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Project Report: Design and Analysis for the Deep Space Network BWG Type 2 Antenna Feed Platform

Introduction

The following report explains in detail the solid modeling design process and structural analysis of the LNA (Low Noise Amplifier) feed platform to be constructed and installed on the new BWG (Beam Wave Guide) Type-2 tracking antenna in Canberra, Australia, as well as all future similar BWG Type-2 antennas builds. The Deep Space Networks new BWG Type-2 antennas use beam waveguides to funnel and “extract” the desired signals received from spacecraft, and the feed platform supports and houses the LNA (Low Noise Amplifier) feed-cone and cryogenic cooling equipment used in the signal transmission and receiving process. The mandated design and construction of this platform to be installed on the new tracking antenna will be used and incorporated on all future similar antenna builds.

Brief Background

NASA’s Deep Space Network currently operates and uses three tracking facilities strategically placed 120 degrees apart from each other around the earth, enabling and maintaining constant contact with spacecraft. The signal is received and fed through a system of beam wave guides, eventually passing through the LNA (low-noise amplifier) which resides on the platform examined in this report. Not only does the platform need to conform to strict tolerances regarding vibrations, frequencies, and deflection, it also needs to maintain signal stability. The new platform must provide all of the necessary functionalities required by the equipment it houses, as well as pass strict structural and human live-load parameters and analysis, all of which ensure necessary RF (Radio Frequency) signal stability and equipment efficiency.

Objectives

The primary objectives of the project are comprised of four main target objectives;

1. Identifying all the necessary mandated requirements from the stakeholders involved with the platform and equipment used, ensuring a symbiotic and correct design/build processes of the platform.
2. Conceptual design of the platform and encompassing equipment using SolidWorks solid-modeling software, incorporating all necessary design requirements and restrictions.
3. Analysis of the platform and behavior under operating conditions including seismic, working and live-loads, using FEMAP and Nastran structural analysis software.

4. Peer review and discussion of the platform design and model, gathering input from all stakeholders involved.

Each of the four main target objectives involved a detailed process of gathering and processing various data and parameters, which were then used in the architecture of each of the main target objective goals explored in more detail as follows.

Approach: Steps Taken and Processes Used in Reaching the Objectives

1. Identifying the Requirements.
   This first objective of specifically identifying and gathering the mandated requirements needed for the design/build is critical. Not only does it establish proper communication in the design phase between all stakeholders (departments interfacing with the platform) involved, the gathering of such requirements/parameters significantly reduces future revisions and the need for expensive retrofitting of designs. The approach used in collections of said requirements was in the form of a functional requirements document. It was fundamental to contact and discuss with all the interfacing stakeholders of the platform, identifying the various build requirements, clearances, codes, and proper engineering procedures to be used. Some of the requirements included electronic layout requirements, structural requirements, facilities and seismic requirements, mechanical engineering requirements, and RF (radio frequency) requirements for the feed cone/LNA tolerances. International codes and regulations also had to be considered and incorporated, as the new antennas for future builds will be located in Australia and Spain. Certain codes were easily obtainable, such as the standardized electrical codes and safety requirements for stair sizing, handrail and head-height clearances, and seismic bracing and material conformity with seismic regulations.
Some of the more problematic and difficult requirements to obtain were those relating to the actual movement restrictions and isolation of the RF feed and the strict positional tolerances for the RF signal stability. It was determined that the movement of the feed cone needed to be restricted to within forty thousandths of an inch in the lateral direction. This had fundamental implications on the materials and bracing to be used on the platform, allowing necessary foot traffic and access as well as conforming to the LNA tolerance requirements. Another challenging and time consuming requirement was the issue of column placement, allowing adequate bracing and preventing platform deflection while also allowing equipment placing and necessary footprints below. There are many interlocking component and equipment facets involved with the platform, some of which are the cryogenic cooling skids and manifold main structures that are located in specific locations below the platform to minimize piping and electrical runs. The placement of these racks is crucial, and due to some of these racks still being developed, it was difficult to get precise measurements, vital in column placement. The columns of the platform are the main support for the entire platform, and not only do they have to allow walking room and access to service the equipment and racks, they also have to maintain adequate spans that can tolerate the loads up top. There were many compromises and placement revisions in order to find column placement that satisfied all criteria. Eventually a design layout was constructed that satisfied all the requirements.

2. **Conceptual Design of the Platform using SolidWorks Solid-Modeling**

   The second main target-objective involved with the design of the platform involved 3D modeling of the platform using SolidWorks software, and incorporating the previously gathered requirements into the model. This powerful modeling software was used from the early stages of design and material procurement and selection, ranging from beam material and sizing options to the 3D layering of flooring and stair placement. One of the first tasks within the modeling phase was to import and re-draw if necessary the components associated with the platform such as the LNA and feed cone themselves, as well as the shroud and sloping concrete pedestal floor, all of which were used in establishing measuring points and critical heights to build from. Some of the components housed in the main pedestal that interface with the platform had already been created and modeled in SolidWorks and could be imported and sketched upon, and other components such as the pedestal concrete floor and axis’s for the various bandwidths had to be created. Column placement took precedence in the early stages, taking into account where the proposed footprints of the equipment racks would go, as well as the structural load limitations such as beam spans. Previous platform designs and beam sizing were analyzed and compared in the modeling phase, ensuring that proper engineering methods as well as on-site construction and fabrication were possible. One of the fundamental drivers in solid-modeling is the use of readily available materials in the design, including region and country specific resources. Steel pricing and sizing were researched in tandem with the design to
ensure the materials and specs designed with could be met. Configuration management within the modeling phase, such as creating one part to work with multiple configurations, played a vital role in component and part design. Simplistic component design and ease-of-manufacturing keep build costs down as well as providing easily duplicated and replicated designs for future installations. An example of parts designed for multiple configurations are the top connection plates that are welded on top of the columns for beam connections. The plates were designed and modeled with bolt patterns that could accept multiple incoming beams at varying angles at one connecting joint. The angles of incoming beams at these connection points were patterned and mirrored whenever possible, reducing the configurations of the plates that needed to be laser cut in manufacturing.

Critical time and examination was spent in this phase of the platform design trying to satisfy all the requirements and objectives, requiring several revisions and setbacks to overcome. One of the problematic themes that seemed to be recurring in the modeling phase was the constant shuffling and trying to achieve agreement of the placement of the equipment racks and cooling equipment needed. As assemblies frequently require a top-down or bottom-up design plan, one change or different placement of a feature can have a ripple effect throughout the entire assembly. The column placement and beam configuration was dependent on the footprint placement, so final agreement of the column placements drove a large section of the modeling. Future builds and replications of the same platform were also a primary driver in the modeling, so whenever possible, a standardized or uniform part/feature design was incorporated to comply with different international building codes and current antenna pedestal layouts.
3. Structural Analysis/Testing and Incorporating the Resulting Data

The most critical component and driver of the platform design were the strict movement tolerances and restrictions regarding the LNA feed location and mounting. The mandated requirements suggested no greater than forty thousandths of an inch movement in the lateral direction under normal operation and foot traffic, and that required significant structural bracing and careful design construction. It was determined through trial and error modeling and design layout scenarios that the best way to achieve minimal vibration and movement was to isolate the LNA component from the rest of the platform on a “trough” or “mini-platform”, a stand-alone frame. The trough section was fixed at a critical deck height due to the feed cone tolerances with focal length alignment parameters of the mirrors and LNA assembly. As these feed tolerances were the driving parameter and necessary requirement for the rest of the platform, all surrounding structural members had to be isolated from the trough, making the trough itself as well as the main platform less rigid than otherwise built as a single unit. The task of isolating the trough from the main platform was achieved by cross bracing the columns with all-thread turnbuckles and gussets welded to the column ends.

Due to the trough or “mini-platform” being a new feature and build technique used on BWG antennas, it was proposed that specific stress-analysis and structural testing programs were to be used such as FEMAP (Finite Element Modeling and Post-Processing) in conjunction with Nastran, a software code program solver. The primary goal and objective of running structural analysis tests is the data acquisition of the trough’s various behaviors and deflection points under critical movement and load case scenarios. Specific target parameters and load limits were established by the project COGE (Cognizant Engineer) regarding lateral and vertical movement, with 1.00 due to gravity in the z or vertical direction being the limit for LC1 (Load Case 1), and 1.00 in the z direction + 0.30 in the x-direction +0.30 in the y-direction load limits for LC2, and for LC3 1.00 due to gravity +150psf (pounds per square foot) scattered at various locations resembling working personal. These limits are established such that antenna receiving and transmission capabilities as well as critical mirror-signal alignment can be adequately maintained. Based on the results and data produced from the stress analysis testing and simulated load conditions, structural bracing or modifications can be made if necessary while still in the conceptual modeling phase in order to comply with deflection and load case requirements.

4. The fourth main target objective of the project consists of a peer review, which is a detailed presentation and critique of the platform design and model, with all the stakeholders that are involved and interfacing with the platform and equipment. The purpose of the peer review is to establish a comprehensive design and modeling “status” briefing, allowing input and critique from affiliated stakeholders while the platform is still in the design phase. The gathered requirements described in objective one of this report are designed to limit the changes and modifications needed in this phase, in hopes that all functionality and operational goals of the
platform have been met. Specific details and careful inspection of the platform model and design will be shown to the group in the form of a power-point presentation, SolidWorks program analysis, pictures of structural members and connections, as well as interfacing equipment placement and connections. In this stage of the overall scope of the platform design timeline and its relation to the overall antenna structure build timelines and build plans, the goal of the design and modeling is to allow for minor changes and modifications if needed, yet to have the main structure and functionalities in concurrence with the various stakeholders. Some of the topics and features reviewed include:

a. Adequate clearance and work zones around manifolds, cryo racks, and hot and cold skids
b. Allowance of LNA replacement if necessary involving a hoist and “cart” for LNA extraction
c. Seismic bracing per country and international building regulations
d. Load limits and design requirements per the requirements document as well as the Deep Space Network Equipment Design Requirements Document.
e. Access to all waveguide and LNA work zones, as well as all operational work and maintenance zones.
f. HVAC compliance and adequate heating and cooling conditions involved with structural members.
g. RF (Radio Frequency) feed cone tolerances met and observed
h. Electrical clearances

Results

Upon completion of the platform design and 3D modeling, three of the four main target objectives have been met with desired results and pending success of the current platform design at the peer review, the fourth main target objective of the project will have been reached at the conclusion of my session at JPL this summer.

Mandated Requirement Gathering Results

The results of the first phase and objective of the project in gathering the necessary requirements proved to be a valuable time saver and pro-active approach to limiting setbacks with future timelines. The gathering of the requirements also proved to be one of the more challenging aspects, partially due to some of the equipment and design plans not yet finalized by some of the various interfacing stakeholders; an example being the dimensions of the final size of the cooling manifolds and hot and cold skids, which had a direct effect on column placement. A close approximation was made in concurrence with the stakeholder involved with the skids, and it was determined that a twelve inch maintenance zone was sufficient around the skids, resulting in an agreeable column placement configuration.
One of the goals and target objectives in gathering and encompassing all of the necessary requirements was to put it in the form of a releasable document, referred to as the “Feed Platform Functional Requirements for BWG Type 2.” At the present time of the formulation of this report, the said document is in the final stages of approval within the JPL/DSN and NASA document release process, awaiting final release. One of the goals and objectives of having the document released and approved was to minimize future design and build problems and setbacks, by providing a foundation and guideline to follow that covers similar procedures and components.

Conceptual Design and Modeling Results

The bulk of the time spent on the project was in the modeling phase with the detailed and meticulous layout of the column placement and beam configurations. The model had to include and conform to all of the gathered requirements, as well fulfill the functionality and operational goals that the platform was designed for. Maintaining the work clearance and maintenance zones around the signal processing and cooling equipment regarding column placement, as well as adequately supporting the beam spans overhead, required collaborative communication between the various stakeholders involved and was applied to the model. Using SolidWorks 3D modeling software, it was possible to incorporate other models of the interfacing components such as the LNA and cryogenic equipment racks below the platform to adequately represent the future layout and functionality of the platform and interfacing components. The modeling went through many revisions and modifications during this phase, eventually reaching a design that was ready for the stress-analysis testing of the trough, as well as being ready for the peer review. Also created in parallel with the platform model was the documentation and creation of the bill of materials and part description for drawing call-outs and future reference.

Stress-analysis Testing and Results

The results and data acquired from the stress-analysis and deflection tests were extremely beneficial in determining the structural efficiency and safety of the trough, as well as conforming to the parameters and established bounds. The FEMAP analysis when integrated with Nastran solving produced data in the form of color-coded stress and deflection data models, as well as numeric data. From a pass/fail criteria standpoint which was established by the requirements gathered, all three load cases that were analyzed passed. Factors of safety of 3.75 on yield and 5 on ultimate were used to calculate the margin of safety, which came back positive for all three load cases, thus passing the stress side of the analysis. The deflection analysis results also passed in the pass/fail criteria, as is demonstrated in the LC1 slide below, with deflection in the z direction being .038, maintaining the .040 inch allowable. The passing criteria of the stress and deflection analysis demonstrated that the trough or “mini-platform” had been adequately supported and braced, ensuring functionality of the LNA and related components that the trough and platform supports. Similar analysis and testing will be performed on the larger platform upon concurrence and briefs from the peer review.
Peer Review

Pending positive feedback and concurrence from the peer review by all the interfacing stakeholders associated with the platform, the fourth primary target of the project will have been met and the platform will be ready for the next phase of its releasing drawings and construction on the new BWG TYPE-2 antennas. The outcome of the peer review will provide valuable input and direction related to changes and modifications if necessary that need to be made in order to move forward with progress of the platform. With the analysis and testing coming back with positive results and the primary objective of operational stability and functionality of the LNA of which the platform supports, the modifications will most likely be that of minor adjusting and modifications.

The next phase of this project will consist of the platform being subject to the same stress and deflection testing, necessary for safety and operational clearance parameters, and then eventually will be approved for released drawings ready for installation. This platform design was and is intended to be applicable to similar future BWG Type-2 antenna installations and the accurate design and modeling of the platform encompassing the necessary build requirements will ensure sustainability.
Discussion

Upon completion of the project and internship, it is paramount and clearly evident how important proper inter-departmental communication and teamwork is, as well as adequate fact gathering and data acquisition such as the requirements document. The engineering fundamentals that I learned, as well as observed on a daily basis, will be applied to future coursework and internships to follow. One of the noticeable setbacks involved with multi-departmental as well as international builds, is the inevitable delaying of certain timelines and design deadlines. One such example was the changing sizes and configurations of the manifolds and klystron cabinets, which were still under development at the same time as the platform design, and changing sizes and locations of said equipment had a direct correlation to the column placement and in-turn the platform stability, therefore proper communication and often times compromising between departments was necessary. One of the noticeably evident benefits of the project was the direct learning process and oversight of the daily operational activities involved with the mechanical engineering and modeling departments at JPL and NASA, as well as the DSN Goldstone tracking facility. It was an extremely beneficial internship, and I personally feel as though the scope and design of the internship project was created and crafted in an extremely beneficial way, covering the beginning stages of the design and requirement procurement stage all the way through the stress and analysis testing phases of the modeling and design, and then ending with the peer review that includes the completion of the project scope. I found the internship as well as the department of which the project occurred to be extremely intuitive, informative, engaging, and personally would like to come back and follow up this internship with similar and higher level internships learning the next level and stages of the engineering and workforce processes.

Acknowledgments

The credit and primary reason the internship and project were so beneficial and informative, is directly due to my mentor, Jason Carlton, as well as my group supervisor, Neil Bucknam, who went above and beyond in not only trying to parlay the practical applications of the lessons learned, but also making sure that every possible aspect and subject that could be learned and experienced was. These reasons and the phenomenal engineering practices and skills of my mentor Jason Carlton, have taught me an un-measurable amount of knowledge and practical lessons to be applied in future engineering work and hopefully continued internships and transition into the JPL and NASA workforce.

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