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Ground Station Design for Satellite and Space Technology Development

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ABSTRACT
Satellite technology facilitates telecommunications, security and technological development. This paper presents a simple satellite ground station system for educational advancement and motivation of students' interest in the field of space engineering and satellite for development. The ground station can serve as a laboratory for future space technology development and facilitation of teaching and learning efficiency with emphasis on the hands-on experience as related to satellite communications research and development. The system design adopts scientific and engineering methodologies with relative available components for successful development. The proposed system operates on Very High Frequency and Ultra High Frequency spectrum ranging from 144MHz to 438MHz for tracking and reception of signals from amateur band satellites, using a set of Yagi-Uda antennas with 18.0dB gain, Low Noise Amplifier with Noise Figure of 0.7dB, rotor, IC-910H transceiver and computer system for automation process. Successful implementation of the proposed system design with margin of 3.37dB, demonstrates a simple technical approach to design an affordable ground station for hands on experience study and research for development of effective future satellite communication systems and space technology.

Index Terms— *Ground station system, satellite technology, link budget, free space loss, downlink, uplink, wireless communication and space technology educational laboratory.*

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I. INTRODUCTION

Satellite communication systems consist of two main segments, the space segment and the earth or ground station. The ground station system coordinates communication process with satellites in the space. In few cases small ground station system could be built on large ships on the sea, could also be found on aircrafts for mobile communication services. Ground station consists of various electronic communication systems including antenna system for transmission and reception of signals. Low noise block down converter, High Power Amplifier (HPA) transmitter with power from a few watts to hundred kilowatts depending on capacity and regulations, Up and Down converters, modem, encoders, multiplexers, control and tracking systems, interfaces for user terminals. These systems are further divided into various sections such as operations, control, radio frequency, networking sections, with different functionalities [1]. Figure 1, shows simple view of different types of ground stations.

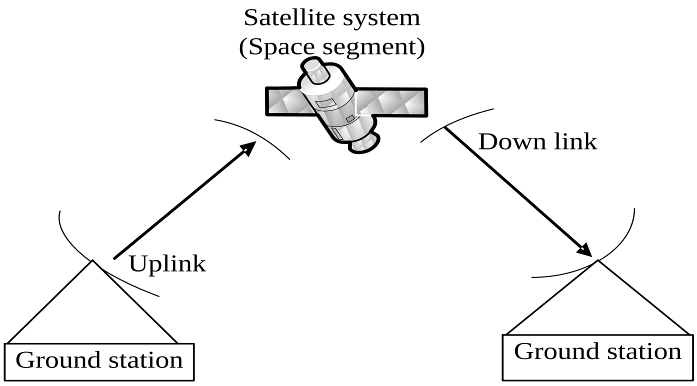

Figure 1: Representation of a typical ground station and space segment

Figure 1, shows typical view of fixed ground station communication processes. Ground segment of satellite communication systems deploy various designs and network configurations to provide required services. The node configuration depends on the size and required services. It ranges from large ground station use as gateways in a telecommunication network to Very Small Aperture Terminals (VSAT) that deliver data communication applications to remote region [2]. Satellite communications systems use various frequencies for signal propagation depending on the purpose, nature and regulations in the region of operation. Examples of frequency bands are Very High Frequency (VHF) ranging from 30 to 300MHz, Ultra High Frequency (UHF) ranging from 0.3 to 1.12GHz, L-band ranging from 1.12-2.6 GHz, S band ranging from 2.6 to 3.95 GHz, C-band ranging from 3.95 to 8.2 GHz, X-band ranging from 8.2 to 12.4 GHz, Ku- band ranging from 12.4 to 18 GHz, K- band ranging from 18.0 to 26.5 and Ka band ranging from 26.5 to 40 GHz. However, communications above 60 GHz are generally challenging because of high power needed and equipment cost. Ground station facilities are used for satellite tracking, controls and provision of Telemetry and Command (T&C) services . Ground stations are also responsible for planning and allocation of satellite resources to each gateway in mobile satellite communications. Various modes of propagation of electromagnetic signals from transmitting antenna to the receiving antenna include ground-wave propagation, sky-wave propagation and Line-of-Sight (LOS) propagation widely deployed in VHF and UHF amateur satellite communications.

There are various ground station design approach in the literature [3][4][5][6][7][8]. In comparison with the discussed models in the literature, the systems are exorbitant, which are often unaffordable by many universities in the developing nations with low capital budget. Thus, the need for investigation and development of an alternative ground station approach that is economical. The objective of the investigation is to gain insight on development of low cost ground station which can function as laboratory for students and researchers and as well motivate students' interest in the field of space technology and satellite communication development. The methodology approach involves system design, implementation, testing and discussion of performance results. The rest of the paper is organized as follows, section 2 presents ground station system architecture. Section 3 explains the design procedures and link budget. Section 4 presents system performance results discussion, Section 5 presents Bill of Engineering and Measurement Evaluation, while Section 6 presents the conclusion.

II. SYSTEM ARCHITECTURE

The investigation aims at developing simple affordable ground station capable of functioning as a laboratory for researchers and students on space technology and satellite communication development. Thus, the system design scope include satellite signal tracking from low earth orbit satellites, nano-satellites and radio stations operating on VHF and UHF frequencies spectrum [9] with capability of supporting students' research and experiments on satellite communications principles, modulation, demodulation, error correction, frame synchronization and digital signal processing techniques. The system architecture is presented in Figure 2.

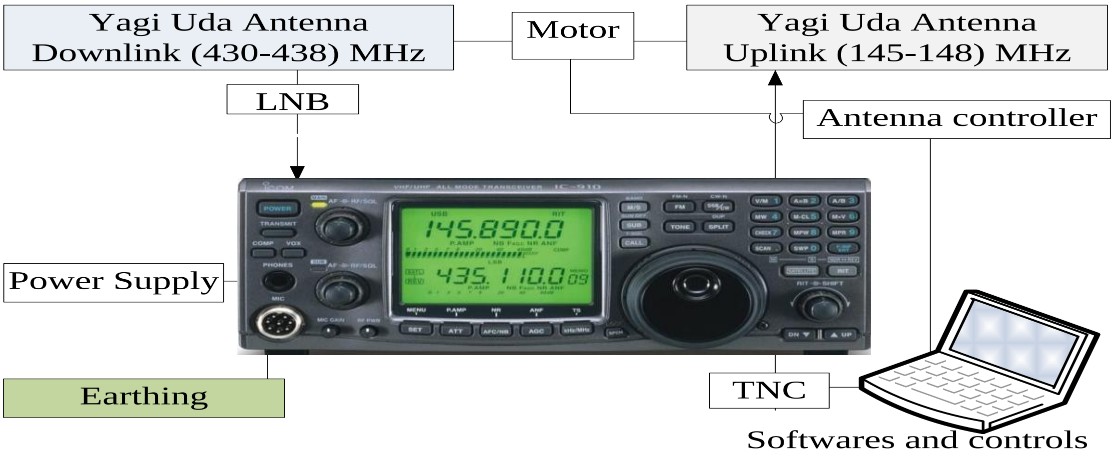

Figure 2: System Architecture

Figure 2, presents the proposed system architecture, consisting of IC-910H transceiver with a receiving sensitivity level of -126dBm, Yagi Uda antenna, earthing system, power module, Terminal Node Controller (TNC), Low Noise Block down converter (LNB), antenna controller, electric rotor for azimuth and elevation adjustment of antennas for optimum alignment with satellites for improved signal reception. The computer system and softwares perform tracking, controls, configuration of transceiver and digital signal processing. A set of two Yagi Uda antennas [10] with a gain of 18.0dB are adopted for the design, serving as a medium for propagation and reception of electromagnetic signals from the ground station system. The downlink antenna is connected to LNB of 15.0dB gain to reduce the effect of noise. The ICOM IC 910H transceiver with low noise figure, good sensitivity, is considered as the brain of the system, connecting other components for synchronization and demodulation of signals in UHF frequency spectrum and modulation of signals during transmission operation at the VHF frequency spectrum. The challenges addressed in this work include design of a simple and affordable satellite ground station capable of communicating with low earth orbit satellites and amateur satellites [11] operating on VHF and UHF frequencies spectrum for research and educational development.

III. DESIGN METHODOLOGY AND LINK ANALYSIS

Standard engineering methodologies have been applied to achieve the set objectives, including laboratory and field tests. Detailed calculations of signal powers, noise and Signal-to-Noise Ratios (SNR) for a communication link are carried out to determine the margin for reliable communication link. In this research work, exchange of information between the ground station and satellite through electromagnetic signal is considered. Signal radiation from antenna creates an electromagnetic wave that spreads outward from the antenna through space. In the design process to establish a communication link, factors such as frequency of operation, transmit power, equipment configuration, atmospheric effects, rain and terrain are considered in the link budget [12]. A detailed link budget is computed to determine the link margin in the design. Various factors are considered in the design process such as financial budget, frequency allocation and permit, interference consideration, identification of possible satellites for communication, services of the target satellites and the rules and regulations governing the satellites services. In this link analysis, free space loss between the reference satellite at a distance of 3300km, with a downlink frequency of 435.300MHz is considered using Friss transmission model [13] such that if the power input to transmitting antenna is $\mathbf{P_t}$, then the power density (**S**) incident on receiving antenna is given by:

$$S = \frac{P_t G_t}{4\pi r^2} \qquad (1)$$

Where, $\mathbf{G_t}$ is the maximum gain of the transmitting antenna expressed by:

$$G_t = \frac{4\pi}{\lambda^2} \times A_e \qquad (2)$$

The received power at the ground station is given by:

$$P_r = \frac{P_t G_t}{4\pi r^2} A_{er} \qquad (3)$$

Where r the maximum range between the satellite and ground station, $\boldsymbol{P_t G_t}$ is the Effective Isotropic Radiation Power and $\boldsymbol{A_{er}}$ is the effective area of the antenna. Substituting $\boldsymbol{G_t}$ and $\boldsymbol{G_r}$ in eqn (3):

$$\frac{P_r}{P_t} = G_t G_r \left(\frac{\lambda}{4\pi r}\right)^2 \qquad (4)$$

Re-arranging eqn (4) in line with Free Space Loss (FSL) [14][15][16]:

$$FSL = \frac{P_t G_t G_r}{P_r} = \left(\frac{4\pi r}{\lambda}\right)^2 \qquad (5)$$

$$FSl_{dB} = 20\log(4\pi) + 20\log(r) - 20\log(\lambda) \qquad (6)$$

$$\text{Where, } \lambda = \frac{C}{f} = \frac{3x10^8}{435.5x10^6} = 0.689m$$

Thus, pathloss at maximum range of 3300km and 800km for minimum range between satellite and ground station are given by:

$$FSl_{dB(max)} = 21.98\text{dB} + 20\log(3300 \text{ x } 10^3) - 20\log(0.689) = 155.58\text{dB}.$$

$$FSl_{dB(min)} = 21.98\text{dB} + 20\log(800 \text{ x } 10^3) - 20\log(0.689) = 143.27\text{dB}.$$

Summary of analysis of signal strength at the maximum and minimum range respectively is presented in Table 1.

Table 1: Downlink signal analysis at maximum and minimum range:

Range	Maximum range (3300km)	Minimum range (800km)
Reference satellite transmit power	1Watt =10log1+30dBm =30dBm	1Watt=10log1+30dBm =30dBm
Satellite antenna gain	2dB	2dB
Satellite transmission line loss	-1dB	-1dB
Polarization loss	-3dB	-3dB
Atmospheric loss	-1dB	-1dB
Path loss	-155.58dB	-143.27dB
Pointing loss	-1dB	-1dB
Receive aspect ratio	-1dB	-1dB
Feeder loss	-1dB	-1dB
Interference loss	-1dB	-1dB
Rain loss (not affected by rain at this freq. range)	0.00dB	0.00dB
Ground station antenna gain	18dB	18dB
Signal at ground station	-114.58 dBm	-102.27 dBm

The signal value -114.58 dBm at the maximum range and -102.27dBm at the minimum range are above the receiver sensitivity level of -126dBm.

The Effective Satellite Isotropic Radiated Power is given by, EIRP$_s$ $= P_{ts} \times G_{ts} \times L_{ts}$ (7), where **P_{ts}, G_{ts}** and **L_{ts}** are the satellite transmit power, satellite antenna gain and satellite transmission loss. Thus, $EIRP_{ts} = 30dBm + 2dB - 1dB$ = 31dBm.

Signal level at ground station antenna at maximum range SL$_{max}$ = EIRP – Losses + G$_r$.

SL$_{max}$ = EIRP$_{ts}$ - L$_{ts}$ + G$_r$, where G$_r$ is the gain from receiving antenna at the ground station, L$_{ts}$ is the total loss -163.58dBm, including path loss. Gr is 18.00dB, the ground station antenna gain.

SL$_{max}$ = 31dBm - 163.58dBm + 18.00dB = -114.58dBm (at maximum range).

Signal level at ground station antenna at minimum range, SL$_{min}$ = EIRP - Loss + G$_r$.

SL$_{min}$ = 31dBm -151.27 dB + 18dBi = -102.27dBm (at minimum range).

Thus, signal value -114.58dBm and -102.27dBm at the ground station antenna are above receiver sensitivity level of -126dBm.

The signal quality is also affected by Signal-to-Noise-Ratio (SNR). SNR indicates strength of received signal from the receiver. It considers the relative factors such as path loss, cable loss and system noise. The relationship between SNR and noise power is given by [17][18][19]:

$$SNR = \frac{Received\ signal\ level\ at\ ground\ station\ antenna}{Noise\ power} \qquad (8)$$

$$SNR = \frac{EIRP - Losses + Gr}{Noise\ power} \qquad (9)$$

The noise power in the reception system is given by = T x B x K (10)

where T, is 25.89dB, the effective receiver noise temperature. B is 15KHz, receiver's bandwidth. K is Boltzmann's constant given as 1.38 x 10^{-23} (dBW/K/Hz).

The target system data rate is 9600bps = 10log 9600 = 39.82 dBHz.

Radio noise power in the reception system = 25.89dBK+10log15000 +10log (1.38x10^{-23})

Noise power in reception system = 25.89 dB + 41.76 + (-228.60) = -160.95 dBW = -130.95dBm

The SNR at ground station receiver = -115.58dBm - (-130.95 dBm) = 15.37dB.

Signal strength of 12.00dB is required to achieve Bit-Error-Rate (BER) of 10^{-6} with the reference satellite' Binary Phase Shift Keying (BPSK) modulation scheme [20]. The ground station link margin M, is calculated by: M = 15.37dB – 12.00dB = 3.37dB.

Based on the calculated margin result, it is possible that with integration of low noise amplifier with average gain of 10dB, to overcome cable loss and improve signal strength, the ground station system design can receive signal from the reference satellite on UHF spectrum with significant margin. Table 2, presents summary of downlink analysis.

Table 2: Summary of downlink analysis

Parameter	**Value**	**Unit**
Spacecraft		
Power output	1.00	dB
Antenna gain	2 .00	dB
Transmission line loss	-1.00	dB
EIRP	2.00	dBW
Ground Station		
Antenna pointing loss	-1.00	dB
Antenna Polarization loss	-3.00	dB
Path loss (maximum range)	-155.58	dB
Interference loss	-1.00	dB
Atmospheric loss	-1.00	dB
Receive aspect ratio	-1.00	dB
Antenna Gain	18.00	dBi
Line loss	-1.00	dB
Effective temperature	25.88	dB/K
Receiver Bandwidth	15.00	KHz
Noise Power (KTB)	-160.95	dBW
SNR	15.37	dB
Service Requirement		
SNR requirements for (10^{-6} BER)	12.00	dB
Margin	3.37	dB

Table 2, presents satellite, ground station and service requirements parameters. The link margin of 3.37dB is achieved without considering LNA gain. However, with integration of LNA the margin will improve significantly.

IV. SYSTEM PERFORMANCE AND RESULTS DISCUSSION

In this section, the ground station system parameters and framework structure are presented. Experimental analysis is performed to validate ground station system performance. Standard engineering test methods were applied ranging physical inspection of the components to detailed testing procedure with sophisticated equipment. The tests were performed for verification of system component parameters and configuration. The system configuration was set up with two Yagi antennas for transmission and reception of signals. The antenna performance was optimized with a computerized control system to align the satellite and ground station antennas for optimum power transfer from satellite to ground station or vice versa. The transceiver, IC-910H was earthed to reduce system noise and interference. The receiver sensitivity test was performed in the laboratory to determine the practical threshold level of the receiver. During the test, signal generator, network analyser, digital multimeter, reference coaxial transmission cable, attenuator, 75Ω termination for impedance matching and a dummy load were applied to determine sensitivity level of the receiver. The loss in reference cable of 1.0 meter length was determined with the network analyser by connecting across the RF input and reflection terminals. The loss of 0.22dB was recorded. The signal generator was connected to the transceiver via the reference cable and the receiver was tuned to 436.00MHz. Figure 3, shows system configuration for receiver's sensitivity test.

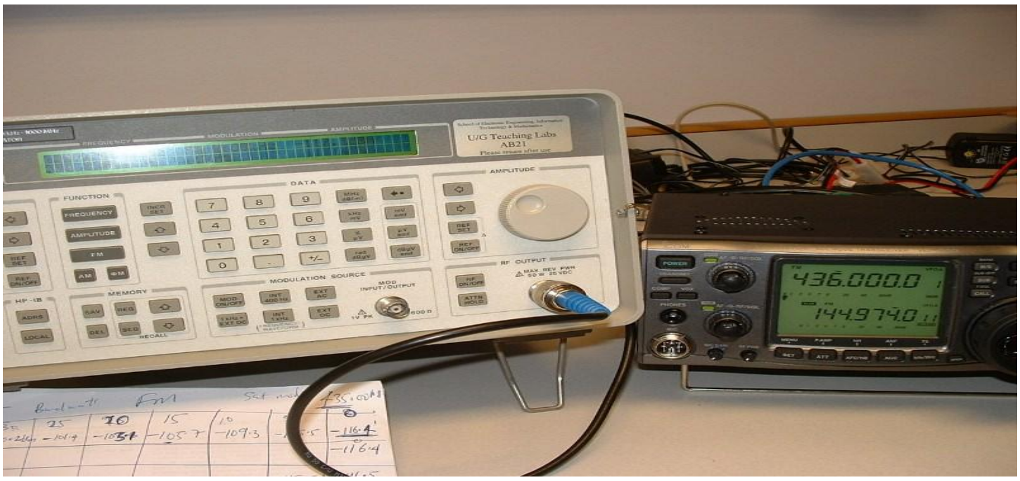

Figure 3: Sensitivity Test Configuration

The sensitivity test result records that at signal level of -136dBm the receiver could not detect the signal until the strength was increased to -126dBm. The saturation level of the receiver, 20dBm was also recorded and precautionary measures taken to avoid damage to the system. The system test result aids in the formulation of operational sequence of the system. Figure 4, shows a plot of system margin and bandwidth.

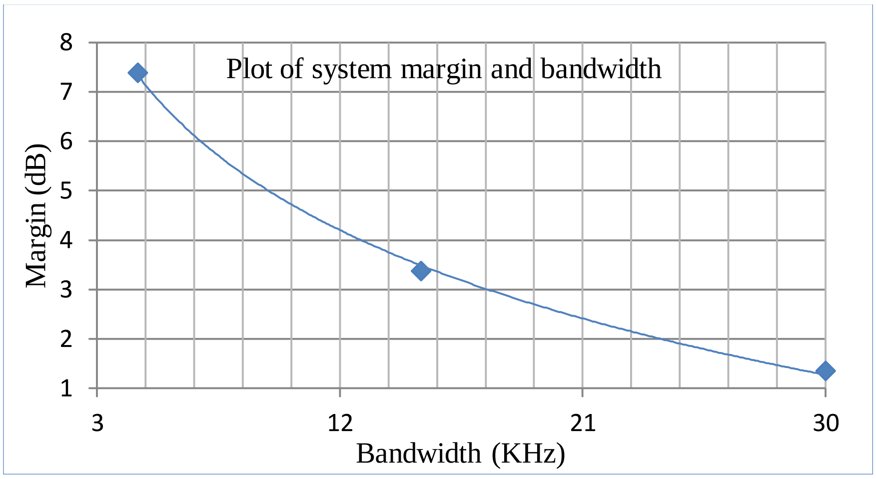

Figure 4: System margin and bandwidth

Figure 4, shows plot of system margin and bandwidth. It is observed that it is more robust to operate at low frequency as the system margin improves with decrement in bandwidth under fixed system condition. System margins of 1.35dB and 3.37dB were recorded at 30KHz and 15KHz operations, respectively. It has been noticed that at 4.5KHz bandwidth, the margin improves to 7.38dB as depicted in Figure 4.

The output signal from the LNB was measured to obtain real practical value before system integration process. Integration of LNB in the system improves the ground station quality performance with a recorded average gain of 10dB. This reduces the effect of noise by increasing signal strength above noise level for clear reception. It was also observed that both satellite and ground station antennas must have same orientation and polarization to enhance optimum satellite signal power transfer to ground station or vice versa. Reduction in signal power was noticed when the antennas were not aligned. However, it is practically difficult to align antenna perfectly at all time.

V. BILL OF ENGINEERING AND MEASUREMENT EVALUATION

This section presents costing of the ground station project. This involves financial reports on the equipment procurement, integration and installation procedures of the ground station project. The project used compatible Commercial Off the Shelf (COTS) components to benefit from the significant time savings due to short time duration allocated for the project. Although the application of ground station and the range of available components are extremely diverse, but the most basic components include, antenna, rotator, microcontroller, Low Noise Amplifier (LNA), Low Noise Block (LNB), Terminal Node Controller, (TNC), digital compass, tower, tracking software, spectrum analyser, cabling system, transceiver, digital multimeter, termination 50Ω, Dummy load 50Ω, record booklet, workstation, power source, earthing system, rack and Close Circuit Television (CCTV) for monitoring of antenna and accessories at the rooftop. The summary of the ground station project cost scheduling, Bill of Engineering Measurement and Evaluation of the project indicating cost information is presented in Table 3.

Table 3: Costing of the Ground Station Project

	Description	Unit Price ($)	Quantity	Amount ($)
1	Computer workstation	299.00	1	299.00
2	UHF/VHF Transceiver (ICOM IC-910H)	1599.00	1	1649.00
3	Yagi Uda Antenna for satellite	149.99	2	349.98
4	Azimuth/Elevation Rotator	449.99	2	899.98
5	Tracking software (NOVA for windows)	60.00	1	60.00
6	Spectrum analyzer	1207.99	1	1207.99
7	Low Noise Amplifier	15.99	1	15.99
8	Digital Compass	40.95	1	40.95
9	Clinometer	39.99	1	39.99
10	Close Circuit Television and accessories	179.99	1	179.99
11	Coaxial cables, BNC and accessories	73.98	Lots	73.80
12	RF terminators 50Ω	7.89	6	47.34
13	Digital Multimeter	36.49	1	36.49
14	Shipping and Miscellaneous			225.50
	Total (Four Thousand, Nine Hundred and Twenty Six Dollar)			$5126.00

Table 3, presents the cost of key equipment and instrumentation system of the ground station project. The project was realized with a total cost of Five Thousand, One Hundred and Twenty Six Dollar ($5026.00).

VI. CONCLUSION

In this paper, a simple affordable satellite ground station system for satellite communication and space technology development is investigated. The research aims at developing a satellite ground station system which can function as laboratory for teaching and research of new wireless technology for future applications. The system performance was improved by integrating a LNB with reasonable gain of 10.0dB to optimise noise level, and effective alignment of antennas to properly capture the radiated power from the satellite. Successful implementation of the system demonstrates a simple technical approach to design and build an affordable ground station to provide a medium for hands-on-experience in the study and research for development of future satellite communication systems and space technology [21][22]. However, we encountered few technical challenges such as delays in delivery and incompatibility of some of the Commercial Off The Shelf (COTS) components and difficulty in the installation of antenna on the roof due to its long size.

DECLARATION OF COMPETING INTEREST

There is no conflict of interest in regard with this manuscript submission and publication of research results.

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