit (STK) are used. These have not yet been integrated into this IDE. Software packages such as Simplorer and Maxwell can even communicate with each other, facilitating the ability of developers to share their simulations with one another.

CHAPTER V

IMPLEMENTATION

An Integrated Design Environment (IDE) for Small Satellites has been implemented in the Visual Basic.Net programming language. The operating system used is Microsoft Windows XP Professional. Microsoft Project has been implemented by using its COM components provided in the library of Visual Basic.Net. A template has been created to assist the user in identifying the major steps involved in designing a satellite. This template can be accessed directly from the IDE for any project. ThreeSL Cradle and Ansoft Simplorer are accessible directly from the IDE. These are coded to open directly, since they need login details to open a particular project. Also, since both Cradle and Simplorer are server-licensed, there have been security issues, keeping their libraries inaccessible. The system used is an Intel Pentium 4 processor running at 3.0 GHz with 512 MB memory.

Section 5.1 of this chapter gives a brief overview of the IDE and contains the screenshots of pages developed to build a satellite. Section 5.2 gives an idea of how project management is performed using Microsoft Project. Section 5.3 discusses how ThreeSL's Cradle software is used for requirements management. And Section 5.4 shows how electrical simulations are done using Ansoft Simplorer.

5.1 The Integrated Design Environment

The IDE is designed in a way that a user can access any particular file at any stage of the satellite design life cycle. It also allows the user to work on more than one phase at a time. Links are provided to sponsored page for specific information or for online help.

The main menu consists of three options: File, Tools and Help. From the File menu, the user can create a new project or open an existing project or file. There is also a facility for printing any document available on the network which belongs to any project. The Tools menu provides an exporting feature through which the user can export a screenshot of a diagram or design to a Microsoft Word document. This feature and the IDE Help are yet to be implemented.

The first page which is accessed when the IDE is opened is shown in Figure 27.

Figure 27: IDE Homepage

When the user clicks on the Start button, the IDE loads a second page which has the links to the six phase process for the satellite appear. Also, from the side menu, the user can visit a particular software website for help and technical support. A screen shot of this page is shown in Figure 28.

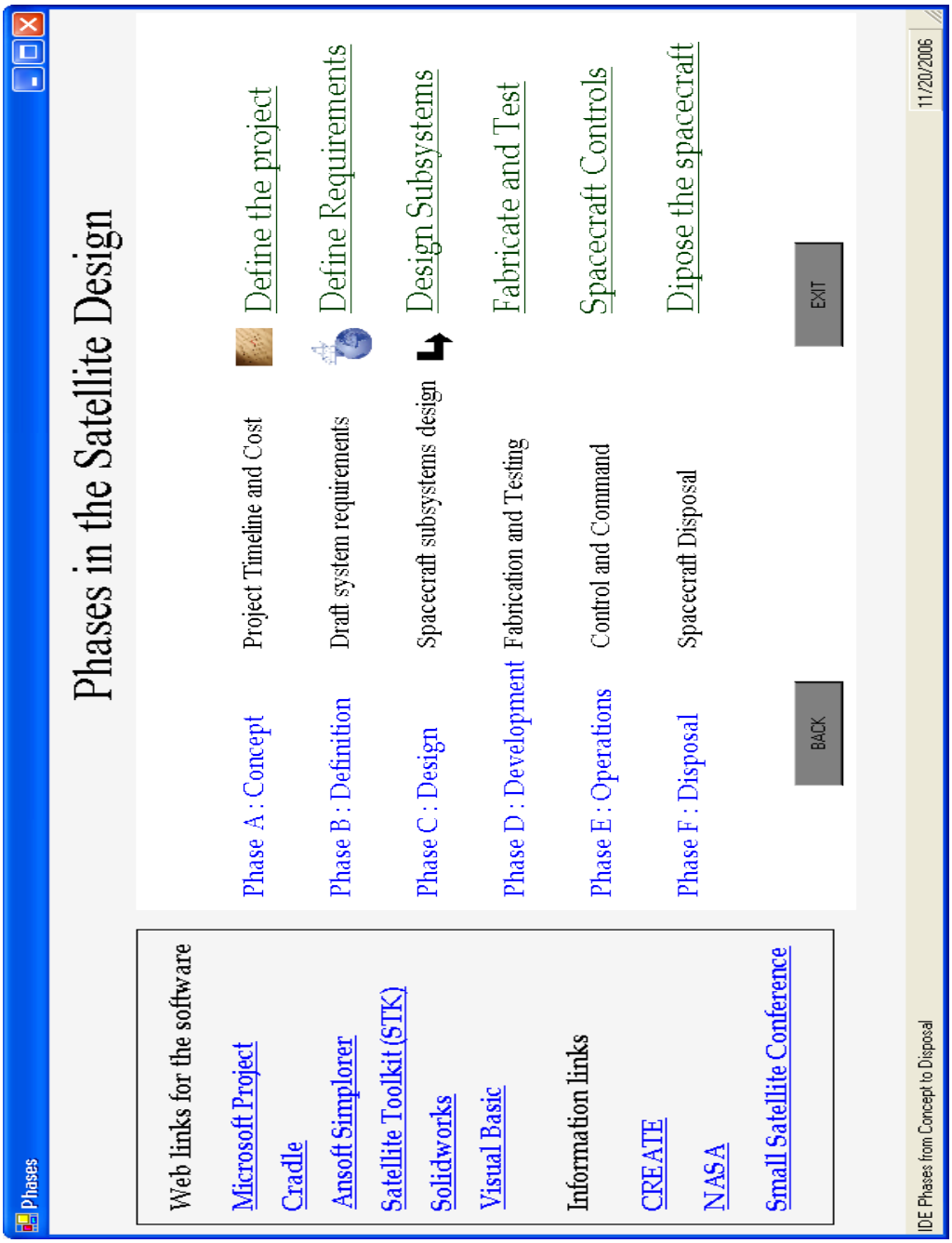


Figure 28: IDE Design Phases Screen

Since the Design phase involves more than one design domain, another window is created which can access various simulation tools such as Simplorer, Maxwell, and the

Satellite Toolkit. So far only the Ansoft Simplorer implementation has been completed. A screenshot for this is shown in Figure 29.

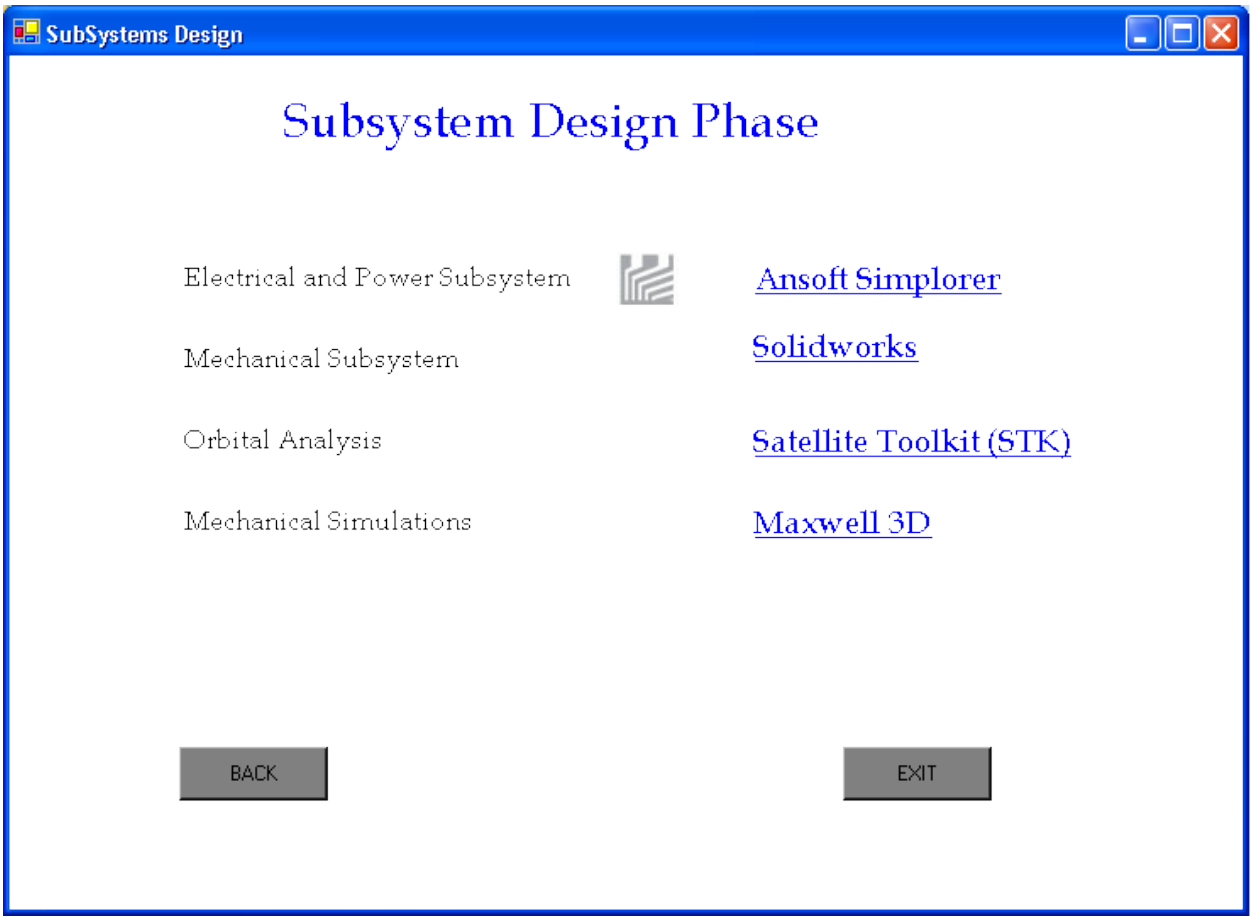


Figure 29: IDE Subsystems Design Phase Screen

5.2 Project Management

For project management, Microsoft Project has been incorporated in this IDE. A template has been created to assist users in identifying the key project elements involved in developing a satellite. Time scheduling and resource management for various tasks are

implemented in this template. All tasks that are involved in building a satellite are listed as Table I in Section 2.3 of Chapter II. Also various graphs for this template are provided in Chapter II. Resources for each task listed in Table I are given in Appendix A as Table III.

5.3 Requirements Management

In this IDE requirements management is achieved using ThreeSL"s Cradle software. Various components and functionalities of Cradle are discussed in Chapter III. Typical requirements for developing this IDE are managed with the help of Cradle and are provided as an example under project code IDE1. Some of the available modeling methodologies are discussed in Section 3.6 along with the figures.

5.4 Design Simulations

For simulating electrical systems for satellite design, in this IDE Ansoft Simplorer v7.0 is used. As an example a three phase rectifier with a DC motor is simulated in Section 4.4.1 of Chapter IV, with Section 4.4.2 discussing its speed control using a PID controller. A periodically switching load is applied to the DC motor. The motor voltage, current, and its speed are plotted against the pulsating load as is shown in Figure 18 and Figure 20.

Another example is an analog-to-digital converter (ADC) module of a PIC microcontroller is discussed in Section 4.4.3 to illustrate how an element is added to the library (discussed in Section 4.3.1). The element is shown in Figure 21 with a simple circuit application in Figure 22. The output results are viewed in a 2D Digital graph and are shown in Figures 23 through 26, with various parameters of the converter.

CHAPTER VI

CONCLUSIONS AND FUTURE WORK

6.1 Conclusions

In this thesis, an Integrated Design Environment (IDE) for the design of Small Satellites has been created. This IDE provides an integrated environment for project management, requirements management and electrical and mechanical simulations. To provide a systematic approach of design and development, this IDE includes a six-step process, namely, Concept, Definition, Design, Development, Operation and Disposal.

The IDE provides an easy to use interface for developing a satellite, and the design page is especially simplified so that a designer can work on any of the subsystems or development phases of the whole project. Also this IDE reduces the total development time by reducing the time expended in exchanging files, since the files can be shared over a network, and the access time, since the designer can open software from a single interface.

Project Management, which is an important aspect of every project, has been implemented in this IDE using Microsoft Project, and it has been programmed in Visual Basic.Net using its libraries, i.e., the COM components. Microsoft Project assists project managers in assigning resources to the tasks, tracking the progress of each task, and modifying the project plan according to current requirements. It also provides a Project Server to share the files over a network, publish the information to the internet or to the local network, providing all the team members access to the updated version of the project file directly.

ThreeSL"s Cradle is used for Requirements Management, which is another important aspect of a development project. Requirements for developing this IDE are managed with Cradle and are provided as an example along with the IDE package. Modeling methodologies such as Class diagrams, Use Case diagrams, State Chart diagrams, Activity diagrams, etc., can be drawn using Cradle. There is full traceability of functional, performance and derived requirements with direct association to each model drawn. Cradle provides Toolset and Workbench as interfaces to manage the requirements, implement modeling methodologies, and manage projects and users.

Toolset, designed in a UNIX environment, provides almost all the functionalities of Cradle and can be said to be the backbone of Cradle. WorkBench, developed in the Windows environment, provides a simpler interface than the Toolset, but it does not provide some of the features such as modeling diagrams and import/export.

Ansoft"s Simplorer is used to simulate electrical circuits in this IDE. Simplorer provides easy access to libraries for modeling various circuits and supports multi-domain

simulations. It also supports the addition of new user-defined elements/models to the existing libraries.

The access time for opening all the software (implemented so far) was measured and calculated to be about 55 seconds on an average[10]. The IDE can be run on various machines, and the minimum PC requirements considered for better functionality of the IDE are:

a. Processor: Intel Pentium 4 and above and running at 1.73 GHz and above.

b. Memory: 512 MB (1 GB recommended)

c. Hard Disk: 2 GB to install all software

The Aerospace Corporation developed the Small Satellite Design Model (SSDM) and Small Satellite Cost Model (SSCM), to gather and analyze small satellite technical and cost data [5]. The IDE, when compared with the above mentioned tools, facilitates implementation for designers, since the SSDM and SSCM models serve as a preliminary analysis tools for systems engineers to understand conceptual spacecraft designs. But the IDE lacks the functionality for gathering preliminary information about the satellite and providing the designer with a matched model based on the requirements.

The fully developed IDE, when compared to the manual approach of satellite design, reduces the total design time since the files can be easily shared over the network, and a designer can work on more than one subsystem at a time.

[10] Average is calculated by opening all the software 20 times, on a Pentium 4 processor running at 3.0 GHz with 512 MB RAM.

6.2 Future Work

This IDE is in its initial stages of development, and hence there is substantial amount of future work to be done. This IDE has implemented only the first two phases of the six-step process successfully, namely, the Concept phase and the Definition phase. The third phase, the Design phase, has been partially implemented. This IDE has the flexibility to allow future implementation of the remaining phases in the six-step process.

This IDE does not have a user-authentication process. A database can be developed which can be used for file management over the network and for user account management. This database can improve the overall safety and accessibility of all the files. Based on the past results, with a database there is a possibility of providing a satellite model in early stages of development by collecting information similar to that of the Aerospace Corporation's Small Satellite Design Model.

This IDE could be made more user-friendly by having a menu bar with options such as Import/Export, Print, User switching, and Search (for a particular File or Project over the network). Web publishing and web access features can be included, so that the user can work from anywhere over the local network or the internet. Another improvement would be the addition of documentation features for exporting the required project summary to Microsoft Word, exporting tabular data to Microsoft Excel, and for assisting users in preparing better presentations.

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APPENDICES

A. Resource Management Table of Microsoft Project Template

TABLE III: ALLOCATED RESOURCES FOR EACH TASK

WBS	Task Name	Days	Start	Finish	% Finish	Cost ($)	Hours
1	Project Name: Test Project	198?	5/2/06	1/31/07	42%	160,081	2,000
2	Phase A :Preliminary Analysis/ Concept	38	5/4/06	6/26/06	100%	$85,920	2,824
2.1	Mission Needs/ Requirements	17	5/4/06	5/26/06	100%	$38,785	1,272
2.1.1	Functional Needs/ Requirements	12	5/4/06	5/19/06	100%	$13,715	448
2.1.1.1	Performance	3	5/4/06	5/8/06	100%	$2,980	96
2.1.1.1.1	Primary Objective	3	5/4/06	5/8/06	100%	$745.00	24
2.1.1.1.2	Payload	3	5/4/06	5/8/06	100%	$745.00	24
2.1.1.1.3	Size	3	5/4/06	5/8/06	100%	$745.00	24
2.1.1.2	Coverage	4	5/8/06	5/11/06	100%	$2,955	96
2.1.1.2.1	Orbit	4	5/8/06	5/11/06	100%	$985.00	32
2.1.1.2.2	Swath width	4	5/8/06	5/11/06	100%	$985.00	32
2.1.1.3	Responsiveness	10	5/8/06	5/19/06	100%	$4,875	160
2.1.1.3.1	Communications architecture	5	5/8/06	5/12/06	100%	$1,225	40
2.1.1.3.2	Processing delays	5	5/15/06	5/19/06	100%	$1,225	40
2.1.2	Operational Needs/Requirements	6	5/8/06	5/15/06	100%	$7,325	240
2.1.2.1	Duration	6	5/8/06	5/15/06	100%	$1,465	48
2.1.2.2	Availability	6	5/8/06	5/15/06	100%	$1,465	48
2.1.2.3	Survivability	6	5/8/06	5/15/06	100%	$1,465	48
2.1.2.4	Data Distribution	6	5/8/06	5/15/06	100%	$1,465	48
2.1.3	Constraints	7	5/18/06	5/26/06	100%	$13,640	448
2.1.3.1	Cost	7	5/18/06	5/26/06	100%	$1,705	56
2.1.3.2	Schedule	7	5/18/06	5/26/06	100%	$1,705	56
2.1.3.3	Regulations	7	5/18/06	5/26/06	100%	$1,705	56
2.1.3.4	Sponsor	7	5/18/06	5/26/06	100%	$1,705	56
2.1.3.5	Environment	7	5/18/06	5/26/06	100%	$1,705	56
2.1.3.6	Interfaces	7	5/18/06	5/26/06	100%	$1,705	56
2.1.3.7	Development Constraints	7	5/18/06	5/26/06	100%	$1,705	56
2.2	Mission Characteristics	23	5/25/06	6/26/06	100%	$37,990	1,248
2.2.1	Data Delivery	5	5/25/06	5/31/06	100%	$2,450	80
2.2.1.1	Space vs. Ground	5	5/25/06	5/31/06	100%	$1,225	40
2.2.2	Communications Architecture	10	5/29/06	6/9/06	100%	$7,275	240
2.2.2.1	Data rates bandwidth	10	5/29/06	6/9/06	100%	$2,425	80
2.2.2.2	Ground System	10	5/29/06	6/9/06	100%	$2,425	80
2.2.3	Scheduling and Control	6	6/12/06	6/19/06	100%	$4,155	136
2.2.3.1	Level of anatomy	5	6/12/06	6/16/06	100%	$1,225	40
2.2.3.2	Central vs. Distributed	6	6/12/06	6/19/06	100%	$1,465	48
2.2.4	Mission Timeline	5	6/13/06	6/19/06	100%	$2,450	80
2.2.4.1	Level of timeline flexibility	5	6/13/06	6/19/06	100%	$1,225	40

2.2.5	Identify system drivers for each	6	6/19/06	6/26/06	100%	$16,115	528
2.2.5.1	Size	6	6/19/06	6/26/06	100%	$1,465	48
2.2.5.2	On-Orbit weight	6	6/19/06	6/26/06	100%	$1,465	48
2.2.5.3	Power	6	6/19/06	6/26/06	100%	$1,465	48
2.2.5.4	Data Rate	6	6/19/06	6/26/06	100%	$1,465	48
2.2.5.5	Communications	6	6/19/06	6/26/06	100%	$1,465	48
2.2.5.6	Pointing	6	6/19/06	6/26/06	100%	$1,465	48
2.2.5.7	Altitude	6	6/19/06	6/26/06	100%	$1,465	48
2.2.5.8	Coverage	6	6/19/06	6/26/06	100%	$1,465	48
2.2.5.9	Scheduling	6	6/19/06	6/26/06	100%	$1,465	48
2.2.5.10	Operations	6	6/19/06	6/26/06	100%	$1,465	48
3	Draft Mission Definition Document	8	6/27/06	7/6/06	100%	$1,945	64
4	Mission Definition Review (MDR)	3	7/7/06	7/10/06	100%	$745	24
5	Phase B: Definition/ System Requirements	15	7/11/06	7/28/06	100%	$3,880	120
5.1	Draft System Requirements	5	7/11/06	7/17/06	100%	$1,270	40
5.2	System Requirements Review	2	7/19/06	7/20/06	100%	$550	16
5.3	Allocate requirements to subsystems	3	7/20/06	7/22/06	100%	$790	24
5.4	Develop Budgets	5	7/24/06	7/28/06	100%	$1,270	40
6	Preliminary Design Review (PDR)	1	7/28/06	7/29/06	100%	$265	8
7	Phase C: Design and Analysis	83?	7/31/06	11/17/06	76%	$38,381	1,259.2
7.1	Propulsion	8	7/31/06	8/9/06	100%	$1,990	64
7.2	Attitude Determination and Control	14	7/31/06	8/17/06	100%	$3,430	112
7.3	Communication	21	8/3/06	8/29/06	100%	$5,110	168
7.4	Command and Data Handling	16	8/14/06	8/31/06	100%	$3,910	128
7.5	Payload	13?	9/11/06	11/11/06	65%	$3,286	107.2
7.6	Structure and Mechanisms	31?	9/25/06	11/6/06	23%	$7,510	248
7.7	Power	30?	9/18/06	11/13/06	80%	$7,270	240
7.8	Thermal	24?	10/9/06	11/17/06	85%	$5,830	192
8	Critical Design Review (CDR)	2?	11/16/06	11/20/06	65%	$505	16
9	Phase D: Development-Integration and Verification	31?	11/20/06	12/29/06	0%	$8,555	279.68
10	Flight Readiness Review (FRR)	2?	1/1/2007	1/2/07	0%	$505	16
11	Operational Readiness Review (ORR)	5?	1/3/07	1/9/07	0%	$1,225	40
12	Phase E: Operations	9?	1/10/07	1/22/07	0%	$2,230	72
13	Phase F: Disposal	7?	1/23/07	1/31/07	0%	$1,750	56

B. VHDL Code for Analog-to-Digital Conversion

```
LIBRARY IEEE;
USE IEEE.STD_LOGIC_1164.ALL;
USE IEEE.ELECTRICAL_SYSTEMS.ALL;                    //Libraries and references

ENTITY PIC_ADC IS                    //Begin of definition for element PIC_ADC
 GENERIC (MIN: REAL:= -1.0;                          //Minimum limit ,default=0
        MAX: REAL:= 1.0;                    //Maximum limit ,default=1
        RES: INTEGER:= 8);                  //Resolution ,default=8
 PORT (TERMINAL VAN, GND: ELECTRICAL; //Terminals Van and GND with
                                                     input electrical signals
         SIGNAL CLK: IN BIT:= '0';          //Clock input signal
     SIGNAL VD: OUT BIT_VECTOR (9 DOWNTO 0):= (OTHERS => '0'));
              //Output digital signals, up to 10 bits
         END ENTITY PIC_ADC;
ARCHITECTURE behav OF PIC_ADC IS //Begin of description of PIC_ADC
QUANTITY V ACROSS VAN TO GND;    //V is the I/P vol. b/w Van and GND

BEGIN
   PROCESS
      VARIABLE delta_v: REAL:= 0.0;                          //Declare variables
delta_v and                                    VARIABLE input_hold: REAL:= 0.0;
                  //input_hold calculating digital
                                                     // value
   BEGIN
      WAIT ON CLK;
      delta_v:= MAX - MIN;                          //Set delta_v and input_hold
      input_hold:= V - MIN;
      IF (CLK'EVENT AND CLK = '1') THEN                          // When clock
is high
      FOR i IN RES-1 DOWNTO 0 LOOP          //Loop RES down to 0
         delta_v:= delta_v / 2.0;                  // calculate the digital output
```

```
        IF input_hold >= delta_v THEN
           VD(i) <= '1';
           input_hold := input_hold - delta_v;
        ELSE
           VD (i) <= '0';
        END IF;
        IF (v>MAX) THEN                          //If input is greater than maximum
value set all
           VD(i) <='0';                          // bits high
        END IF;
      END LOOP;
   END IF;
END PROCESS;                                     //End of process and
END ARCHITECTURE;                                //End of architecture
```