Satellite Communications System Simulaiton Report

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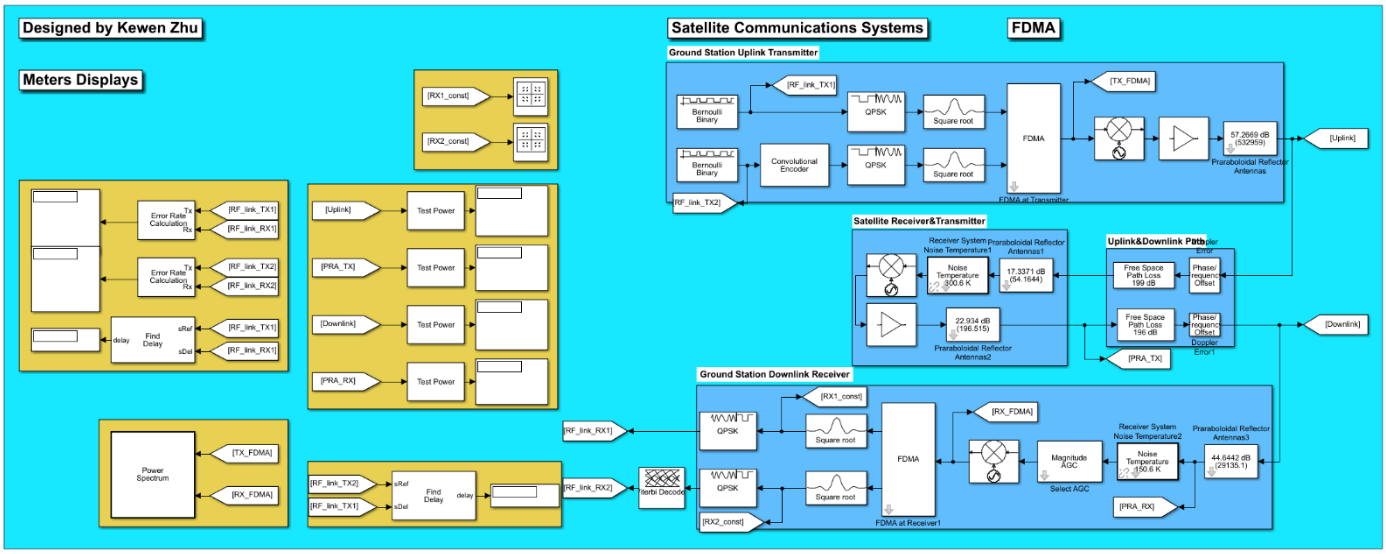
My final overall designs:

I construct 3 models of a whole satellite communications systems(including uplink and downlink) in 3 different types of multi-access technique(FDMA,TDMA,CDMA) in order to let multiple users communicate simultaneously over the satellite communications systems.

I install 2 users in my models to simulate multi-access and test the systems' respective performance of each multi-access respectively. The performance metrics include outage probability, throughput, bit-error rate, and power attenuation.

To begin with my **FDMA** model as an example to introduce my design with the non-ideal communication channel.



This model use the blocks from the Communications Toolbox™ RF Blockset and RF Toolbox to simulate the following impairments:

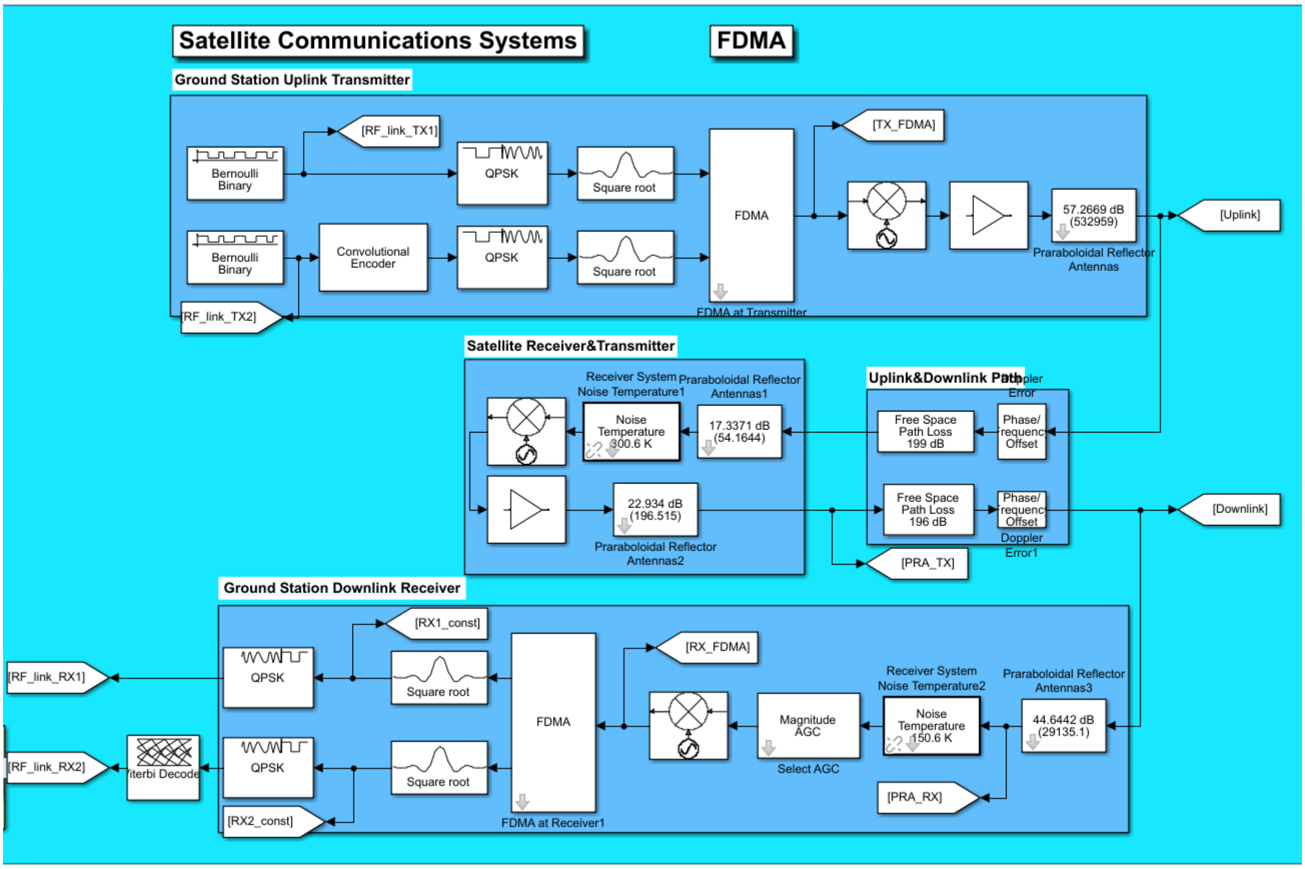
- Memoryless nonlinearity
- Free space path loss
- Doppler error
- Receiver thermal noise
- Phase noise
- In-phase and quadrature imbalances

- DC offsets

In order to observe the power attenuation and enhancement, I add many Blocks to detects the power at significant points.

The electromagnetic signal carrying information is inflicted upon a lot of impairments such as Free Space Path Loss, Memoryless Nonlinearity, etc. In the current Simulink radio frequency (RF) satellite Link model, these impairments are modeled in the form of respective blocks with the provision of various mask parameters in each of them which allows us to vary those parameters to see the corresponding changes in the nature of the signal.[1]

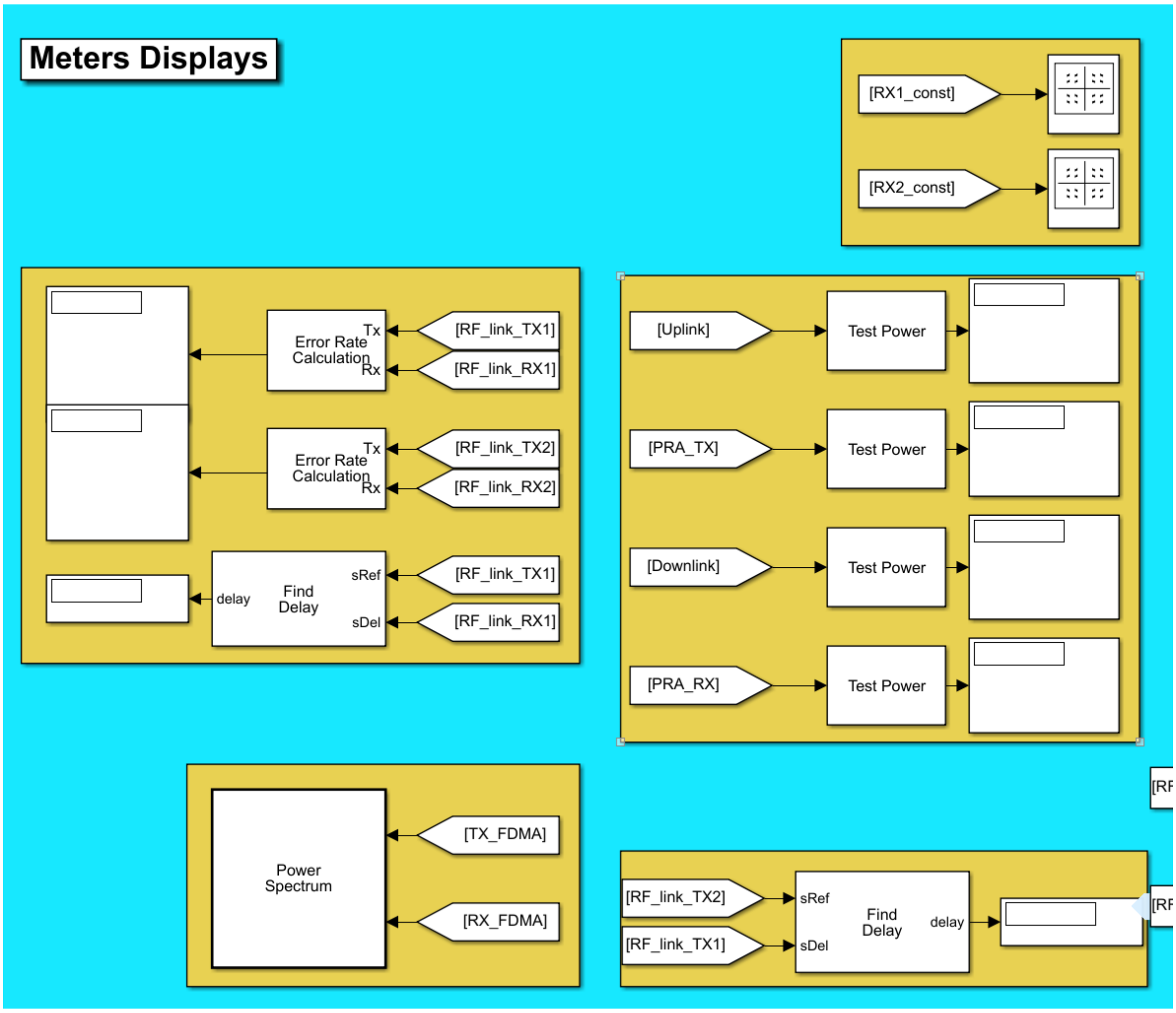
In order to rebuild the complicate question situations in the reality as possible as I can. I design such Uplink&Downlink Path considering the free space path loss of 36000km distance for GEO satellite with 6000MHz and 4000MHz[2], doppler error and phase noise in the real non-ideal communications channel.



This system has showed a whole satellite link including Ground Station Uplink Transmitter, Uplin&Downlink Path, Satellite Receiver&Transmitter and Ground Station Downlink Receiver. Because it is suitable to represent the conditions of applying the satellite network architecture of multipoint-to-multipoint.

I use the power spectrum to demonstrate the overall systems' capabilities' performance because Power law noise plays an important role in the description of high performance oscillators.[3] Assuming that the constellation diagram can detect the BER-performance more intuitively, I installed 2 Constellation diagram displays at the received end for 2 users respectively.

My measuring values were put in this area:

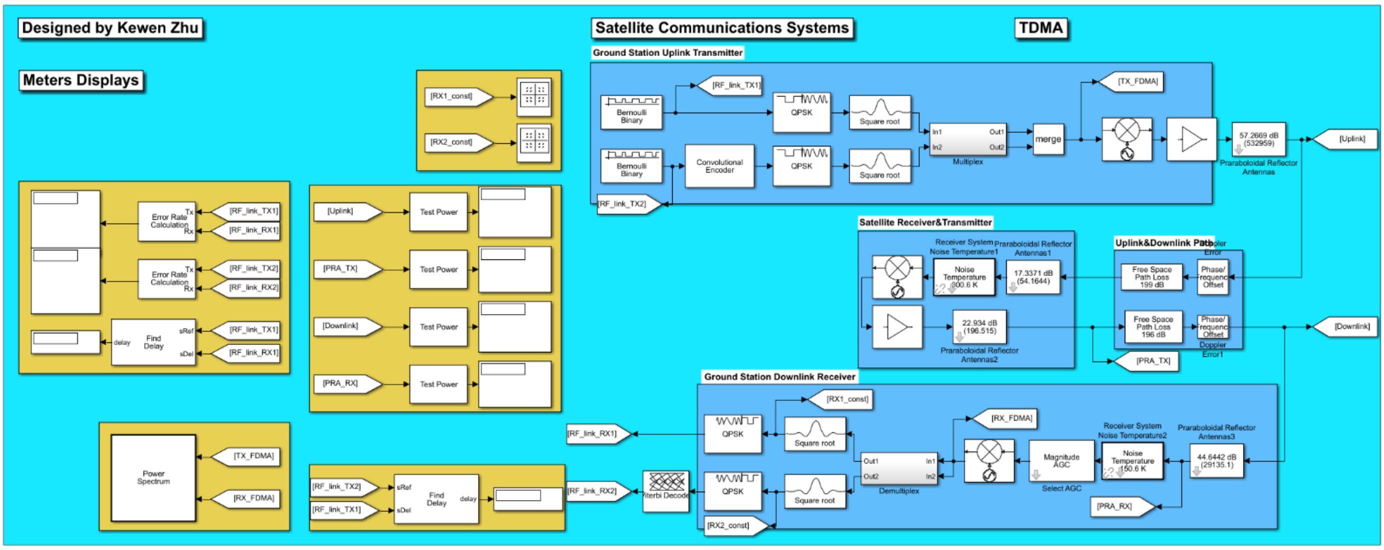


In this way the performance can be observe in many aspects including BER for each users, the find delay for user 1, and the power change in each steps. The comparison between transmission signals and received signals in the power spectrum, and the constellation diagram also reflect the performance directly.

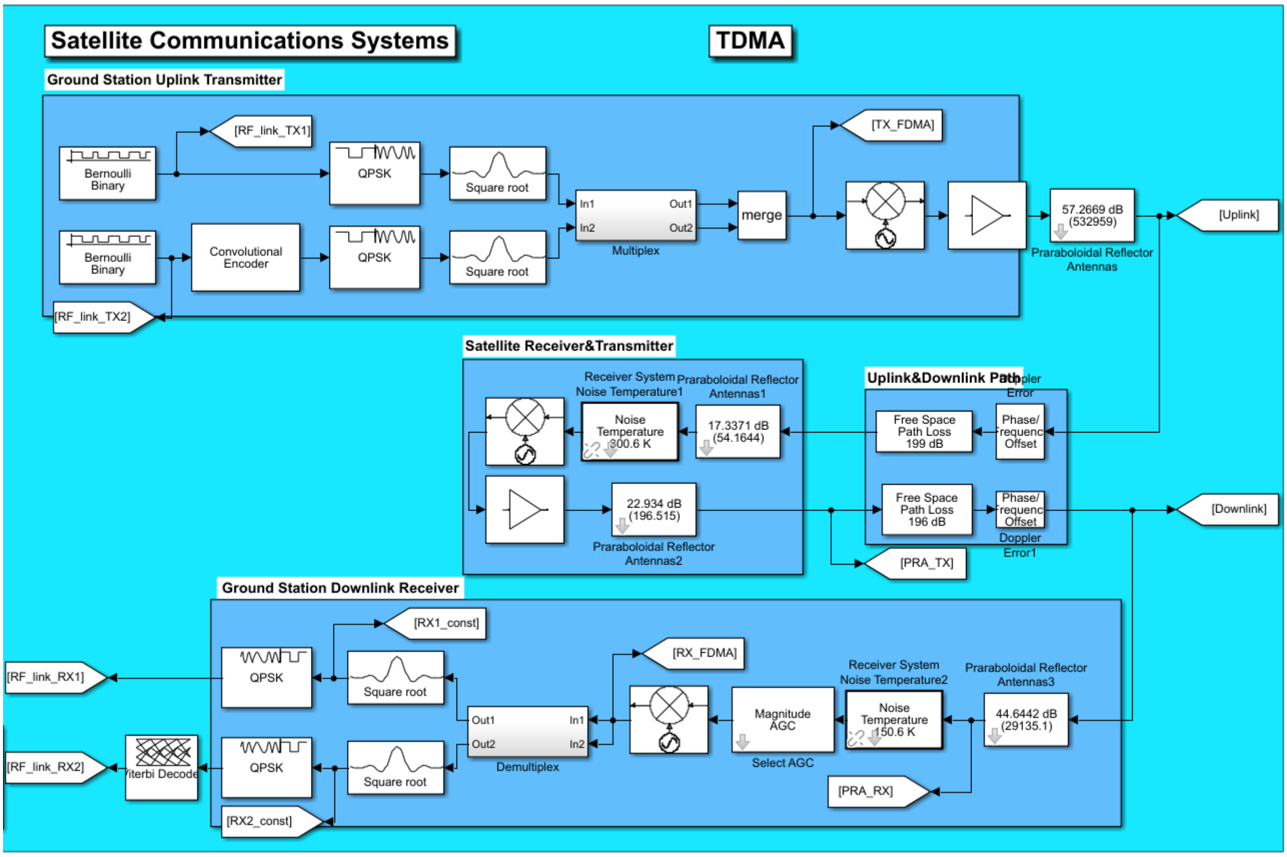
I will listed other 2 multi-access so as to compare and select a best one to apply in the model satellite communications systems.

TDMA

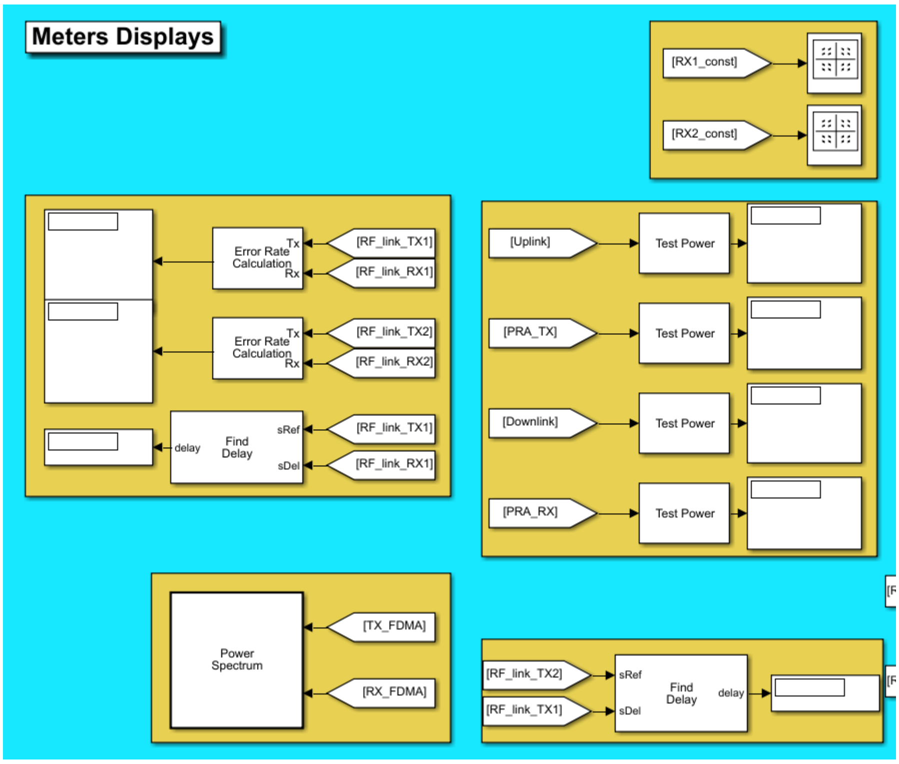
The whole systems:



The satellite communications system:

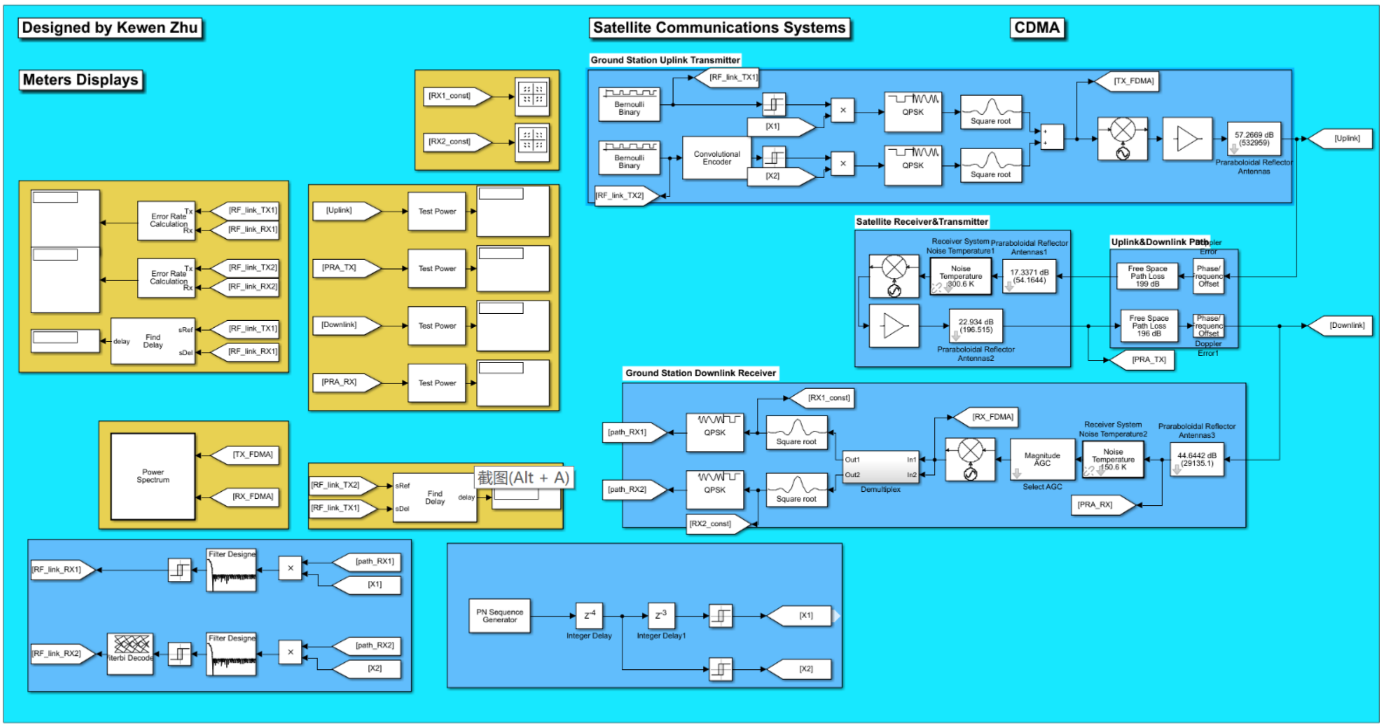


The meters displays:

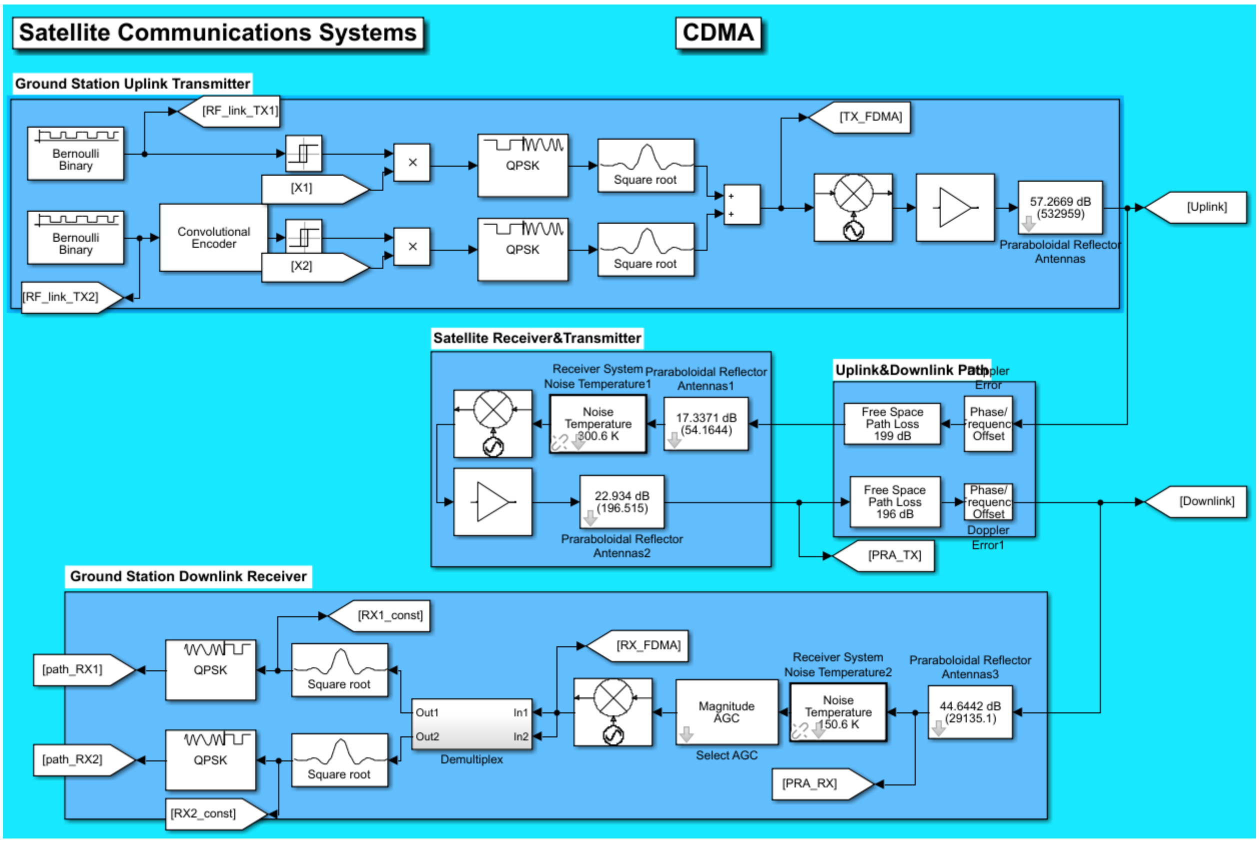


CDMA

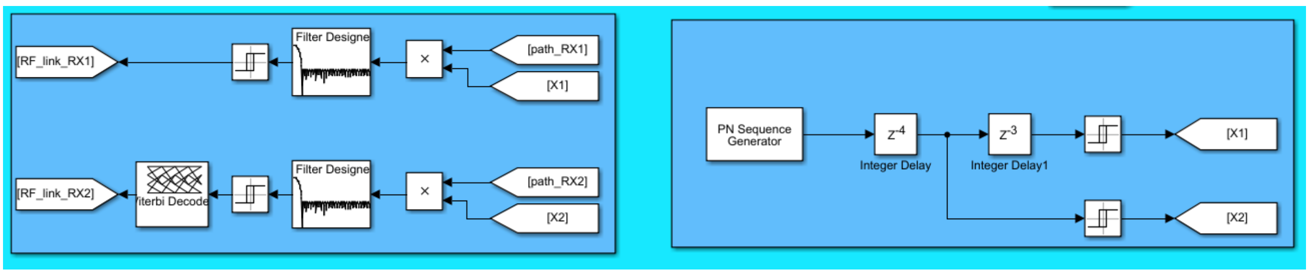
The whole systems:



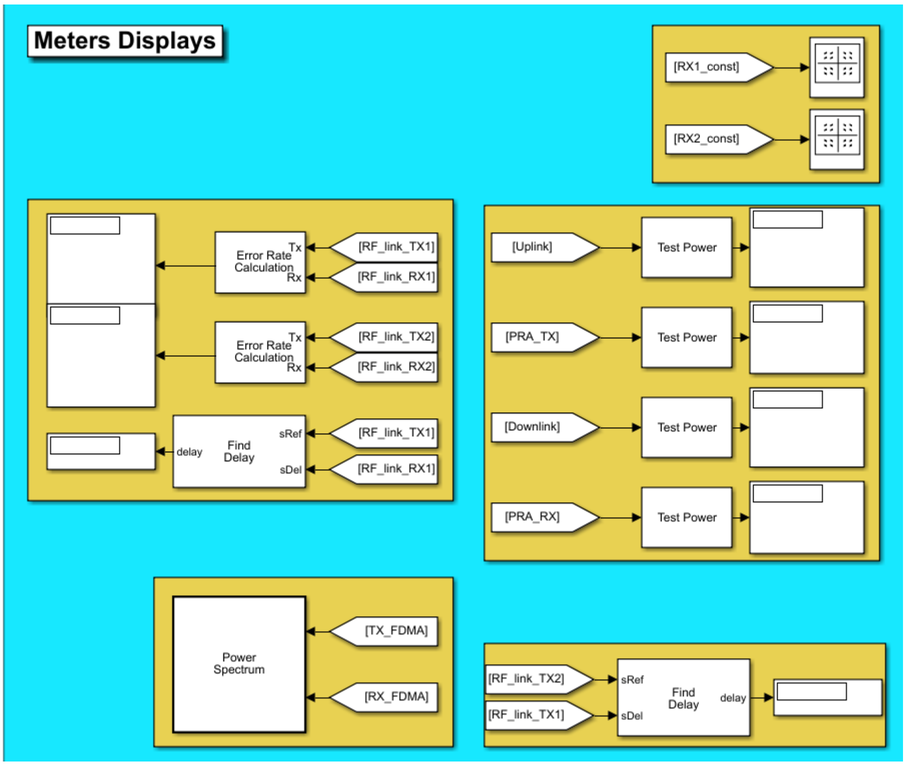
The satellite communications system:



The system of CDMA[4]:



The meters displays:



Components' descriptions:

1. **Bernoulli Binary Generator** -

（Generate a Bernoulli random binary number）Creates a random binary data stream.

Probability of a zero:0.5

Sample time:1/64000

2. **Convolutional Encoder/Decoder of Rate 1/N Codes**- The Convolutional Encoder block encodes a sequence of binary input vectors to produce a sequence of binary output vectors. **A**llows the user to input a source code to be encoded and also input the values of the generator polynomials. It outputs the encoded data bits, where 1/n is the code rate.

3. **Rectangular QPSK Modulator Baseband** - Maps the data stream to QPSK constellation.

4. **Raised Cosine Transmit Filter** - Upsamples and shapes the modulated signal using the square root raised cosine pulse shape.The Raised Cosine Transmit Filter block upsamples and filters the input signal using a normal raised cosine FIR filter or a square root raised cosine FIR filter. The purpose to install this is to maximum the signal that is within the range of frequency bandwidth.

5. **FDMA** - （frequency division multiple access，FDMA），Divide the spectrum into several sub-bands, frequently applied in most of the GEO communication satellites. In satellite communications, subdivision of the 36 MHz transponder bandwidth may be assigned to different users. Each users receive a specific bandwidth allocation to access the transponder.

6. **Mixer**-The Mixer block generates a complex baseband model, modulate the transmitted sigals into RF signal(higher frequency) ,then each frequencies occupied a channel, so that each channel will avoid interferent each other. Mixer in the receiver transfer the RF signal into frequencies that easier to received and demodulated.
RF-
Efficient generation of signal power

Radiates into free space
Efficient reception at different point

7. **Amplifer**-The Amplifier block generates a complex baseband model of an amplifier with thermal noise. The purpose to install amplifiers is to avoid attenuations. Because the losses happened in many places, Free-space spreading loss, receiver feeder loss, antenna misalignment loss, atmospheric absorption loss and polarization mismatch loss. In order to simplify the circumstance, I install an amplifier in the transmitter to offset the free-space spreading loss and atmospheric absorption loss, an amplifier in the communication satellite to offset the free-space spreading loss, receiver feeder loss, antenna misalignment loss and atmospheric absorption loss, in the receiver to offset the free-space spreading loss, receiver feeder loss, antenna misalignment loss and atmospheric absorption loss.

8. **Paraboloidal reflector antennas**- Based on the Paraboloidal Reflector Antennas formula ,Gain factor is G=(pi*D*f/c).^2*g
Transmit Frequency(GHz): 4
Antennas Caliber/Diameter(m): 0.4
Gain factor(less than 1): 0.7
This block is to simulate the received antennas and their antenna gains related by the frequencies and antenas' parameters.

9. **Phase/Frequency Offset**-The Phase/Frequency Offset block applies phase and frequency offsets to an incoming signal. he block inherits its output data type from the input signal. The block applies a frequency offset to the input signal, specified by the Frequency offset parameter. Alternatively, when you select Frequency offset from port, the Frq input port provides the offset to the block. The frequency offset must be a scalar value, vector with the same number of rows or columns as the data input, or a matrix with the same size as the data input.

This block is placed to simulate the doppler error.

10. **Free Space Path Loss**- The Free Space Path Loss block simulates the loss of signal power due to the distance between transmitter and receiver. The block reduces the amplitude of the input signal by an amount that is determined in either of two ways:By the Distance (km) and Carrier frequency (MHz) parameters, if you specify Distance and Frequency in the Mode field.By the Loss (dB) parameter, if you specify Decibels in the Mode field.This block accepts a column vector input signal. The input signal to this block must be a complex signal.

11. **Noise Temperature**- consist of reference temperature, effective noise temperature and temperature of the source.
Parameters:
Sky Temperature(K)
Surface Temperature(K):
Beam Efficiency(less than 1):
The Noise Temperature of Receiver Facility(K):

12. **Magnitude AGC-**The function of the automatic gain control circuit is to keep the output voltage of the receiver constant or substantially constant when the input signal voltage varies greatly. Specifically, when the input signal is weak, the gain of the receiver is large, and the automatic gain control circuit does not function; when the input signal is strong, the automatic gain control circuit controls to reduce the gain of the receiver. Thus, when the received signal strength changes, the voltage or power at the output of the receiver is substantially constant or remains constant. Therefore, the requirement for the AGC circuit is that the AGC

circuit does not function when the input signal is small, and only when the input signal is increased to a certain extent, the AGC circuit plays a control role, so that the gain decreases as the input signal increases.

13. **Viterbi Decoder-**Decode the encoded signal.
14. **Test Power**-to detect the power in specific point. In order to observe the signals' power in any significant point so as to directly demonstrate the power loses and gain, so that it helps to test the system's performance in satellite communications systems.

15. **Error Rate Calculation**- to detect the BER. In order to observe the transmission performance so as to directly demonstrate the systems' capabilities, so that it helps to test the system's performance in satellite communications systems.

16. **Find Delay-**Find the delay between two signals sRef and sDel by finding the maximum of the cross-correlation function between them.

17. **Power Spectrum-** directly compare the original signal and the received signal so as to detect whether the communications system performance well or bad. It can both detect the distortion and the ability to immune the interference and the power losses. It can also reflect the systems' stabilities.

Design choices & calculations:

The whole system:

Equivalent Isotropic Radiated Power(EIRP) :
EIRP can be defined as the power input to one end of the transmission link and the problem to find the power received at the other end.

$\mathrm{Pr} = \frac{GP}{4\pi^2} = GPs$ (G-Gain of Trans antenna in decibels)(Ps-Pow of Sen in Watt)

$[EIRP] = [G] + [Ps] dBW$

Transmission Losses: losses will occur along the way, some of which are constant.

$[LOSSES] = [FSL] + [RFL] + [AML] + [AA] + [PL]$

free-space spreading loss
receiver feeder loss
antenna misalignment loss
atmospheric absorption loss
polarization mismatch loss

Equation for the received power is:

$[P_R] = [EIRP] + [G_R] - [LOSSES]$

The system noise:

$P_N = k * T_N * B_N \quad N_0 = P_N / B_N \quad N_{0,ant} = k * T_{ant}$

The main source of noise in the satellite equipment's is the noise arising from the random thermal motion of electrons in the various devices in the receiver.
Include: power from a thermal noise source, the AWGN & the input noise energy from the antenna.

Carrier to noise spectral density ratios $\frac{C}{N} = [EIRP] - [LOSSES] - [k]$

Saturation power $[P_{HPA,sat}] = [P_{HPA}] + [BO]_{HPA}$

The earth station HPA has to supply the radiated power plus the transmit feeder losses. These include waveguide, coupler losses between the HPA output and filter.

Amplification & Attenuation

$$P_{out} = GP_{in} = \frac{P_{in}}{L}$$

The link budget analysis:

$$\frac{E_b}{N_0} = \frac{S}{N}(\frac{W}{R})$$

It is a balance sheet of gians and losses on the link.

Antenna gain: $G = \frac{4\pi A_e}{\lambda^2}$ (for $A_e >> \lambda^2$)

Isotropic receive antenna: $P_r = \frac{EIRPA_{er}}{4\pi d^2} = \frac{EIRP}{(4\pi d/\lambda)^2}$

Path loss $L_s = (4\pi d/\lambda)^2$

Received signal power: $P_r = \frac{EIRP}{L_S}$ $P_r = \frac{EIRPG_r}{L_S}$ $EIRP = P_t G_t$ $A_{et} = \frac{\lambda^2 G_T}{4\pi}$ $A_{er} = \frac{\lambda^2 G_r}{4\pi}$

Noise figure: $F = \frac{(SNR)_{in}}{(SNR)_{out}} = 1 + \frac{N_{ai}}{N_i}$

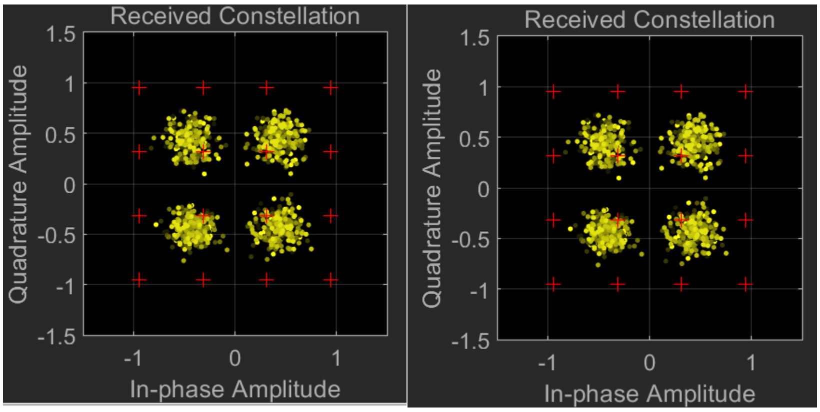
Noise temperature: $kT_R W = (F-1)kT_0 W$ $T_R = (F-1)290^0 K$

Line noise: $N_{out} = GkT_g W + GkT_R W$

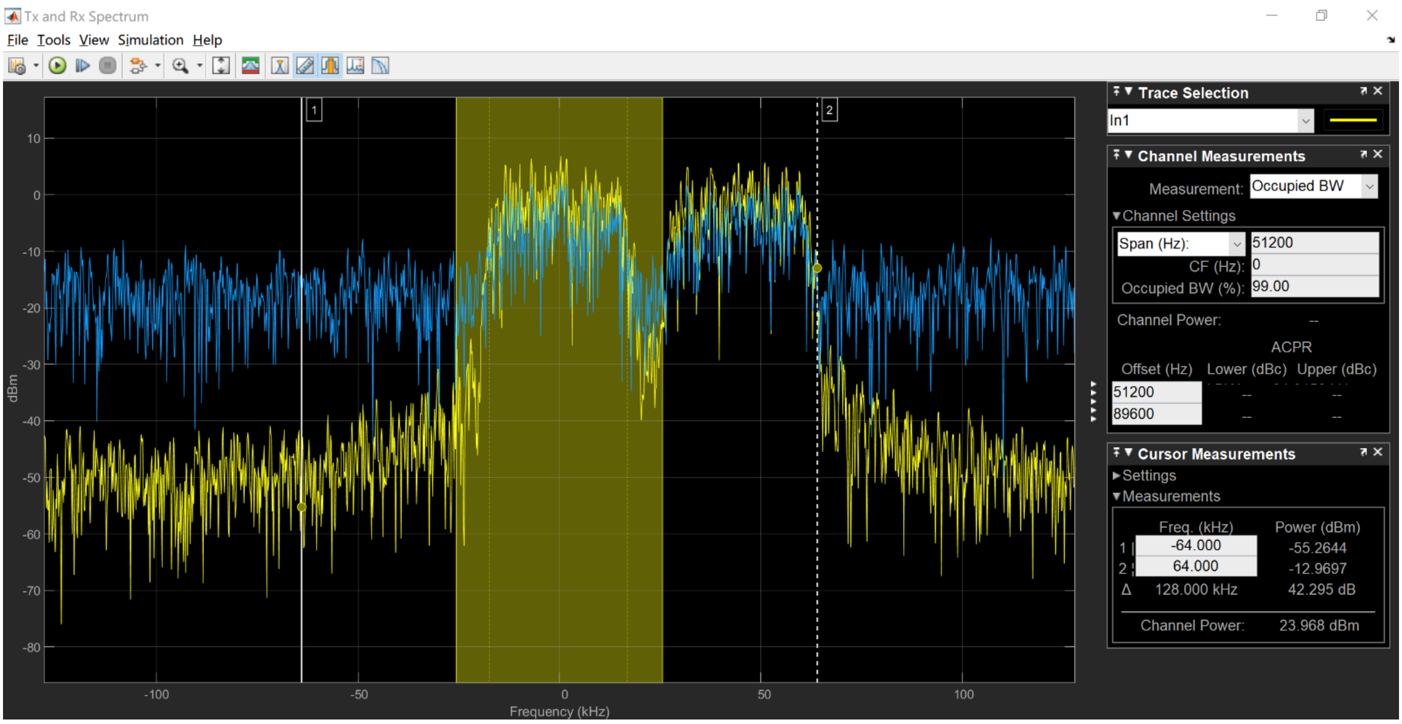
Composite Noise Figure: $F_{comp} = F_1 + \frac{F_2 - 1}{G_1} + \ldots + \frac{F_n - 1}{G_1 \ldots G_{n-1}}$ $T_{comp} = T_1 + \ldots + \frac{T_n}{G_1 \ldots G_n}$

The output among 3 multi-access

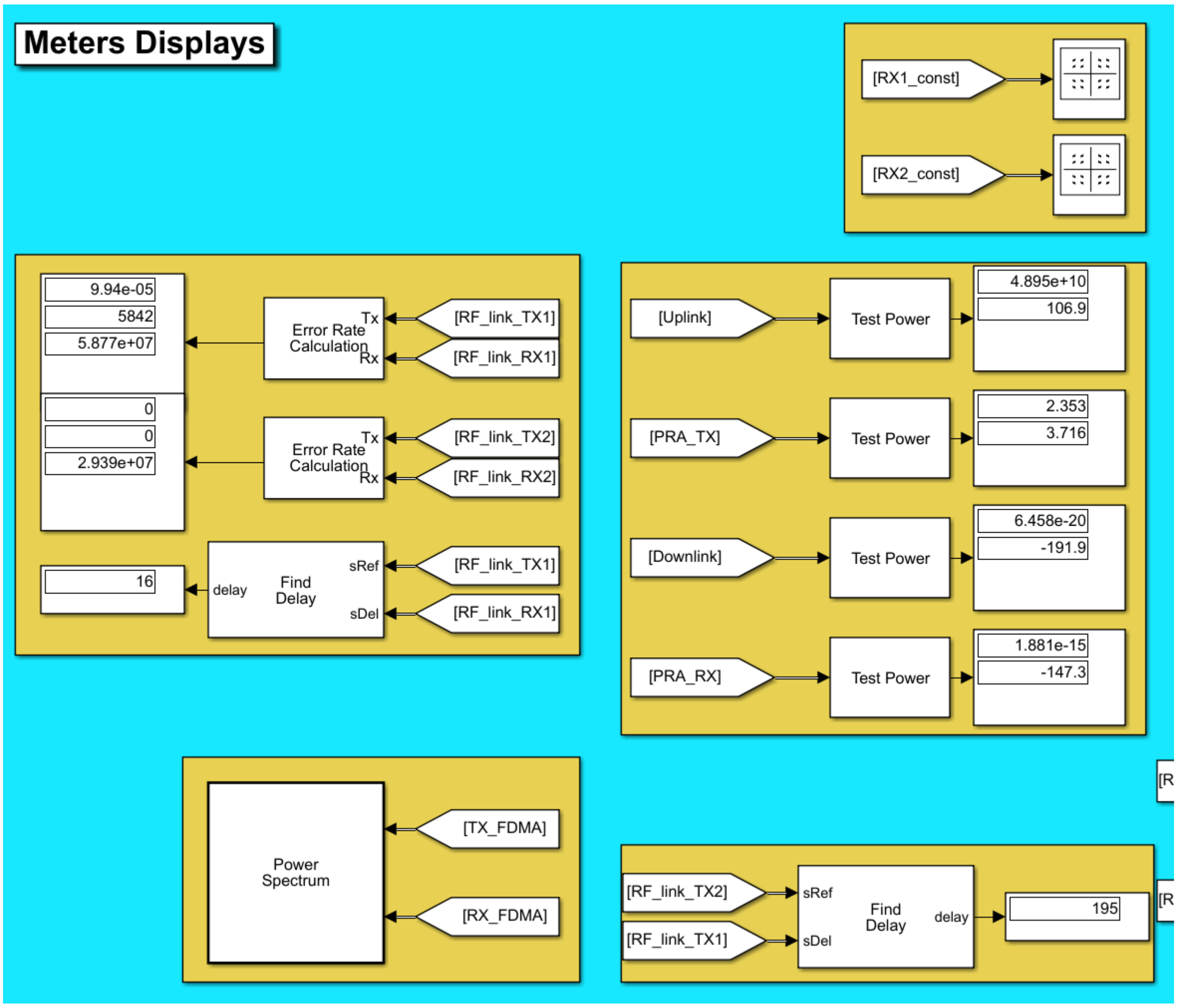
FDMA:



The BER performance of 2 users(X1,X2) seems to be satisfied in FDMA according to the constellation diagrams.



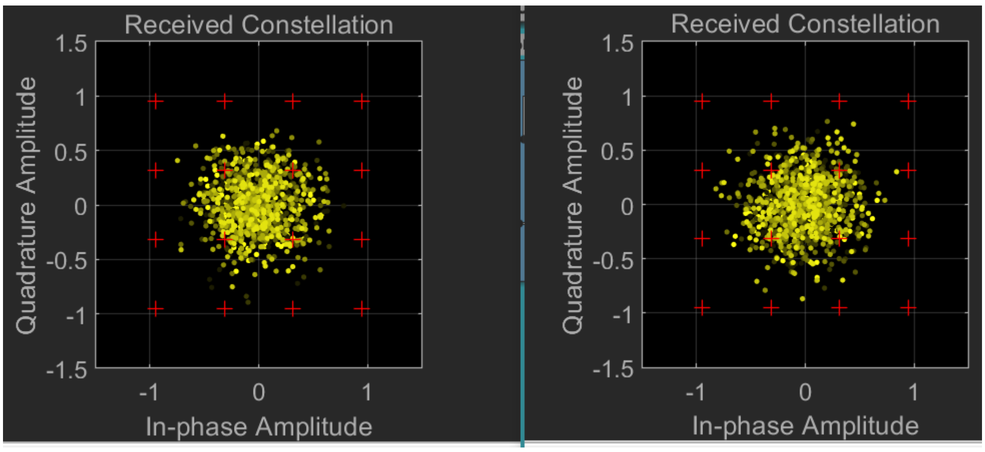
The satellite communications over FDMA seemed to perform very well according to the power spectrum because it is very obvious to observe both the transmitted signal and the received signal in 2 frequency channels.



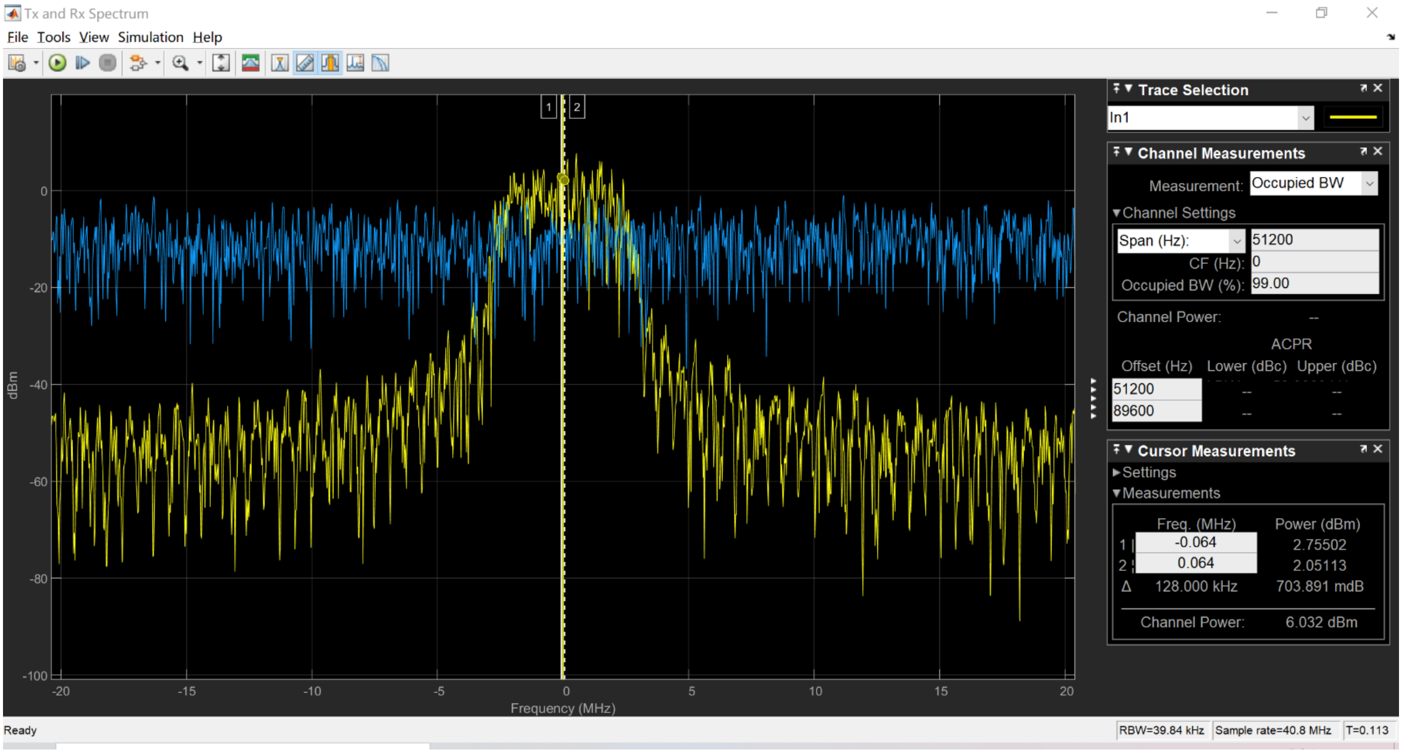
From the displays of blocks test power in 4 point, the power of signal attennuate sharply not only in the free-space path, but also inside the communications satellite.

And according to the Error Rate Calulation, the user X2 (with convolutional encoder) have better BER performance than user X1.

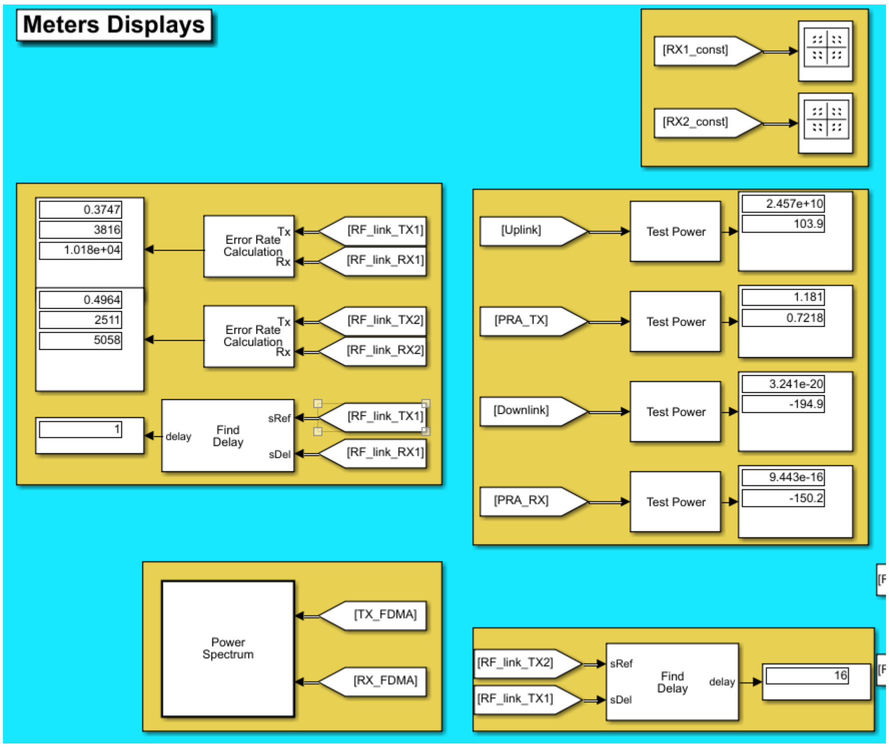
TDMA:



The BER performance of 2 users(X1,X2) seems to be very unsatisfied in TDMA according to the constellation diagrams. Most of the sampled point were mixed in a mess.

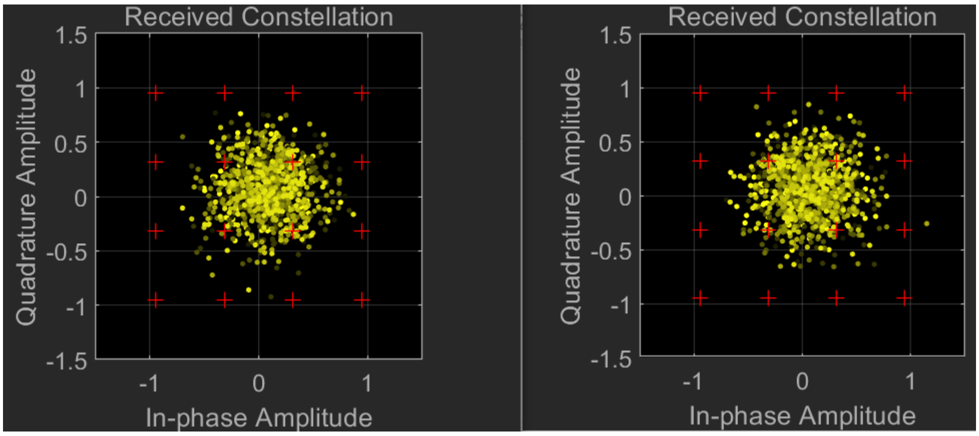


The satellite communications over TDMA seemed to perform nearly to invalid according to the power spectrum because it is very obvious to observe the transmitted signal but the received signal almost disappeared.

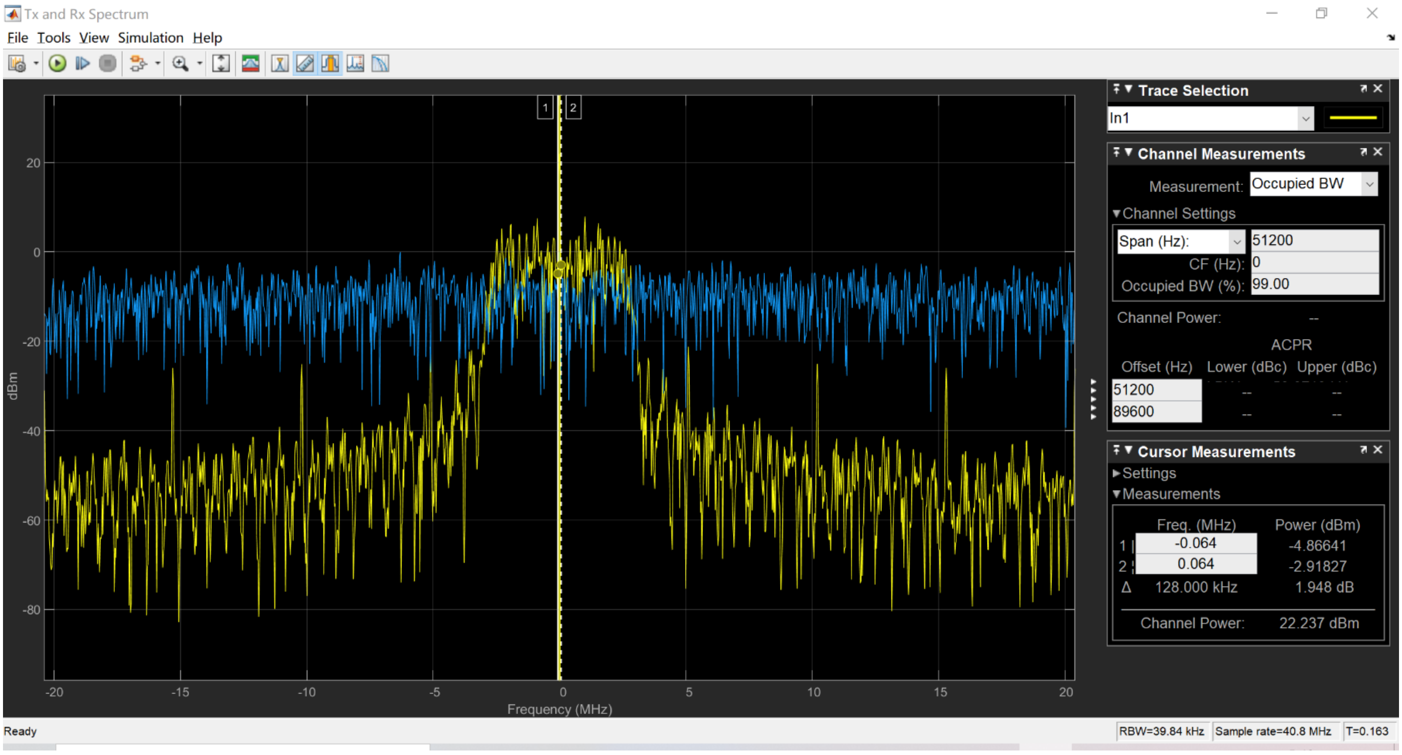


From the displays of blocks test power in 4 point, the power of signal attenuate sharply not only in the free-space path, but also inside the communications satellite.
And according to the Error Rate Calulation, the user X2 (with convolutional encoder) have almost the same BER performance than user X1.

TDMA:



The BER performance of 2 users(X1,X2) seems to be very unsatisfied in CDMA according to the constellation diagrams. Most of the sampled point were mixed in a mess.



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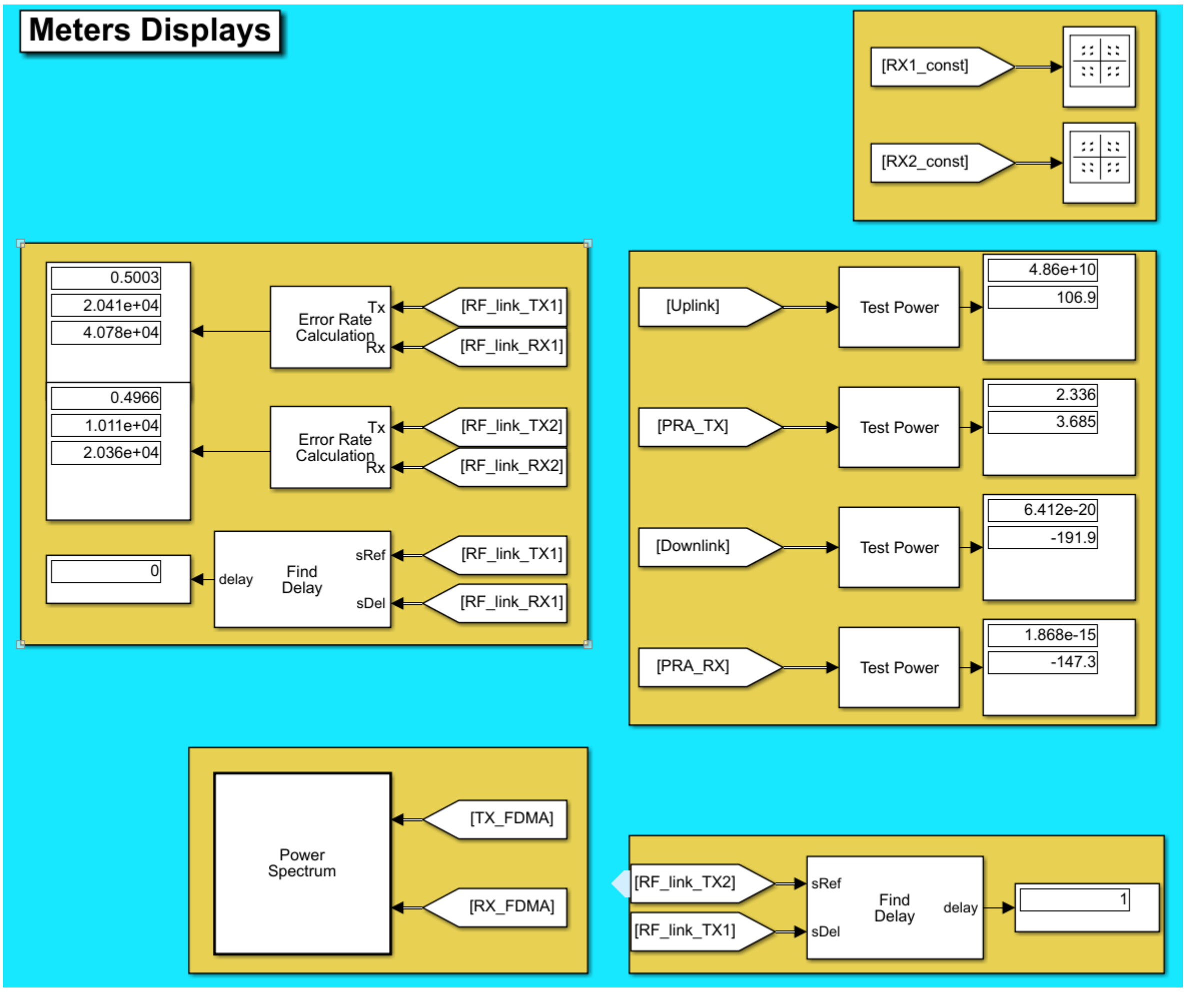


From the displays of blocks test power in 4 point, the power of signal attenuate sharply not only in the free-space path, but also inside the communications satellite.
And according to the Error Rate Calulation, the user X2 (with convolutional encoder) have almost the same BER performance than user X1.

Choose to apply FDMA:

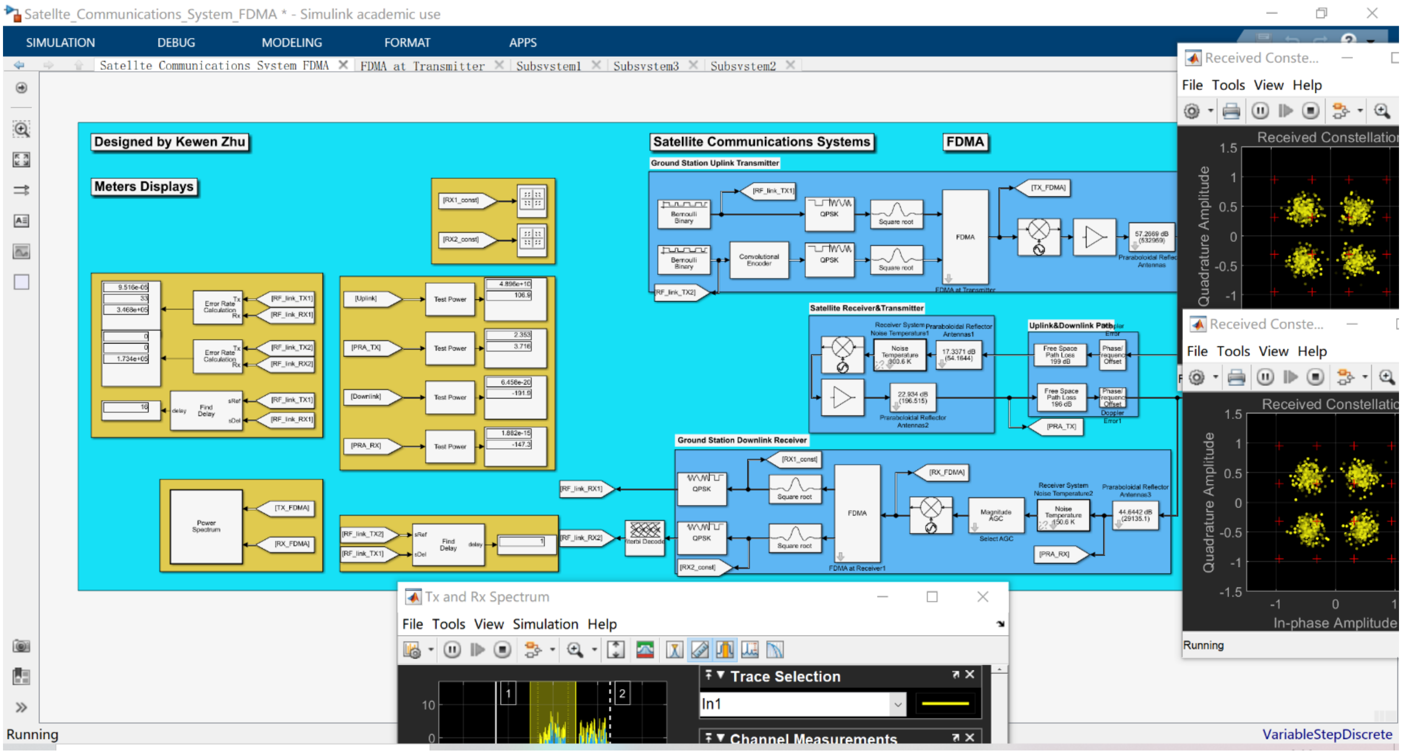
According to the comparation above, the FDMA has a much better overall performance, its bit-error-rate is low enough to satisfy and the output is also clear to see.

The power efficient of 3 multi-access in GEO satellite communication have not typical difference

Although the throughput and the bandwidth efficiency might higher in other 2 multi-access, it is obvious that the FDMA is the most proper multi-access to apply and implement in the GEO satellite communication systems which confirm that the frequent use of FDMA in GEO satellite communication is reasonable and have practical advantages.

We compare CDMA and FDMA (or TDMA) schemes in multibeam non-geostationary satellite systems, taking the effects of antenna patterns on inter-cell interference into consideration. The maximum acceptable number of users per cell in the uplink is employed as a measure of the system capacity. We have found that in FDMA (or TDMA) systems the maximum acceptable number of users varies according to the altitude of the satellites. While the performance is insensitive to the altitude in CDMA systems. For this reason, the altitude of the satellites is found to be an important factor for selecting multiple access schemes in non-geostationary satellite systems.[5]

Final working satellite communications system:



[1] K. P. and M. Shah, “Laboratory experiments for understanding effects of RF impairments on received signal in satellite link,” Navi Mumbai, 2017.

[2] S. R. and H. X. X. Luan, J. Wu, X. Xu, “Research on the propagation delay characteristic of multi-beam GEO satellite communications system,” Seoul, 2011.

[3] N. J. Kasdin and T. Walter, “Discrete simulation of power law noise (for oscillator stability evaluation),” Hershey, PA, USA, 1992.

[4] L. L. H. L.-L. Y. E.-L. K. K. Yen, *CDMA Overview*, IEEE. IEEE, 2004.

[5] T. Y. and A. O. N. Ichikawa, M. Katayama, H. Okada, “Comparison of CDMA and FDMA/TDMA in non-GEO satellite systems,” Helsinki, Finland, 2001.