BIT ERROR SIMULATIONS AND PERFORMANCE INVESTIGATION IN IMAGE DATA PROCESSING CHAIN

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Abstract: The FORMOSAT-5 is an optical remote sensing satellite with 2m resolution, which is being developed by the National Space Program Organization (NSPO) in Taiwan. There are one Panchromatic (PAN) band with 12,000 pixels and four Multi-Spectral (MS) bands with 6000 pixels in the remote sensing instrument. The image data compression method follows the Consultative Committee for Space Data Systems (CCSDS) standards. In order to achieve high compression performance, CCSDS 122B utilizes correlation among much more pixels than FORMOSAT-2 JPEG. Therefore, the influence of an error bit is much more severe than JPEG for on board image compression. In this article, defected compressed image and source formatted data due to transferring or processing error are simulated for evaluation the performance of de-compression. Simulation tools containing compression, ciphering, source formatting and channel coding are developed for defected data generation in different processing chain. Simulation cases show that the degradation is dependent on the position of the error bit in compressed data. The error control strategy is also proposed in this study.

1. INTRODUCTION

The general ingestion system is the reverse processing of on board image compression, ciphering, source formatting and channel coding (figure 1a), simulated image data according to the on board processing chain (figure 1b) are used to verify the Data Ingestion System. Between the on board image processing chain, there are chances for data transfer error: SSR transfer stage, RF downlink stage etc., due to shift register in cipher algorithm, an error bit behind the correctly de-ciphered data will not be de-ciphered correctly, compression algorithm (CCSDS 122B) which apply wavelet transform utilizes correlation among much more pixels than JPEG which utilizes correlation among only 64 pixels. Therefore, the influence of an error bit is much more severe than JPEG as shown in the following simulation (section 2b). Test cases and results based on the defected image simulation and FORMOSAT-2 real defect image cases are described in section 3, section 4 proposes some Error Control Strategy, and conclusions are stated in Section 5.

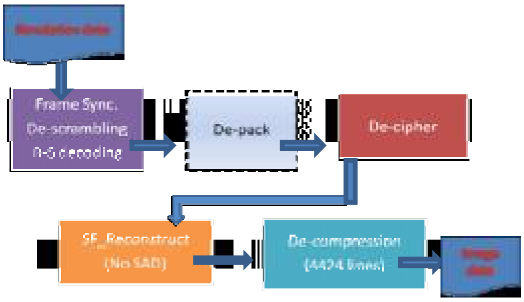

Figure 1a: Image processing chain

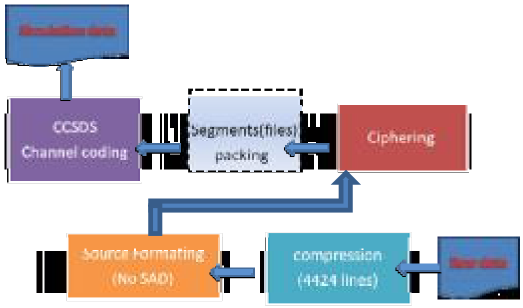

Figure 1b: simulated image data chain based on on-board processing

2. RSI IMAGE SIMULATION

2a. Normal Image

The FORMOSAT-5 RSI (Remote Sensing Instrument) onboard image data processing chains include 4 major parts: compression, source formatting, encryption and CCSDS packetization. The overall data flow is briefed in figure 2a.1(a),(b),(c).

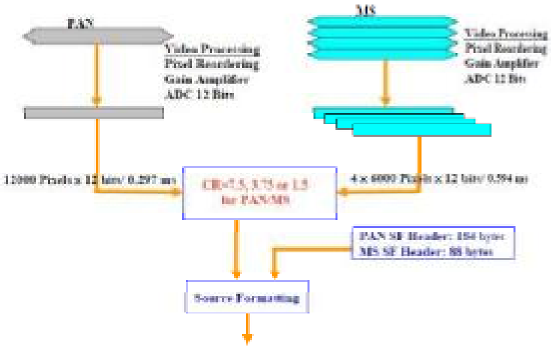

Fig2a.1 (a) image raw data to source formatting

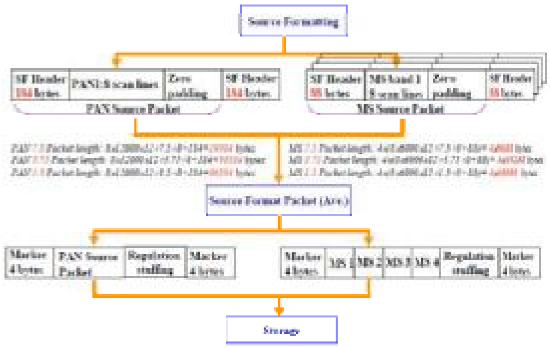

Fig 2a.1 (b) Source formatting to SSR storage

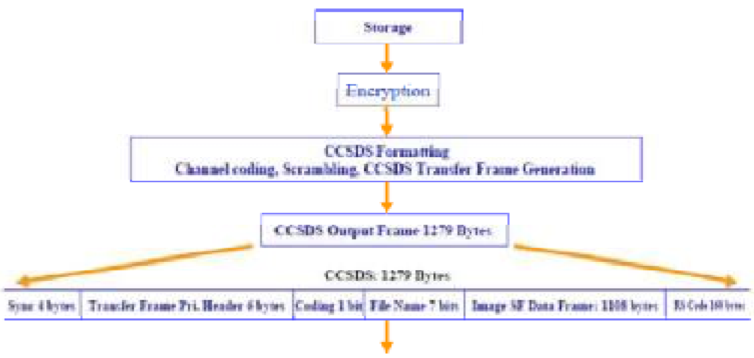

Fig2a.1(c) SSR storage to output

The development of image generation simulation tool is based on the above processes containing compression, ciphering, source formatting and channel coding for image data generation in PAN and MS processing chain.

a) Image Compression: Consists of two functional parts, as depicted in figure 2a.2, a Discrete Wavelet Transform module that performs decorrelation and a Bit-Plane Encoder which encodes the decorrelated data.

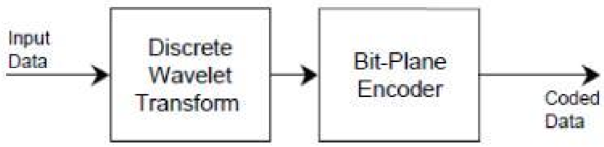

Fig2a.2 CCSDS 122.0 compression schematic

b) Encryption: Scheme as shown in Figure 2a-3 consists of 64-bits PSN and 24-bits selector as inherited from Formosat-2. The PSN initial status is used to initialize a linear shift register of 64-bits implementing polynomial (64,4,3,1,0) loop. The initial selector status is used to initialize a linear shift register of 24 bits implementing polynomial (24, 4, 3, 1,0) loop.

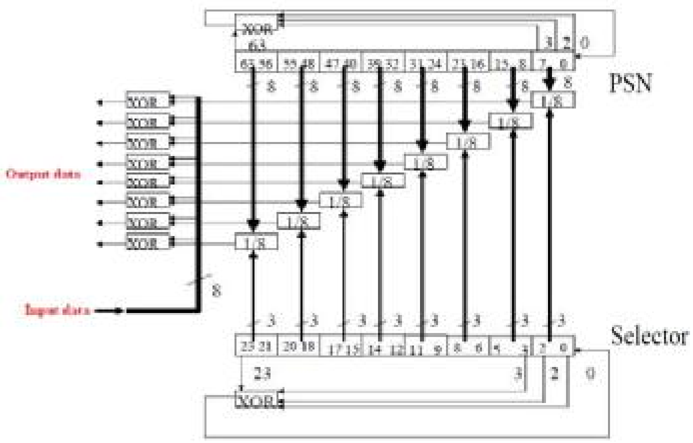

Fig2a.3 The encryption scheme

c) Source Formatting: Add the source format header into the PAN/MS packet.
d) Channel Coding: Includes Reed-Solomon coding, pseudo randomization and frame sync. Marker attachment is added according to CCSDS telemetry standard to packet image data output.

The functions of image data generation simulation tool are shown in Fig 2a.4.

a) To preselect the header parameters of compression and source formatting such as PAN/MS channel, compression ratio, Integer/Float DWT, TDI stage, Gain, File name…etc.
b) To specify PSN & scramble cipher key and to enable/disable encryption.
c) To convert 8-bit image raw data to 12-bit.
d) To generate CCSDS virtual channel output data.

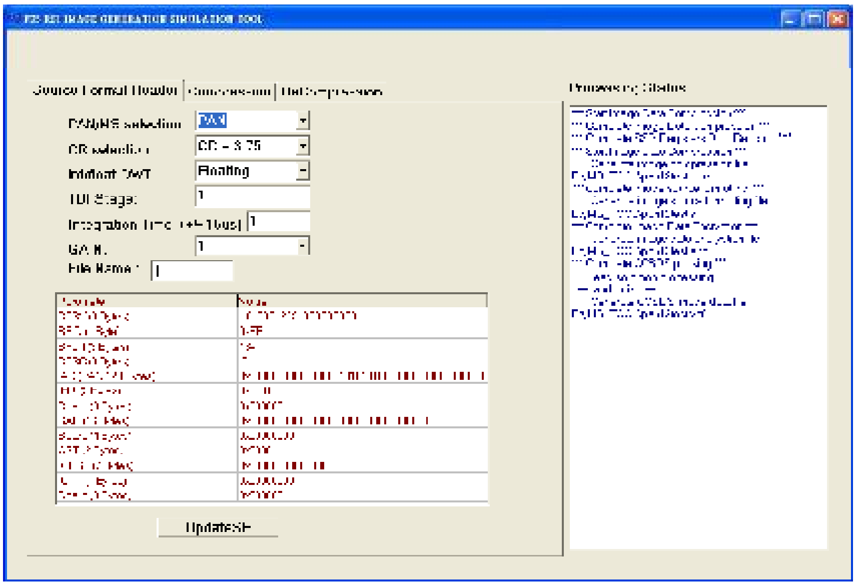

Fig 2a.4 FS5 RSI image generation simulation tool diagram

2b. Simulated Image with Defects

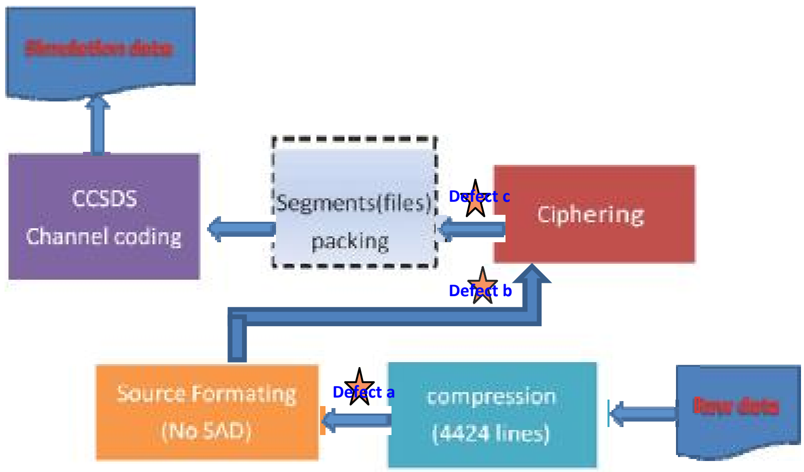

Figure 2 Defect data simulation test cases design

As shown in figure 2, we simulate defected image data at 3 transfer data stages, a, b, and c, by changing the bit value (0 → 1 or 1→0), the detail test cases are described in section 3.

3. TEST CASES AND RESULTS

3a. FORMOSAT-5 RSI adopts CCSDS 122B compression algorithm [1]. The following simulation works investigates the effect of single error bit (SEB) in CCSDS 122B compressed image.

3a.1 Simulation Background

First, we adopt the 8-bit CCSDS 122B standard image as a test image shown in Figure 3.1. For convenience, we only consider 1 segment (16384 blocks) per image. Thus the header bits are the 1st bit throughout 160th bit. Other bits are compressed image data. The compressed ratio (CR) is 4. Without any error bit, the decompressed image is provided in Figure 3.2 and the PSNR is 50.64dB.

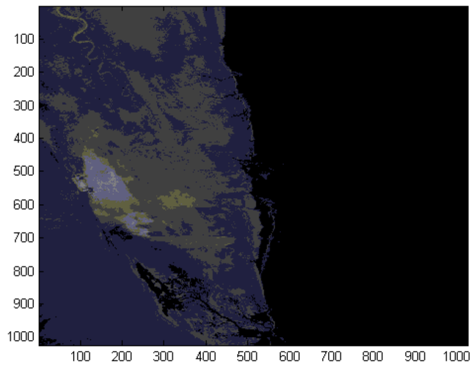

Figure 3.1 CCSDS 122B standard image of 1024x1024 pixels [2].

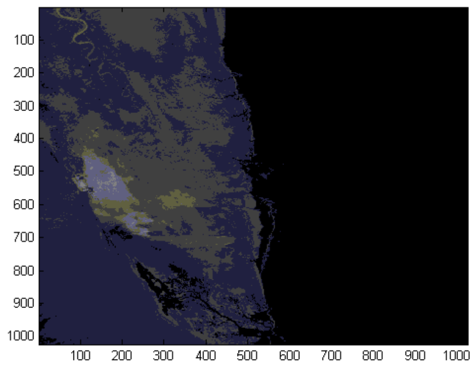

Figure 3.2 Decompressed image when no error bit occurs and CR=4.

Next, we develop a program to insert a single error bit in the header or in the compressed data, and then decode the simulated data. The results are shown in the following.

3a.2 Simulation Result when SEB Occurs

3a.2.1 SEB in The Header: The performance degradation can be very different depending on the location of the error bit. For example, the performance may be not affected (e.g. the 10th bit), or degrade significantly (e.g. the 15th bit, the result is provided in Figure 3.3), or even cannot be decoded if the failure case is not considered in the decoding program. (e.g., the 2nd bit.)

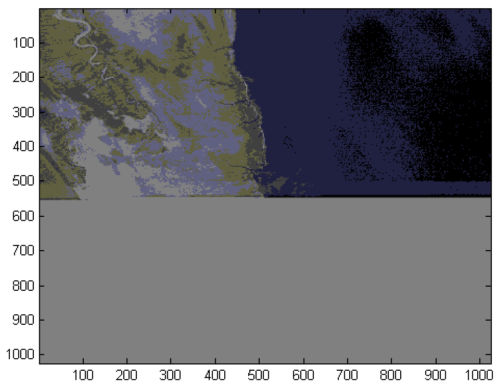

Figure 3.3 Decompressed image when SEB is occurs at the 15th bit.

3a.2.2 SEB in The Compressed Data:

The performance degradation is also different depending on the location of the error bit. In general, the error in the front part affects more severely than the later part. In order to understand more about the performance degradation, a number of examples are provided in Figure 3.4- Figure 3.7.

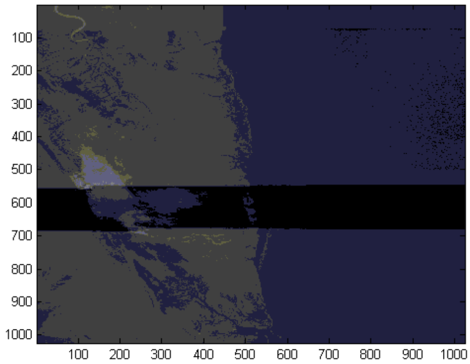

Figure 3.4 Decompressed image when SEB occurs at the 161th bit.

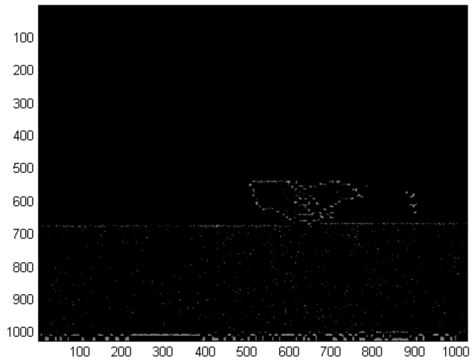

Figure 3.5 Decompressed image when SEB occurs at the 3000th bit.

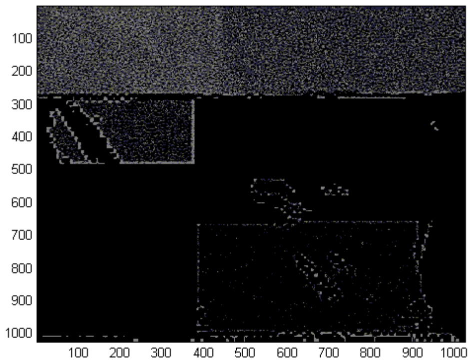

Figure 3.6 Decompressed image when SEB occurs at the 10000th bit.

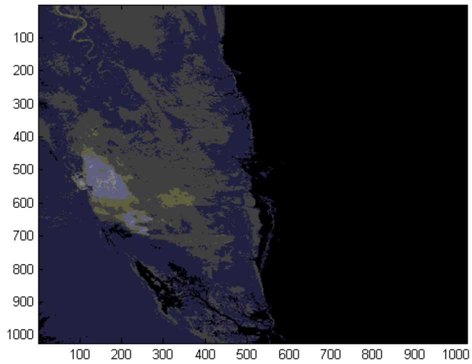

Figure 3.7 Decompressed image when SEB occurs at the 100000th bit.

3b. The following simulations are based on different image data sets**:** The original compressed image used for bit error simulation is 12000 pixels per line and CR = 7.5, 12 bits per pixel, which is the real case for FORMOSAT-5. We apply the PSNR to compare with the one of non-bit error de-compressed image to specify the image quality.

3b.1 Error in Head:

Change bit 15(header contain 20 bytes): The PSNR compared with the non-bit error de-compressed image is 40.20

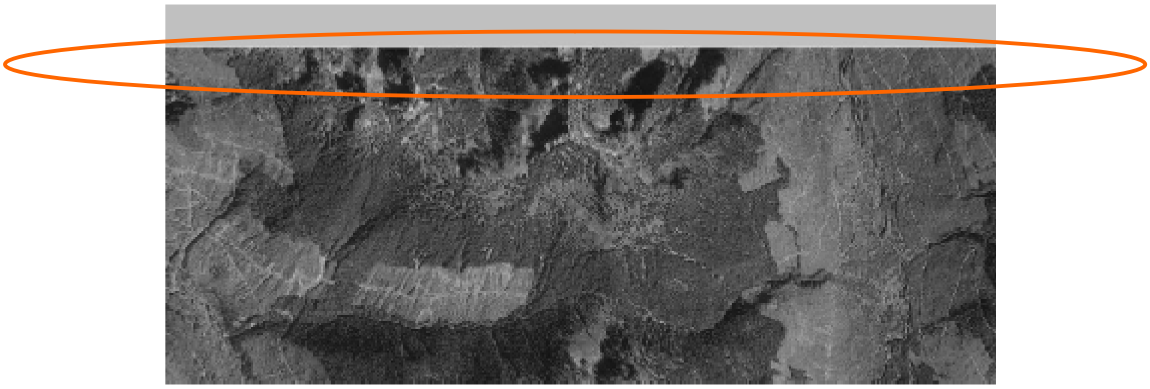

Figure 3.8 Decompressed image when SEB occurs at the 15th bit.

3b.2 Error in Compressed Image:

Change bit 161(segment image 1st bit): The PSNR is 16.32

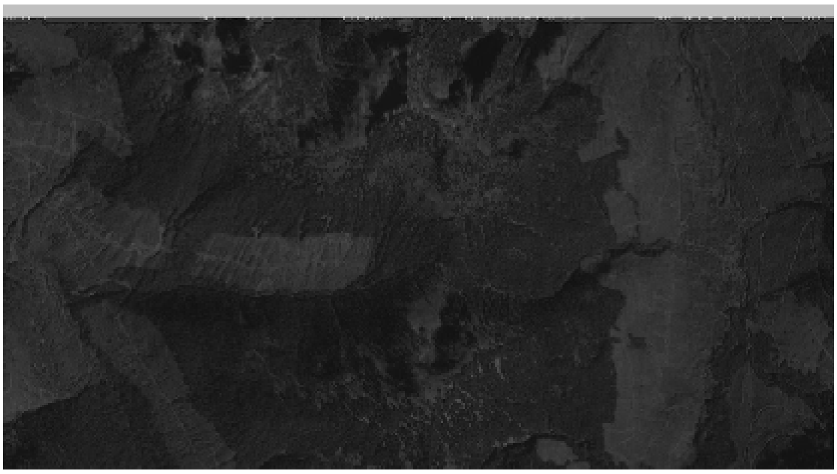

Figure 3.9 Decompressed image when SEB occurs at the 161th bit.

Change bit 3000: the PSNR compared with the non-bit error de-compressed image is 73.761

Figure 3.10 Decompressed image when SEB occurs at the 3000th bit.

Change bit 10000: The PSNR compared with the non-bit error de-compressed image is 48.70
Change bit 200000: The PSNR compared with the non-bit error de-compressed image is 95.40

A brief summary for 3a and 3b: The affected area of de-compressed image for the serious bit error cases (PSNR < 50) are more than one segments. For the two (different data size and CR) simulated bit error compressed image category shown above, the SEB location dependent influences are observed .

3c. The SEB Occurs Between Source Formatting and Ciphering

Apply the data after Ciphering, simulated bit error, and then run Source Format Re-construction, image de-compression.

Error bit occurred in Source Format header, marker, program will detect as frame loss, if in ancillary data, the post-processing will apply appropriate data interpolation scheme; if in image data, same as in compressed image defect simulation, the error in the front part affects more severely than the later part.

3d. The SEB occur between Ciphering and Depacketization

Apply the data after De-packing,, simulated bit error, then run decipher, Source Format Re-construction, image de-compression. We put the error in the front part and later part separately, then apply de-cipher, SF_reconst, de-compression, no defect in de-compressed image, this is likely due to error occurred in ancillary data part; the other case we simulated 2 bit error in 4th and 5th frame simultaneously, then de-compression processing, got PSNR equal to 62.015

3e. FORMOSAT-2 Defect Data Analysis

Launched in 2004, the FORMOSAT-2 has acquired lots of remotely sensed image data. These data have been wildly used for different studies ranged from global to domestic environmental monitoring and civil applications. Though the FORMOSAT-2 performs well, partially losses of image data it acquired were observed occasionally. While the FORMOSAT-2 adopts JPEG-based on-board image compression algorithm, analyzing its defected data might be helpful for understanding the impacts of similar data loss mechanism on image data processed by CCSDS-122 on-board image compression algorithm. Raw data of four image segments suffered from data losses (case 1 – 4) and one good image segment (case 5) are studied. These raw data are DRD (Dated Raw Data) formatted, a modified RT-STPS (Real-Time Telemetry Processing System developed by NASA) tool which converts DRD formatted data to frame-synchronized data is used to analyze these five data sets. Shown on Figure 3.11 and 3.12 are RT-STPS output reports for case 1 and 5. The frame loss rates for the five cases studied are 8.62%, 18.92%, 6.05%, 3.39% and 2.17% respectively. At the first glance, frame loss rate contributes to degradation of image data significantly. Yet, for case 5, a 2.17% frame loss rate seems making no obvious impact on image data. Further analysis works are thus conducted to pinpoint the root cause of data loss.

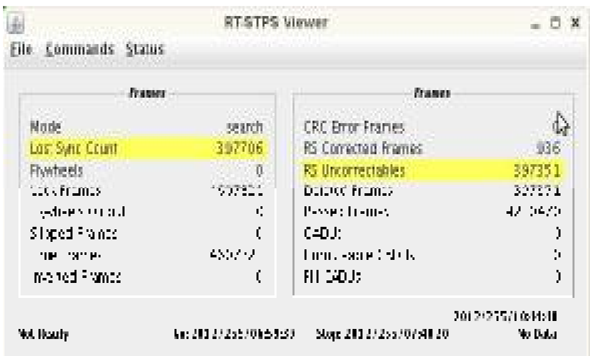

Figure 3.11 Test case1 data for

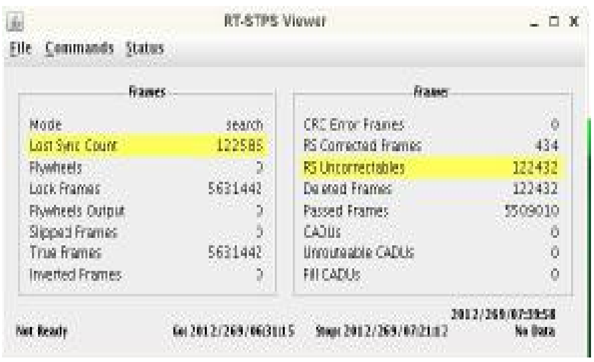

Figure 3.12 Test case5 data for

ROCSAT_2_DRD_6000005931_0_40216_RSI_1_2012-04-01.

ROCSAT_2_DRD_6000006277_0_42652_RSI_1_2012-09-22.

4. Error Control Strategy

For the SEB in compressed image, if we select the smaller segment size, there is chance to reduce the influence for de-compressed image degradation. For ciphered error check, to avoid the fault propagation, the idea is to check the marker in each segment; the detail will be the near future work.

5. Conclusion and Future Work

From the simulation results, the SEB (Single Error Bit) influence in FORMOSAT-5 image quality is un- negligible, most in loss data or low PSNR compared with original image data. Optimization in image segmentation will be needed in future work. And severe specification for BER (< 10-6 for FORMOSAT-5 spec.) will reduce the chance of SEB, the error control scheme for FORMOSAT-5 deciphering algorithm is a valuable topic in the future work.

Reference:

[1] CCSDS 122.0-B-1, “Image Data Compression,” Green Book, November 2005.
[2] CCSDS 122.1-G-1, “Image Data Compression,” Green Book, June 2007.