

## **LABWORK: SATELLITE ORBITS AND LINK BUDGETS**

This course contains some “virtual” labwork conducted in industry-standard satellite communications simulation software. The aim of this labwork is to give students some insight into orbits and link budgets, reinforcing some of the lecture material.

The labwork uses **Satellite Toolkit (STK)** produced by Analytical Graphics Inc. This software is used by all the major space organisations for mission planning and design. It normally retails at about £50,000 per licence, but AGI has very kindly issued student licences to the University of Wales, Newport, for use on this course.

During this labwork students will be given a series of experiments to perform using STK. For each experiment the student will be asked to:

- Create scenarios and objects in STK, following a set of instructions.
- Record data from STK reports, screenshots and graphs.
- Analyse the data.
- Answer questions about the scenario.

Students are required to submit the answers to these questions by **24<sup>th</sup> January 2011**

For each experiment the student is required produce a short report containing:

- A brief description of the method
- The results, including any tables and graphs.
- Any analysis of the data
- The conclusions from the experiment, in the form of answers to the questions for that experiment.

Note that this is an individual exercise. Marks will be deducted if there are signs of collusion.

STK lets you save screenshots and graphs as images to include in your report. STK can produce some very large reports, some of which comprise tens or even hundreds of pages. Marks will be allocated for the quality of the report; there are no bonus marks for the number of pages.

You will find the course textbook, Maral and Bousquet, useful for answering some of the questions.

**Note that the software licence will expire on 31 Dec 2010. If you wish to use the software beyond that date you MUST request a licence before 10 Dec 2010, otherwise you'll have to wait until after the Christmas break.**

# Getting Started

## Installing STK

The first task is to install STK. This is a standard windows installation so it should present no problems.

- Insert the “Installation” CD and ensure that the box titled “STK with STK Engine V9” is checked. Leave all other boxes unchecked.
- Run the installation, choosing defaults.

## Obtaining a Licence

Run the “Licence Manager” in the ”AGI Support Tools” folder. This will generate a window with the following content at the bottom of the page:



Email the following information to [phil.charlesworth@googlemail.com](mailto:phil.charlesworth@googlemail.com)

- Your name
- Your PC’s operating system (Windows XP or Vista)
- The contents of the Host ID and Registration ID fields.

Your computer's Host ID (aka Physical or MAC Address) is a unique identifier based on your computer’s network adapter (NIC) card.

I’ll generate an educational licence which will be automatically emailed to Dr Singh-Baicher. He will forward the email and licence it to you. This might take 24 hours.

When the licence arrives restart “Licence Manager”. Click the “help” button and you’ll find instructions for installing the licence.

## Getting Started

It is strongly suggested that students who have no prior experience of STK have a look at the training videos on the AGI website. You’ll need to register with the website first, then watch the videos at <http://www.agi.com/training/video.cfm>.

# **Experiment 1: Properties of the Geostationary Orbit**

## ***Method***

### Create the Scenario

Open STK, and create a new scenario called “GEO\_properties”

Set the analysis period to show the start time as **1 Aug 2010 00:00:00.000 UTCG** and the end time as **1 Nov 2010 00:00:00.000 UTCG**. The central body is the earth.

### Create a Satellite

Use the **Orbit Wizard** to create a satellite with orbit type **geosynchronous** and subsatellite point 0 degrees, inclination 0 degrees. Click **OK** to close the orbit wizard.

### Change the Orbit Properties

Double click on the satellite in the **Object Browser** window, opening a page with the satellite’s orbital elements. Set the **Propagator** to **J2 Perturbation**. This treats the Earth and the satellite as point masses but takes account of the Earth’s oblateness.

If required, set the epoch time to **1 Aug 2010 00:00:00.000 UTCG**.

Press **OK** to close the window.

### Eclipses

Reset the scenario time to the start using the red arrow.

Change to the **3D window**, and use the **View From/To** set the view to and from the satellite. Select **Unconstrained Rotation** and deselect **Track Ball** to get rid of the circle onscreen. click **OK** to close the window.

Pressing the left mouse button, rotate the satellite until you’re looking at the Earth from behind the satellite.

Set the **Step Time** to 600 sec using the blue double arrows.

## ***Results***

Run the scenario from **1 Aug 2010 00:00:00.000** to **1 Nov2010 00:00:00.000** paying particular attention to the change in position of the Sun as each day passes. You can see during this period that the sun is occasionally hidden behind the Earth, causing the satellite to go into eclipse. Record the dates of the first and last eclipses, and the number of eclipses

Date of first eclipse	
Date of final eclipse	
Number of eclipses	

Select the satellite in the **Object browser** window. Press the **Report and Graph manager** button and scroll down to the **Eclipse Times** report and graph. Open them

both. Note that you can save graphs as images if you want to include them in your report.

### ***Analysis Task 1***

Use the data, pictures and graphs to answer the following questions.

- 1.1. On which dates do the first and last eclipses of this “season” occur?**
- 1.2. From the graph, how many eclipses occur during this period?**
- 1.3. How does the duration of each eclipse change during this period?**

Use the course textbook, Maral and Bousquet, answer the following Questions about eclipses:

- 1.4. How many eclipse seasons are there each year?**
- 1.5. What time of year do they occur?**
- 1.6 Which two satellite systems are affected significantly by the eclipse?**

Save and close this scenario.

## Experiment 2: Comparing Orbits

### **Method**

#### Create the Scenario

Create a new scenario and title it “Comms\_properties”. Accept the default start and end times.

Set the analysis period to show the start time as **1 Nov 2010 00:00:00.000 UTCG** and the end time as **2 Nov 2010 00:00:00.000 UTCG**

#### Create a GEO satellite

Open **Insert STK Objects** and use the **Orbit Wizard** to create a geosynchronous satellite with **Subsatellite Point** -30 degrees. Rename the satellite “**GEO**”

#### Create a HEO Satellite

Open **Insert Object** and use the **Orbit Wizard** to create a satellite in a Molniya orbit. Set the **Apogee Longitude** to -10 degrees. Rename the satellite **HEO**

#### Create a LEO Satellite

Open **Insert Object** and use the **Orbit Wizard** to create a satellite in a circular orbit at an altitude of 500km. Set its **Inclination** to 70 degrees. Rename the satellite **LEO**

#### Create a Facility

Add a Facility selected from the city database, city name **Newport**, country name **United Kingdom**.

### **Results**

#### GEO Access, Azimuth, Elevation and Range

Select the **GEO** satellite in the **Object Browser** window.

Press the **Access Tool** button in the STK Tools toolbar.

When the **Access** window opens select **Newport** and press Compute.

Create an **Access Report** and note down:

Number of Accesses	
Total Access Duration	

Return to the **Access** window and create an Azimuth Elevation and Range (**AER**) graph.

Save the graph for your report, calling it **AER GEO**.

#### HEO Access, Azimuth, Elevation and Range

Select the **HEO** satellite in the **Object Browser** window.

Press the **Access Tool** button in the STK Tools toolbar.

When the **Access** window opens select **Newport** and press Compute.

Create an **Access Report** and note down:

Number of Accesses	
Total Access Duration	
Longest Access	
Shortest access	

Return to the **Access** window and create an Azimuth Elevation and Range (**AER**) graph.

Save the graph for you report, calling it **AER HEO**.

### LEO Access, Azimuth, Elevation and Range

Select the **LEO** satellite in the **Object Browser** window.

Press the **Access Tool** button in the STK Tools toolbar.

When the **Access** window opens sect **Newport** and press Compute.

Create an **Access Report** and note down:

Number of Accesses	
Total Access Duration	
Longest Access	
Shortest access	

Return to the **Access** window and create an Azimuth Elevation and Range (**AER**) graph. Save the graph for you report, calling it **AER LEO**.

## ***Analysis Task 2***

Use the data and graphs to answer the following questions.

**2.1 Over a 24 hour period, what percentage of the time is each type of satellite visible to the Newport ground station?**

**2.2 How many HEO satellites would be required to give continuous 24 hour visibility to the Newport ground station?**

**2.3 Explain why the LEO satellite is visible so infrequently from Newport, and for such short periods.**

Save and close this scenario.

## **Experiment 3: Communications from Orbits**

### ***Method***

Open the scenario “Comms\_properties”.

#### Add Transmitters and Receivers

Select each of the satellites GEO, HEO and LEO in the Object Browser window. Use the Insert Object button to add a transmitter to each satellite. Name them **GEO\_Tx**, **HEO\_Tx** and **LEO\_Tx**.

Add a receiver to the ground station at Newport. Name it **Newport\_Rx**.

Close the “Insert STK Objects” window.

#### Configure Transmitter

Double click on GEO\_Tx to open its properties window.

In the “Model Specs” tab set the EIRP to 40 dBW and the Frequency to 14.5 GHz.

Click on the Modulator” tab, and set the “Modulation Type” to QPSK, and the “data rate” to 10 Mbit/s.

Click on **OK** to close the window.

Repeat this step for HEO\_Tx and LEO\_Tx.

#### Configure Receiver

Double click on Newport\_Rx to open the properties window.

Set the G/T to 20 dB/K.

Click on **OK** to close the window.

### ***Results***

#### Link Budgets & AER

Right click on the receiver at Newport and select the Access Tool.

Expand the GEO satellite object to show the transmitter, select the transmitter, and press **Compute**

In the reports section press the **AER** button to generate an Azimuth, Elevation and Range report.

In the Reports section press the **Report and Graph manager** button. Scroll down the list of reports and graphs and select **Link Budget-Detailed**. Press **Generate** to generate a detailed link budget

Repeat this for the HEO and LEO satellites. You should end up with six reports: three AER and three Detailed Link Budget reports.

Inspect the Link Budget reports and, for each orbit type, find the maximum and minimum values of the Free Space Loss and record them in the table below. Note the time at which this occurs.

Inspect the AER report. Using the time information from the previous step, find the range at which the maximum and minimum Free Space Loss occurs.

	GEO	HEO	LEO
Max Free Space Loss (dB)			
Time of max			
Range at max (km)			
Elevation at max (degrees)			
Min Free Space Loss (dB)			
Time of min			
Range at min (km)			
Elevation at min (degrees)			

### ***Analysis Task 3***

**Use the data to answer the following questions:**

**3.1. Describe the relationship between range and path loss. Use the data to quantify this relationship.**

**3.2 For HEO and LEO, explain the relationship between range, elevation and Free Space Loss.**

Save and close this scenario.

## Experiment 4: Availability of Usable Signal

### **Method**

Open the scenario “Comms\_properties”.

#### Access Periods

Right click on the receiver **Newport\_Rx** and select the Access Tool.

Expand the GEO satellite object to show the transmitter **GEO\_Tx**, select the transmitter, and press **Compute**

In the reports section press the **Access** button to generate an Access report.

Repeat this for the HEO and LEO satellites. You should end up with three access reports.

### **Results**

From the Access report, establish the total time for which the signal is available. Record the times below in the “no constraints” rows of the table.

		Number of Accesses	Total Time Available (sec)	Percentage of 24 hours
GEO	No constraints			
	With constraints			
HEO	No constraints			
	With constraints			
LEO	No constraints			
	With constraints			

#### Applying Constraints

STK allows you to put constraints on the signal so you can analyse when the signal exceeds the required performance for your system. In this experiment we’ll assume that a good signal requires an Eb/No of greater than 12 dB and an elevation angle of better than 10 degrees.

Go to the **Object Browser** window and double click on the **Newport\_Rx** to open it.

In the receiver section click on **Constraints – Basic** and set the minimum elevation angle to 10 degrees.

Click on **Constraints – Comm** and set the minimum Eb/No to 10 dB.

Press the OK button to save these values and close the window.

### Access Periods

From the Access report, establish the total time for which the signal is available. Record the times in the “with constraints” rows of the table.

### ***Analysis Task 4***

**4.1 Explain why the constraints reduced the time for which a usable signal was available (You might gain additional insight by examining AER and Link Budget reports)**

Save and close this scenario.

## **Experiment 5: Satellite Frequencies**

### ***Method***

#### Create the Scenario

Create a new scenario and title it “Comms\_frequencies”.

Set the analysis period to show the start time as **1 Nov 2010 00:00:00.000 UTCG** and the end time as **2 Nov 2010 00:00:00.000 UTCG**

#### Create a GEO satellite

Open **Insert Object** and use the **Orbit Wizard** to create a geosynchronous satellite with **Subsatellite Point** -30 degrees. Rename the satellite “**GEO**”

#### Create a Facility

Add a Facility selected from the city database, city name **Newport**, country name **United Kingdom**.

#### Set Rain and Atmospheric Absorption Models

In the **Object Browser** window double click on the scenario object.

Select the tab **RF-Environment**.

Tick the box **Rain Model – Use** and select the model ITU-R P618-9.

Tick the box **Atmospheric Absorption Model – Use** and select the model ITU-R P676-5.

Click OK to apply these settings and close the window.

#### Add Transmitters and Receivers

Select the satellite in the Object Browser window. Use the Insert Object button to add three transmitters to the satellite. Name them **Transmitter1**, **Transmitter2** and **Transmitter3**.

Add three receiver to the ground station at Newport. Name them **Receiver1**, **Receiver2** and **Receiver3**.

Close the “Insert STK Objects” window.

#### Configure Transmitters

Double click on each Transmitter to open the window.

In the **Model Specs** tab set the transmitter power to 40 dBW.

Click on the **Modulator** tab, and set the **Modulation Type** to QPSK, and the **data rate** to 10 Mbit/s.

Set the transmitter frequencies as follows:

Transmitter 1: 4 GHz (C band)

Transmitter 2: 12 GHz (Ku band)

Transmitter 3: 21 GHz (Ka band)

Click on **OK** to close the windows.

#### Configure Receivers

Double click on each Receiver to open the window.

Set the G/T to 20 dB/K.

Deselect **Auto Track** and set the receiver frequencies as follows:

Receiver 1: 4 GHz (C band)

Receiver 2: 12 GHz (Ku band)

Receiver 3: 21 GHz (Ka band)

Click on **OK** to close the window.

### Establish Comms Channels

Select Receiver1 in the Object Browser window. Press the **Access** button and select Transmitter1 from the satellite. Press **Compute**.

In the Reports section press the **Report and Graph manager** button. Scroll down the list of reports and graphs and select **Link Budget-Detailed**. Press **Generate** to generate a detailed link budget.

Repeat this for the other two transmitter-receiver pairs. You should end up with three detailed link budgets:

Receiver1-Transmitter1 (4 GHz)

Receiver2-Transmitter2 (12 GHz)

Receiver3-Transmitter3 (21 GHz)

## **Results**

From the link budgets, record the values of free space loss, atmospheric loss and rain loss at each of the frequencies.

	4 GHz	12 GHz	21 GHz
Free Space Loss (dB)			
Atmospheric Loss			
Rain Loss			
Total Loss			

## **Analysis Task 5**

**From the data and the link budgets answer the following questions**

**5.1 Does free space loss increase or decrease with frequency.**

**5.2 Does rain loss increase or decrease with frequency**

**5.3 Does atmospheric loss increase or decrease with frequency**

**5.4 Which is the most significant impairment to propagation: Atmospheric absorption or rain loss.**

Save and Close the scenario.

## **Experiment 6: Modulation**

### ***Method***

#### Create the Scenario

Create a new scenario and title it “Comms\_frequencies”.

Set the analysis period to show the start time as **1 Nov 2010 00:00:00.000 UTCG** and the end time as **2 Nov 2010 00:00:00.000 UTCG**

#### Create a GEO satellite

Open **Insert Object** and use the **Orbit Wizard** to create a geosynchronous satellite with **Subsatellite Point** -30 degrees. Rename the satellite “**GEO**”

#### Create a Facility

Add a Facility selected from the city database, city name **Newport**, country name **United Kingdom**.

#### Add Transmitter and Receiver

Select the satellite in the Object Browser window. Use the Insert Object button to add a transmitter to the satellite and name it **Transmitter1**.

Add a receiver to the ground station at Newport and name it **Receiver1**.

Close the “Insert STK Objects” window.

#### Configure Transmitter

Double click the Transmitter to open the window. In the **Model Specs** tab set the transmitter power to 40 dBW. Click on the **Modulator** tab, and set the **Modulation Type** to QPSK, and the **data rate** to 10 Mbit/s.

Click on **OK** to close the windows.

#### Configure Receiver

Double click on the Receiver to open the window. Set the G/T to 20 dB/K.

Click on **OK** to close the window.

### ***Results***

Select Receiver2 in the **Object Browser** window. Create a link budget report and note down the values of Eb/No and BER.

Repeat the above steps for BPSK, 8PSK, 16PSK and FSK. Record the results in a table. (Tip: You can refresh a report by selecting it and pressing F5 instead of opening a new report).

	Bandwidth	Eb/No	BER
QPSK			
BPSK			
8PSK			

16PSK			
FSK			

### ***Analysis Task 6***

Use the data to answer the following questions:

- 6.1 Which modulation scheme (or schemes) would be the best to use on a bandwidth-limited satellite channel? Why would you choose this modulation scheme?**
- 6.2 Which modulation scheme (or schemes) would be the best to use on a power-limited satellite channel? Why would you choose this modulation scheme?**
- 6.3 Explain why the BER is different for QPSK, 8PSK, 16QAM.**
- 6.4 Which of BPSK and FSK gives the better error performance? Explain your answer.**