Satellite Link Budget Calculator by Using Matlab/GUI

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Abstract- **In this paper, a satellite link budget calculator was done by using MATLAB – GUI program, the link budget is represented in one active screen, and it is designed to show the parameters that affects the RF signal when it is passing through the three main parts of the satellite communication system and regardless of the input signal power level. The results of the link budget program with the effects of changing the parameters will be shown inside the same active screen, which makes the users (students and trainers) analyze the reason that causes the weak signal when it reaches the satellite receiver.**

*Keywords***:** *Satellite link budget, GUI. Simulation, gain margin, satellite link statues***,**

I. INTRODUCTION

Nowadays, satellite communication systems are evaluated and tested by using simulation programs which adds the environmental factors that affects the signals and observes the performance of the satellite link. A RF satellite link consists of an uplink (transmit earth station to satellite) and a downlink (satellite to the receiver earth station). The signal power and quality over the uplink depends on how strong the signal is when it leaves the source (earth station) and how the satellite receives it. While, on the downlink side, it depends on how strongly the satellite can retransmit the signal and how the ground station receives it. The signal from the source in the ground station will processes the signal to reach the satellite. The sending process contains modulation, frequency conversion and amplification, then it will transmit the signal to the satellite by a narrow beam antenna. Through the free space attenuation and massive loss appeared effect on the signal, so a weak signal will be received by the satellite. Signal amplification and some processing is needed to convert the signal from uplink frequency to down link frequency. Many studies were done with different methods such as RF link budget - Simulink -MATLAB, which shows the effects of the power level, antenna gain and S/N ratio only [1]. RF- café offers a program named RF calculator workbook by excel, and it deals with main factors of the link budget and calculates the power received [2].

In this paper, the net power transmit from the earth station will be calculated in consideration with the main factors which makes the loss and attenuation in the path for the signal before transmitting on the free space channel. This paper shows all the factors affecting the signal on the receiver side, and the factors that gives the again and loss on the signal. Finally the results will show the effects of all factors and calculates the status of the satellite link.

The rest of the paper is organized as follows, section 2 explains the RF satellite link budget program, section 3 demonstrates the sending signal and what follows, section 4 shows the analysis and the result of the program, and finally section 5 concludes the paper.

II. RF SATELLITE LINK BUDGET.

The purpose of a satellite system is to provide reliable transmission with a specified quality of the received signal. The transmitted information has to be modulated on an RF carrier. In analog systems, the frequency modulation (FM) is the dominating modulation method, the signal-to-noise ratio (S/N) after the demodulator is the measure of signal quality. In digital satellite links, the measure of quality is the bit error rate (BER). The modulation method mostly often used in digital system is phase shift keying (PSK). In both analog and digital systems, there is a unique relationship between the carrier-to- noise ratio (C/N) and the signal-to-noise (S/N) ratio or the bit error rate (BER). Given the modulation method, the

performance of the total link is generally specified in terms of a minimum C/N in a certain percentage of time. In order to establish the link quality, we need to calculate the carrier power (C) and the noise power (N) at the receiving station. [3].

Figure (1) shows the main parts of a satellite communication system (uplink), where each part contains a block can be represented as mathematical model by simplifying their function or the process needed on the transmitted signal.
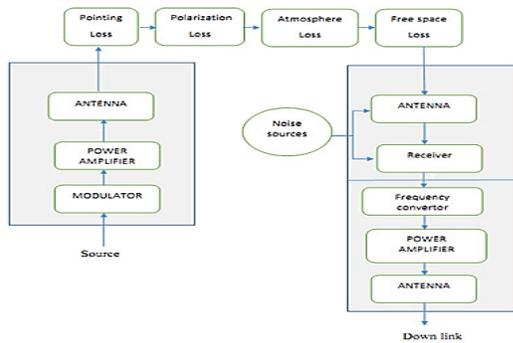

Figure (1): Main Block Diagram of Satellite Communication System

The link budget calculation are usually made using decibel (dB and dBm), the transceiver designer's objective is to close the link for the specified distance and required availability as efficiently as possible, whereas the link designer's task is to use an existing transceiver to satisfy a specific communication requirement. The link designer may then trade off availability for link distance.

III.   TRANSMITTER STATION

The discussion in this section is about the ground station, the main process on the signal will be to modulate the signal or change the form of the signal then it is to convert the band of the signal from intermediate frequency band L- band to C, X or Ku band, then amplifying the signal by power amplifier to increase its amplitude and its power. After that the signal is directed to the satellite by a reflector antenna, which gives the signal extra gain with respect to isotropic radiation, that signal called (power flux density), which radiates in a given direction by any antenna that have gain GT, the equivalent isotropic radiated power (EIRP) is:

EIRP = PT GT   in(watt)   ..

or   (1)

ERIP = PT (dB) + GT (dB)   in (dB)   (2)

GT can be calculated in the following equation

GT= η (10472 D F)^2 (3)

Where η is the aperture efficiency which has a value (0.5 to 0.65), F is the carrier frequency in (GHz), and D is the reflected antenna diameter in (m), or by using the equation (4) to calculate GT or GR, along with the carrier frequency in (MHz).

GT dB = -42.2+20log F(MHz) +20log   (4)
D(m).

with typical value for aperture efficiency is (0.55) [4].

Adding to that, some kind of loss must be consecrate in this stage like modulation process loss, connection and cable loss,

ERIP = PT . + GT – Lt.   in (dB)   (5)

Where Lt is total of transmission loss in dB.

IV.   SPACE CHANNEL PART.

The biggest attenuation on the signal happens in this section. Where the constitute path losses in the link equations. These losses include system loss (due to thermal noise), transmission loss due to ionosphere (cloud, rain, fog and gazes), and directional (pointing) loss.

Free space loss (FSL) have two important factors which are frequency F and the range R or distance between earth station and the satellite, so that, it can be calculated by the following equation:

FSL(dB) = 32.4 +20 log R+20 log F   (6)

Where R in Km and F in MHz [5]

The other losses also must be considered for final calculation, and these are simply added to FSL. The losses for clear –sky condition is

Total losses dB = FSL+AML+AA+ PL   (7)

where AML is antenna misalignment loss in (dB), Anais atmospheric absorption loss in (dB), PL is polarization mismatch loss in (dB), and some other loss such as cables and connecters loss in the transmitter and the receiver, that will call as (Rx) in (dB).

V.   NOISE AND NOISE FIGURE

Receiver noise includes contributions from thermal noise, short noise and possibly flicker noise. These may arise in the input RF section of the receiver. The total receiver noise Tso can be calculated from the following equation.

TS= TRF + Tin   +   Tm/Gr   in(K)…(8)

Where TRF is the temperature on the front end of RF part in the receiver, Tin is the input temperature to the receiver, Tm is the frequency convertor unit or the mixer temperature, all in Kelvin (K), and Gr antenna gain. An alternative way of representing amplifier

noise is by means of its noise factor, F. In defining the noise factor of an amplifier, the source is taken to be at room temperature, denoted by T0, usually taken as 290 K. the noise figure can be calculate by this equation

$$F = TS/T0 + 1$$

Or   (9)

$$F(dB) = 10 \log F$$ (10)

Noise power depend on the bandwidth of the receiver (B) and noise figure (F) so the noise power is given by

$$N = k \, T0 \, B \, F$$ in(watt)..
                                                            (11)

Where k is Boltzmann's constant ($1.38 \times 10\text{-}23$ J K-1), B is the bandwidth in (Hz).

And it can be simplified that equation (11) in (dB) with T0 = 290 k.

$$N (dB) = -174. \, dB/Hz + 10\log (B)Hz + F \, dB$$ (12).

Or

$$N(dBm) = -114. \, dB/MHz + 10\log (B)MHz + \quad (13) . \, FdB$$

V.1. FIGURE OF MERIT G/T

The G/T ratio is a key parameter in specifying the receiving system performance. the antenna gain Gr and the system noise temperature Tso can be combined in the following equation

$$Gr \, dBi = -42.2 + 20\log FMHz + 20\log Dm$$ (14).

$$G/T \, dBi = Gr - 10\log Ts$$ (15).

by adding antenna receiver Rx loss in (dB) to G/T, then

$$G/TdB = Gr - 10\log Ts - Rx \, loss$$ (16).

Signal power received (PR) can be calculate by the following equation

$$PR.= ERIP - total \, losses + G/T$$. (17)

That power must be greater than minimum signal power requires (C min) to the receiver.

V.2. LINK BUDGET ANALYSIS

A measure of the performance of a satellite link is the ratio of carrier power to noise power at the receiver input, and link-budget calculations are often concerned with determining this ratio. Conventionally, the ratio is denoted by C/N (or CNR), which is equivalent to PR/ N. In terms of decibels,

$$C/N \, dB = PR - N$$ (18)

The Link Margin obtain which tells how tight we are in closing the link:

$$Margin \, dB = PR - C \, min$$ (19)

The allowed margin depends on the required reliability (egg link maintained for (99.99%) of time, averaged over one year) and the range of climatic conditions which are predicted along the link. Typical margin values are 2dB (C band) and 8dB (Ku band) [6]. The link status depends on the value of link margin, which will be close for positive value, that means the system is working well, and if the negative value for the margin is open, it is means that the system is not working.

VI. SIMULATION OF THE RF LINK BUDGET

This program is designed to show all the input and output parameters together on an active screen in order to study the effects on the output results when one or more parameter is changed. The program has many variables that must be given to that program, such as the following parameters which are shown in table (1).

Table (1) input measurement

o	Input parameters	Units
	Operating frequency F	MHz
	Output power P	W
	Transmitter Antenna Diameter D	m
	Loss in antenna complex TX Loss	dB
	Operation bandwidth BW	MHz
	Modulation loss Mod Loss	dB
	Slant range R	Km
	Atmosphere loss AA	dB
	Polarization loss PL	dB
0	Antenna misalignment loss AML	dB
1	Threshold level	dBm
2	Satellite antenna diameter D	M
3	Receiver loss RX Loss	dB
4	Equivalent temperature Te	K
5	Reference temperature TO	K

Then the program is going to calculate the require parameters which are shown in the table (2).

Table (2) output measurements

No	Output measurements	Units
1	Wave length	Cm
2	Antenna transmitter gain Gt	dBi
3	ERIP	dBm
4	Free space loss FSL loss	dB
5	Total space loss	dB
6	Antenna receiver Gr	dBi
7	Figure of merit G/T	dB/K
8	Received power Pr	dBm
9	Noise figure	dB
10	C/N	dB
11	Gain margin	dB
12	Link status	-

After entering the parameters, the program decides if the link is closed or not. Depending on the condition that if PR is greater than the threshold level the link is closed, and if PR is less than threshold level the link is open. [7] .The link status depends on the value of link margin, it will be closed for positive value, that means the system is working well, and negative value for the margin is open and it is means the system is not working. By using GUI/ MATLAB program to design the simulation, the graphical user interface (GUI) is a graphical display in one or more windows containing controls, called components that enables the user to perform interactive tasks. The user of the GUI does not have to create a script or type commands at the command line to accomplish the tasks. Unlike coding programs to accomplish tasks, the user of a GUI needs not to understand the details of how the tasks are performed.

The figure (2) shows the final active screen of satellite link budget simulation, the white color fields for the input parameters and blue sky color for useful output parameters which are using in link budget equations.
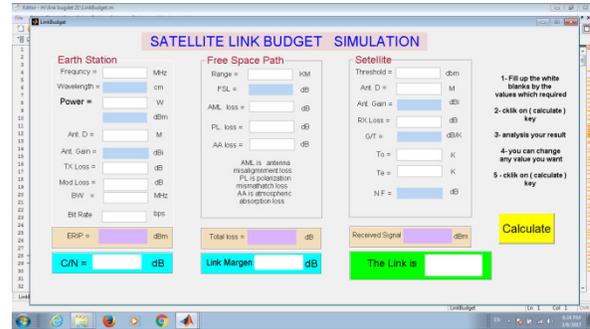

Figure (2) shows the final active screen of satellite link budget simulation

VI.1. RESEARCH METHODOLOGY

The following steps shows the procedure for the analysis of a satellite link:

(1) Run the MATLAB program. (2) Call GUI file then open it (our simulation file). (3) Write the value of the uplink carrier frequency. (4) Select the transmission powers. (5) Choose any value for antenna diameter. (6) Estimate the loss in transmitter such as cable loss and connectors. (7) Estimate the loss for modulation. Write the range of the satellite. (8) Give a value for antenna misalignment loss. (9) Give a value for polarization loss. (10) Estimate the loss in free space or atmosphere loss such as (rain, gas and foggy). (11) Give a value for minimum signal required to the receiver. (12) Chose the diameters for the satellite antenna. (13) Give a value for receiver loss. (14) Write the reference temperature. (15) Write a value system temperature (of the noise temperature) then Click on calculate key. The figure (3) has shown the active screen after feed all input parameters.

Figure (3) all input parameters are feed to the active screen

VI.2. THE RESULTS

The results shown in the figure (3) shows how the program calculates the parameters which are shown in the table (2), the results with all input parameters will show in the active screen. As shown in figure (4). On the same screen. The value of any parameters can be changed then click on (calculate key), the results will change according to the new value, for example, the

AML Loss is changed from 1 to 2 the result also change as shown in figure (5), same thing if AA change from 0.5 to 4 such as a heavy rain. the figure (6) shown the results ware change. And so on.
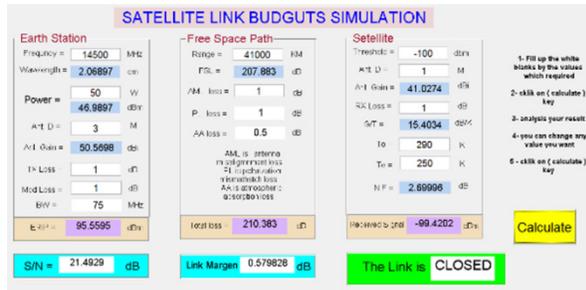

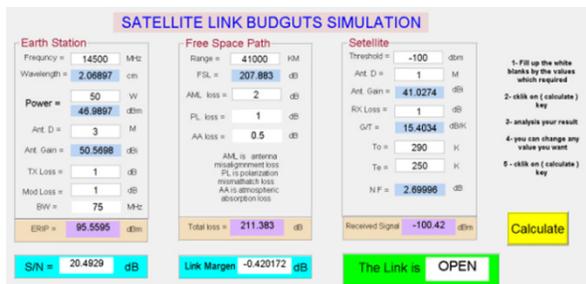Figure (4) active screen shown the results after click on calculate bottom

Figure (5) on the same screen and only change one parameter such as AML is change from 1 to 2   and the result shown changes on the outputs.
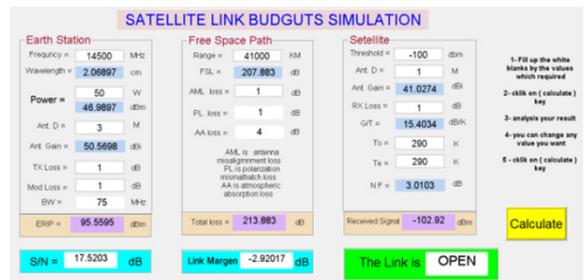

Figure (6) on the same screen, change the value of AA loss such as heavy rain

VI.3. CONCLUSION

This simulation system provides a nice way for users to examine the effects of all the parameters on the system. Students and trainers can change all the parameters of the system and see the effects at the same time. The screen shows the three basic units of communication and their parameters. The dynamic of change can trace the effect. It is easy to use and to calculate. The program can be developed and modified for new ideas. The program can be used in a satellite lab, for antenna gain measurement, free space loss calculation, noise figure measurement, figure of mired measurement, and link budget design, so the students can perform experiments.

The program covers the requirements of the satellite laboratory for experiments of the design and analysis of the RF link budget for overall system which it can show the effects of all input parameters on the output results. The simulation of the satellite link budget by using MATLAB/GUI, gives us some extra flexibility to prove and sense the relationship between some parameters in the link budget calculation. Unlike the RF Satellite Link example in MATLAB that have two variables SNR and Adaptive Noise, our program have thirteen variables and it will show the changes in all the important parameter when changing any variables. The simulation is open source available for other users to add or modify the system for any development in the future.

The final results were evaluated with a referenced with results from an international company web site which is used to examine their product in the same field [8].

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