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The analysis of LAPAN-A3/IPB satellite image data simulation using High Data Rate Modem

Chusnul Tri Judianto*, Eriko Nasemudin Nasser

National Institute of Aeronautics and Space (LAPAN), Jl. Cagak Satelit Km.04 Rancabungur, Bogor-16310, Indonesia

Abstract

LAPAN-A3/IPB is one of the satellite development programs from National Institute of Aeronautics and Space (Lapan) Indonesia which was designed for specific experimental mission such as remote sensing, marine and fisheries research, land cover and shipping monitoring using AIS as well, that were needed to observe the Indonesian territory. In order to simulate LAPAN-A3/IPB line imager data acquisition using high data rate modulator and demodulator (HDRM), it is required two independent simulation program. The background behind that was the data rate constraint. It took a large amount of CPU resources to simulate 105 Mbps CCSDS packet data formation. So the simulation was divided into two parts, the first part will simulate the 5 mbps CCSDS packet data formation and the second will simulate the 105 mbps pseudo random binary sequence (PRBS). This four channel payload of R,G,B and Ni system of LAPAN-A3/IPB satellite is quite similar with Landsat camera standard as an earth observation satellite. This paper will describe about the modulation and demodulation simulation process of the LAPAN-A3/IPB satellite data image by using HDRM.

Selection and peer-review under responsibility of the LISAT-FSEM Symposium Committee

Keywords: HDRM; LAPAN-A3/IPB; acquisition ground station

1. Introduction

LAPAN-A3/IPB satellite is the first imager experiment satellite program that has been conducted by Lapan as a space agency of Indonesia which aims to accelerate the National program on imager operational satellite

* Corresponding author. Tel.: +62-251 8621667
E-mail address: youdianto@gmail.com

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development. As a huge country in Asia region, Indonesia has natural resources such as forestry, fishery, marine, land, and agriculture. More over Indonesia also has many kinds of disaster that need to be predicted to reduce the social damages. By refering to these situations, the technology should come in picture for creating some tools to answer the problem. There are two kinds of problem that the technology should face. *First*: how the technology can handle the limitation of resources while human needs are not limited. *Second*: how the technology can face many things related to the impact of climate change. So, the LAPAN-A3/IPB was designed to give actual, frequent and accurate data for observing and predicting the condition of Indonesia archipelago. At some condition, Indonesia still has the limitation for accessing the International imager satellite to get frequent data which also expensive for the annual fee as well. The decision to have Indonesian own earth observation satellite was started from the micro satellite imager project which was considered as the proper way to strengthen the national innovation. To maximize the utilization of the satellite data, then the preparation of the data extraction of LAPAN-A3/IPB should be done properly before launching. In order to simulate LAPAN-A3/IPB line imager data acquisition using high data rate modulator and demodulator (HDRM), it is required two independent simulation program. The background behind that was the data rate constraint. It took a large amount of CPU resources to simulate 105 mbps CCSDS packet data formation. So the simulation was divided into two parts, the first part will simulate the 5 mbps CCSDS packet data formation and the second will simulate the 105 mbps pseudo random binary sequence (PRBS).

Having our own satellite system is the main target to obtain confidence in the regional and Global satellite technology development competition. The satellite developments by some developing countries in regional regent (Asia and the Pacific) tend to increase drastically in the last 5 years. Thailand has started their satellite program by developing their own remote sensing satellite THEOS-1 at 2008, Vietnam with their VinREDSat-1 for 140kg optical remote sensing small satellite, Malaysia continues their RAJAKSAT remote sensing satellite programs, and Singapore who just launched their first micro satellite X-SAT on 2014, that was designed to demonstrate the remote sensing and onboard image processing technology. The collaborative research and satellite data sharing in this region will be more beneficial for getting more accurate prediction and useful impact especially for disaster management and mitigations.

If referring to the real condition of Indonesia as the biggest archipelago in the world with more than 17,500 islands and 2/3 of them are sea with various species of fish and 1/3 are land mostly covered by forest and agriculture, then the development of satellite technology to measure and monitor the huge territory is essential to be developed. Many activities in this huge territory would be able to be monitored and measured from space such as :

1) Weather extremes (flood, drought)
2) Geo-hazards (quakes, volcanic, tsunami)
3) Agriculture, crop yield estimation (rice, corn, cassava, sugarcane, oil palm, rubber tree)
4) Climate and long-term changes (sea level rise, land subsidence)
5) Environment and ecosystem degradation/restoration (forest cover, biodiversity, coastal erosion and pollution).
6) Social wellness and security (narcotics, human trafficking, smuggling)

The continuity of the LAPAN satellite program in micro satellite class for various missions has gradually increased the ability to build its own satellite. The LAPAN-A3/IPB satellite design, assembly, integration and testing will be done by using Lapan's satellite facilities at the Satellite Technology Center of Lapan, Bogor, Indonesia. The development of National Satellite program also increases the national independence in the control of satellite technology through continuous research and development and will improve national resilience. The development of LAPAN-A3/IPB satellite will focus on the National food security missions that are related to how to ensure the availability of satellite remote sensing imagery for monitoring the cultivation area for the entire Indonesia, natural resource management, development planning, and disaster mitigation.

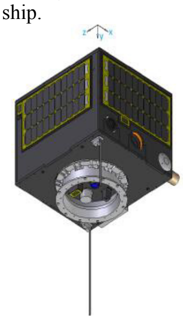
2. The Lapan-A3/IPB : Technical System and Data utilization Plan

LAPAN-A3/IPB will have the main mission as an imager satellite with 4 bands multi spectral imager using optical line scan camera to monitor the land cover, cultivated area and sea. Another mission is for shipping monitoring using Automatics Identification System (AIS). Because of this satellite have a polar orbit path; we will have only 2 passed per day with the equator crossing at 09.00. After having LAPAN-TUBSAT and LAPAN-A2, LAPAN is confident to operate the next satellite in orbit and to utilize the satellite for research purposes and daily life of human kind.

2.1. Lapan-A3/IPB Technical System

Tabel 1. LAPAN-A3/IPB Specification

Mission	Payload	Spectral resolution	Spatial resolution	Orbit	Communication:	Total weight
Design, integration, test and operation is down in Indonesia	Push-broom 4-band multispectral Imager Experiment with ~18 m resolution and 100 km swath.	0.45-0.52: blue	18 m resolution and 100 km swath.	Polar sun-synchronous at 97° Inclination	Payload Tx: X - Band (8200 MHz, BW:168 MHz)	80-100 kg
Earth observation with 4 bands multi-spectral imager for	Digital Space camera with 4 m resolution, 8 km swath.	0.52-0.60: green	4 m resolution, swath 8 km		Ttc: UHF	
land use classification and environment observations.	Automatic Identification System (AIS) Receiver ex. AISSat (Norwegian Satellite)	0.63-0.69: red				
Supporting global maritime awareness by the receptionof AIS signal of ship.		0.76-0.90: NIR				



The LAPAN-A3/IPB satellite will be flown in polar sun-synchronous orbit and will have equatorial crossing time at 09.00. This orbit will make two times contact per day (day and night) about 11 minutes average. In this limited contact, many of data will be downstreaming in near real time to the ground station through X band communication link that contain the information of data imagery and shipping monitoring data as well.

3. LAPAN-A3/IPB Line Imager Data acquisition Simulation

In this LAPAN-A3/IPB Line imager data acquisition simulation, we used High Data Rate Modem (HDRM) as the source/satellite and as the receiving ground station. This HDRM itself consist of 5 modules as follows; IF Filter, Demodulator,Modulator, Processor and FEC decoder. Those modules then were set to have the same configuration as LAPAN-A3/IPB satellite transmission system. The block diagram detail of the high data rate modulator and demodulator is shown in figure 1.

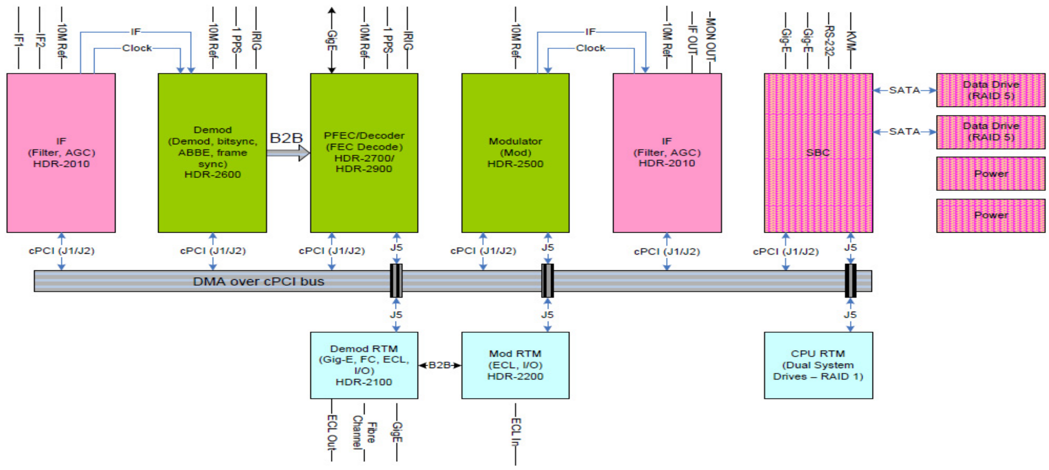


Fig 1. High Data Rate Modem (HDRM) block diagram

In order to have the same characteristics and performance as the satellite equipment, some measurements were carried out. The occupied bandwidth, data rate, and filter characteristic were the example of those measurements. After finished with the satellite transmission characterization, the next step was performed to model the equipment with modules available in HDRM. The LAPAN-A3/IPB satellite transmission system consists of data source from payload, payload data handling, transmitter and antenna. The payload data handling will manage all payload data streams according to the available physical channel capacity and the ground station pass duration. The payload data handling is also designed to be able to tolerate channel noise, control and manage the data flow to ground stations in an orderly manner.[5]. The transmitter will handle the convolutional code and Quadrature Phase Shift Keying (QPSK) Modulation. Detail block diagram of payload data handling and transmitter is shown in figure 2 below. The first step in the payload data handling was the source data packet formation. Since we used the Consultative Committee for Space Data Systems (CCSDS) recommendation for packet telemetry [6] then we had to follow some rules in this recommendation. The next process is the multiplexing process of various source packets followed by Virtual channel Data Unit (VCDU) formation. Furthermore, the next process is Outer encoder Reed-Solomon parity insertion followed by the symbol interleaving process. Subsequently the process continues with pseudo-randomizer and attached sync marker (ASM) insertion process. The output from payload data handling then will go to the transmitter which has the function to encode using convolutional code (rate ½, k=7) and also to modulate into QPSK. The explanations of how to handle the payload data until the process of sending it to the transmitter system for transmitting it down to the ground station can be seen at Figure 2.

3.1 Methods

In order to simulate LAPAN-A3/IPB line imager data acquisition using high data rate modulator and demodulator (HDRM), it is required two independent simulation program. The background behind that was the data rate constraint. It took a large amount of CPU resources to simulate 105 mbps CCSDS packet data formation. So the simulation was divided into two parts, the first part will simulate the 5 mbps CCSDS packet data formation and the second will simulate the 105 mbps pseudo random binary sequence (PRBS). The detail block diagram of this simulation is shown in Figure 3.

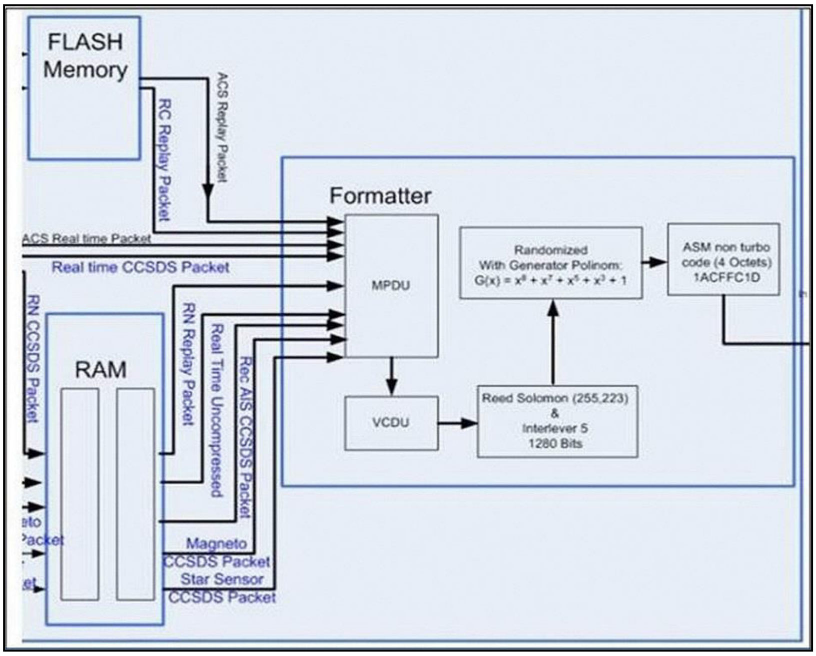


Fig 2. LAPAN-A3/IPB payload data handling block diagram

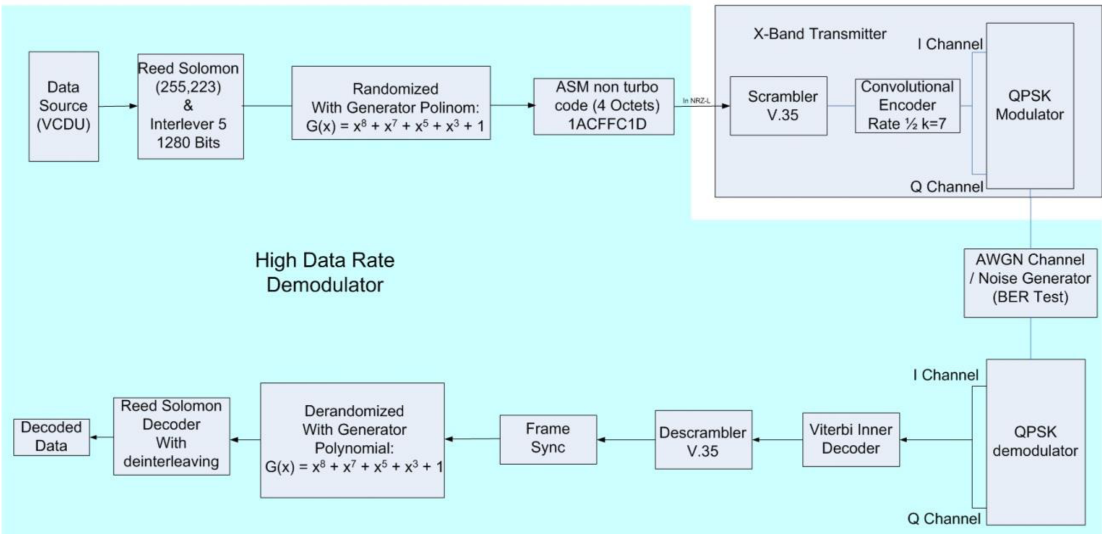
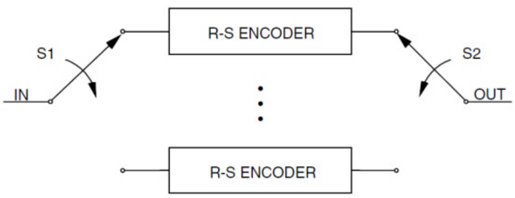


Fig 3. LAPAN-A3/IPB line imager data acquisition simulation

The Line Imager data acquisition simulation was started from defining the real specification of LAPAN-A3/IPB transmission system. Specifications of LAPAN-A3/IPB transmission system mostly come from payload data handling and transmitter. Subsequently those specifications will dictate the high data rate modulator and demodulator parameters. Figure 3 also shows that the simulation starts from CCSDS Source packet formationwhich consists of *packet primary header* which contains identification package, sequence control package, data length package and data field package. Data field package contains the source data from Line imager payload. The length of Source data field can be fixed or varied according to the design requirement. The maximum length of source data field should not exceed 65542 octets. In this simulation, the packet data field was set to 500 octets, and no packet sequence control.

The next step was multiplexing protocol data units (MPDU) formation. Since we use the Reed-Solomon (255,223) interleave 5, subsequently the MPDU Packet zone maximum length is 8856 bits. It comes from the VCDU data field requirement. Consequently the total input data per symbol will become 1115 octets. The first header pointer in MPDU header has a function to indicate the source packet header location. After that, the next step was VCDU formation, it consists of a VCDU primary header which contains several information such as version number, Spacecraft ID, Virtual channel number, virtual channel counter and signaling field. In this simulation, we used version-2 which identifies the CCSDS VCDU and 85 for Spacecraft ID.

The next step was to arrange the output as per CCSDS recommendation symbol interleaving. The allowable values of interleaving depth are I = 1,2,3,4,5,and 8. [5]. If, for I = 5, the original symbol stream and the symbol interleaving output are shown in figure 4b. After symbol interleaving the next step was reed-solomon encoding.



(a)

$$\overset{1}{d_1} \cdots \overset{5}{d_1} \overset{1}{d_2} \cdots \overset{5}{d_2} \cdots \overset{1}{d_k} \cdots \overset{5}{d_k} \quad [2E \times 5 \text{ spaces}]$$

$$\overset{1}{p_1} \cdots \overset{5}{p_1} \cdots \overset{1}{p_{2E}} \cdots \overset{5}{p_{2E}}$$

(b)

Fig 4. (a) functional representation of R-S interleaving; (b) original symbol stream and the symbol interleaving output

CCSDS also recommend using one of the several types of channel coding, in order to provide an excellent forward error correction capability in a burst noise channel [7]. We used Reed Solomon (255,223) since it will give a higher coding gain and the lowest Eb/No (concatenated with convolutional rate ½ k=7) compare to the others. The parameters of the selected Reed-Solomon code is as follows: 8 bits per symbols, 255 symbols per codeword, 32 check symbols/parity per codeword. The field generator polynomial as per CCSDS recommendation $F(x) = x^8+x^7+x^2+x+1$ over GF (2). The first root of polynomial generator = 112 and root spacing in generator polynomial = 11[8]. Finally the total output of VCDU data is 1275 byte.

The next process was the pseudo random and attached sync marker (ASM) insertion generator as per CCSDS recommendation. ASM is necessary during a frame or code block synchronization. The ASM for data that is not turbo coded shall consist of 4 octets marker with a pattern: 1A CF FC 1D. After pseudo random encoder generates 1275 bytes randomized VCDU data, this ASM will be added to it.

Those process were modeled using HDRM module SBC (processor) as per detail description above, main parameters for those processes are shown in the table 2.

The second part of the simulation was the 105 mbps PRBS data transmission. This simulation starts with data source formation which use PRBS $x^{23}+x^{18}+1$. After that, the proccess continues with reed-solomon encoding and attached sync marker insertion as per CCSDS recomendation. Furthermore, the process followed by a scrambler and convolutional which were modeled also using HDRM SBC module. The scrambler that was used in this simulation was CCITT V.35, as for the convolutional was CCSDS rate ½ k=7. Main parameters for those processes are shown in the Table 3.

The last model for this simulation was the QPSK modulation, which was modeled using Modulator HDR-2500. The data rate of LAPAN-A3/IPB transmitter is 105 mbps and occupied bandwidth of 168 MHz. Main parameters for those processes are shown in the table 4.

Table 2. Main parameter for SBC module for simulating CCSDS packet

Parameter	Value
CCSDS version	Ver-2
Frame Length	1279
Reed-Solomon Interleave	Interleave 5
Reed Solomon Virtual Fill	0
Output Differential Code	NRZ-L
Sync Pattern	1ACFFC1D
MPDU Frame Length	1115 bytes
Randomizer	CCSDS randomizer
Bit rate	5 mbps
Virtual Channel ID	0
Packet ID	0
Packet Length	500 octets

Table 3. Main Parameter for SBC Module for Simulating Scrambler and Convolutional

Parameter	Value
Scrambler	CCITT V.35
Convolutional Code	Rate ½ k =7
Inverter	G2
G1	111001
G2	011011
Differential Code	NRZ-M

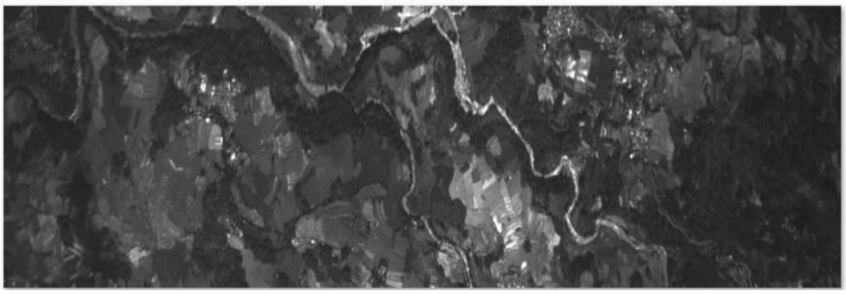
Table 4. Main parameter for HDR-2500 module for simulating QPSK and AWGN channel

Parameter	Value
Modulation Type	QPSK
Data rate	105
Filter Type	Root Raised Cosine
Alpha	0,6
Frequency Output	720 MHz

3.2 Simulation Result

3.2.1 CCSDS Packet Formation Simulation Test Result

Simulation of CCSDS packet formation was done using Line imager flight test data. This data was taken in 2010 during flight test near Rancabungur. This file consist of 8002 pixel and 2000 lines with 14 bit resolution per pixel. The raw image captured from this event is shown in Figure 4a and 4b.



(a)

y-1.tif

Offset(h)	00	01	02	03	04	05	06	07	08	09	0A	0B	0C	0D	0E	0F
00000000	49	49	2A	00	08	00	00	00	0F	00	FE	00	04	00	01	00
00000010	00	00	00	00	00	00	00	01	04	00	01	00	00	00	42	1F
00000020	00	00	01	01	04	00	01	00	00	00	D0	07	00	00	02	01
00000030	03	00	01	00	00	00	10	00	00	00	03	01	03	00	01	00
00000040	00	00	01	00	00	00	06	01	03	00	01	00	00	00	01	00
00000050	00	00	11	01	04	00	D0	07	00	00	C2	00	00	00	15	01
00000060	03	00	01	00	00	00	01	00	00	00	16	01	04	00	01	00

(b)

Fig 5. (a) single band line imager flight test data result; (b) hex format of line imager flight test data result

Figure 5b shows the hex format of the raw image, and for the result of CCSDS source packet data formation is shown in figure 6 below. It shows that there are additional 14 octets or 112 bits (black circle) before the raw data image (49 49 ...) which is belong to the source packet header, MPDU header and VCDU header.

y-1.tif | y1_encoded.dat | y1_decoded1.dat

Offset(h)	00	01	02	03	04	05	06	07	08	09	0A	0B	0C	0D	0E	0F
00000000	55	40	FF	FF	00	00	00	00	00	00	00	00	04	5A	49	49
00000010	2A	00	08	00	00	00	0F	00	FE	00	04	00	01	00	00	00
00000020	00	00	00	00	00	01	04	00	01	00	00	00	42	1F	00	00
00000030	01	01	04	00	01	00	00	00	D0	07	00	00	02	01	03	00
00000040	01	00	00	00	10	00	00	00	03	01	03	00	01	00	00	00
00000050	01	00	00	00	06	01	03	00	01	00	00	00	01	00	00	00
00000060	11	01	04	00	D0	07	00	00	C2	00	00	00	15	01	03	00
00000070	01	00	00	00	01	00	00	00	16	01	04	00	01	00	00	00
00000080	01	00	00	00	17	01	04	00	D0	07	00	00	02	20	00	00
00000090	1A	01	05	00	01	00	00	00	42	3F	00	00	1B	01	05	00

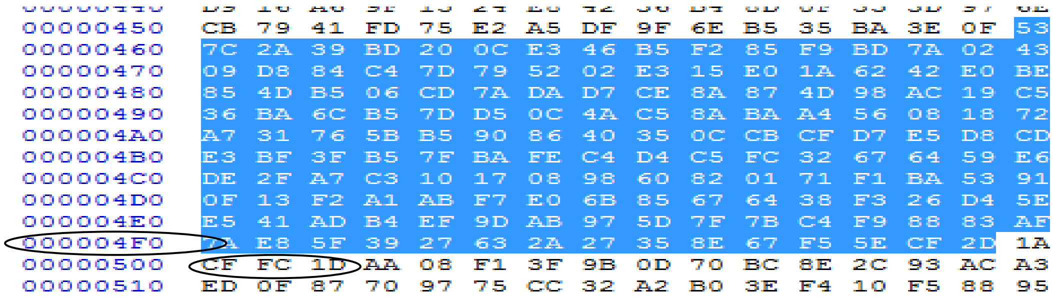
Fig 6. CCSDS source packet data formation result

The other result was the output from pseudo randomizer, symbol interleaving, reed-solomon encoder and attached sync marker shows in figure 7a and 7b below. Figure 7a shows that AA (red circle) was the result from 55 Xor with FF. This was the result of pseudo randomizer. In this figure also shows the attached sync marker insertion which is 1A CF FC 1D (black circle). As for the reed-solomon encoder simulation result, it shows in figure 6b. Reed solomon will create 160 octets parity after 1115 octets data, it shows in figure from 45F (1119-1279) till 4FD (blue block). The placement of each parity was the result of symbol interleaving (Interleave 5).

y-1.tif | y1_encoded.dat

Offset(h)	00	01	02	03	04	05	06	07	08	09	0A	0B	0C	0D	0E	0F
00000000	1A	CF	FC	1D	AA	08	F1	3F	9A	0D	70	BC	8E	2C	93	AD
00000010	A6	44	B9	2E	56	90	FE	FD	CC	62	07	75	26	E3	16	07
00000020	A2	B0	1B	F7	75	04	A5	4A	48	CB	13	BE	27	23	F5	68
00000030	10	AA	97	12	A3	E7	46	71	2C	C8	89	39	5E	2D	A4	BA
00000040	09	6F	B1	DD	35	9D	72	0F	CF	52	9D	B6	72	1E	4D	37
00000050	2E	33	71	C1	49	48	1F	79	E7	39	93	22	3E	0A	2B	E9
00000060	0F	F2	50	85	93	39	E5	FF	52	DA	8B	42	F6	F7	A6	97

(a)



(b)

Fig. 7.(a). Pseudo randomizer and ASM simulation result; (b). Reed-Solomon (255,223) with interleave 5 symbol interleaving simulation result

3.2.2 LAPAN-A3/IPB 105 Mbps Transmission Simulation Test Result

Simulation of LAPAN-A3/IPB 105 Mbps Transmission was done using Pseudo random binary sequence data. This PRBS $x^{23}+x^{18}+1$ data was generated during real-time test using HDRM in LAPAN-Rancabungur. It was generated for 2.1 hours which is equal to 109.9 GBps. The simulation result is shown in figure 8 below.

Figure 8 shows that all module such as receiver, bit synchronizer, frame synchronizer, viterbi decoder, reed-solomon decoder and BER test demodulator were in the lock condition. As for the average receive power signal was measured around -12.68 dBm. Carrier offset frequency was detected at 119 Hz where, consequently the carrier frequency becoming 1200.000119 MHz. Estimated EB/No was at 12.93 dBm (red Circle). There were 98.6 million total Frame sync detected during the simulation, 324 frame were checked with no flywheel, dropout and bit slip were detected. Viterbi decoder was only detected a few node sync drop with no error bit in both I and Q channel. As for reed-solomon decoder, it was able to correct 300 bits.

The Bit error rate test result shows that the BER value was in the rate of 6.03 x 10^{-10} with 531 bits error from 109.9 GBps total data. It also shows that there are 2 BERT dropouts.

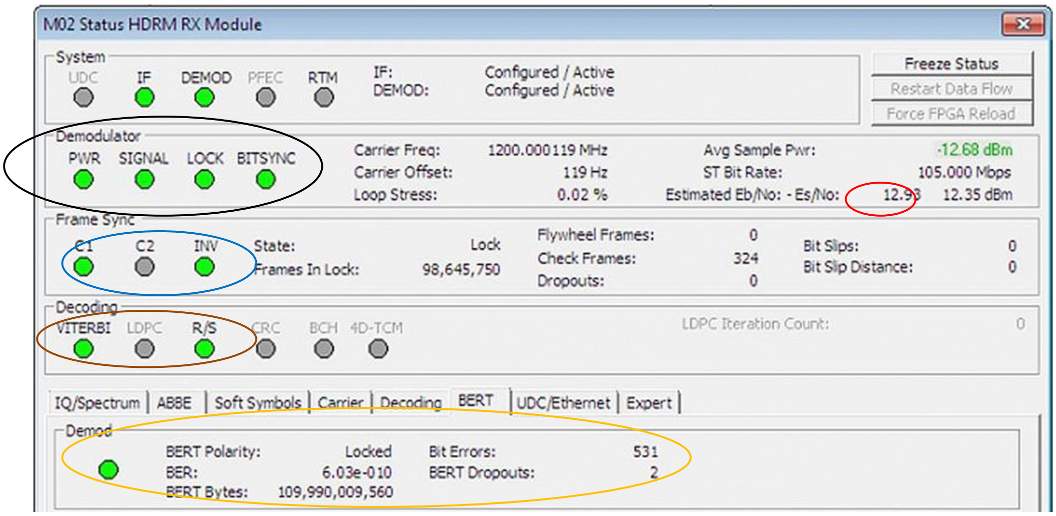
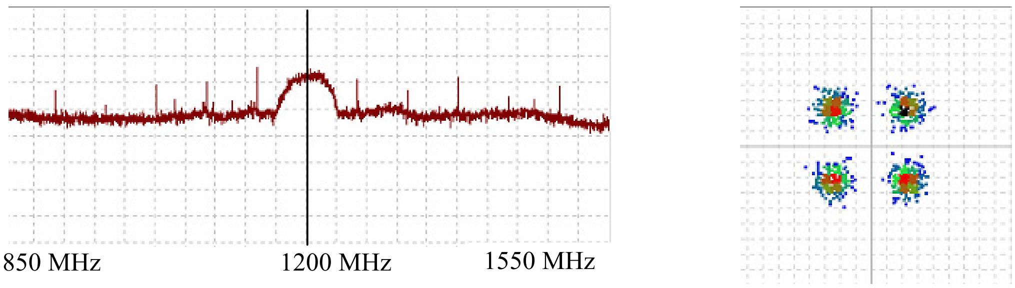


Fig. 8. 105 Mbps transmission simulation test result

Beside that, the simulation result also shows the occupied bandwidth and the IQ channel constellation, shown in Figure 9 . This result shows the QPSK performance and characteristic of the HDR-2500 Modulator. During the simulation, the attenuator was set to the maximum in order to simulate the actual ground station receive power. The maximum attenuator value that can be achive to decode the PRBS data was 65 dB.



(a) (b)

Fig. 9. (a) occupied bandwidth; (b) constellation diagram for QPSK

Figure 9a above shows that the occupied bandwidth for this simulation was around less than 70 Mhz. It was as expected since the filter characteristic has alpha value 0.6. Figure 9b shows that the IQ constellation were divided into 4 poles as the QPSK should have. Some of them were point with red color which means that the receiver was able to precisely detect the IQ phase difference.

4. Ground Station and Image data handling System

To ensure that the ground station for receiving data from the satellite able to work properly, then the preparation of the receiving data equipment and related system should be done and tested. Over all ground system for this specific task will contain of all aspect of a ground station such as RF front end (antenna dish, feed and LNA), antenna control unit (ACU) and Base band system contain of Modem and Receiver. The specific Base band system will be applied for the specific data streaming of LAPAN-A3/IPB. For receive the image data form LAPAN-A3/IPB satellite, LAPAN has prepared the specific receiver on the Ground Station. The specific ground station to receive and doing data simulation in the ground is showed in figure 10.

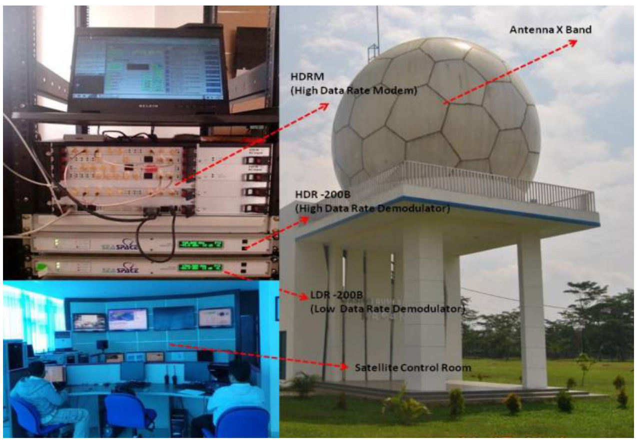


Fig.10. Ground station equipment and configuration for LAPAN-A3/IPB Satellite data acquisition

Link budget parameter values were obtained by using equation (1) to determine the value of Eb/No, equation (2) was used to find the value of EIRP while equation (3) was used to obtain the amount of the value of the received power at the earth station. The calculation of the all satellite link budget parameters can be seen at Tabel.5.

$$C/N = Eb/No + Rb - B \ [dB] \quad (1)$$
$$C/N = EIRP + G/T - FSL - k - B - Lt \ \ [dB] \quad (2)$$
$$Pr = P_t G_t A_e / 4\pi R^2 \ Watts \quad (3)$$
$$= (P_t G_t)\, G_r\, (\lambda/4\pi R)^2$$
$$= EIRPs + G_r - Path\ Loss$$
$$Pr = EIRPs + Gr - [32.5 + 20 \log R\ (km) + 20 \log F\ (MHz)]$$
$$C/N = Pr+G/T-k-B-Lt-Gr$$

EIRP – *Effective Isotropic Radiated Power*
C/N – *Carrier to Noise Ratio*
Eb/No – *Energy per bit to Noise Density Ratio*
Pr – *Power Receive at Ground Station*

Table 5. LAPAN-A3/IPB down link budget

No	Link Paramater	Value	Unit
1	Altitude	650	km
2	Slant Range (El 5 deg)	2448	km
3	Transmission power (5 Watt)	7	dBW
4	Frequency Operation	8200	MHz
5	Waveguide/cable loss (satellite)	1	dB
6	Antenna gain (satellite)	5	dBi
7	EIRP (satellite)	11	dBW
8	Free space loss	178,5	dB
9	Atmosphere Absorption Loss	0.1	dB
10	Antenna Gain (Ground Station)	52,1	dBi
11	Received waveguide/cable loss (Ground Station)	1	dB
12	Received Carrier Power (Ground Station)	-35,4	dBm
13	G/T (Ground Station)	29,5	dB/K
14	Boltzmann's constant	-228,6	dBW/Hz/K
15	Data Bandwidth (168 MHz)	82,3	dB Hz
16	Data Rate (105 MBPS)	81,8	dB
17	Carrier to Noise Ratio (C/N)D	8,3	dB
18	Eb/No	10,3	dB

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