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# ENGAGING ENGINEERING STUDENTS IN SYSTEMS ENGINEERING IMPLEMENTATION IN SOFTWARE DEFINED RADIO TECHNOLOGY DEVELOPMENT

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## **Engaging Engineering Students in Systems Engineering Implementation in Software Defined Radio Technology Development**

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*Topics/Areas:* Technology & Engineering – Industrial Engineering and Management

*Presentation Format:* Paper – Talk

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### **Abstract**

There is an increasing demand for systems engineers recently in this country, especially in aerospace industry and defense industry. This presentation will discuss our experience in engaging engineering students in serving the systems engineer role in software defined radio (SDR) technology development project at Morgan State University. There are a variety of projects with many components and categories in the system or subsystems. These projects can range from designing a computer chip to designing a spacecraft. Thus, how can these projects be managed efficiently when they involve so many people working on the various critical parts of the project? Systems Engineering provides the solution to this question. Researchers in the Electrical Engineering department at Morgan State University are developing a more advanced software defined radio technology for space communication. NASA systems engineering approach and protocol are used as a guideline for the new technology development. The CORE software is used to document requirements, develop the context diagrams and help with the systems requirements review and design review.

## **1. Introduction**

There are various technical challenges in space missions, which include the efficient and convenient communication approach. Software Defined Radio (SDR), one of the advanced communication technologies, can be used in the space transportation vehicles dispatching cargo to the International Space Station and returning back in real-time to the planet. NASA is predicting that there will be a significant cargo of approximately 40 metric ton shortfall between now and the near future.<sup>[1]</sup> Therefore, NASA wants to expand and use mixed vehicles outfitted with software defined radio technology that will help deliver cargo to the ISS and return it to the planet in an allowable time frame.

The SDR project will hopefully reach a technology that will be able to define the signal through a digital means instead of the analog methods. The SDR project will also allow a wider range of signals in order to transfer the data. In addition, it would be able to reduce the analog system errors, and speed up the communication especially in emergency cases. The SDR project has been transformed into a system at Morgan State University (MSU), and systems engineering team and students are trying to improve the level of system engineering implementation. The use of the conceptual design stage allows enhanced communication between subgroups when implementing identical requirements. Systems engineering has been used in order to clarify the requirements. This has allowed projects to be completed on time. The product breakdown structure can categorize the project into smaller pieces in order to allow the subgroups to meet the specific goals.

The application of systems engineering can allow the SDR project to meet its goals accurately through the increased communication within the subsystems development teams. The increased interaction between the subsystems may even lead to a better product without the unnecessary loss of time and other valuable resources. Through an effective systems engineering method, each subsystem team can reach its goals, produce the desired product. Through an efficient method, the product can be produced on time through the data available to monitor the progress in the subsystems. Also, in this project, the systems engineering team and students were applying the systems engineering method to the SDR development project through a variety of helpful software such as CORE software, and Microsoft project tools. At the same time, the NASA Systems Engineering Handbook plays a vital role, and serves as the basic guideline in accomplishing our goal. Through the effort of applying systems engineering in the SDR project, the systems engineering team, especially several engineering students, also develops the systems engineering skills and gains the experiences in coordinating the technical people with diverse backgrounds.

## **2. Systems Engineering**

The main guidelines for this project were drawn from the NASA Systems Engineering Handbook, the NASA Requirement Protocol, and the Criteria for Flight and Flight Support Systems Lifecycle Reviews by NASA. Using the NASA Systems Engineering Handbook, the current statuses of the systems were first checked, and then compared to the proper guidelines set in the handbook. The results were evaluated and their statuses were improved, through the clarification of the systems overview. After several joint and individual meetings with the subgroups, the components were identified, and a more complete product breakdown structure was created.

NASA’s formal definition of systems engineering states, “Systems Engineering is a methodical, disciplined approach for the design, realization, technical management, operations, and retirement of a system.”<sup>[2]</sup> Systems Engineering (SE) is a kind of interdisciplinary approach to allow the fulfillment of successful systems. It primarily focuses on the needs of customers or clients, and the needed functionality early in the development stage. This involves cataloging requirements, creating a design synthesis, along with the system confirmation while in turn, acknowledging the complete problem. The task may involve scheduling and cost, operations, training and support, performance, test, manufacturing and disposal. Basically, System Engineering ponders both the technical and business needs of all customers with the purpose of bringing up a high-quality product that fulfills user’s needs. It can be used to manage the complexity of other projects including software integration, computer chip designs, and even spacecraft design. Furthermore, SE starts with recognizing the needs of the stakeholders and customers while making sure that the correct problem has been described. SE is a management and technical process. The technical process considers the design and implementation efforts needed to configure the operational need into a system of acceptable size and generates the necessary documentation to implement, perform, and conserve the system.

Table 1. NASA Project Life Cycle <sup>[3]</sup>

Phase		Purpose	Typical Output
Formulation	Pre-Phase A Concept Studies	To produce a broad spectrum of ideas and alternatives for missions from which new programs/projects can be selected. Determine feasibility of desired system, develop mission concepts, draft system-level requirements, identify potential technology needs.	Feasible system concepts in the form of simulations, analysis, study reports, models, and mockups
	Phase A Concept and Technology Development	To determine the feasibility and desirability of a suggested new major system and establish an initial baseline compatibility with NASA's strategic plans. Develop final mission concept, system-level requirements, and needed system structure technology developments.	System concept definition in the form of simulations, analysis, engineering models, and mockups and trade study definition
	Phase B Preliminary Design and Technology Completion	To define the project in enough detail to establish an initial baseline capable of meeting mission needs. Develop system structure end product (and enabling product) requirements and generate a preliminary design for each system structure end product.	End products in the form of mockups, trade study results, specification and interface documents and prototypes
Implementation	Phase C Final Design and Fabrication	To complete the detailed design of the system (and its associated subsystems, including its operations systems), fabricate hardware, and code software. Generate final designs for each system structure end product.	End product detailed designs, end product component fabrication, and software development
	Phase D System Assembly, Integration and Test, Launch	To assemble and integrate the products to create the system, meanwhile developing confidence that it will be able to meet the system requirements. Launch and prepare for operations. Perform system end product implementation, assembly, integration and test, and transition to use.	Operations-ready system end product with supporting related enabling products
	Phase E Operations and Sustainment	To conduct the mission and meet the initially identified need and maintain support for that need. Implement the mission operations plan.	Desired system
	Phase F Closeout	To implement the systems decommissioning/disposal plan developed in Phase E and perform analyses of the returned data and any returned samples.	Product closeout

Table 1 shows how different phases of a life cycle are used to allow various products of the project to be developed. It starts with the Formulation Section. Pre-Phase A (Concept studies) is used to

show a broad spectrum of ideas and alternatives for missions in which new projects are selected. Next comes Phase A, whose purpose is to determine the practicability and value of a suggested new major system. Phase B is used allocate enough detail to establish a baseline that is capable of meeting mission requirements. Next is the implementation section of the Implementation Phases. The purpose of Phase C is to finish the detailed design of the system, and also conjure up the software and hardware. Phase D is to build and integrate the whole system. Phase E involves conducting the mission and identifying the need and maintaining the support for that need. Finally, Phase F is a sort of decommissioning phase. It involves a sort of closeout of the whole project in which a disposal plan has been developed.

### **3. Software Defined Radio (SDR)**

It is a type of radio communication system where the functions of many hardware components (amplifiers, modulators, mixers, filters etc.) are replaced by software in a personal computer or other types of embedded computing devices. It also serves as a type of modem that modulates and demodulates the incoming Radio Frequency (RF) signals. This SDR project at MSU started in 2008. The main goal of this project is to discover alternative solutions to advance in SDR applications which are managed by the electrical engineering department. The System Engineering and Management Institute (SEMI) was established to collaborate with the electrical engineering student researchers and industrial engineering student researchers to apply systems engineering in the SDR project.

The MSU engineering team will fabricate the technologies that are befitting to the SDR platform on an unmanned cargo supply spacecraft (“MSU-Sat”) that brings provisions and equipment to the ISS in a hypothetical scenario. This is the illustration on the SDR system architecture and demonstration or context diagram (Figure. 1)<sup>[4]</sup>. “A context diagram is a useful tool for grasping the system to be built, and the external domains that are relevant to that system and which have interfaces to the system. The diagram shows the general structure of a context diagram.<sup>[5]</sup> The MSU team will make the system as: Front-end and back-end subsystems, and the Digital Radio subsystem. The part in red is NASA’s facilities, including the TDRSS (Tracking and Data Relay Satellite System). The part in black is developed by the MSU team. It includes all the main components of the back end, front end, and digital radio subsystems.

#### ***SDR Subsystems***

*MSU RF Front-End Subsystem (RFS):* The general idea of the RF Front End Subsystem includes the collection of all components in-between the antennae and the digital base band system (first intermediate frequency stage). The constituents within the receiver include a band pass filter, low noise amplifier, mixer and impedance matching circuit. These components in turn convert the archetypal incoming radio signal at a particular frequency before it is then brought down to a lower intermediate frequency (IF). The MSU RF Front- End is comprised of different parts. For instance, it includes power amplifiers, mixers and low noise amplifiers. The power amplifier increases the amplitude of the input RF signal by converting input DC supply power to RF output power. A tunable filter is a sort of passive circuit which passes to the output only input signals that are in a desired range of frequencies called the pass band and can be adjusted or controlled externally. A mixer is a type of nonlinear electrical circuit that makes new frequencies from the two signals applied to it.

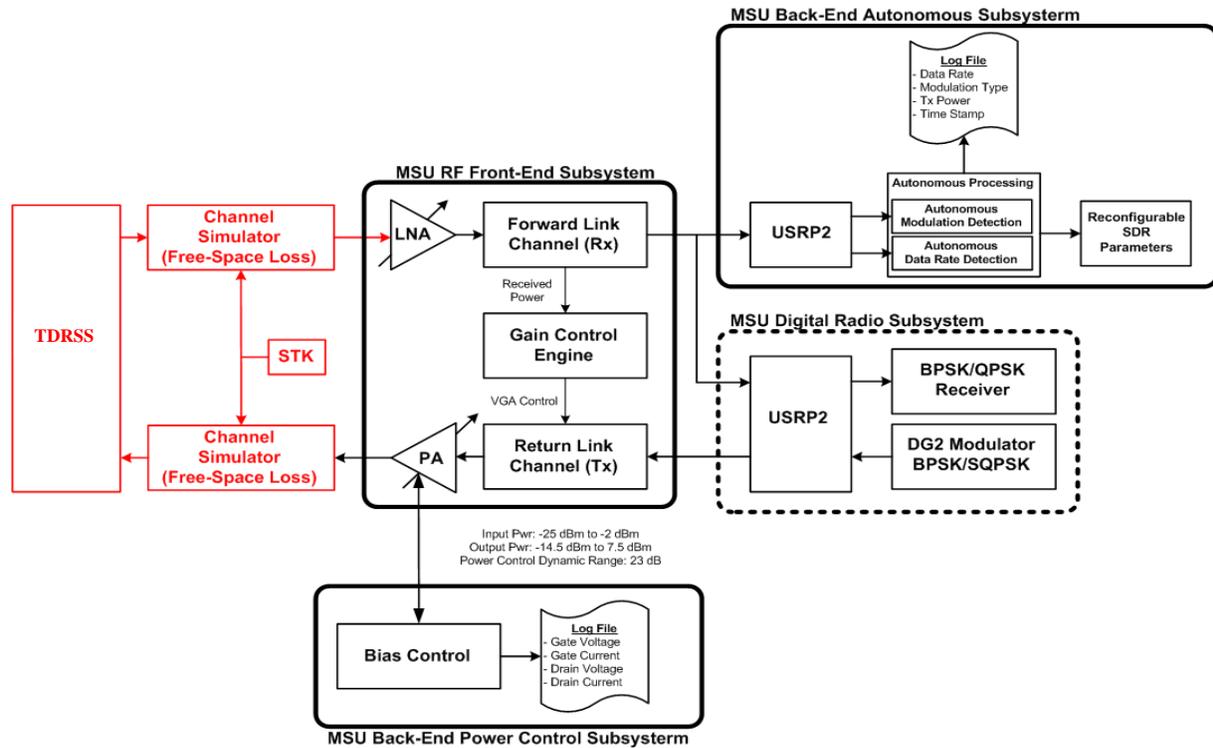


Figure 1. The Context Diagram of MSU SDR Technology Test Plan

*MSU Power Control Subsystem:* The general idea of the Power Control subsystem involves signal processing. In a way it is supposed to be able to control the Data Conversion sub-system and also adjust various parts of the RF front end by sending out different voltages to accommodate the frequency.

*Digital Radio Subsystem:* The Digital Radio Subsystem is part of modulation scheme for the S-band communication link. It helps in first converting signal from analog to digital where it is processed before converting it back<sup>[6]</sup>

### Space Network

The Space Network is comprised of both ground and space segments, as seen in Figure 2.<sup>[7]</sup> A space segment is a Tracking and Data Relay Satellites System (TDRSS) which is composed of six operational TDRS spacecraft's in the geostationary orbits to communicate with customers deliver wide-ranging coverage. Also, the Ground Segment obtains the data to follow the spacecraft's telemetry signals. The Ground Network is made of two ground segments which includes the Guam Remote Ground Terminal (GRGT) and the White Sands Complex (WSC).

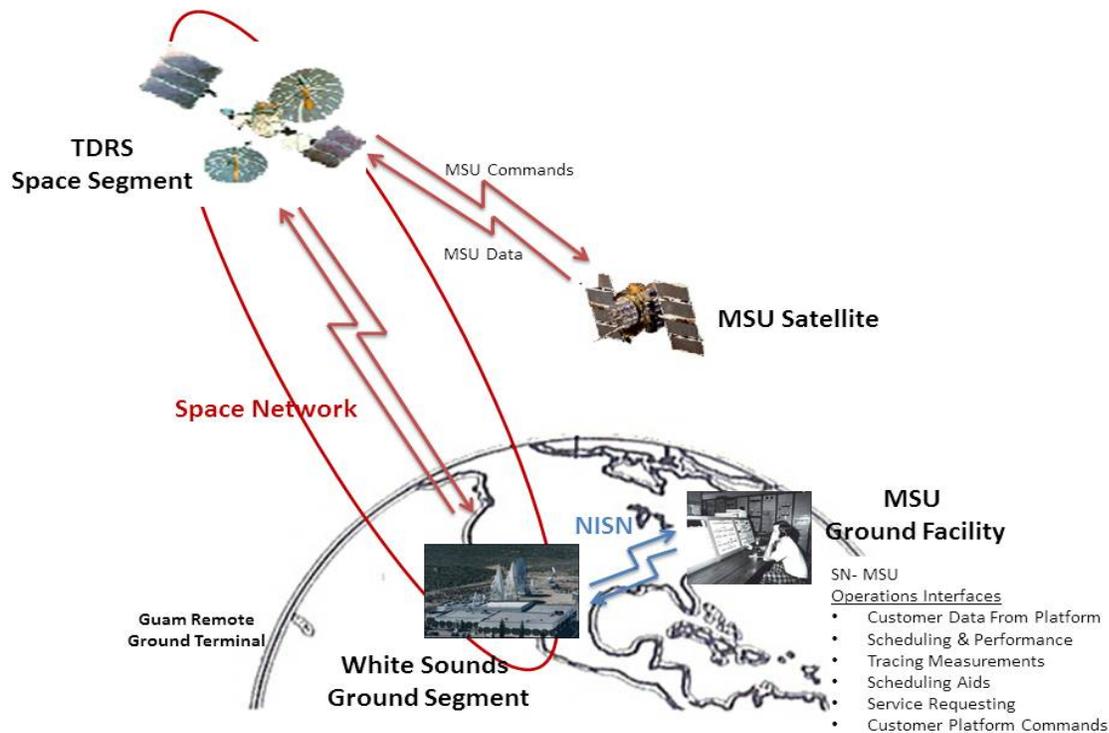


Figure 2. Space Network

#### 4. CORE Software

CORE software is a popular systems engineering tool developed by Vitech. It is an inclusive modeling environment made for complex system engineering problems. It has many integrated modeling capabilities to evaluate and command design and program risks, while capturing customer's needs accurately. CORE basically connects all the elements of your system through a principal model, where one can have greater clarity and expeditiously see any weaknesses in the design. Its architecture development tools allow the user to easily see the subsystems and components of the project. [8]

CORE is made up of classes which include the requirements, functions, items etc. Some of the elementary user activities of CORE involve putting in and changing the elements of classes and creating relations between those elements of classes. [9]

CORE Benefits include:

- **Integrated Development Lifecycle Support**  
It has a capability of developing the lifecycle charts.
- **End-to-End System Traceability**  
It manages project requirements with tracing statements for product architecture.
- **Change Impact Analysis**  
Assess proposed changes in terms of the process or product improvement that will be derived from new functionality or system re-configuration.

- **Multiple Modeling Notations Support 360° System Views**  
Evaluate the system through a variety of integrated graphical views: hierarchies, functional flow and enhanced functional flows, N2, IDEF0, and physical block. Change one diagram and see the update reflected on all impacted views.
- **Integrated System Simulation**  
Analyze the integrated architecture by dynamically interpreting the behavior model to evaluate, validate, and compare architecture capabilities throughout the design process.
- **On-Demand Document Delivery**  
Create formal documentation and a complete set of DoDAF 2.0 views instantly from the system definition database to deliver consistent work products reflecting the latest design details.
- **Integrated SysML Representations**  
Work in - or simply report out in - a comprehensive set of SysML diagrams: Requirements, Activity, Sequence, Block Definition, Class, Internal Block, and Package Use Case.
- **Risk Management**  
Manage risks and plan contingencies by linking directly to those aspects of the system architecture that cause concern.
- **Program Management**  
Track schedules, tasking, and WBS information from inside the CORE environment.
- **Collaborative System Development**  
Collaborate with seamless access to the latest development information while managers and reviewers contribute via CORE2net.
- **Proven System Definition Language**  
Utilize a well-defined schema that fully supports the systems engineering and systems architecture dialect natural to complex problem solving. Easily extend and tailor the schema to support specific customer needs.

### *Core Diagrams*

In Figure 3, the user is able to input the requirements of specific components dealing with the SDR. In this case, an originating requirement is Power Control, and it is broken down into its different components (elements). Here you can see the elements. (The elements represent a “thing” that can be uniquely identified.) The system name is located towards the top and underneath that comes is number designation. Immediately after that comes the description of the component. At the bottom, the relationships can be created. For instance, it can be refined by something or it refines another item.

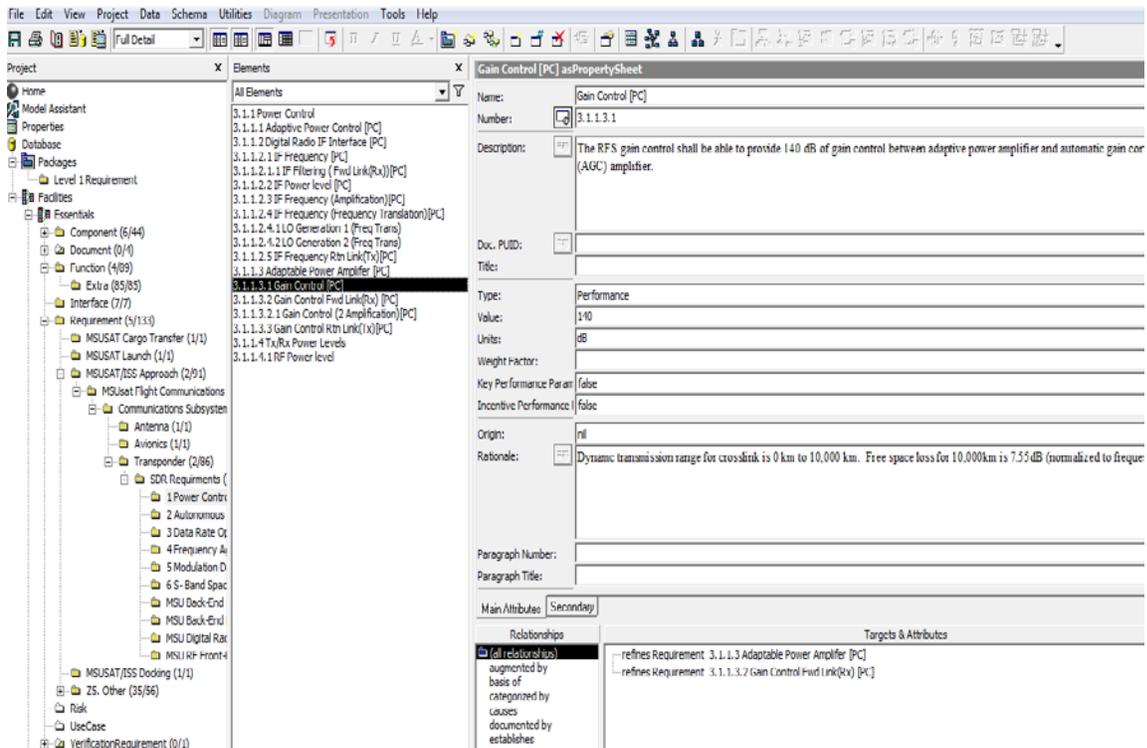


Figure 3. Requirement Input Sheet.

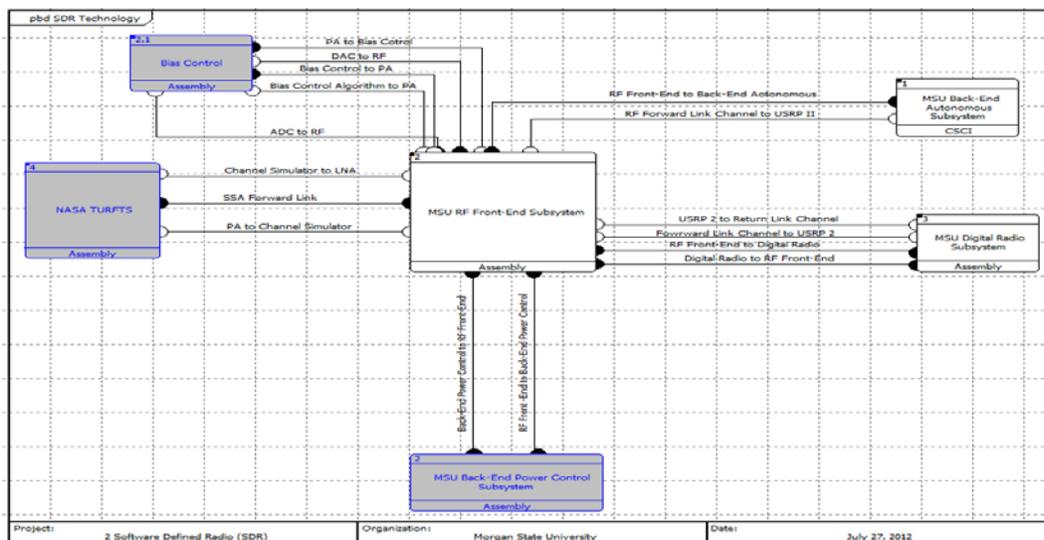


Figure 4. Physical Block Diagram of MSU SDR.

Figure 4 is the Physical Block diagram. It gives the physical interfaces that relate the components of the SDR. It is the CORE version of the context diagram. Here it shows how the different components of the SDR, (RF Front-end, Back-end, and Digital Radio) and the NASA TURFTS system is connected. Some subsections of the RF Front-end are shown. This includes the MSU Back End Power control subsystem and the Bias control. This was generated in CORE by creating links between the different subsystems

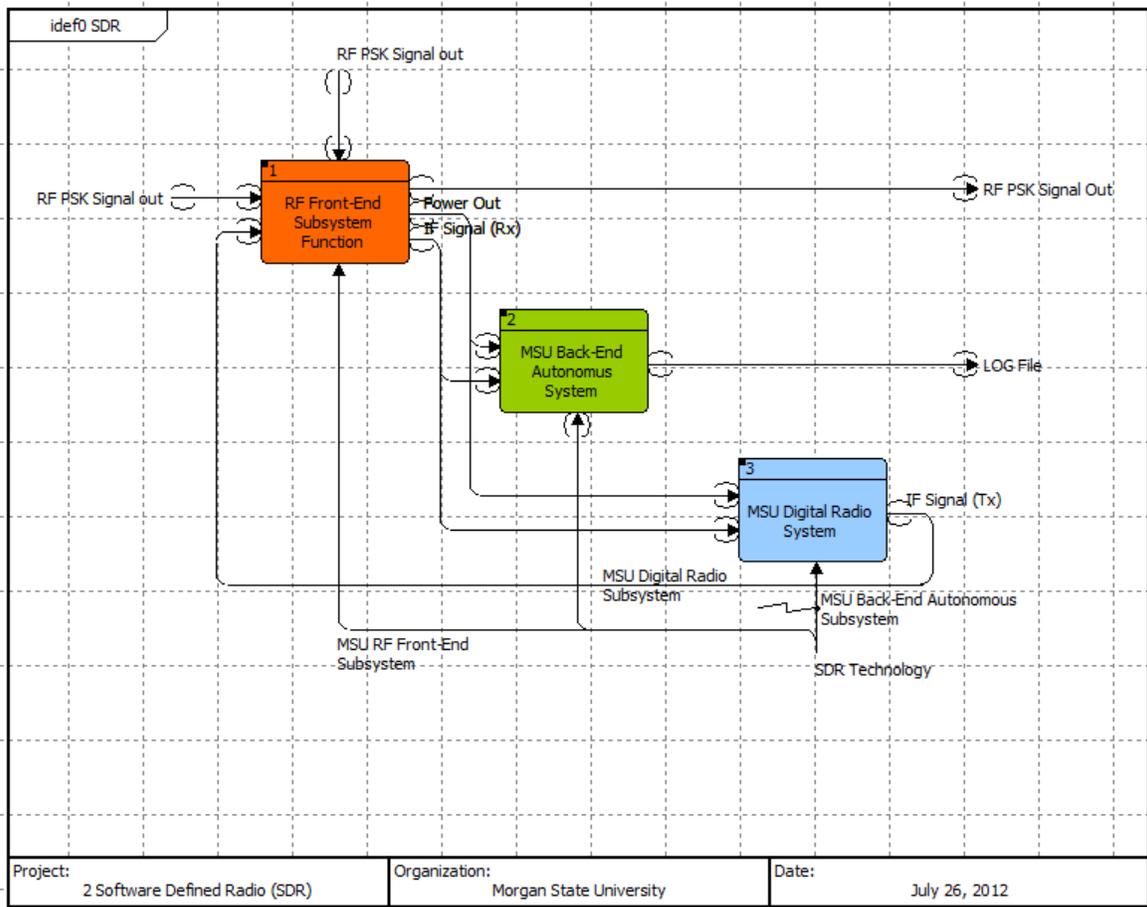


Figure 5. The IDEF0 Diagram

Figure 5 is the IDEF0 diagram of SDR, where the major components are shown along with some of the inputs and outputs. This diagram was also generated in CORE. The IDEF0 (Integrated Definition for Function Modeling) is a process modeling technique,<sup>[10]</sup> or a model, “any incomplete representation of reality, and abstraction.”<sup>[11]</sup> Thus, the IDEF0 focuses on the functional model of a system. The colored boxes (subsystems) represent a function. A function is a sort of modification that changes inputs into outputs. The inputs and outputs are represented by “flow of material or data” which is shown by arrows going into or out of the different boxes. As seen in the diagram, the RF signal first enters the RF Front-End subsystem where it is broken down into IF signal which is then sent into the Back-end autonomous, and Digital Radio subsystem where it will be further broken down into its base band signal.

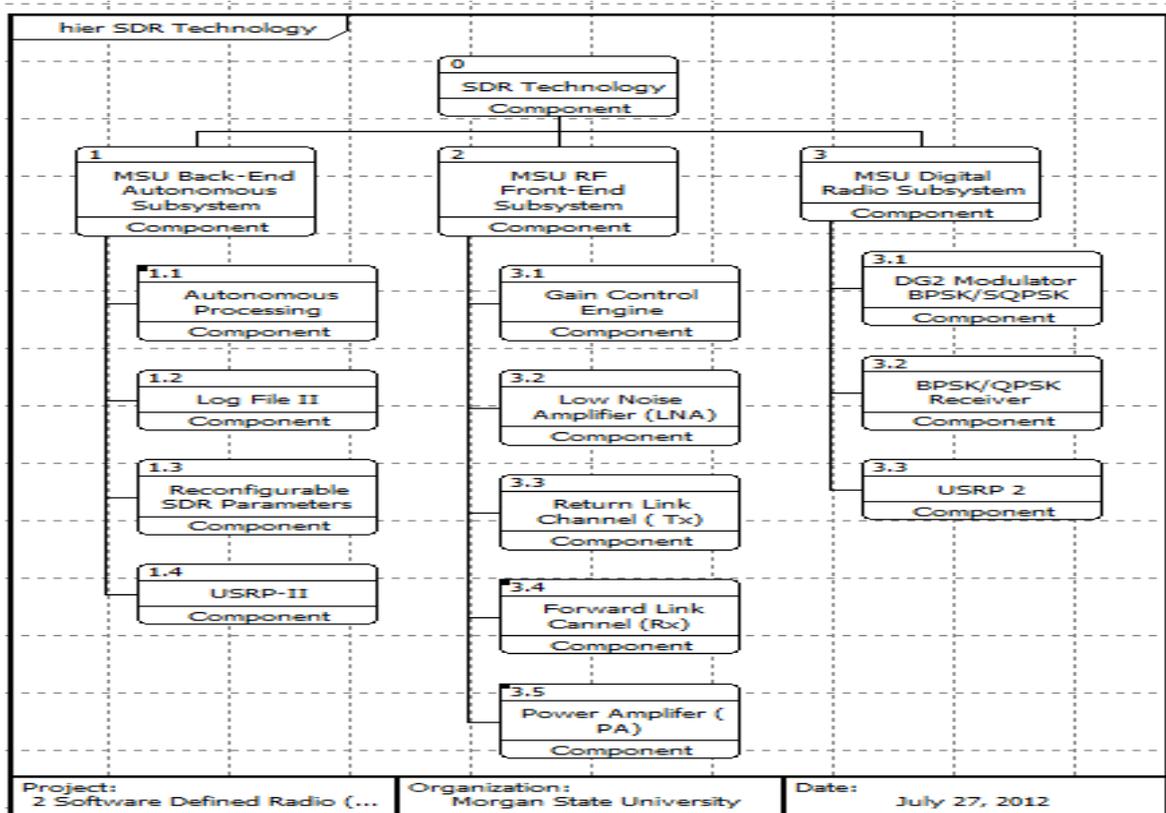


Fig 6. Component Hierarchy Diagram

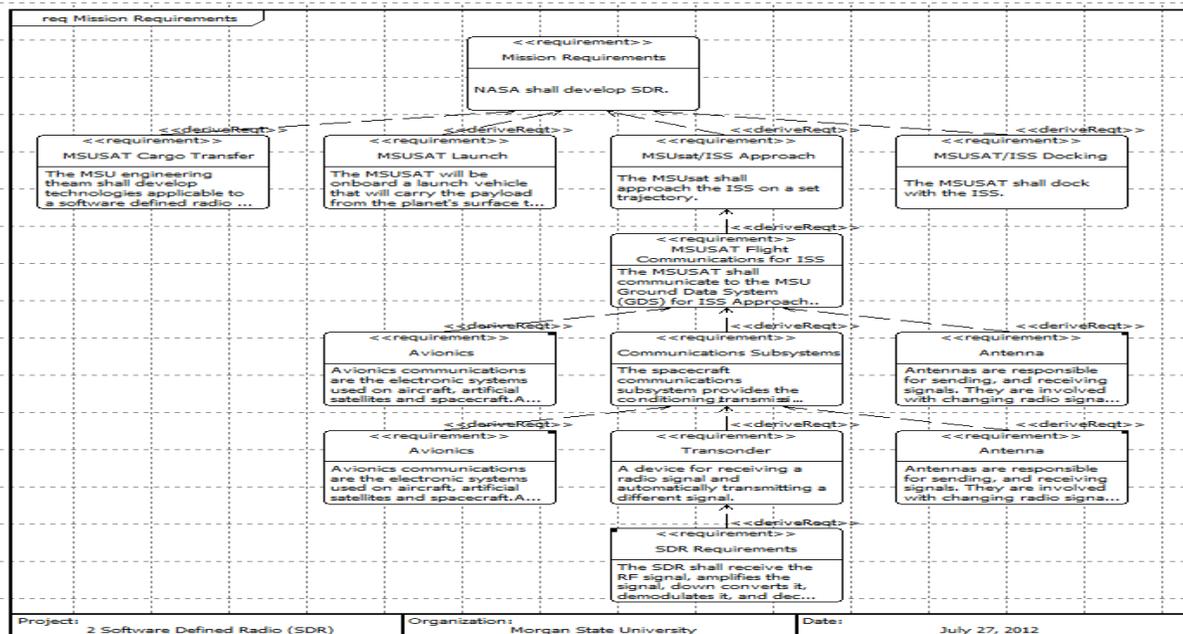


Fig. 7. SDR Hierarchy Diagram

Figure 7 shows another way that CORE can represent the major components of the SDR similar to the Context Diagram. This particular type of diagram is known as the Hierarchy Diagram which also depicts the component hierarchy of the whole system. Here the SDR technology serves as the parent and the subsystems, Digital Radio, Front-End, and Back-End, as the children otherwise known as the second level requirements.

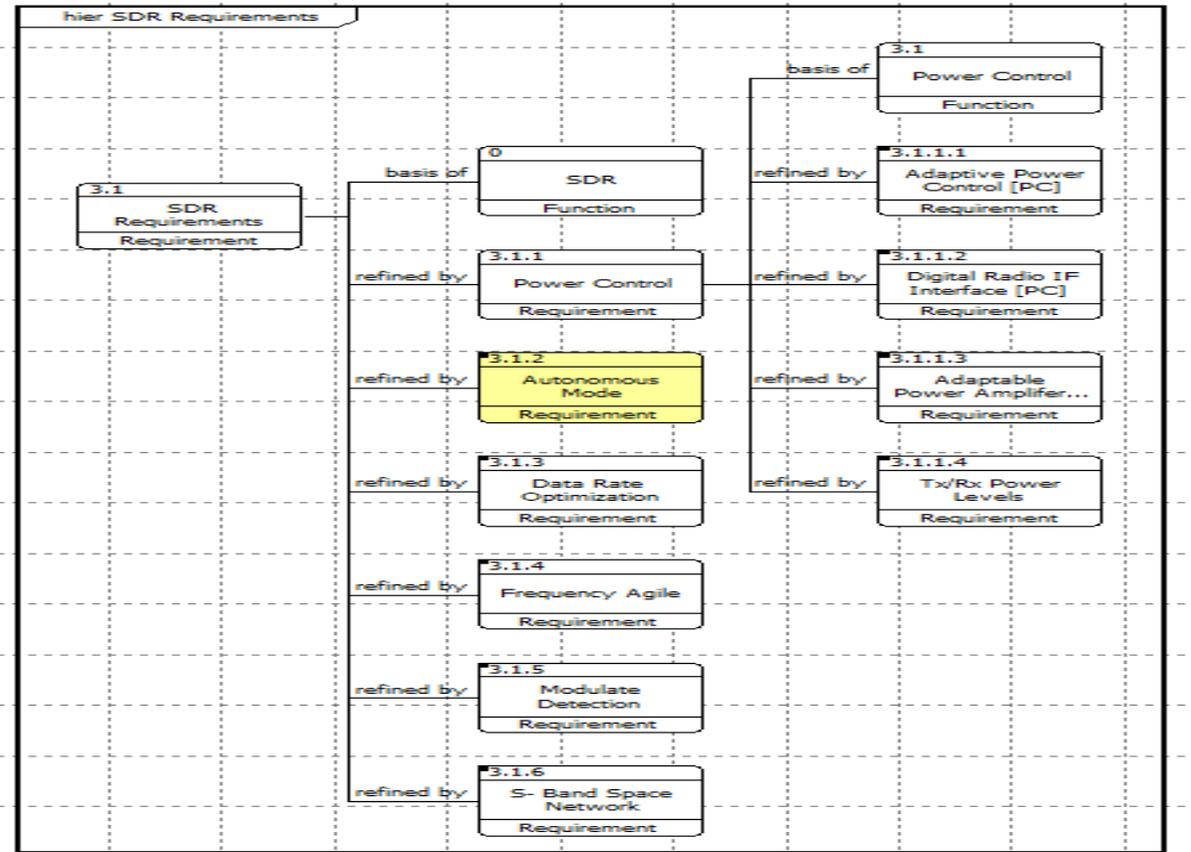


Figure 8. SDR Mission Requirement Diagram.

Figure 8 is the Requirements Diagram. It represents a sort of product breakdown structure. In a sense, it shows the SDR project as a whole and how the actual SDR is connected with the larger mission system. In the figure, the main mission objective is defined at the top, and it is then broken down into the different stages of the MSU satellite with respect to the ISS. It is further decomposed until we reach the SDR requirement which includes most of its subsystems and components. In CORE, the requirements have a parent-child designation. For instance, the larger requirement such as the transponder, is known as the parent, while the subsystem underneath it is considered the child. The requirements were put into CORE and the relationships were made. “A requirement is either an originating requirement extracted from source documentation for a system, a refinement of a higher-level requirement, and a derived characteristic of the system”. [12]

Another ability of CORE is to generate various hierarchy diagrams according to components (Figure 6) or requirements (Figure 7 and Figure 8). The top-level requirements include:

- a. **CESET SDR technology shall be compatible with the S-band NASA Space Network Services.** Rationale: All communication systems are mandated to be compatible with Space Network for the next-generation space communications architecture.
- b. **CESET SDR technology shall be able to operate in autonomous mode.** Rationale: Autonomous functionality would enable new mission operations that will minimize the human-in-loop requirements and improve the reliability during contingency modes.
- c. **CESET SDR technology shall be able to optimize performance based on data rate.** Rationale: Optimization of receiver sensitivity, transmit power and power consumption can be performed based on the data rate.
- d. **CESET SDR technology program shall be able to perform modulation detection with minimum prior knowledge of link conditions and transmitter configuration.** Rationale: Modulation detection can enhance the autonomous functionality of communication systems during different mission phases and configurations.
- e. **CESET SDR technology shall be able to optimize performance based on transmission range.** Rationale: Crosslinks required operation across a broad transmission range from 0 meter to 10,000 kilometers. For optimum crosslink performance, the transmit power must be adapted based on transmission range to minimize interferences and prevent damage to receiver front-end components.
- f. **CESET SDR technology shall be able to optimize performance based on frequency allocation.** Rationale: Users are assigned frequency allocation by the Space Network. As a result, CESET technology should be able to be reconfigured and optimized based on the frequency allocation.

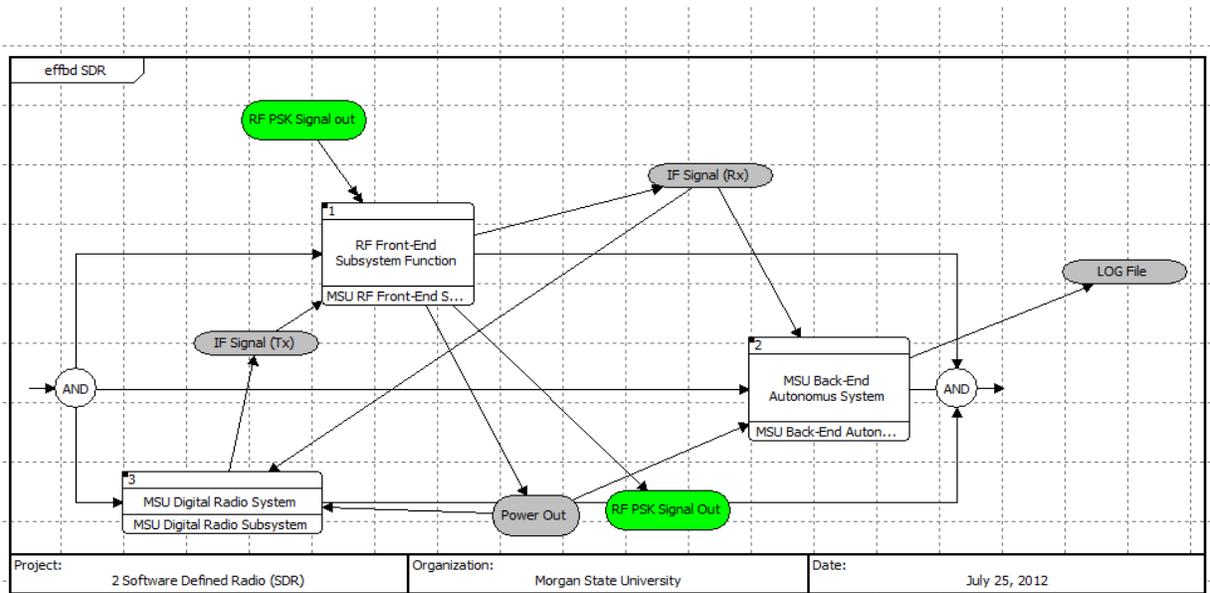


Fig 9. EFFBD diagram

CORE also has the capability to generate an Enhanced Function Flow Block Diagram (EFFBD) as seen in Figure 9. It shows the conducts of a system, or SDR in this case. It also shows the control dimension of the model in this format, “with a data flow overlay to effectively capture the behavior.” That behavior similar to the functions described in the IDEF0 diagram where the RF signal is first received from TDRSS. Then it is down converted to IF (intermediate frequency) in

the RF front-end. Then the IF signal enters forward link where it does frequency translation, then it enters the USRP2 where it does frequency translation from IF to the base band. The signal eventually goes back to the Front End where it is unconverted to RF by the Return Link. Also, the bias control in the power control system ensures that the Power amplifier has enough power to transmit the signals back to the ISS.

## **5. Conclusion**

After the research was conducted on the SDR project, multiple vital problems from the systems engineering perspective were found. SEMI, through engaging several engineering student's efforts, has helped, to create a concept of operation, build a product breakdown structure, complete a context diagram, and create a master schedule, so that the systems engineering requirement levels set by NASA could be reached and documented. This project was developed and organized through the use of various project programs including the Microsoft Office package and CORE as the main software systems. Through the use of well-planned systems engineering methods, the SDR project can move towards its goal in order to provide NASA with a complete cognitive SDR system. The SDR should be built and tested, based on these requirements.

The phases of the project were developed based on the NASA lifecycle protocol. The Master Schedule and phases drawn for the project are helpful, which guide the project to be completed successfully. However, there have been significant changes made to the schedule set in the NASA protocol book in order to accommodate the unique schedule of the academic engineering faculty and students who may be interested in these subjects. The use of CORE software can help develop the training of students and the curriculums revision at MSU in preparing for our future systems engineers. MSU has been given the advantage of receiving free professional software, and therefore is able to use the provision in order to create more inclusive and higher-end projects.

## ***Acknowledgement***

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