

# Intuitive Tools for the Design and Analysis of Communication Payloads for Satellites

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In an effort to make future communications satellite payload design more efficient and accessible, two tools were created with intuitive graphical user interfaces (GUIs). The first tool, the Visual Communication Payload design software, allows designers to graphically design their payload by using a simple drag and drop action with payload components onto an area within the program. Information about each picked component is pulled from a database of common space-qualified communication components sold by commercial companies. Once a design is completed, various reports can be generated, such as the Master Equipment List. The second tool, RF Link Budget Calculator software, is a link budget calculator designed specifically for ease of use. Other features of this tool include being able to access a database of NASA ground based apertures for near Earth and Deep Space communication, the Tracking and Data Relay Satellite System (TDRSS) base apertures, and information about the solar system relevant to link budget calculations. The link budget tool allows for over 50 different combinations of user inputs, eliminating the need for multiple spreadsheets and the errors associated with wrong inputs. Both of the aforementioned tools increase the productivity of space communication systems designers, and have the colloquial latitude to allow non-communication experts to design preliminary communication payloads.

## Nomenclature

<i>CLI</i>	Command-Line Interface
<i>dB</i>	Decibel: logarithmic measure of a ratio
<i>dBW</i>	Decibel relative to 1 Watt
<i>DSN</i>	Deep Space Network
<i>DSS</i>	Deep Space Station
<i>GUI</i>	Graphical User Interface
<i>IDE</i>	Integrated Development Environment
<i>NASA</i>	National Aeronautics and Space Administration
<i>RF</i>	Radio frequency
<i>TDRSS</i>	Tracking and Data Relay Satellite System

## I. Introduction

Space communications system design can be tedious and complicated when using unoptimized design tools. This is certainly the case with previous link budget calculator tools, which rely on complicated and contrived spreadsheet operations. In such operations, information is easily lost and/or miscalculated because of the lack of scalability of the spreadsheet formulas. This, in turn, makes communication payload

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design hard to learn for a newcomer to the field. After a link budget is determined for a NASA mission, physical communication payload components must be picked to create and close this link. This step of the process involves looking up each company’s product and comparing the product’s characteristics with the requirements, which takes a lot of time. Creating a more intuitive user interface for calculating the link budget and picking payload components can reduce any possible error with calculations, obtaining component information, and increase efficiency for experienced communications engineers.

### I.A. Background

In the past, other link budget tools have been created to aid the user in calculating a link budget. They have evolved from CLI programs, to formulae across spreadsheets, to primitive GUI programs. For example, an older optical link budget calculator tool created by Emily Kukura previously used command line queries as shown in Figure 1.

```

*****
The Optical Channel
*****
          Transmitter/Receiver Range (km):      44087.7
          Atmospheric Losses (dB):              0
*****
The Optical Receiver
*****
          Satellite Receiver Diameter (cm):      7
          Satellite Receiver Obscuration Diameter (cm): 2
          Satellite Receiver Optical Losses (dB): 1
          Focal Plane Losses (dB):              .5

```

Figure 1. Command Line Link Budget Program

Even more, a satellite communications toolbox has been created by Mathworks to also help calculate basic characteristics for a satellite link. It allows a user to use predefined functional blocks to create graphs for carrier to noise power. However, using this toolbox involves substantial monetary purchase of MATLAB software and time to become acquainted with the MATLAB software and programming language.

A link budget is a first step for communications payload designers and potential users to determine if a wireless transmitter and receiver can “close” a link, meaning if a wireless signal has enough power at the receiving end such that its information is retained and readable.<sup>5</sup> The link budget is a way for designers and users to obtain a preliminary understanding of the dynamics which will be involved in drafting the communications systems of a mission.

Naively, one could say a link budget equation appears:

$$Received\ Power = Transmitted\ Power + Gains + Received\ Area - Losses \quad (1)$$

Eq. (1) is a simplistic way of showing the idea behind calculating a link budget. Received and Transmitted Power is measured in *dBW*, while Gains, Received Area, and Losses are measured in *dB*.

This equation becomes far more complex when one considers how to calculate each term. For example, how one determines the gain of DSS 27 based on its inclination, frequency, and surrounding wind from a cursory reading of the DSN Telecommunications Link Design Handbook easily demonstrates this.<sup>3</sup> So, the difficulty/complexity in these calculations is the primary motivation for the creation of a user-friendly program which aides in link budget calculation.

Once the link budget is finalized, a rough sketch of the generic components needed for the payload is made to obtain an estimate of the power and mass to meet the requirements of the NASA mission. Figure 2 shows a generic communication payload for a single fault relay communication system. The switches switch in redundant components if the primary one fails. The diplexers in Figure 2 allows the same antenna to transmit on one frequency band and receive on a different one. The use of up and down converters allow a communication relay to receive and transmit signals between two different communication sources.

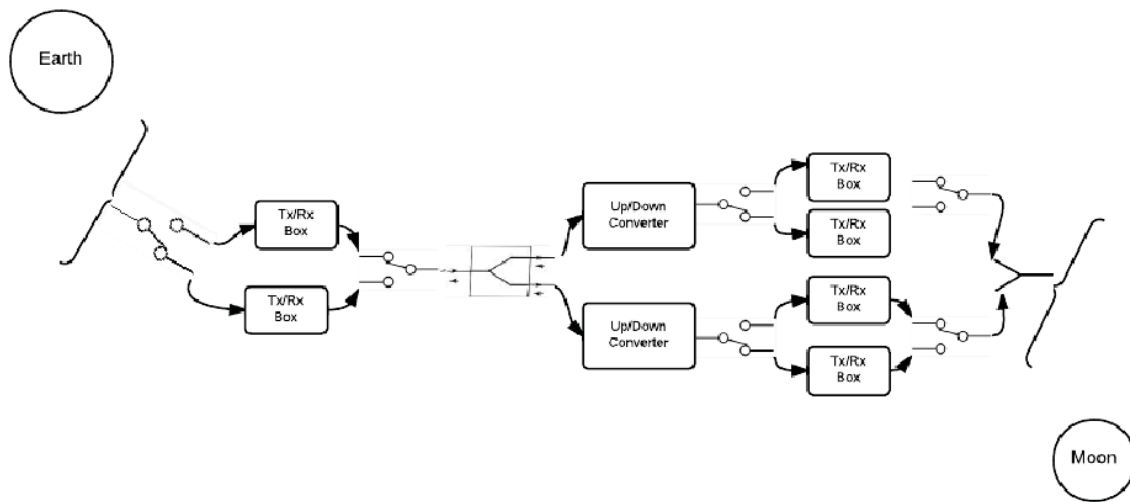


Figure 2. Schematic of  $K_u$ -S/ $K_a$  Band Space-Based Relay Communication Payload

After determining the general components needed, the more tedious part of the process begins as the components either need to be custom-made or bought from a commercial company. Space-qualified components can be limited in variety as they can be made for specific missions, while others can be more generic as waveguides and switches. Looking up those components online, calling the companies for more detailed specifications, and browsing through physical catalogs takes time. Integrating all the information into one place would be more efficient, and a database is perfect for this. However, once all of these components are picked, the important characteristics of each component are recorded usually into an Excel document to get an estimate of the mass, power, and cost requirements for the mission. These steps are used each time a communication payload is designed, and going through them takes time. However, if all of the information is saved and easily accessible, the amount of time for this part of the design process can be greatly reduced.

## II. Design Philosophy

The idea behind the two tools was to create interfaces which were user friendly for experts and newcomers to communication payload design. To get a better idea of the program's appearance, Visual Studio was chosen to aid in creating and designing these tools. Visual Studio is an IDE for Visual Basic which allows the user to design the appearance of the program in situ. With it, common objects such as buttons, radio buttons, textboxes, and combo boxes can easily be moved, resized, and programmed for events. Visual Basic was chosen as the language to program in as it is relatively easy to learn, and versatile when compiled across Microsoft products (as NASA most commonly utilizes).

To choose the kind of databases to use for the RF Link Budget Calculator and Visual Communication Payload design tool, the portability of each program had to be considered. Excel spreadsheets were used in the link budget tool to store the ground antenna information since it was much easier to update and move the database from any computer. The MySQL database was used for the communication payload design software, because it is open-source and can be installed on any computer. The database of all commercial payload components contains pictures of each component, leading to a larger sized database, so an Excel spreadsheet database is not the best implementation for this program. Microsoft Access was also a strong consideration as a database since NASA uses Microsoft products, but the open-source MySQL was chosen since it could store images. This program could be implemented with an Access database for wider use within NASA, but MySQL allows any person to be able to use this program easily.

The programs were designed to be modular - so that future developers would be able to remove and/or insert modules and classes as needed.<sup>2</sup> This is more practical for the payload design tool because in the future new components will be designed for problems that have not yet been realized. The modularity of the program will allow these components to be easily added. The link budget calculator can also be reprogrammed to allow for greater precision in its various calculations, without rewriting major portions of its codebase.

### III. Design Implementation

Stepping through the process, for the Communication Payload Design Tool, there were several interfaces that needed to be created: main interface, inputting component details, and generating the report form. The main interface is shown in Figure 3.

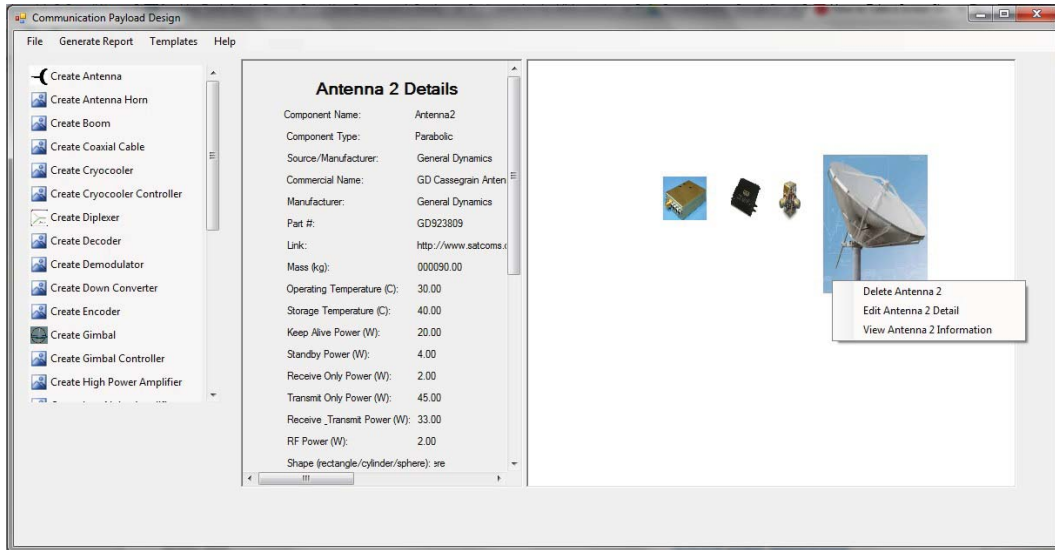


Figure 3. Main interface of Communication Payload Design Tool

The left panel allows the user to create the components onto the white design area on the right. Generic components can be picked on the communication payload design tool and arranged in the certain configuration. As each component is added to the design area, the user can pick from a list of commercially available components from a database that the database automatically retrieves as shown in Figure 4.

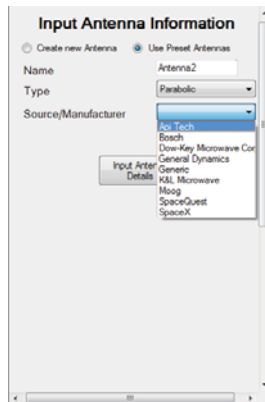


Figure 4. List is pulled from a database

The database stores all relevant information for each component such as mass, power, operating temperature range, and dimensions as seen in the middle panel in Figure 3. When someone right clicks onto the component, it gives the user options to delete, edit, or view the component's information, also shown in Figure 4.

The database skeleton was set up and populated with a few example components as shown in Figure 5:

Name	Image	Manufacturer	Part #	Link	Mass (kg)	Operating Temperature	Storage Temperature	Keep Alive Power	Standby Power	Receive Only Power	Transmit Only Power
GD Cassegrain Ant...	C:\NASA\Database RF...	General Dyn...	GD92...	http://www.satcoms.com...	000090.00	30.00	40.00	20.00	4.00	2.00	45.00
Parabolic Antenna 1	IMAGE	Generic	P1-JK...	IMAGE	000009.00	50.00	10.00	20.00	IMAGE	IMAGE	IMAGE
Parabolic Antenna 2	IMAGE	Generic	P2-93...	IMAGE	000025.00	60.00	78.00	99.00	IMAGE	IMAGE	IMAGE
IMAGE	IMAGE	IMAGE	IMAGE	IMAGE	IMAGE	IMAGE	IMAGE	IMAGE	IMAGE	IMAGE	IMAGE

Figure 5. Sample Component for Parabolic Antennas

An overview of the features of the Communication Payload Design Tool is located in Appendix A.

Likewise, for the Link Budget Calculator Tool, several interfaces were needed: a main interface, a system noise interface, a solar system body distance selection interface, and a antenna database interface.

The main interface is shown in Figure 6.

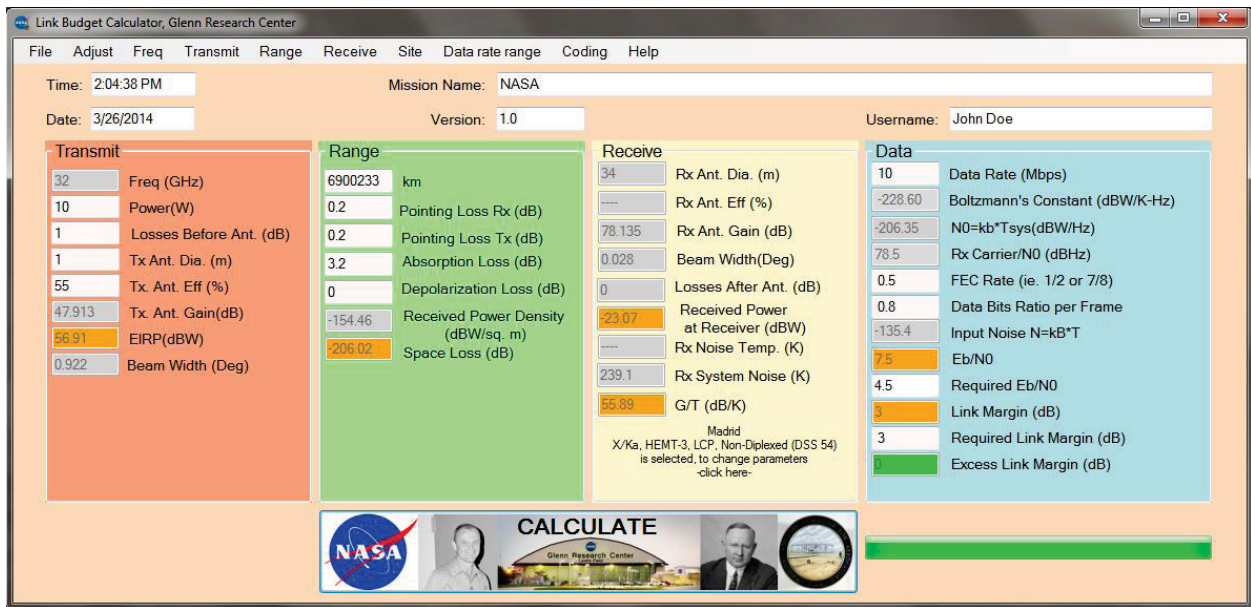


Figure 6. Main interface of link budget calculator

The four colored boxes each denote a general domain of discussion for what will be entered/returned. The leftmost is for transmitting information, the next for range information, then for receiving information, and finally for data information. In each box there are some fields which are open for input, and some blocked to prevent error (depending upon which options are chosen for a particular calculation). Prior to running a calculation, each enabled input is checked to be sure it is numeric and in the correct range.

To allow the user the option of calculating system noise temperature directly, an interface for calculating the system noise temperature was added as seen in Figure 7.

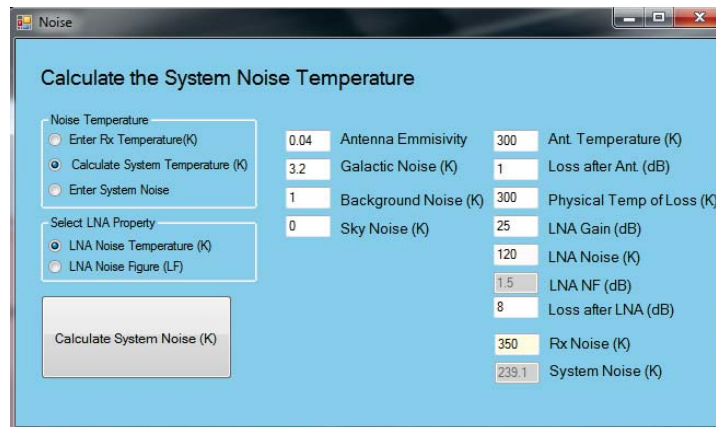


Figure 7. System noise temperature calculator interface



One can see the various different parameters which can be taken into account when calculating system noise temperature. The program allows the user to calculate the system noise temperature three ways: entering the system noise temperature directly, entering the receiver noise temperature along with backgrounds and antenna temperatures, or by entering the backgrounds and antenna temperatures above and the low noise amplifier gain and noise temperature, and the losses after the LNA.

The solar system body distance calculator is shown in Figure 8.



Figure 8. Solar system body distance calculator interface

This interface allows a user to select either a close, medium, or far approach from a solar body and obtain a range without leaving the program, as the data is preprogrammed in.

Finally, the antenna database interface for DSN sites is shown in Figure 9. It allows the user to select the site, the frequency band used, the antenna, the elevation angle, and the cumulative distribution.

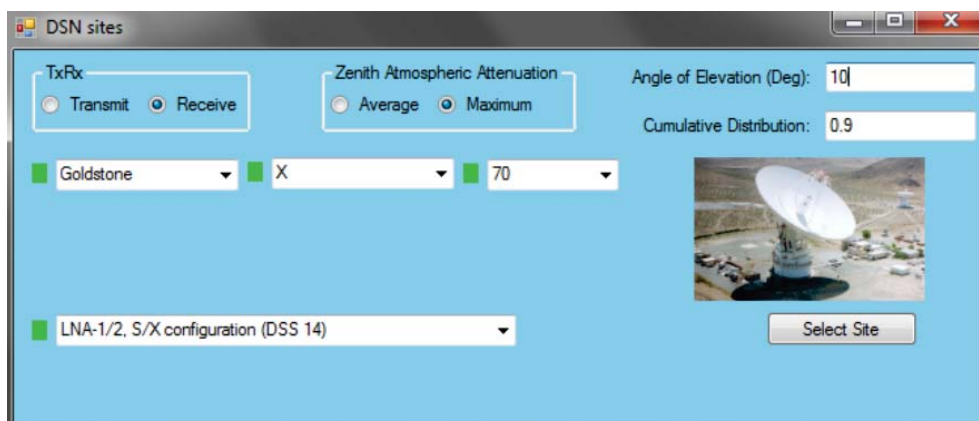


Figure 9. Antenna database interface

The antenna database interface greatly simplifies the process of obtaining data on a particular antenna such as what power, frequency, and gain the antenna is able to transmit/receive. Usually, one must leaf through a telecommunications design handbook to obtain this information, but the program was designed to automatically integrate all of the antenna data from the Excel database into this interface.

## IV. Results

After using the link budget calculator tool to calculate a link, the results of each parameter that goes into calculating the link can be saved as an Excel or pdf file. A sample of the pdf output is shown in Figure 10.

Link Budget	Data	Enabled?	ARGB Color
Mission Name:	NASA	TRUE	-1
Time:	1:59:30 PM	TRUE	-1
Date:	3/26/2014	TRUE	-1
Version:	1	TRUE	-1
Username:	John Doe	TRUE	-1
<b>Transmit</b>		<b>TRUE</b>	<b>-1</b>
Freq (GHz)	2.295	FALSE	-2894893
Power(W)	10	TRUE	-1286
Losses Before Ant. (dB)	1	TRUE	-1286
Tx Ant. Dia. (m)	1	TRUE	-1286
Tx. Ant. Eff (%)	55	TRUE	-1286
Tx. Ant. Gain(dB)	25.026	FALSE	-2894893
EIRP(dBW)	34.03	FALSE	-23296
Beam Width (Deg)	12.856	FALSE	-2894893
<b>Range</b>		<b>TRUE</b>	<b>-1</b>
Distance (km)	1482053	TRUE	-1286
Pointing Loss Rx (dB)	0.2	TRUE	-1286
Pointing Loss Tx (dB)	0.2	TRUE	-1286
Absorption Loss (dB)	0.2	TRUE	-1286
Depolarization Loss (dB)	0	TRUE	-1286

Figure 10. A portion of the results given by the link budget calculator's pdf output

The same goes with the Visual Communication Payload Design Tool:

3/15/2014  
12:46:43 AM

Project Name: **NASA Example Mission**

Project Description: **The purpose of this mission is to allow a link from Ku band from ground to Ka/S band out in GEO.**

Developers: **Michael Culver, Christine Soong, Joe Warner**

Figure 11. Project Description of Design Report


The Visual Communication Payload program will generate a report that always consists of the project description cover page as shown in Figure 11.

NASA Example Mission	Quantity	Mass (kg) Per Item	% Mass Margin	Total Mass (kg)	TRL	Power Modes						Operating Temperature Range	Shape	Dimensions (cm)			
						Keep Alive (W)	Standby (W)	Receive Only (W)	Transmit Only (W)	Receive & Transmit (W)	RF (W)		rectangle	Cylinder	Sphere	x/d	y/d
Same Freq	1	0.1	20.00%	0.12	8						0		rectangle	0.07	0.15	0.07	0.000735
Antenna2	1	90	20%	108	3	20	4	2	45	33	2	30	sphere	2	2	2	4.18879
Gimbal3	1	4.99	20%	5.988	9	22							rectangle	0.222	0.127	0.127	0.003581
Receiver4	1	0.04	20%	0.048	10			0.03				-10A°C to +60	Rectangle	0.058	0.039	0.015	3.39E-05
<b>Total</b>				<b>114.036</b>													

Figure 12. MEL/PEL Equipment List of Design Report

In addition, the second page of the report contains a table of the relevant characteristics for each payload component for a mission, which is often the mass and power equipment list as shown in Figure 12.

Component Name	Antenna2	Receive & Transmit Power (W)	33
Mass (kg)	90	RF Power (W)	2
Technology Readiness Level	3	Operating Temperature (C)	30
Keep Alive Power (W)	20	Shape (rectangle/cylinder/sphere)	sphere
Standby Power (W)	4	x/d/d (m)	2
Receive Only Power (W)	2	y/d/z (m)	2
Transmit Only Power (W)	45	z/d/d (m)	2



Component Type	Parabolic	Source/Manufacturer	General Dynamics	Commercial Name	GD Cassegrain Antenna
Manufacturer	General Dynamics	Part #	GD923809	Link	<a href="http://www.satcoms.com/general-dynamics-vertex-model-111m-only-band-port-cassegrain-antenna-p-1595.html">http://www.satcoms.com/general-dynamics-vertex-model-111m-only-band-port-cassegrain-antenna-p-1595.html</a>
Storage Temperature (C)	40	Radiation Hardness	1	Diameter (m)	11.1
F/D (Focal Length to Diameter)	1	Emissivity	0	Frequency 1 (GHz)	3.63
Efficiency 1 (%)	60	Gain1 (dB)	52	Frequency 2 (GHz)	4.2
Efficiency 2 (%)	60	Gain 2 (dB)	51.9	Frequency 3 (GHz)	7.25
Efficiency 3 (%)	60	Gain 3 (dB)	57.2		

Figure 13. Component Description of Design Report

Then, the rest of the report will contain detailed descriptions of each component such as in Figure 13. Each page is one component, and within each page, a picture is in the top right corner while the relevant characteristics are in the top left table. Then the rest of the components characteristics are in the main table.

## V. Conclusions

The creation of these two tools will have shortened the pre-design process for a NASA by performing all the functions needed for a designer as well as making it easy to use for the designer. The link budget calculator tool calculates scenarios with different parameters such as the link between Earth and weather-observing satellites or transmitting images from rovers on the Jupiter moon, Io, back to Earth. Then the calculator saves these different scenarios in a way so they are easier to compare while integrating relevant



information into the program. Having all the information in one program allows the link budget analysis to go more smoothly instead of having to look up the radius of a ground station antenna or distance between two planets. The communication payload tool will shorten the the process of designing the payload by integrating all the information of commercial components in one place, instead of looking up each and every component through separate catalogs. Also, it allows the user to create a visual representation of their design with an intuitive main interface. These two tools are or will be used for NASA missions in communication payload design, and these tools in the future can be expanded on to include more features such as connecting the link budget calculator tool together with the communication payload design software to see what components are available to meet the requirements of the specific mission.

## Appendix

### Appendix A

**Option for user to delete, edit, and view component details**

### Visual Communication Payload Design Software

By: Christine Soong

**Objective:** Support rapid payload design for user by having all relevant information of components in one central location

**Commercial Component Option:**

- Allows user to select from a list of commercial parts stored in MySQL database
- Once a component is selected, program will retrieve all details of the component from the database & automatically fill it in

**User-Defined Component Option:**

Allows user to define their own component and fill in the characteristics associated with it

**Commercial Component Option:**

- Allows user to select from a list of commercial parts stored in MySQL database
- Once a component is selected, program will retrieve all details of the component from the database & automatically fill it in

**General Features:**

- Developed through VB.Net on Visual Studio 2012
- Connects to MySQL database of component information
- Graphical User Interface:**
  - Create as many components as needed
  - Arrange components to user's configuration
  - Resize drawing area & individual components
  - Contains premade configuration of basic payload designs
- Output:**
  - Export details of all components onto Excel & Text File
  - Exports screenshot of current configuration
  - Can save current configuration & reopen later

**MySQL Database:**

- Contains tables of components & their details: antennas, diplexers, gimballs, receiver, transmitters, transceivers, up/down converters
- Can enter component information anytime & program will automatically retrieve the list
- Can associate an image for a specific component

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