Lunar Radio Telescope

Project report submitted to Prof. Durgin

By

Mohammad Omer GT ID # 902129062

TABLE OF CONTENTS

1. Overview of the project report and highlights

Lunar radio telescope was the project assigned for this year's satellite communication class. The project report below outlines the complete development plans of a gear that can be used to achieve this task. It is obvious that a mission of this proportion cannot be completely detailed out in a report of this magnitude, however maximum effort has been made to highlight the systems to be deployed down to the circuit level details of individual components which are crucial to the success. Several resources have been used to prepare the material, and these primarily include NASA reports and projects based on space observatories around the world. We present the breakdown of the repot below.

1.1 Breakdown of the contents

The contents presented can be broadly classified into the following areas. It is important to note that we present the complete design details in a top down fashion, whereby we begin from the very large integrated setup and descend to smaller and intricate details. In this case we begin from celestial launching, planning and geometry to individual electronic components of the system. The progression is underlined below

1.1.1 Satellite system geometry

In the first part, the mission link establishment is detailed out. This give the specifics of how will the lunar observatory communicate with the earth data center. So the entire link for the same is setup. A link design based on a relay satellite is proposed. The design of the link is taken from University of Washington NASA AMITUS project, whereby a similar setup like this project but based on an optical telescope was proposed. This link has been tailored to the requirements of our radio telescope and the associated orbital details have been worked with the help of an orbital profiler available open source from the web.

1.1.2 Communication system design / simulation

The communication system has been designed for the relay link between the observatory and the earth via satellite. This link has to be a duplex link both ways, relaying data and commands to and fro. The link specifications were worked out in accordance with the ARECIBO observatory and then the top level link design was done is MATLAB / SIMULINK. In this regard, a demo program for satellite link calculation and subsystem design was employed. The demo structure has all the necessary constituents of a complete receiver in place. Those were modified to achieve the link performance and the modulation type required by our scheme. The demo system used 16 QAM modulation setup which was changed to QPSK as needed by our design and the link parameters were tuned to the noise temperatures encountered in the region of the moon. Constellation simulations and detailed spectrum analysis were performed from the simulation setup.

Link budget analysis is an integral part of the link too. The detailed link budget analysis was performed using link performance software available online, which cannot be downloaded. Therefore link performance charts calculated online have been referenced in the report in appropriate places.

1.1.3 Telescopic front end circuits and systems

The front end circuits for capturing RF energy in the desired frequency band is a very important part of the entire system and the one that needs a careful engineering. The telescopes desired region of capture calls for high performance analog circuitry which can have all the hallmarks of low noise and high gain. The third part of the report, presents a possible solution which can be used. Although it is built around a lot of off the shelf components, yet some important parts of circuit have been manually designed. The primary architecture is the one used in an actual radio observatory, built on experimental basis by university of Calgary space sciences school.

1.2 Software Used

Matlab

Simulink

Communication blocksets

Signal processing blocksets

Orbital mechanics Orbit 2.3

Link design based on http://www.satsig.net

LT PSpice

XCircuits for schematic capture

2. Lunar observatory basics :-

The task is the design and mission deployment of a lunar telescope on the far side of the moon, where it will stay shielded from the effects of man made radiation. The project report below will detail out the complete mission design from launching to individual system design tasks. We will look at how all the various components of space mission fit together in one complete whole and lead to a successful scientific mission.

2.1 Overview : -

The mission design calls for the placement of a 300 meter aperture telescope on the far side of the moon in a crater called Daedalus . This will be accomplished with two spacecraft - the Lunar Observatory Craft (LOC) and a communication satellite (ComSat) which will be launched soon after the review of the project is completed by professor Durgin and ECE approves further funds for it. The two spacecraft will separate near perilune, and the LOC will autonomously land at Dadelius on the lunar surface while the ComSat proceeds to a halo orbit around the Earth-Moon L2 point (LL2). Once operations begin, the lunar base will serve as both an important scientific observatory and an autonomous expandable outpost. The lander's power and communications systems are designed to be accessible to future missions near the site. A radio observatory on the far side of the moon is ideally suited for radio astronomy. For power, the LOC will use triple junction Gallium Arsenide solar cells during the lunar day and Stirling Radioisotope Generators during the night, with a bank of Lithium-Ion batteries that handle backup and peak power.

2.2 The Orbital placement of the Satellite

Earth Launch, Lunar Transport, & Communication Satellite Set-Up

The LOC and its ComSat will launch into a trans-lunar injection orbit. At perilune, the package will separate, sending the ComSat on a path for the Earth-Moon Lagrange 2

(LL2) point, while the LOC maneuvers itself into a lunar orbit. After a brief checkout of all landing systems, the LOC will autonomously descend on the moon. The ComSat will enter a halo orbit around the LL2 point and begin relaying lander status and data to and from the LOC as well as to and from the Earth.

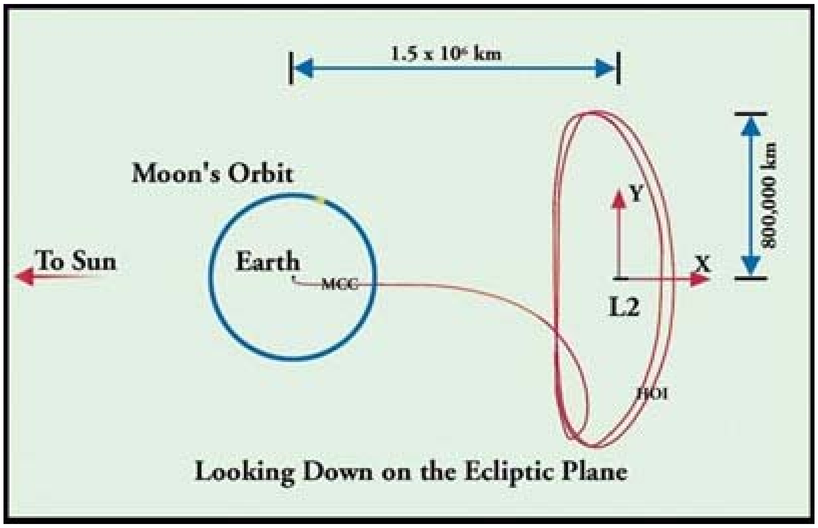
2.3 Mission Duration

The LOC will function using the power, thermal regulation, and communications systems described in the following sections. Other aspects, such as the landing site, telescope, structures, navigation, propulsion, power, and lunar surface operations are also detailed in the following sections.

2.4 Understanding mission geometry

In order to understand mission geometry, we will have a look at the explanations based on a feasibility study conducted by NASA.

During the feasibility studies (1995-96), NASA and the STScI considered a wide variety of orbits. The most promising was the second Lagrange point (L2), approximately 1.5 million km from Earth, outside the orbit of the Moon. The region about L2 is a gravitational saddle point, where spacecraft may remain at roughly constant distance from the Earth throughout the year by small station-keeping maneuvers.



If placed in a large halo orbit in a plane slightly out of the ecliptic plane. This orbit avoids Earth and Moon eclipses of the Sun. The halo orbit period is about 6 months. Nominal station keeping maneuvers will be performed every half orbit (3 months). Near the L2 point, spacecraft is in a benign and essentially unchanging environment. There are no significant gravitational torques and thermal influence from the Earth and Moon are greatly reduced. The main operational influence to consider is the torque created by the Solar wind on the sunshield.

2.5 Mission Requirements

Program Requirements

– Budget < $350 million

– Use of near-term technology and materials

– NASA Exploration vehicle architecture

– Mission to commence by 2007.

– Operational life ≥ 10 years

• Observatory Requirements

– Radio Telescope

• 2-meter diameter

• 1 GHz to 4 GHz

– Power Supply

• 2 kWe for at least 14-hr continuous

• > 200 We at all times

• Output voltage: 24V or 48V

• Interface for future observatory instruments.

– Observatory communications system

• Download link rate: ≥1 MBit/sec

• Upload link rate: ≥ 20 kBit/sec

• System Requirements

– Deliver lander to observatory site

– Soft landing of payload

– Provide thermal control for transit spacecraft and lunar operations

– Provide navigation and communication system

3. Communications architecture Top Level system design

3.1 Communications

Communication between the LOC and the Earth is essential for transmitting the telescope data back to the Earth station. Information about the health of the LOC during lunar operations will also be relayed to the Earth to ascertain the viability of expanding the lunar outpost.

3.2 Communications Challenges

Given that the lunar outpost will be located on the far side of the moon, and there is no line of sight between the LOC and the Earth, a relay is required for communications.

3.3 Design Methods

Several options are available for communication between the LOC and the Earth. The first is a surface relay system, which would relay communications to the moon's near side and then transmit to Earth. A second option is a moon-orbiting relay satellite, and the third option is to place a communications satellite in a halo orbit near the Earth-Moon Second Lagrange point (LL2). In the design process for the communications system, the goal was to design the operating frequency and beamwidth to sustain the required transmission bit rates. The beamwidths were defined in order to avoid the complexity of tracking antennas--an acceptable design choice given that the angles remained small enough for high gain antennas [8]. The power required and dish diameters were then calculated from those values and were determined to be acceptable within the power and structural limitations.

3.4 Solutions

The option of placing a ComSat in a halo orbit around LL2 was deemed the most practical for this mission. The will have a 3500 km orbit around LL2, which will ensure constant contact between the far side of the Moon and the Earth. Adding to the benefit of constant communication, the amount of necessary station keeping maneuvers in the halo orbit is dramatically less than the large delta-V (and consequent fuel mass) required for a lunar orbit. Even though enabling communication with the far side of the Moon will be the primary purpose of the satellite, the halo orbit placement allows for the spacecraft to act as a relay communications satellite for future NASA missions. The frequency band selected was the X-band, with a downlink frequency of 8.4 GHz and an uplink frequency. of 7.145 GHz. This choice was driven by the existence of NASA's Deep Space Network (DSN). The choice to operate at this frequency not only facilitates the ComSat's occasional use of the DSN to more accurately determine its position and velocity, but also allows for mission expandability. Future NASA DSN Architecture includes a relay satellite in a halo orbit around LL2. Therefore, the satellite placed around LL2 for this mission could be used by the DSN instead of placing a new satellite in the halo orbit. The satellite will be equipped with a 1 meter diameter, duplex (two way, two frequency), parabolic dish, and the LOC will have a 0.5 meter, duplex, parabolic dish. A limitation of having one antenna on the satellite is that although data can be received from the LOC and transmitted to Earth simultaneously, commands from Earth cannot be received until the data downlink ends. However, the data from the LOC will be sent in a 12 hour cycle, which allows for communication between the Earth and the ComSat a majority of the time.

4. Relay network Communication system design

In this chapter we will go from end to end design of the communication system for the relay part of the telescope. This will consist of two major portions, the baseband communication part and the RF communication end. We begin by looking at the requirements of communications system, then laying out a broad architecture form for the system and then filling out the details that exist within those blocks.

4.1 Requirements for Communication system

Communications system requirements are now being laid out and we will then design a complete system around these. The following are the major requirements. These requirements have been spelled out by extensive data collection, survey of NASA previous missions, evaluation of radio telescopy requirements and these references are listed extensively in the bibliography as well as the text where appropriate.

- Data rates

  Download link rate: ≥1 MBit/sec

  Upload link rate: ≥ 20 kBit/sec

- Freq Bands

  Downlink frequency of 8.4 GHz

  Uplink frequency. of 7.145 GHz

- Dish size

  Satellite 1 meter parabolic reflector

  Moon site 0.5 meter parabolic reflector

4.2 Base-band Communication system design

The modulation scheme selected for this link is QPSK with reed Solomon error coding to lower the SNR requirements for the link. We move from the error probability and into the digital communication chain

Error probability required = 1 E -6

$$\text{Error probablity required} = 1\text{x}10^{-6}$$

$$QPSKerror\ \Pr obablity = Q\sqrt{\frac{C}{N}}$$

$$\frac{C}{N} = \frac{1}{1}[Q^{-1}(1x10^{-6})]^2$$

Bandwidth = 1 / 2T where T is the symbol rate

For a 1 Megabit uplink using QPSK, the symbol rate would be 500 kilo symbols per second

Bandwidth = 250 KHz

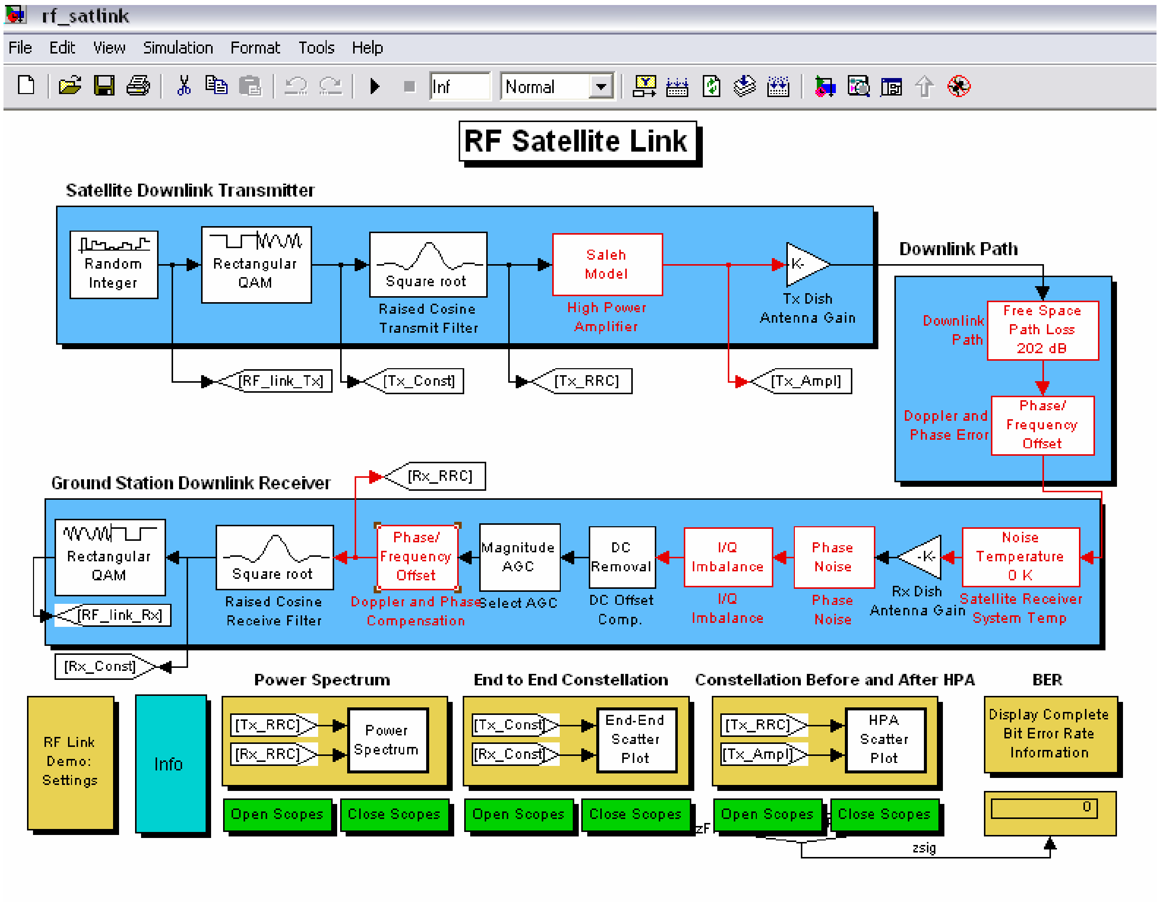
Calculating C/N = 22.56 = 13.5 dBs

Transmit power needed = Eb x Rb , where Rb is the data rate of the system

= 22.56 x 500k = 70.5 dBW

Noise power in this case would be given by = NoW

In order to simulate the satellite link in the communications system domain, a simulation setup from simulink was used. SIMULINK is a matlab adds-on which allows the top level communication machine of the systems to be simulated in detail. Here is the top level model of the system in simulink.



The description of various blocks used in the simulation is as follows.

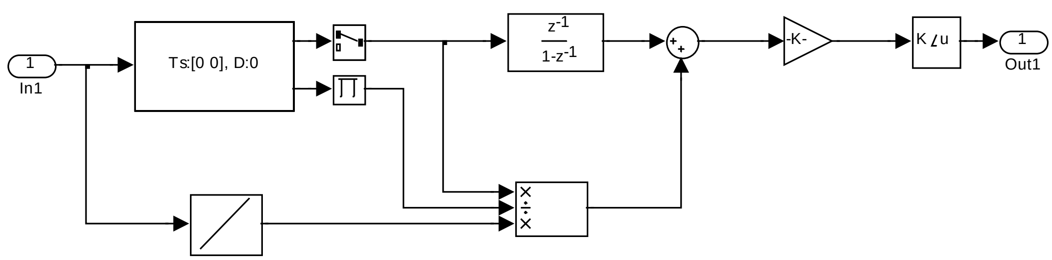
4.2.1 Random integer : - generates a continuous stream of random data at the required data rates

4.2.2 Rectangular QAM :- Maps the data bits in accordance with the QAM or QPSK symbols, as set by the user of the simulation. One can also upgrade the scheme to higher and denser constellations at the expense of higher susceptibility to noise.

4.2.3 Root Raised cosine transmit filter :- The transmit filter is the usual pulse shaping filter to constrain the bandwidth of the system for a band limited channel. In this demo, the root raised cosine filter has been used which conveniently satisfies the nyquist criterion for zero ISI over band-limited channels.

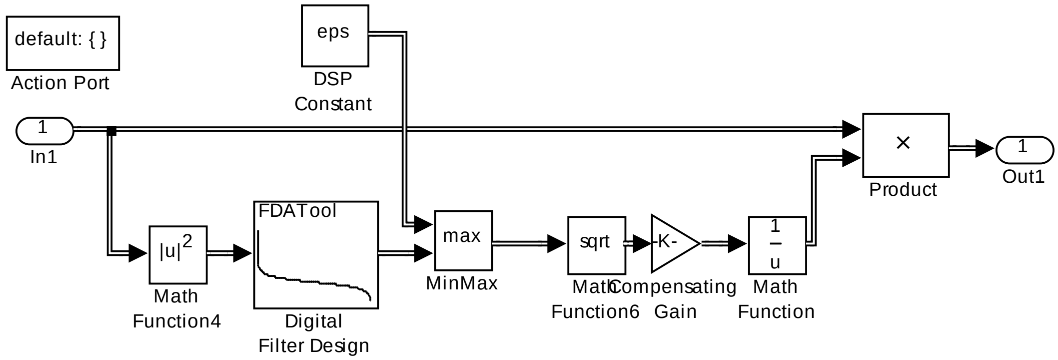
4.2.4 Free space and Path Loss :- These sub-models are there to simulate the effects of an additive white Gaussian noise channel and also the impact of a frequency offsets upon the satellite signal.

4.2.5 Phase / Frequency offset :- Phase frequency offset is the correction block that measures and rectifies the frequency offset introduced by the channel. It uses an internal architecture of the form used in pilot correction blocks. The block internals are high lighted below.



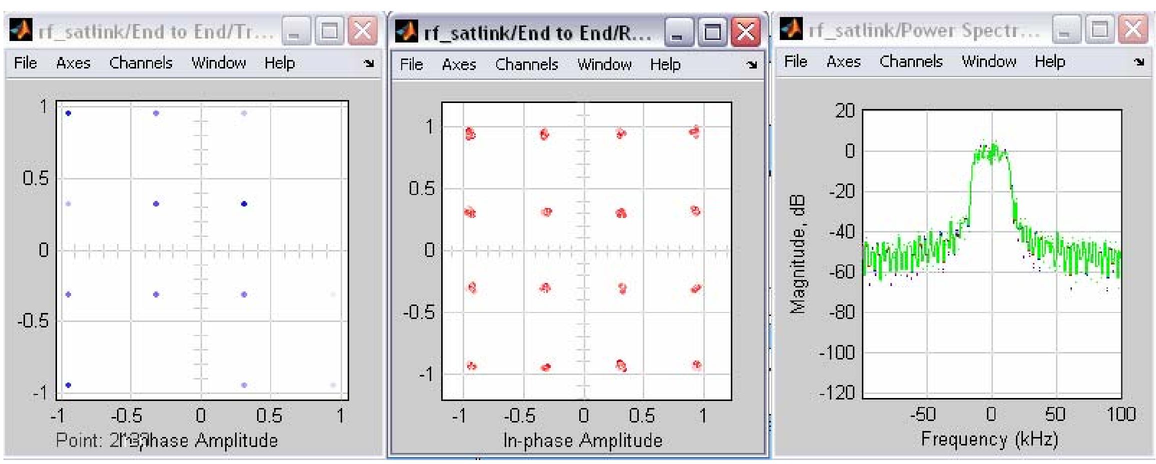
4.2.6 AGC Design and implementation

AGC is a very important block in receiver front ends, and the main purpose of it is to provide a measure of predictability in receiver performance by equalizing all the signal levels encountered by the receiver in different propagation environments and due to different receiver non linear ties and signal decay. AGC is normally implemented by averaging the signal energy over a certain time frame and then deciding the gain of the variable gain amplifier based on this averaged energy content.

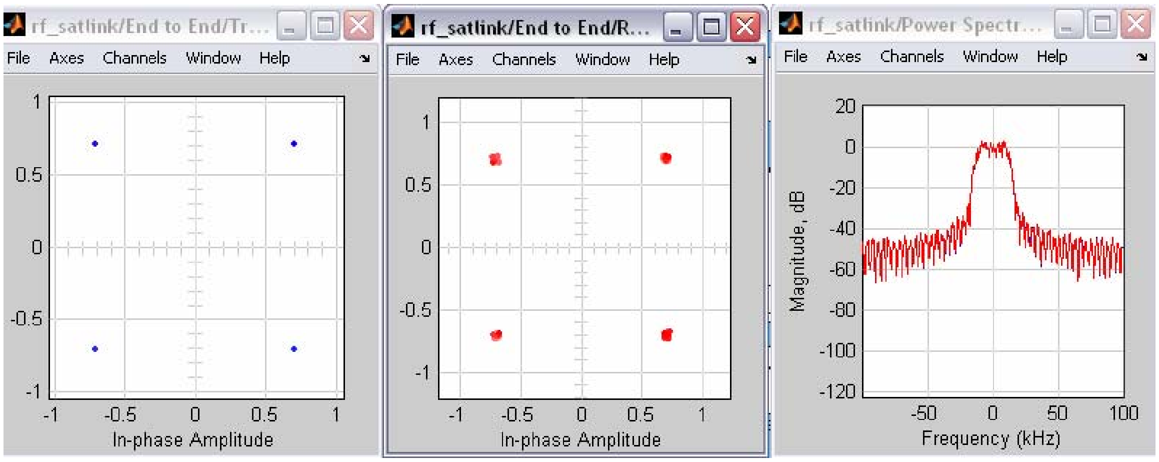


4.2.7 Simulation Results

The system was simulated to view the constellation diagram, the associated noise and the receiver performance in the presence of that noise. With the QAM type constellation, our receiver performed in the following manner.



With our own modified simulation, designed to perform at QPSK, we get a much better SNR and performance from the link. As shown below, the first graph represents the constellation at the transmitter, the second graph represent the constellation received and the one available to receiver for its decisions and the third graph shows the bandwidth occupied by the satellite signal.



4.3 Link budget calculations

In the link budget section we will perform four link calculations for our mission. Two, uplink and downlink for Moon to the relay satellite, and the same two for relay satellite to the

4.3.1 From moon to the relay satellite

Formula for antennae gain = $0.65x(\pi D/\lambda)^2$

For most of the calculations used in detailed link budget analysis, I used the link budget softwares available on the web. One example of such a software can be found at http://www.satsig.net/satellite-links.htm

Uplink frequency GHz	7.14
Uplink antenna diameter m	1
Uplink antenna aperture efficiency e.g. 0.65	0.7
Uplink antenna transmit gain dBi	35.92550
Uplink antenna, power at the feed W	5
Uplink EIRP dBW	42.91520
Range	67500000
Uplink path loss dB	266.1100
Uplink pfd at satellite dBW/m^2	-184.671[illegible]
Bandwidth Hz	250000
Satellite uplink G/T dB/K	2
Uplink C/N dB	-46.5742[illegible]

Downlink frequency GHz	8.4
Downlink receive antenna diameter m	0.85
Downlink receive antenna aperture efficiency e.g. 0.65	0.6
Downlink system noise temperature(antenna+LNA) K	200
Downlink receive antenna gain dBi	35.25604
Downlink receive antenna G/T dB/K	12.24574
Downlink satellite EIRP dBW	48
Downlink path loss dB	267.5216
Downlink C/N dB	-32.6553[illegible]

The overall link summary can be put in the following form

Observatory-Satellite Communications Link

Carrier Frequency (GHz) = 7.14
Transmitter Power = 5.0 W

LTU Free Space Loss (FSL)
Inputs Input
Dish Aperture = 1 Distance between Observatory and Satellite = 67500000
Antenna efficiency = 0.7
FSL = 7.19E+21
FSL (dB) = 218.57
Effective Area = 0.55
Gain = 69087.23 **Incidental Losses (Li, in DECIMAL)**
Gain (dB) = 48.39 Input
Li = 1.2
Satellite
Inputs **Receiver Noise (Nr)**
Dish Aperture = 1.5 Inputs
Antenna efficiency = 0.7 Temperature of receiver (K) = 303
Bandwidth (MHz) = 10
Effective Area = 1.24 Nr = 4.18E-14
Gain = 155446.27 Nr (dB) = -133.78
Gain (dB) = 51.92

Signal to Noise (SNR)

SNR = 148.67
SNR(dB)= 21.72

4.3.2 From relay satellite to Earth

The satellite conveys the data to earth through another dish mounted upon it. This is the broad outline of the parameters which are the result of calculations performed for link budgeting.

Satellite-Ground Network Communications Link

Carrier Frequency (GHz) = 8.14
Transmitter Power = 5.0W
Satellite Free Space Loss (FSL)
Inputs Input
Dish Aperture = 0.5 Distance between Satellite and GN = 4.49E+08
Antenna efficiency = 0.7
FSL = 3.18E+23
FSL (dB) = 235.03
Effective Area = 0.14
Gain = 17271.81 **Incidental Losses (Li, in DECIMAL)**
Gain (dB) = 42.37 Input
Li = 1.2
Ground Network (Using NASA DSN)
Inputs **Receiver Noise (Nr)**

Dish Aperture = 34 Inputs
Antenna efficiency = 0.41 Temperature of receiver (K) = 28.8
Bandwidth (MHz) = 50
Effective Area = 372.25 Nr = 1.99E-14
Gain = 4.68E+07 Nr (dB) = -137.02
Gain (dB) = 76.70

Signal to Noise (SNR)

SNR = 531.87
SNR(dB)= 27.26

5. Observatory RF system design

In order to design the RF front end of the observatory, every astronomer or prospective researcher can lay out his own requirements for observing a particular spectrum but we will concentrate on a broad band front end acceptable to a large class of observers. The system discussed has been used from a graduate project at the Calgary university space design school.

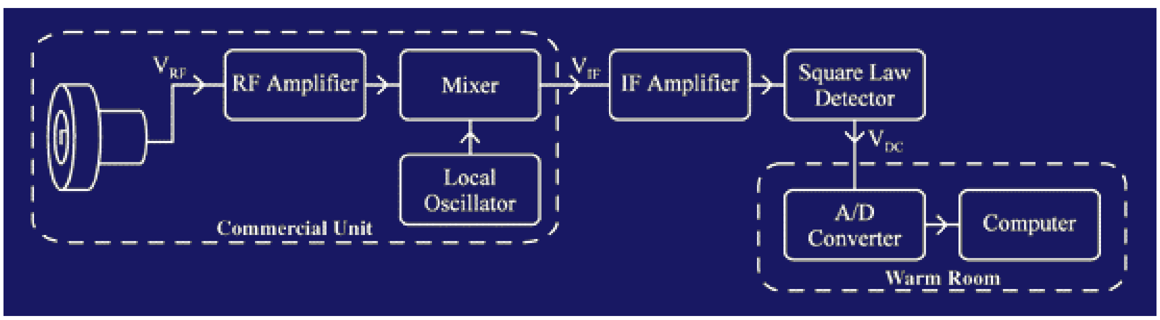
5.1 Radio astronomy basics

Radio signals are weak--the total power received from all observed radio sources at all observatories throughout history is scarcely enough to strike a match. A typical radio signal has a power of only $2x10^{-15}$W. The need for the amplification of the signal is obvious and is one of the main purposes of the receiving system. The ***Super Heterodyne Receiving System*** (SHRS) achieves high amplification while introducing very little internal noise. Each part of the SHRS will be discussed in more detail below, but first a basic overview of the system will be given to provide the reader with some background knowledge.

Although we are only interested in wavelengths of ~7.5cm (~4 GHz), the dish reflects a wide range of wavelengths. Therefore, a large range of signal frequencies is reflected into a waveguide called a horn. The horn is an open-ended cavity which permits standing waves from signals of particular wavelengths to be formed. Due to the nature of this cavity, the horn acts as a preliminary filter, screening out some signals with unwanted frequencies. To first order, the wavelength at which resonance occurs is equal to the diameter of the waveguide. A probe is placed in the horn at an antinode position of the standing wave pattern. There, the signal creates a current in the probe proportional to the intensity of the wave.

5.2 Top level system diagram for front end

The ***front-end*** of the receiver system is generally regarded to be those components of the system physically mounted on the antenna itself. From the front-end, the signal is sent to the ***bac-end*** --that part of the system located elsewhere. Because the impedence of transmission lines increases with frequency, the signal is down-converted at the front-end to a lower frequency, called the intermediate frequency (IF), which is then sent to the back-end with smaller losses. This is the reason for the location of the break between the front and back ends of the receiver system. The square law detector was included in the front-end for this project, although, often the break occurs between the IF amplifier and the square law detector (see the diagram below).



The front-end achieves two important goals: amplification and conversion of the signal to a DC voltage, through four main components, the radio frequency (RF) amplifier, the mixer, the IF amplifier and the square law detector

5.3 RF Amplifier and Mixer

The ***RF amplifier*** does what its name suggests. It operates over a particular bandpass containing the desired radio frequency and amplifies only those input signals with frequencies contained in its range. Ideally the frequency response function of the RF amplifier would be a perfect boxcar function with height of desired gain centered at the observing frequency. Unfortunately the transformation from the ideal world to the real world, produdes a frequency response function that resembles not like a boxcar . It is noteworthy that the RF amplifier noise is usually the predominant noise source in the receiver system. Therefore, effort is spent on minimizing the noise contribution of the RF amplifier.

5.3.1 Amplifier – Mixer interface

From the RF amplifier the signal enters the ***mixer*** where the conversion of the signal to the intermediate frequency occurs. The mixer accepts two input signals, the actual signal from the RF amplifier, and a signal produced from the ***local oscillator*** (LO). The mixer adds these two signals and outputs the square of the sum. The output signal is carried on a frequency given by:

$f_{IF} = f_{RF} - f_{LO}$.

Because the frequency of the oscillator signal can be arbitrarily chosen, the intermediate frequency can also be chosen. Since the RF amplifier, the mixer and the LO used were combined in a single commercial unit, our oscillator signal cannot be varied. Thus the mixer produces a new signal carrying the same information as the original signal (scaled by a known factor from the LO signal), but with a frequency less than the observing frequency of the horn.

5.4 IF Amplifier

There are two main components to the amplifier, those being the op-amps and the filters. With these two components the primary goals of the amplifier are achieved, namely the amplifying of the signal and obtaining a narrow bandpass about the IF. In the circuit design two amplifiers are used to reach the desired gain.

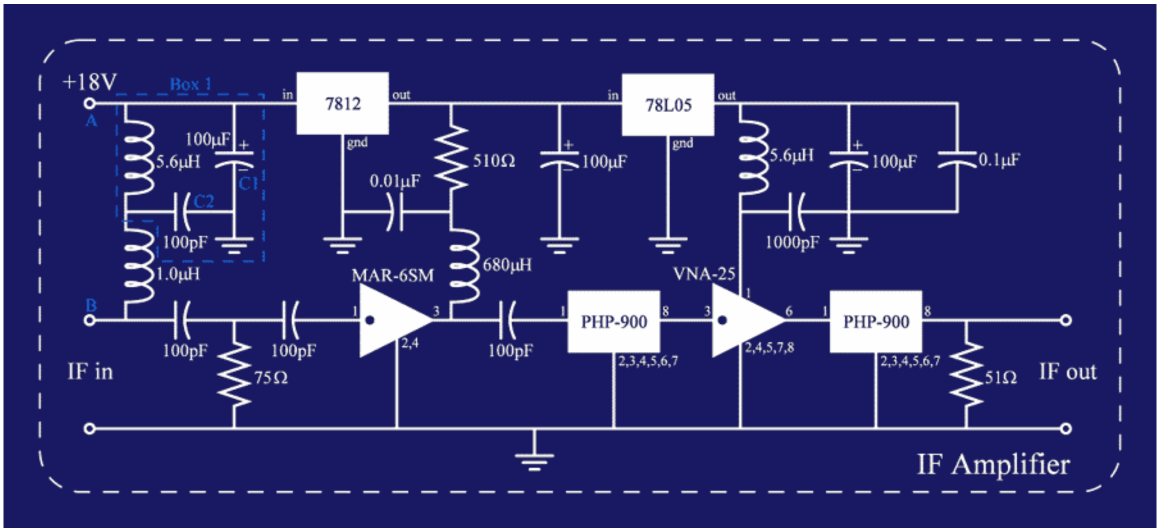
5.4.1 Design motivation

The need for two stages of amplification arises due to the appearance of circuit oscillations if too much gain is present at a single stage. Op-amps used are the MAR-

6SM with a gain of 15dB at 1.2GHz and the VNA-25 with a gain of 20dB. Thus while passing through the IF amplifier, the signal receives a gain of 35dB.

5.4.2 Circuit operation

Before discussing the circuit below, we look at the detailed circuit diagram.



The operation of this circuit is fairly straightforward. Ideally we want to pass the IF signal through the two gain stages and through the filters and end up with a high gain in a narrow bandpass. The op-amps need to be powered by external sources of DC voltage; the MAR-6SM needs to operate over a range of 0-12V and the VNA-25 needs to operate over 0-5V. As seen from the schematic , the IF signal enters the circuit riding on the same line as the +18VDC supplied by the DC power supply. Because 60Hz AC has been rectified to produce the DC, there will still be rippling in the DC voltage along with other AC signal interference. Since any signal entering the op-amps will be amplified along with the IF signal, we want to filter out this DC noise. This is done using the LC filters enclosed in Box 1. Because the complex impedance varies with the frequency of the signal, by choosing the values for L and C selectively, unwanted signals can be blocked effectively from entering the gain stages of the circuit. The LC impedance goes to infinity at the resonant frequency given by:

$$f_o = 1/(LC)^{1/2}.$$

In Box 1 there are two different capactitors, with C1=100uF and C2=100pF. A range in the capacitance is needed in order to set up large impedances for both low and high signal frequencies. A high frequency signal will see a large impedance along the C2 path but a low impedance along the C1 path. The signal will then be grounded out through C1. And vice-versa for low frequency signals. They will see a large impedance along C1, and as such, will be grounded out through C2. The DC signal however with a zero frequency, will see zero impedance and will continue unimpeded towards the MAR-6SM. The 1.0uH inductor below Box 1 along with capacitor C2 prevents the IF signal from travelling back towards the power supply.

The IF signal enters at B sitting on top the DC signal and travels unimpeded to the first gain stage. However before the op-amp are two blocking capacitors with have infinite impedance for the DC signal. Capacitor C3 forms a voltage divider with the 75 Ohm resistor. The voltage divider produces an output voltage of:

$V_{out} = R_2(R_1 + R_2)^{-1}\ V_{in}$.

With R_1=75 Ohms, and R_2=infinity, V_{out} = 0. Thus the DC voltage is blocked effectively from entering the op-amp, and only the IF signal will be amplified.

As mentioned above MAR-6SM requires +12VDC to operate. This voltage is supplied from the 7812 voltage regulator. The regulator itself has a potential drop of 2V. Thus with +18VDC being supplied to it, the regulator will easily produce the needed +12V for the op-amp. Along the path from the output of MAR-6SM to the voltage regulator a 680uH inductor along with a 0.01uF capacitor prevents the IF signal from travelling back along that route and forces it to continue to the filter PHP-900. PHP-900 is a high-pass filter, theoretically attenuating signals with frequencies below 900MHz. In between this filter and the MAR-6SM is another 100pF capacitor. Since we have a DC signal entering the line at C, this needs to be blocked from continuing onwards.

After the filter, the signal enters a second gain stage, the VNA-25 op-amp. The VNA-25 requires +5VDC to operate, and this is supplied to it by a 78L05 voltage regulator. As with the previously discussed voltage regulator a series of filters is present to clean the DC signal and to prevent IF signal from straying back through the circuit. The IF signal exits the second gain stage with a total amplification from the IF amplifier of 35dB and lastly passes through a hi-pass filter identical to the previous one. The second filter was added in hopes of steepening the frequency response of the system. However, the filters achieved disappointing results compared with specs. The frequency response of the system is discussed in more detail below.

5.5 Square-Law Detector

Even though the original signal has been down-converted to a lower IF, the frequency of the signal through the electronics is still on the order of a GHz. The system needs some way of detecting this signal to produce a meaningful output. This is the function of the ***Square Law Detector*** (SLD).

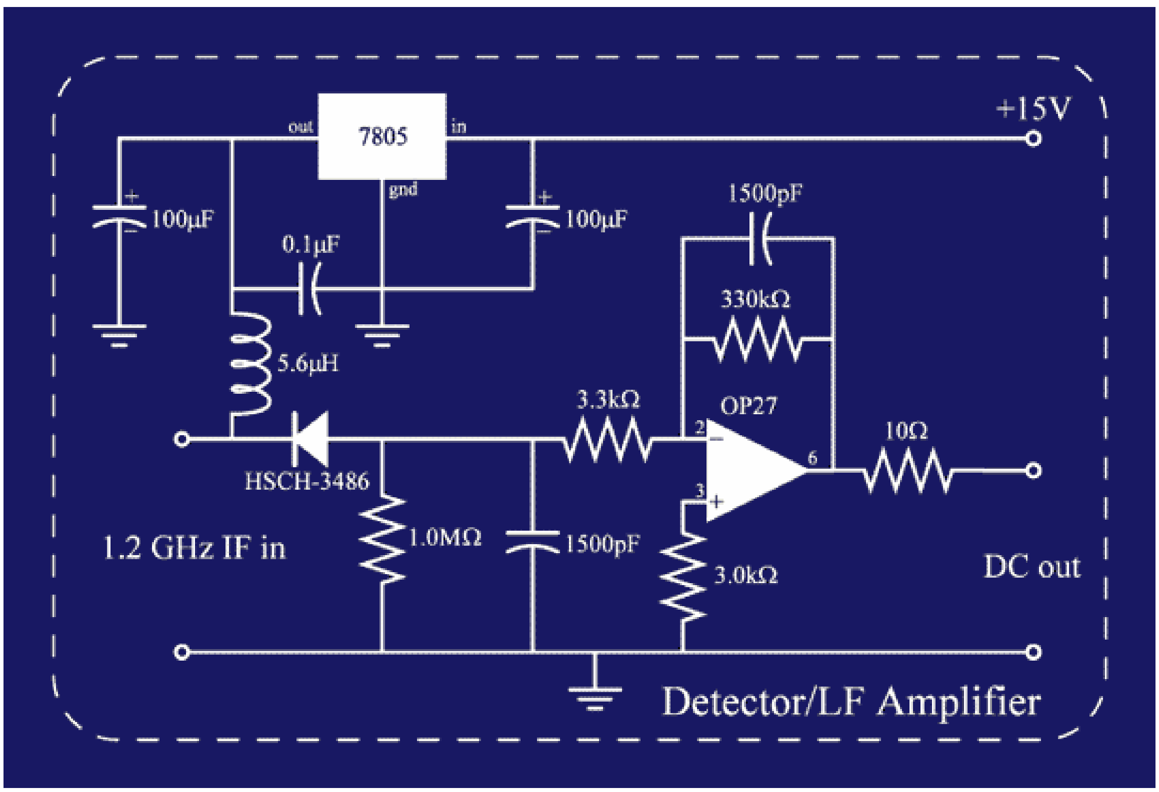
5.5.1 Theory of operation

Radio radiation received at a radio telescope is distributed as white noise. By this, it is meant that the amplitude of the received electromagnetic (EM) wave varies randomly with time. Thus, the amplitudes of the EM signals are distributed evenly about zero. Since observation of astronomical sources requires a finite integration time, measuring only the amplitude of the incoming waves would be problematic since the time average would always be zero for any integration of reasonable duration. However, the variance of the signal will always be greater than zero and therefore will have a non-zero time average. Thus a system that is able to measure the variance of a signal is required.
The signal enters the SLD with a power proportional to the square of the amplitude of the incident EM wave. Through the use of a diode, the SLD outputs a DC RMS voltage level which is proportional to the power of the signals. Because the detector is measuring the variance of the signal, the error of the variance is inversely proportional to the number of events measured. In order to get lower errors in the output signal, it is necessary to use a larger integration time to collect a larger number of events. The noise can also be lowered by integrating over a wider bandpass which also allows a larger number of events to be measured. In summary, the error in the output is inversely proportional to the square root of the integration time and the bandpass.

5.6 *Circuit details of the Square Law Detector*

5.6.1 Design considerations

Initial designs of the SLD called for a VNA-25 op-amp at the first stage of the detector before entering the diode. This would provide a gain of 20dB to the IF signal. However, after testing the detector, this op-amp was removed due to its large gain. In order for the response of the diode to be linear with respect to its input, the input signal cannot be larger than 0.2V. With the op-amp in place, this limit was exceeded, and the diode operated in a regime where its behavior was non-linear. The circuit diagram for the modified version is shown below.



5.6.2 Circuit explanation

The 7805 voltage regulator steps down the +15VDC supply to the necessary +5VDC for the op-amps. Once again the power supply is cleaned with LC filters. The diode permits the current to flow in one direction only. The current allowed through charges the 1500pF capacitor. The RC circuit which follows the diode sets the time constant of the capacitor (t=RC) determining how long it takes the capacitor to charge or discharge to 1/e of its initial charge. With R=1.0M and C=1500pF, this produces a time constant of 1.5msec. The time constant determines how smooth the DC signal is. If the capacitor charges and discharges on time scales large compared with the variability of the input signal, it will have a slow response to any sharp peaks or valleys in the input signal. Since 1.5msec is large compared with the 1.2GHz signal, the capacitor won't "see" short term variability and will roughly stay charged at the same level, smoothing out large scale variations in the signal.

Because the diode outputs a negative voltage, the second op-amp is negatively biased, inverting the signal as it amplifies it to a maximum of +10VDC. The +10VDC is the maximum input to the A/D converter. The gain of the op-amp is the ratio of the feedback resistor, R_f=330K, to the input resistor, R_{in}=3.3K, a gain of 100dB.

6. Conclusion and References

The complete plans for a lunar based radio observatory have been outlined, and some of the issues discussed in details. The report borrows extensively from a variety of sources and I have made all efforts to list them extensively but these might not qualify for exhaustive. Omissions therefore are apologized for.

[1] Cowing, Keith, A Closer Look at NASA's New Exploration Architecture. (2005) Retrieved May 2, 2006 from http://www.spaceref.com/news/viewnews.html?id=1069

[2] Kokh, Peter, Moon Miner's Manifesto (2001).Retrieved March 7, 2006, from http://www.asi.org/adb/06/09/03/ 02/010/farside.html

[3] Chen, P. C., A First Generation Lunar Ultraviolet Observatory (1999). Retrieved January 26, 2006 from http://www.aa.washington.edu/courses/aa420/references/Chen.pdf

[4] Bussey, Ben and Spudis, Paul D., The Clementine Atlas of the Moon. Cambridge University Press.

[5] Stathopoulos, Vic. Lunar Reconnaissance Orbiter (2000). Retrieved March 7, 2006, from http://www.aerospace guide.net/lunar.html

[6] CERAC Incorporated, Magnesium Fluoride, MgF2 for Optical Coating. Retrieved March 8, 2006, from http://www.cerac.com/pubs/proddata/mgf2.htm

[7] Lithion Inc., Model NCP350-1 3.6V, 350 Ah Lithium Ion Cell Spec Sheet.

[8] Wertz, James R. & Larson, Wiley J. (1999), Space Mission Analysis and Design (3rd Ed.). El Segundo, CA: Microcosm Press.

[9] Spitzer Science Center, CalTech, Spitzer Space Telescope Observers Manuel ver. 6.0

[10] Bhasin, Kul and Jeffrey L. Hayden. Developing Architectures and Technologies for an Evolvable NASA Space Communication Infrastructure. NASA/TM—2004-0213108.

[11] Alcatel Space, Heat Pipes (2005). Retrieved January 19, 2006, from http://www.alcatel.com/space/obeqpt/bus/mechathe/ b102.pdf

[12] Ionnotta, Ben, Space Rendezvous, Aerospace America March 2004, AIAA. Retrieved March 7, 2006, from http://www.aiaa.org/aerospace/images/articleimages /pdf/iannottamarch05.pdf

[13] Orbital Sciences Corporation, DART (Demonstration of Autonomous Rendezvous Technology) (2006). Retrieved March 7, 2006,

[14] Goodrich Optical and Space Systems Division, Star Tracker (2004). Retrieved March 7, 2006, from http://www.oss.goodrich.com/datasheets/oss/Goodrich_HD1003_StarTracker.pdf from http://www.orbital.com/NewsInfo/Publications/DART.pdf