Jurnal E-Komtek
Vol. 7, No. 1 (2023) pp. 59-71
https://jurnal.politeknik-kebumen.ac.id/index.php/E-KOMTEK
p-ISSN : 2580-3719 e-ISSN : 2622-3066

The Simulation of Very High Frequency (VHF) Voice Communications at Aeronautical Mobile Satellite (Route) Service (AMS(R)S)

AA Kompiyang Karmana Putra, Muhammad Suryanegara
Department of Electrical Engineering, Indonesia of University, Indonesia, 16424

aa.kompiyang@ui.ac.id
https://doi.org/10.37339/e-komtek.v7i1.1168

Published by Politeknik Piksi Ganesha Indonesia

Artikel Info
Submitted:
09-05-2023
Revised:
05-06-2023
Accepted:
05-06-2023
Online first :
28-06-2023

Abstract

To expand the coverage of current aviation VHF communication services, it is necessary to develop a satellite-based VHF communication system. This research aims to analyze the satellite link budget calculations for VHF AMS(R)S frequencies using a Low Earth Orbit (LEO) satellite at an altitude of 600 km, in accordance with the studies conducted by ICAO and ITU. The link budget calculation, using parameters such as aircraft antenna gain = -1 dBi, satellite antenna gain = 8 dBi, RF power of the aircraft = 16 watts, and RF power of the satellite = 85 watts, results in satellite receiver sensitivity between -107 dBm - 25.56 dB, as well as aircraft receiver sensitivity between -93 dBm - 38.65 dB. When simulating an end-to-end link budget (loopback: aircraft-satellite-aircraft between 14.92 dB - 14 dB. Simulations were also carried out for voice communication using an AWGN channel illustration with an Eb/No of 10 dB, resulting in the performance of the VHF audio link.
Keywords: *Information Systems, Petty Cash, Waterfall, UML*

Abstrak

Untuk memperluas cakupan layanan komunikasi VHF penerbangan saat ini, perlu dikembangkan sistem komunikasi VHF berbasis satelit. Penelitian ini bertujuan untuk menganalisa perhitungan link budget satelit untuk frekuensi VHF AMS(R)S dengan menggunakan satelit Low Earth Orbit (LEO) pada ketinggian 600 km, sesuai dengan studi yang dilakukan oleh ICAO dan ITU. Perhitungan link budget, dengan menggunakan parameter seperti gain antena pesawat = -1 dBi, gain antena satelit = 8 dBi, daya RF pesawat = 16 watt, dan daya RF satelit = 85 watt, menghasilkan sensitivitas receiver satelit antara -107 dBm - 25,56 dB, serta sensitivitas receiver pesawat antara -93 dBm - 38,65 dB. Saat simulasi link budget end-to-end (loopback: pesawat-satelit-pesawat antara 14,92 dB - 14 dB. Simulasi juga dilakukan untuk komunikasi suara dengan menggunakan ilustrasi kanal AWGN dengan Eb/No sebesar 10 dB, sehingga menghasilkan performansi link audio VHF.

Kata-kata kunci: *AMS(R)S, VHF, ICAO, Link Budget Satelit, C/N, Eb/No, BER,*

1. Introduction

International Civil Aviation Organization (ICAO) sets standards, procedures, principles, and technical requirements for air navigation and civil aviation organizations to ensure safety, security, and future technological advancements **[1]**. One of the protocol standards established is the communication standard between aircraft pilots and Air Traffic Controllers (ATC) using the Very High Frequency (VHF) communication system known as the air band. This system is used for voice and data communication, utilizing frequency allocation between 118 to 137 MHz. Until now, the VHF communication system has been used mainly for limited ground communication or air-to-ground communication. As a result, the network still needs to cover areas such as remote regions over the oceans. Therefore, ICAO and ITU (International Telecommunication Union) are considering implementing the VHF communication system for the Aeronautical Mobile Satellite (Route) Service (AMS(R)S) **[2] [3]**.

AMS(R)S is a satellite-based communication service for aviation. It enables pilots to communicate with ATC and other aircraft pilots using voice and data communication. AMS(R)S is designed to provide reliable and secure communication services for air traffic management, including air traffic control, flight information, and meteorological services. AMS(R)S is a critical component of modern air traffic management as it allows real-time communication between pilots and ground controllers, enhancing air transportation safety and efficiency. It operates on specific frequency bands regulated by ITU and ICAO.

Based on the distance calculations, the AMS(R)S system that can support VHF aviation communication is a Low Earth Orbit (LEO) satellite with an orbit altitude of 600 km. The communication delay is approximately 4 ms at the closest point and 18.9 ms at the farthest point. These delays do not significantly impact the quality of aviation communication services.

This research aims to review and analyze the satellite link budget calculations for the AMS(R)S communication system using the frequency allocation of 118 - 137 MHz (VHF), per the studies conducted by ITU and ICAO. The research considers that there are no changes in the VHF communication system devices on aircraft, both for voice and data communication. Additionally, the research aims to create a simulation of voice communication using the Mathematical Programming Language. The link budget calculations that will be analyzed focus solely on the communication link between the aircraft and the AMS(R)S satellite in both directions. The feeder link from the AMS(R)S satellite to the ground station connected to ATC will not be discussed, as it is assumed to utilize fixed satellite services (FSS) operating in specific Satcom bands such as L-Band, C-Band, Ku-Band, or K/Ka-Band, as shown in **Figure 1**.

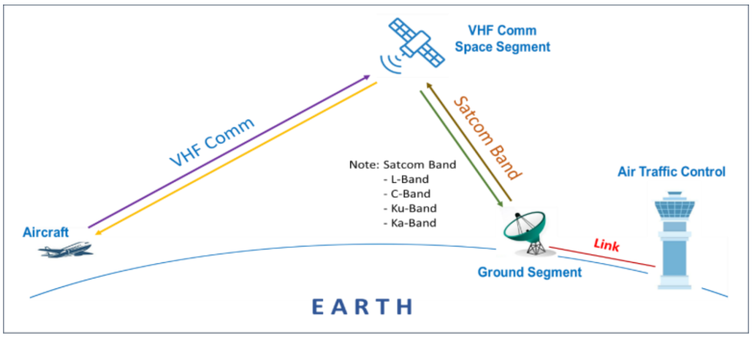


Figure 1. The Concept of the AMS(R)S - VHF Satellite Communication System

2. Method

a. The satellite link budget calculation

The satellite link budget calculation is a process that determines the power and signal quality required at each end of the satellite communication link to achieve the desired performance level. The link budget calculation considers various factors of losses and gains within the system, including transmission losses (path losses), antenna gains, atmospheric attenuation, and other factors that affect the strength and quality of the signal. **[4] [5]**. Here are the factors to consider in satellite link budget calculations:

1) The effective distance (slant range) between an aircraft and a satellite

The effective distance (slant range) between an aircraft and a satellite depends on various factors, including the satellite's altitude and the changing positions of both the satellite and the aircraft. Determining the maximum distance for satellite operations is crucial for evaluating system performance and plays a vital role in the overall architecture design. Illustrate the position of the aircraft relative to the AMS(R)S-VHF satellite is presented on **Figure 2**.

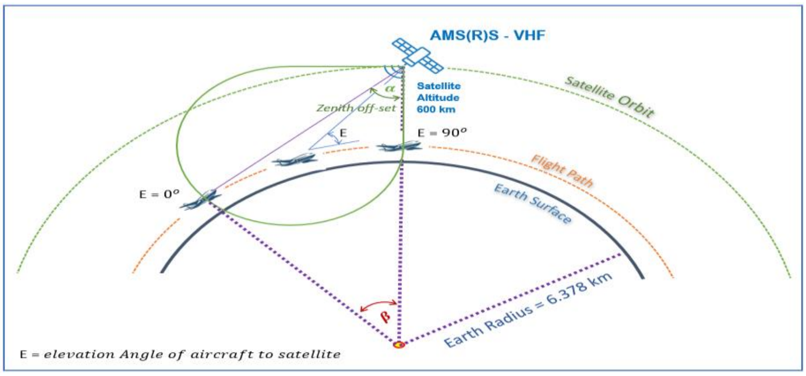


Figure 2. Illustration of the aircraft's position relative to the AMS(R)S satellite.

2) The satellite uplink (aircraft to AMS(R)S) link budget calculation

After obtaining the calculation of the effective distance (slant range) between the aircraft and the satellite, the next step is to perform the satellite uplink link budget calculation from the aircraft to the satellite. According to ICAO regulations, the development of VHF communication via AMS(R)S should not involve any changes to the VHF transmission equipment on the aircraft. Therefore, the uplink link budget calculation aims to determine the received power at the satellite, which provides the sensitivity value for the AMS(R)S satellite receiver device. The following is the formula for calculating the received power level on the satellite side:

$$[P_{Rx}] = [EIRP] - [FSL] - [SL] - [PL] - [FL_{Rx}] + [G_{Rx}] \;\; dBW \qquad (1)$$

In this formula, the transmitted power refers to the power transmitted by the aircraft's VHF transmitter, and the gains and losses account for factors such as antenna gains, path loss, cable losses, atmospheric attenuation, and other miscellaneous losses. The sensitivity requirements for the AMS(R)S satellite receiver can be determined by calculating the received power.

EIRP (Effective Isotropic Radiated Power) is the total power transmitted from the transmitter $[P_{Tx}]$ that is amplified by the antenna gain $[G_{Tx}]$ and reduced by the losses in the transmitter channel (feeder loss) $[FL_{Tx}]$ [6]. In formula form, the EIRP can be calculated as:

$$[EIRP] = [P_{Tx}] + [G_{Tx}] - [FL_{Tx}] \quad dBW \qquad (2)$$

Electromagnetic signals propagating through space experience losses due to attenuation, known as Free Space Losses (FSL). FSL refers to the power loss that occurs when electromagnetic signals pass through free space without obstacles or external interference. The formula for calculating Free Space Loss (FSL) in satellite link budget calculations is as follows [7].

$$[FSL] = 32{,}4 + 20\, log\, log\, (d) + 20\, log\, log\, (f) \quad dB \qquad (3)$$

whereas

d = the distance between transmitter and receiver (km)

f = operating frequency (MHz)

SL (Scintillation Losses) are losses that occur in the ionospheric layer and have a significant impact on VHF frequencies. The influence of SL related to geometric positioning is determined using the recommendations of the Global Ionospheric Scintillation Model, as per Recommendation ITU-R P.531-14 [8]. In this research, the value of SL is set at 5 dB by the ITU recommendation.PL (Polarization Losses) occur due to electromagnetic signals passing through a magnetic field. In this link budget calculation, PL is determined to be 3 dB by the ITU-R P.531-14 recommendation [8].

To determine the performance of a link, it is necessary to calculate the Carrier to Noise Ratio (C/N). The calculation of C/N for the uplink can be done using the formula [9].

$$[C/N_{up}] = [EIRP] - [FSL] - [SL] - [PL] - [FL_{Rx}] + \left[\frac{G}{T}\right] - [k] - BW \quad dB \qquad (4)$$

whereas:

G/T : *Gain to Noise Temperature* at the receiver (dB/ °K)

k : Constant of Boltzmann = -228,6 dBW/°K.Hz

BW : *Bandwidth* (Hz)

3) The satellite downlink (AMS(R)S to aircraft) link budget calculation

The calculation of the satellite downlink link budget from the satellite to the aircraft is performed to determine the required RF transmit power from the satellite so that the receiving device in the aircraft can receive the signal with the desired performance as per the regulations of ITU and ICAO. The sensitivity of the receiving device on the aircraft is set to -90 dBm or Power Flux Density (PFD) on the aircraft = -116,2 dBW/m^2 [3].

The link budget calculation considers various factors such as path loss, antenna gain, and atmospheric losses SL's influence ensures that the received signal power at the aircraft meets the specified sensitivity requirements.

4) Performance Link Calculation

To assess the performance of a link, we need to calculate the values of the total Carrier-to-Noise ratio (C/N), Energy per bit to Noise density ratio (Eb/No), and Bit Error Rate (BER) using the following formulas [9] [10] [11].

$$\frac{1}{\left(\frac{C}{N}\right)total} = \frac{1}{\left(\frac{C}{N}\right)up} + \frac{1}{\left(\frac{C}{N}\right)down} \qquad (5)$$

$$\frac{Eb}{No} = \left(\frac{C}{N}\right) total - Rb + BW \quad dB \qquad (6)$$

$$Rb = \frac{BW*N*FEC}{(1 + Roll\ of\ factor)} \qquad (7)$$

$$BER = \frac{1}{2}\ erfc(Eb/No)^{1/2} \qquad (8)$$

whereas:

Rb : information rate (bps)

BW : bandwidth (Hz)

N : modulation index

FEC : Forward Error Correction

b. Voice Communication simulation using Mathematical Programming Language

Simulation of voice communication here involves simulating how communication between pilots and ATC or communication between pilots in different aircraft can take place using VHF communication via the AMS(R)S satellite. **Figure 3** shows the block diagram of a voice simulation using QPSK modulation and an AWGN channel.

In this research, the VHF communication channel of the AMS(R)S satellite is simulated using an AWGN channel, where the performance of the AWGN channel is referenced to the Eb/No calculations from the satellite link budget. Block diagram of voice communication simulation is presented on **Figure 3**.

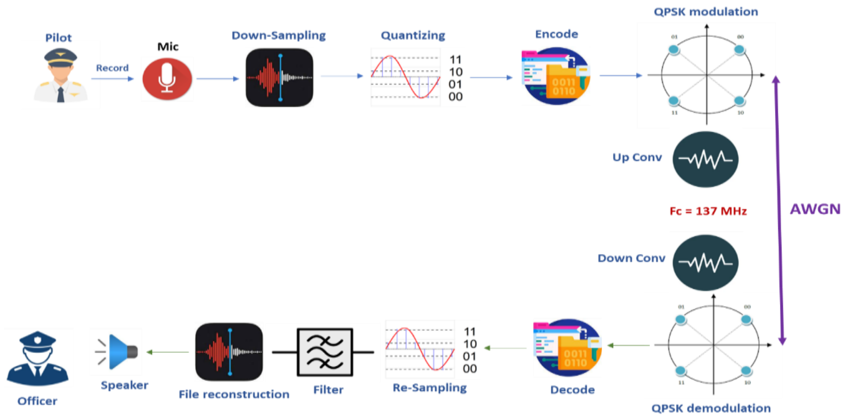


Figure 3. Block Diagram of Voice Communication Simulation

3. Results and Discussion

The results and analysis can be broadly categorized into two main sections: satellite link budget calculations and voice communication simulation.

4.1 The result of satellite link budget calculation.

In the simulation of satellite link budget calculations, the positions of the aircraft and satellite are constantly changing, as illustrated in **Figure 2**. The effective distance calculation between the aircraft and satellite is obtained using the trigonometric formulas of the sine and cosine laws, resulting in the values shown in **Table 1**.

Table 1. Results of Effective Distance Calculation from Aircraft to AMS(R)S Satellite

Par	Unit	Value																		
h_S	km	600	600	600	600	600	600	600	600	600	600	600	600	600	600	600	600	600	600	600
r_E	km	6.378	6.378	6.378	6.378	6.378	6.378	6.378	6.378	6.378	6.378	6.378	6.378	6.378	6.378	6.378	6.378	6.378	6.378	6.378
h_A	km	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10
E	(deg)	0	5	10	15	20	25	30	35	40	45	50	55	60	65	70	75	80	85	10
E_{ES}	(deg)	90	95	100	105	110	115	120	125	130	135	140	145	150	155	160	165	170	175	180
α	(deg)	66,08	65,60	64,19	62,01	59,21	55,94	52,34	48,48	44,45	40,27	35,99	31,62	27,20	22,73	18,22	13,69	91,34	45,70	0,00
β	(deg)	23,92	19,40	15,81	12,99	10,79	9,06	7,66	6,51	5,55	4,73	4,01	3,38	2,80	2,27	1,78	1,31	0,87	0,43	0,00
SR	km	2.833	2.330	1.933	1.627	1.393	1.214	1.075	967	882	815	761	718	683	656	635	619	608	602	600

whereas:

h_S : altitude of AMS(R)S satellite
r_E : earth radius
h_A : aircraft altitude from ground surface
E : elevation angle, the angle between the aircraft and the horizon of AMS(R)S
α : nadir off-set angle of AMS(R)S satellite
β : central earth angle between the earth, aircraft, and AMS(R)S satellite
SR : effective distance between the aircraft and AMS(R)S satellite (slant range)

From the calculations in Table 1 above, it can be observed that the changing positions of the aircraft and satellite result in varying distances, with the closest distance being 600 km and the farthest distance reaching 2,833 km

Table 2 shows the results of the satellite uplink link budget calculation, which is the link budget from the aircraft to the satellite. The transmission parameters in the aircraft are RF Power (P_{Tx}) = 16 watts, antenna gain (G_{Tx}) = -1 dBi, and assumed feeder losses (FL_{Tx}) = 2 dB. Meanwhile, the receiving antenna gain on the satellite (G_{Rx}) is determined to be 8 dBi, and assumed feeder losses at the satellite (FL_{Rx}) = 1 dB. The satellite uplink link budget calculation simulates the calculations performed in the Studies on WRC-23 agenda item 1.7 [3], where the results are the same. Still, in this research, the author adds the parameter of changing the elevation angle every $5^o$and calculating C/N_{up}. In the C/N_{up} calculation, the assumption of parameters is G/T = 1 and BW = (137-118) MHz.

Table 2. The Result of Satellite Uplink (aircraft to AMS(R)S) Link Budget Calculation

Par	Unit	Value																		
F	MHz	137	137	137	137	137	137	137	137	137	137	137	137	137	137	137	137	137	137	137
h_S	km	600	600	600	600	600	600	600	600	600	600	600	600	600	600	600	600	600	600	600
E	(deg)	0	5	10	15	20	25	30	35	40	45	50	55	60	65	70	75	80	85	10
SR	km	2.833	2.330	1.933	1.627	1.393	1.214	1.075	967	882	815	761	718	683	656	635	619	608	602	600
VHF Transmitter on the Aircraft																				
P_{Tx}	watt	16	16	16	16	16	16	16	16	16	16	16	16	16	16	16	16	16	16	16
P_{Tx}	dBW	12,04	12,04	12,04	12,04	12,04	12,04	12,04	12,04	12,04	12,04	12,04	12,04	12,04	12,04	12,04	12,04	12,04	12,04	12,04
G_{Tx}	dBi	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-2	-4	-6	-8
FL_{Tx}	dB	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2
EIRP	dBW	9,04	9,04	9,04	9,04	9,04	9,04	9,04	9,04	9,04	9,04	9,04	9,04	9,04	9,04	9,04	8,04	6,04	4,04	2,04
Transmission Losses																				
FSL	dB	144,3	142,6	141	139,5	138,1	136,9	135,9	135	134,2	133,5	132,9	132,4	132	131,6	131,3	131,1	130,9	130,8	130,8
SL	dB	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5
PL	dB	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3
PFD_{eff}	dBW/m²	-139	-137	-136	-134	-133	-132	-131	-130	-129	-128	-128	-127	-127	-126	-126	-127	-129	-131	-133
VHF Receiver on the AMS(R)S Satellite																				
G_{Rx}	dBi	8	8	8	8	8	7,9	7,8	7,4	6,9	6,2	5,5	4,6	3,6	2,2	0,7	-0,8	-2,2	-3,9	-5,5
FL_{Tx}	dB	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
P_{Rx}	dBW	-136	-135	-133	-131	-130	-129	-128	-127	-127	-126	-127	-127	-128	-130	-130	-133	-136	-140	-144
P_{Rx}	dBm	-106	-105	-103	-101	-100	-99	-98	-97	-97	-96	-97	-97	-98	-100	-100	-103	-106	-110	-114
P_{Rx_tar}	dBm	-107	-107	-107	-107	-107	-107	-107	-107	-107	-107	-107	-107	-107	-107	-107	-107	-107	-107	-107
Rx_{mar}	dB	0,8	2,5	4,1	5,6	6,9	8,1	9,2	10,1	9,9	10,6	10,2	9,7	9,1	7,5	6,8	4,0	1,1	-2,8	-6,8
[C/N] uplink																				
C/N_{up}	dB	12,57	14,27	15,89	17,39	18,74	19,94	20,99	21,91	22,70	23,40	23,99	24,50	24,93	25,28	25,56	24,78	22,93	21,03	19,06

whereas:

F	: operating frequency
h_S	: altitude of AMS(R)S satellite
E	: elevation angle, the angle between the aircraft and the horizon of AMS(R)S
SR	: effective distance between the aircraft and AMS(R)S satellite (slant range)
P_{Tx}	: VHF transmitter power level RF on the aircraft
G_{Tx}	: antenna gain on the aircraft
FL_{Tx}	: Feeder losses at transmitter (aircraft)
EIRP	: EIRP at aircraft
FSL	: Free Space Losses
SL	: Scintillation Losses
PL	: Polarization Losses
PFD_{eff}	: Effective Power Flux Density
G_{Rx}	: antenna gain at receiver (AMS(R)S)
FL_{Rx}	: Feeder losses at receiver (AMS(R)S)
P_{Rx}	: received RF power level on the AMS(R)S
P_{Rx_tar}	: The target received RF power level on the AMS(R)S satellite
Rx_{mar}	: margin level on the receiver
C/N_{up}	: Carrier to Noise Ratio uplink

From the calculations in **Table 2**, it can be observed that the value of C/N_{up} ranges from 12.57 dB to 25.56 dB. The highest C/N_{up} value is obtained at a distance of 635 km or an elevation angle of $70^{o,}$ between the aircraft and the satellite. At this distance, the aircraft is closest to the satellite, and the antenna gain in that area has not yet decreased below -1 dBi.

Table 3 shows the results of the satellite downlink link budget calculation, which represents the link budget from the satellite to the aircraft. The calculation of the satellite downlink link budget also simulates the calculations conducted in the Studies on WRC-23 agenda item 1.7 **[3]**, The results are the same, but in this research, the author added parameters for the variation of elevation angle every $5^{o,}$ and C/N_{down} calculation. In C/N_{down} calculation assumes parameters of G/T = 1 and BW = (137-118) MHz.

Based on the Studies on WRC-23 agenda item 1.7, the link budget calculation reveals that the maximum power level required to cover the entire slant range from the aircraft to the satellite is greater than 300 Watts. To optimize RF power efficiency in the satellite, ICAO has decided that one AMS(R)S satellite should be designed to cover the aircraft-to-satellite elevation angle range of 20^{o} to 70^{o} herefore, the RF power required in the satellite is only 85 watts.

Table 3. The Result of Satellite Downlink (aircraft to AMS(R)S) Link Budget Calculation

Para	Unit	Value																		
F	MHz	137	137	137	137	137	137	137	137	137	137	137	137	137	137	137	137	137	137	137
h_s	km	600	600	600	600	600	600	600	600	600	600	600	600	600	600	600	600	600	600	600
E	(deg)	0	5	10	15	20	25	30	35	40	45	50	55	60	65	70	75	80	85	10
SR	km	2.833	2.330	1.933	1.627	1.393	1.214	1.075	967	882	815	761	718	683	656	635	619	608	602	600
VHF Transmitter on the AMS(R)S Satellite																				
P_{Tx}	watt	85	85	85	85	85	85	85	85	85	85	85	85	85	85	85	85	85	85	85
P_{Tx}	dBW	19,29	19,29	19,29	19,29	19,29	19,29	19,29	19,29	19,29	19,29	19,29	19,29	19,29	19,29	19,29	19,29	19,29	19,29	19,29
G_{Tx}	dBi	8	8	8	8	8	7,9	7,8	7,4	6,9	6,2	5,5	4,6	3,6	2,2	0,7	-0,8	-2,2	-3,9	-5,5
FL_{Tx}	dB	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
EIRP	dBW	26,29	26,29	26,29	26,29	26,29	26,19	26,09	25,64	25,19	24,49	23,79	22,84	21,89	20,44	18,99	17,54	16,09	14,44	12,79
Transmission Losses																				
FSL	dB	144,3	142,6	141	139,5	138,1	136,9	135,9	135	134,2	133,5	132,9	132,4	132	131,6	131,3	131,1	130,9	130,8	130,8
SL	dB	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5
PL	dB	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3
PFD_{e}	dBW/m²	-121,7	-120,0	-118,4	-116,9	-115,6	-114,4	-113,3	-112,4	-112,6	-111,9	-112,3	-112,8	-113,4	-115,0	-115,8	-117,5	-118,4	-120,3	-122,3
PFD_{re}	dBW/m²	-116,2	-116,2	-116,2	-116,2	-116,2	-116,2	-116,2	-116,2	-116,2	-116,2	-116,2	-116,2	-116,2	-116,2	-116,2	-116,2	-116,2	-116,2	-116,2
PFD_{r}	dBW/m²	-5,5	-3,8	-2,2	-0,7	0,6	1,8	2,9	3,8	3,6	4,3	3,9	3,4	2,8	1,2	0,4	-1,3	-2,2	-4,1	-6,1
VHF Receiver on the Aircraft																				
G_{Rx}	dBi	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-2	-4	-6	-8
FL_{Tx}	dB	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2
P_{Rx}	dBW	-129	-127	-126	-124	-123	-122	-121	-120	-120	-119	-120	-120	-121	-122	-123	-126	-129	-133	-137
P_{Rx}	dBm	-99,0	-97,3	-95,7	-94,2	-92,8	-91,6	-90,6	-89,7	-89,9	-89,2	-89,6	-90,1	-90,6	-92,3	-93,0	-95,8	-98,6	-102,5	-106,5
[C/N] downlink																				
C/N_{dn}	dB	28,83	30,52	32,15	33,64	34,99	36,19	37,24	38,16	37,96	38,65	38,25	37,75	37,18	35,53	34,82	33,03	32,19	30,28	28,31

whereas:

F : operating frequency

h_S : altitude of AMS(R)S satellite

E : elevation angle, the angle between the aircraft and the horizon of AMS(R)S

SR : effective distance between the aircraft and AMS(R)S satellite (slant range)

P_{Tx} : VHF transmitter power level RF on the AMS(R)S satellite

G_{Tx} : antenna gain on the AMS(R)S satellite

FL_{Tx} : Feeder losses at transmitter (AMS(R)S satellite)

EIRP : EIRP at AMS(R)S satellite

FSL : Free Space Losses

SL : Scintillation Losses

PL : Polarization Losses

PFD_{eff} : Power Flux Density at receiver (aircraft)

PFD_{rec} : Power Flux Density recommendation by ICAO at receiver (aircraft)

PFD_{m} : margin of Power Flux Density at receiver (aircraft)

G_{Rx} : antenna gain on the receiver (aircraft)

FL_{Rx} : Feeder Loss on the receiver (aircraft)

P_{Rx} : received RF power level on the receiver (aircraft)

C/N_{down} : Carrier to Noise Ratio downlink

If one AMS(R)S satellite only serves coverage as calculated above, a minimum satellite constellation of 40 satellites is required to cover the entire Earth's surface. This can be seen from Table 1, where the aircraft-to-satellite elevation angle from 20^o to 70^o covers only 9^o ($10,79^o$ to $1,78^o$) of the earth's central angle. If the entire Earth's surface is calculated as 360^o the minimum number of satellites needed is 360^o *divided by* 9^o, resulting in 40 satellites.

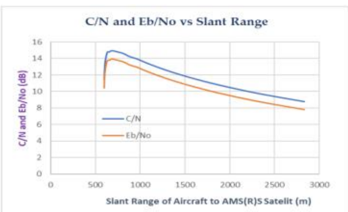
If the uplink and downlink link budget calculations are simulated as end-to-end communication (aircraft-satellite-aircraft), the values of C/N_{total}, Eb/No, and BER can be calculated as shown in Table 4, The aircraft-to-satellite elevation angle ranges from 20^o to 70^o assuming the use of QPSK modulation, FEC = ¾ and ROF = 20%. Results of the link budget calculation for AMS(R)S-VHF satellite is presented on **Table 4**.

Table 4. Results of the Link Budget Calculation for AMS(R)S-VHF Satellite (End-to-End Communication)

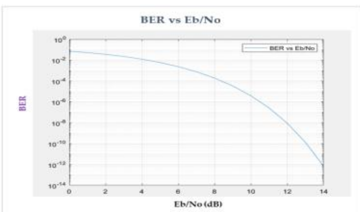
Parameter	Unit	Value										
h_S	km	600	600	600	600	600	600	600	600	600	600	600
E	(deg)	20	25	30	35	40	45	50	55	60	65	70
SR	km	1.393	1.214	1.075	967	882	815	761	718	683	656	635
$[C/N]_{up}$	dB	18,74	19,94	20,99	21,91	22,70	23,40	23,99	24,50	24,93	25,28	25,56
$[C/N]_{down}$	dB	34,99	36,19	37,24	38,16	37,96	38,65	38,25	37,75	37,18	35,53	34,82
$[C/N]_{tot}$	dB	12,20	12,86	13,42	13,92	14,21	14,57	14,74	14,86	14,92	14,77	14,74
Eb/No	dB	11,2	11,9	12,5	12,9	13,2	13,6	13,8	13,9	14,0	13,8	13,8
BER	BER	$3x10^{-7}$	$3x10^{-8}$	$3x10^{-9}$	$3x10^{-10}$	$8x10^{-11}$	$1x10^{-11}$	$5x10^{-12}$	$3x10^{-12}$	$2x10^{-12}$	$4x10^{-12}$	$5x10^{-12}$

From the calculations above, it can be observed that as the distance between the aircraft and the satellite decreases within the range of aircraft-to-satellite elevation angles from 20^o to 70^o, the values of C/N, Eb/No, and BER improve.

Figure 4 shows the graph of C/N_{total} and Eb/No for the end-to-end communication simulation (aircraft-satellite-aircraft) vs. the effective distance from the aircraft to the AMS(R)S satellite (slant range). **Figure 4** depicts the BER vs. Eb/No graph for QPSK modulation.



(a)



(b)

Figure 4. (a) Graph of Eb/No and C/N vs *Slant Range* aircraft to AMS(R)S (b) Graph of BER vs. Eb/No for QPSK modulation

4.2 Result and analysis of voice Communication Simulation using Mathematical Programming Language.

The Voice Communication simulation, following the block diagram in Figure 3, illustrates the pilot communicating with the ATC or with other pilots in different aircraft. Therefore, the VHF satellite communication link is simulated using an AWGN channel with an Eb/No value of 10 dB, referring to the link budget calculation that sets the maximum Eb/No value at 14 dB.

In the voice communication simulation using Mathematical programming language, the audio is recorded in the 'wav' file format and processed according to the standard Pulse Code Modulation (PCM) technique. The process involves down-sampling, quantization, and encoding. The audio signal is then modulated using QPSK and transmitted through an AWGN channel with a frequency of 137 MHz and an Eb/No of 10 dB. On the receiver side, the process is the reverse of the transmission side, involving demodulation, decoding, re-sampling, filtering, and file reconstruction. The results of the voice communication simulation are shown **in Figure 5.**

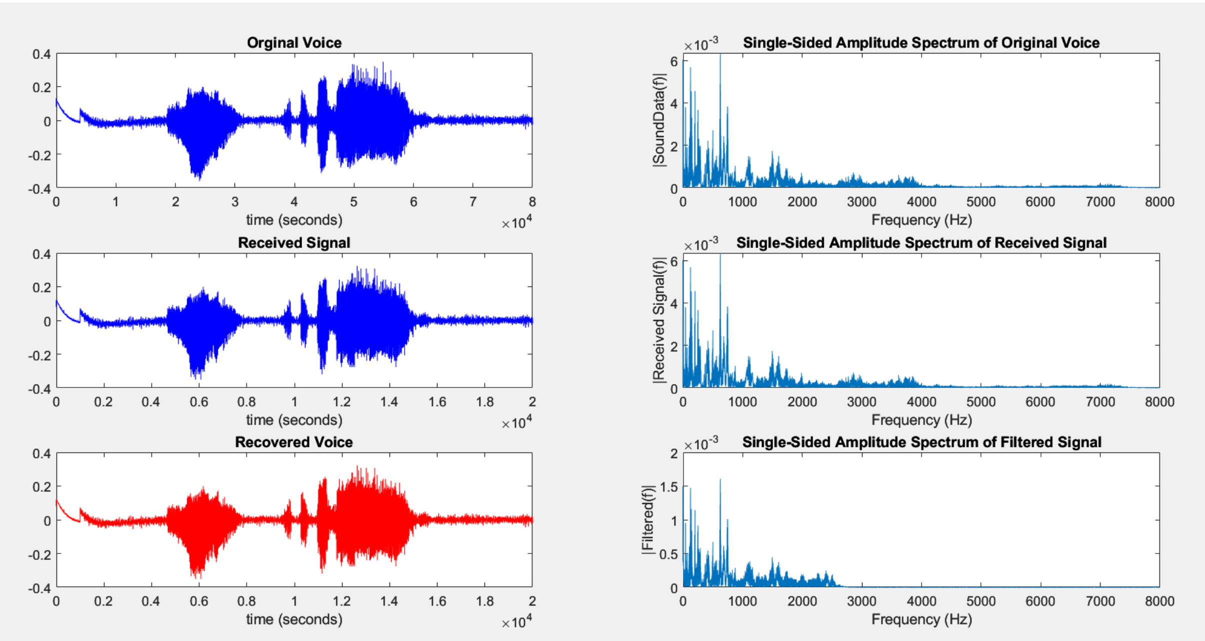


Figure 5. The results of the Voice Communication Simulation Using Mathematical Programming Language

From **Figure 5**, it can be observed that the simulation results of the voice communication show that the original audio signal closely matches the received signal both before and after filtering, both in the time domain and frequency domain. When listened to directly, the quality of the received audio is still apparent. However, the quality is slightly decreased compared to the original audio (rated at 4 out of a standard range of 1-5).

Here is the graph of BER vs. Eb/No for QPSK modulation, both theoretically and based on simulation results using an AWGN channel, as shown in **Figure 6**.

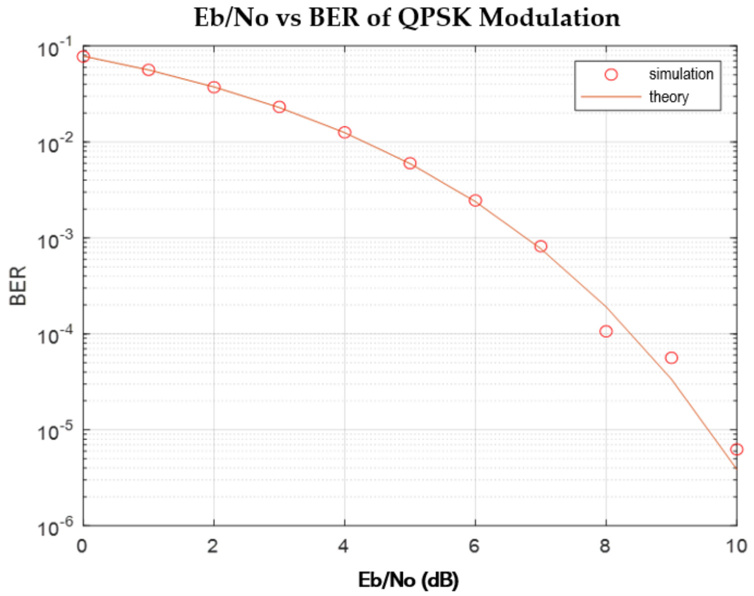


Figure 6. BER vs. Eb/No for QPSK Modulation

The higher the value of Eb/No in a communication link, the better the network performance, as indicated by a smaller BER value.

The satellite link budget calculation conducted in this research is a re-simulation of the link budget calculation performed by ICAO, with more detailed parameters regarding the changes in the aircraft's elevation angle concerning the satellite. While the ICAO calculation considers changes in elevation angle of 10^o, this article incorporates calculations for changes in elevation angle every 5^o.

The author also included performance calculations such as C/N, Eb/No, and BER as references for conducting voice communication simulations, particularly the Eb/No values used in evaluating the performance of the AWGN channel.

The feeder link for communication from the AMS(R)S satellite to the ground segment has not been discussed in this research by the ICAO study. If the FSS for the feeder link is determined, it would be possible to calculate the end-to-end link budget from the aircraft satellite ground and simulate voice communication between the pilot and ATC, and vice versa.

4. Conclusion

This research has analyzed the satellite link budget calculations using parameters according to the study conducted by ICAO. The parameters used include a satellite altitude of 600 km, with a service coverage angle of 20° to 70° from the aircraft to the satellite. The satellite's RF power is 85 watts, with a satellite antenna gain of 8 dBi. The aircraft's RF power is 16 watts, with an aircraft antenna gain of -1 dBi. The aircraft's recommended minimum received power flux density (PFD) is -116.2 dBW/m², corresponding to a minimum receiver sensitivity of -107 dBm and a maximum C/N_{up} value of 25.56 dB. The minimum receiver sensitivity at the aircraft is -93 dBm, with a maximum C/N_{down} value of 38.65 dB. Furthermore, the simulation of the end-to-end link budget calculation (aircraft-satellite-aircraft) showed variable results based on the changing distance between the aircraft and the satellite. The C/N_{total} ranged from 12.20 to 14.92 dB, the Eb/No ranged from 11.2 to 14 dB, and the BER ranged from $3x10^{-7}$ to $5x10^{-12}$.

References

[1] The History of ICAO and the Chicago Convention from https://www.icao.int/about-icao/History/Pages/default.aspx

[2] ICAO Doc 9432 Manual of Radiotelephony (4th ed. 2007)

[3] Annex 33 to Document 5B/481-E 23 December 2021 English only, "Radiocommunication Study Groups," ITU.

[4] Nurul Fadilah, Maulana Ali Arifin, Aulia Haque Qonita, Nayla Najati, Bina Pratomo, Dwiyanto, Eriko Nasemudin Nasser, "Link and Doppler Analysis for LEO Constellation Space-Based IoT" 2022 IEEE International Conference on Aerospace Electronics and Remote Sensing Technology (ICARES)

[5] Huang Linshu, Li Hongke1, Zhao Yiteng "Research on Satellite Communication Link Budget and Performance under the Influence of Multiple Factors" College of Electronic Engineering, Naval Univ. of Engineering, Wuhan, China, 2022 IEEE 5th Advanced Information Management, Communicates, Electronic and Automation Control Conference (IMCEC)

[6] Alan Bensky, "Short-range Wireless Communication: Fundamentals of RF System Design and Application" 3rd Edition.

[7] Dennis Roddy, "Satellite Communications" Fourth Edition, Copyright © 2006, 2001, 1996 by The McGraw-Hill Companies, Inc.

[8] Recommendation ITU-R P.531-14 (08/2019), "Ionospheric propagation data and prediction methods required for the design of satellite networks and systems."

[9] Roesdy Saad, Kun Fayakun, & Harry Ramza1, "Perhitungan Link Budget Satelit Telkom-1", Program Studi Teknik Elektro, Fakultas Teknik, Universitas Muhammadiyah Prof. Dr. HAMKA, Jakarta, Rekayasa Teknologi Vol. 2, No. 2, 2011

[10] Daniel Minoli, "Innovations in Satellite Communication and Technology", The Industry Implications of DVB-S2X, High Throughput Satellites, Ultra HD, M2M, and IP, Secure Enterprise Systems Inc. New York, USA, Copyright © 2015 by John Wiley & Sons, Inc. All rights reserved

[11] Muhammad Aditya Ramadhan, Ahmad Tri Hanuranto, Agus Dwi Prasetyo, "Perencanaan Jaringan Infrastruktur Terintegrasi Satelit Untuk Penerapan Pada Public Protection and Disaster Relief (PPDR)," Teknik Telekomunikasi, Fakultas Teknik Elektro, Universitas Telkom, e-Proceeding of Engineering: Vol.7, No.3 December 2020.