Link Budget Design Project

ECE 4432a – Radiation and Propagation

Fall 2020

DESIGN PROJECT #1

December / 5 / 2020

Modulation Scheme:

For a CubeSat, or any satellite, selecting a modulation scheme for a data link is a big task. One must consider the BER, cost, power consumption, circuit complexity, SNR, bandwidth and reliability.

Spectral efficiency:

Starting with a look at FM (FSK, MSK) schemes, they tend to have an advantage in unfiltered spectral efficiency, however with filtering using other methods, the others can be made just as spectrally efficient.

Be it known that BPSK, QPSK and MSK are only 3 dB worse than FSK.

Power efficiency:

Power efficiency in this term is defined by the energy required in each bit to transmit the data at a specified BER.

BPSK, QPSK, OQPSK and MSK are theoretically optimal for power efficiency

Circuit Complexity:

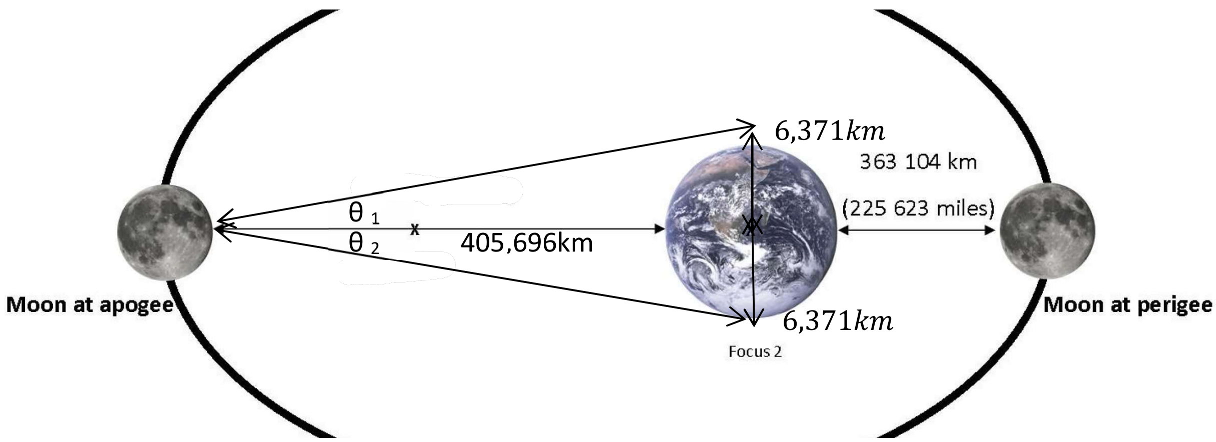
- FSK
    - Simple modulator
    - Signal is obtained from voltage-controlled oscillator
    - Demodulator may use a simple discriminator
- OOK
    - Simplest modulation scheme if non-coherent detection is used
    - Demodulator is just an envelope detector
- BPSK
    - Very simple modulator
    - carrier recovery circuit is needed and a 180-phase ambiguity in the recovered carrier must be resolved
- QPSK and OOPSK
    - Both an I and a Q channel must be generated and combined making it similar to 2 BPSK modulators with the two oscillators phases 90° apart.
    - The demodulator is also complex because, like the BPSK case, a carrier reference must be recovered and a 90° phase ambiguity in the recovered carrier must be resolved.
- MSK
    - This requires that an I and Q channel be generated, but the rectangular symbol pulses from QPSK and OQPSK must be replaced by half-sinusoidal symbol pulses complicating the circuitry
    - Same as the above two, the modulator gets complex as it needs to be recovered, phase checked and shapes of the signal must be properly detected

Final Choice on next Page

All this considered, I think OQPSK will be the best option

This is for the reasons:

- It has a good power efficiency
- Not as complicated circuitry as MSK
- The complex demodulator will be on the ground end and on earth and we are not constrained for the earth design.
- It has a 3dB advantage over FSK and good signal envelope and spectral characteristics allowing the use of a non-linear amplifier without significant sidelobe regrowth.
- OQPSK outperforms QPSK in the presence of reference carrier phase jitter



I started the problem off with the type of notion that our half power beam width should encompass the surface of the earth.

The value I used for the distance between earth and the satellite was the distance of the moon to the earth at apogee (405,696 km).

Using Pythagorean Theorem, we can see $\theta_1 = \tan^{-1}(\frac{6{,}371km}{405{,}696km})$ and therefore the Half power beam width is $\mathrm{HPBW} = 2 * \theta_1$. The resulting value is in the chart at the end of the assignment report.

Once I found the beam width, I was able to calculate the physical parameters. I chose a parabolic dish antenna for this application. I looked at an example CubeSat named "RaInCube" which came equipped with a deployable parabolic dish. The calculations for the parabolic were as follows in AMTLAB:

```
%-----Physical-Antenna-Type-Calculations--------------%
beam_width = 2*atan(6.371/405)*180/pi;%beam width in degrees from graphical method
ds_max = 70*lamb/beam_width; %max antenna diameter based off of desired frequency
```

```
and Beam width where k = 70
%if d_s gets a bit smaller beam width gets larger
d_s = 0.5;%choosing d_s to be smaller but will be sacrificing with a larger half power beam width
%I also chose d_s to be 0.5m since the RaIn cubesat uses a 0.5m parabolic
%dish antenna
beam_width_real = (70*lamb)/d_s;%is the beam width for the chosen d_s
A = pi*d_s^2/4;%Apperature physical area
ea = 0.65;% The aperture efficiency of typical parabolic antennas is 0.55 to 0.70 so I chose 0.65
Ae = ea*A; %Effective apperature
```

The only parameter above which was not calculated was d_s and ea. Effective aperture ratio, from research, typically ranges from 0.55 to 0.7. In class examples it hovered around 0.65 so I figured I would stay with that value.

For d_s, we have the antenna size, which I chose to be as this is the diameter typically used in CubeSats (like the RaInCube) with parabolic dish antennas.

The CubeSat antenna of mine would also be a deployable dish to conserve space on launch etc.

Moving onto the constraints:

```
time_download = 15*60; %seconds: time it takes to download to earth
downloads_in_a_day = 2;%The frequency of downloads/day
time_day = 24*60*60; %seconds in a day
L = time_day*R_recorded/downloads_in_a_day;%gives packet size since bps*s = bits
R_min = L/time_download; %bits/sec: Data rate for sending the file within 15 mintues
```

I took the time it took to download and put it into seconds.

For a packet size of L, it would be the time in the day in seconds*the recording data rate. Since it downloads to earth twice a day, we divide this packet size by 2 or download_in_a_day.

Once L was found, we could find the minimum download rate needed for the satellite to download to earth in the specified time.

I then chose a Bandwidth which would yield a good SNR.

Then I calculated my gain and power as taught through assignments and lectures as follows for parabolic dish antennas:

```
%----------Gain-and-power-recieved-calculations------------%
squiggle = 0.85; %Chose a radiative efficiency of 0.85
Pt = 3;%I chose 3 from the range given
D_t = ea*((pi*d_s/lamb)^2);%directivity of transmitter
G_t =(squiggle*D_t);%gain of transmitter
D_e = ea*((pi*d_e/lamb)^2);%Directivity of reciever
G_r = (squiggle*D_e);%gain of reciever
L_f = (lamb/(4*pi*r))^2; %free space loss
%can use priis transmission since d>>lamb
Pr = Pt*G_t*G_r*L_f;
```

Note on this Pr. I did not want to add a transponder gain since I was not comfortable with how to and the implementation, however, during my preliminary calculations, I found Pr as Pr(boosted) and then solved for the transponder gain using a sketchy ratio so I ditched that idea and stayed with the class type examples. I also solved for a good transponder boost by using trial and error in MATLAB finding it at about 22 DB for the Pr to agree with the Noise to find SNR however I wanted to stay without transponder gain.

Moving onto the Noise Calculations we will look at this in sections:

```
%-------Calculating-Noise-and-Noise-Temp------------%
%Noise temp for the earth receiver

T_Galaxy = (10^8)/((f/(10^6))^2);T_sun = (10^8)/(f/(10^6));T_Atmosphere = 300;%This is Tsky without the factors being taken into account
T_AE = ((1-(beam_width/beam_width_real))*(T_Galaxy + T_sun)) + (beam_width/beam_width_real)*T_Atmosphere;%This is Tsky
```

This here was essentially my T_{sky}. I took the galaxy, sun and earth noise into account with the chosen frequency. One I found T_{Sky}, I used percentages like in class, however I did not arbitrarily choose these. I took our beam_width value which is the half power beamwidth as a minimum that we need to encompass the whole earths surface. Then I divided this by our beamwidth of the smaller dish diameter which gives us a ratio of how much is covered by the earth, and how much is from the outside(galaxy and sun noise).

Moving onto the internal circuit noise:

```
T_A0 = 288;%assuming the earth recieving antenna has about 15 celcius in temp (1 degree above worlds average)
L_t= sqrt(2);
L_m= 4;
T_t=(L_t-1)*T_A0;
T_rf=1/(10^(G_t/10));
T_m=(L_m-1)*T_A0;
T_if= 870;
T_E = T_t+L_t* T_rf+ (L_t/G_t)*T_m+(L_t*L_m*T_if)/G_t;%internal circuit noise
Tre = T_AE*squiggle + T_A0*(1-squiggle) + T_E;
```

The highlighted section was from lecture “Noise-antenna-receiver-system-SNR-Lec18-19-102120.pdf”. There was not much I could find for internal noise so I kept this about the same.

```
%Noise temp for the satellite transmitter
T_AEs = 300;%K looking at earth which has an average noise temp of 300K
T_A0s = 2.7;%average temp of space which is what the antenna would feel outide.
T_Es = 290;%assuming the noise of space stays at about the average of 290K
Trs = T_AEs*squiggle + T_A0s*(1-squiggle) + T_Es;
T_sys = Tre + (G_t*G_r*L_f*Trs);
k_db = -228.6; %boltzmann constank k in db
k = 10^(k_db/10);
Nre = k*Tre*B;
```

For the above highlighted section, I do not this this was important since we are only caring about downlink, however, when taking this into account, it did not change my SNR, R or C noticeably. I added this for good measure.

Finally, then end of the calculaitons:

```
%-----Calculate-the-SNR-for_downlink-and-compare-to-total--%
SNR_downlink = Pr/Nre;
SNR_downlink_db = 10^(SNR_downlink/10);
C = B*log2(1+SNR_downlink);
R_accomplished = B*SNR_downlink/Eb_div_N0;
Nr = k*T_sys*B;
SNR_tot = Pr/Nr;
SNRdb = 10^(SNR_tot/10);
C_tot = B*log2(1+SNR_tot);
R_accomplished_tot = B*SNR_tot/Eb_div_N0;
%can see the downlink dominate once again as the two of the R_accomplished
%are the same
%Done
```

So nothing special here, just used the equations needed. I compared the R_accomplished to R_accomplished total where R_accomplished_tot was the addition from the noise of the Satellites view. This did not matter as its only the earths reciever, and when taking into account all the gain going into the earth receiver, the first noise calculations dominates as in the downlink dominates.

Variable and Value Figure

Variable	Value	Desciption
beam_width	1.80247558277829 [degrees]	Calculated needed beamwidth
beam_width_real	4.991087344	Beamwidth with the diamter chosen after consideration of the calculated needed
ds_max	1.384509003	Max diameter to have the halfpower beamwidth encompass the whole earth.
d_s	0.5	Choosing a smaller diamter, however risking more noise due to a larger half power
A_dish	0.196349541	Area of the chosen diameter dish
ea	0.65	effective area coefficient
Ae_dish	0.127627202	Effective area of the dish
Eb/No	9.094646742	Eb/No
ξ_r	0.85	This was represented as squiggle in my MATLAB code and was chosen to be less than
G_t	1.07E+03	Gain of the transmitter
G_r	4.96E+06	Gain of the reciever
f	8.41E+09	frequency chosen since X-band satellites (and cube sats) usually operate around 8.4-
Pt	3 [W]	low yet higher than what the transmitting module of typical X-band transmitters require for power (which was specced out to
Pr	7.80E-13	Calculated Power received value
T_Galaxy	1.412185537	Noise temperature, in Kelvin, from the Galaxy at the chosen frequency
T_sun	1.19E+04	Noise temperature, in Kelvin, from the Sun (or quiet sun) at the chosen frequency
T_Atmosphere	300	Average noise temp of the atmosphere since rain, snow, etc all effect the noise
T_sky = T_AE	7.70E+03	Noise temperature, in kelvin, by considering the ratio of the beamwidth that would hit
Nre(noise)	7.41E-13	Total noise
R_accomplished	9.26E+05	R accomplished after everything considered
R_accomplished_tot	9.26E+05	R accomplished after considering the uplink aswell but not needed since we are designing
C	8.30E+06	Link capacity
R_min	28800	Minimum R to accomplish the download to earth within the 15 minutes
SNR_downlink	1.052548401	SNR achieved
SNR_downlink_db	1.27425058039063 [db]	SNR achieved in db