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Cause Analysis and Improvement of Signal Interference in Byteflight Data Bus

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Abstract

Byteflight is developed based on RS-485 communication (an international standard), and it can be used as a data bus during the operation of an integrated avionics system in the latest aircraft. Therefore, the integrated avionics system can perform an effective and safe flight mission only when the accurate and seamless display of flight information, communication, and accurate functions of navigation are implemented. In this study, cause analysis and failure investigation were performed on screen abnormalities and communication interruptions due to signal interference in the Byteflight data bus of the integrated avionics system during aircraft operation. To improve signal interference between avionics units, the branch point and wiring path of the Byteflight data bus were changed, and the verification result of the improved method was also described.

Key Words : Byteflight Data Bus, RS-485, FTA(Fault Tree Analysis), Wire Harness Matrix, Stub point, Impedance Mismatching, Display Unit

1. Introduction

Byteflight is a data bus that is developed based on the RS-485 communication (an international standard), which is a data communication standard developed to satisfy the standard specifications of each avionics device [1]. RS-485 is a serial communication protocol and can configure a network up to 1.2 km at a maximum speed of 10 Mbps [1]. Therefore, Byteflight (which was developed as an international standard) can be used as a data bus during the operation of an integrated avionics system in the latest aircraft [2-3]. An integrated avionics system is constructed with avionics units such as the integrated display unit, communication unit, and flight control unit. The units are designed to communicate with each other via Byteflight data buses. However, signal interference in the data bus in the integrated avionics units (developed by applying Byteflight) during aircraft operations can lead to abnormalities and loss of communication. Signal interferences have occurred in the data bus during operations after the development of the Byteflight-applied integrated avionics system. This affected ground and flight operations. Hence, in this study, we describe the results of improvements, which are derived based on a cause analysis and failure investigation [4].

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2. Analysis of Signal Interference Phenomenon

2.1 Phenomenon Analysis

As shown in Fig. 1, the integrated display unit is mounted on the cockpit instrument panel and transmits/receives and displays communication/navigation data and system status information such as the aircraft's attitude and engine status. The communication unit is used to assist the navigation and communication control, and it can control the radio and navigation equipment. The flight control unit integrates inertial data to generate the aircraft's attitude and sends commands to the control surface via the control loop algorithm to ensure that the aircraft performs the necessary flight. Therefore, the communication and navigation functions should be precisely implemented by displaying accurate and seamless information via smooth transmission and reception between avionics units [5].

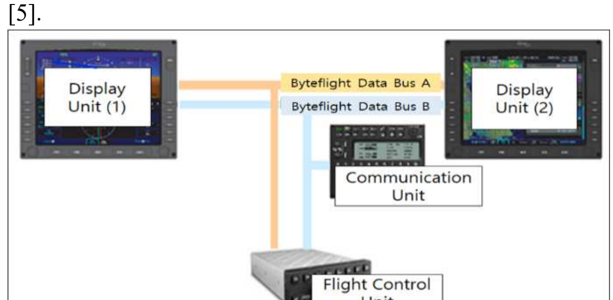

Fig. 1 Byteflight data bus of Avionics units.

We examined specific fault occurrences, as shown in Table 1 and Fig. 2, to accurately investigate failure of the integrated avionics system. We observed intermittent occurrences of blank or flickering display in the integrated display unit, loss of communication, and GPS faults.

Table 1 Details of the abnormal phenomenon.

Category	Detail Phenomenon
Display	Intermittent flickering, blanking
Navigation	Intermittent GPS fault
Communication	Uncommunicative and fault

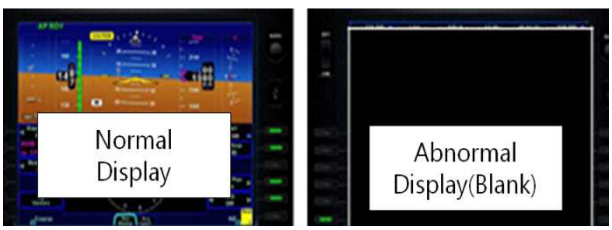

Fig. 2 Abnormal display.

2.2 Data Analysis

The integrated display unit has the function of storing data transmitted/received between the ground and flight operations. Hence, it is easy to download and analyze the data. By analyzing the event data of the abnormal phenomenon, we determined various error codes related to the Byteflight data bus as shown in Table 2.

Table 2 Event data log analysis for error messages.

Code	Type	Error Message	Remark
CBIT	WARNING	Data bus overflow	Data sync fail
CBIT	WARNING	Data bus overflow	
CTP	ERROR	Heartbeat lost	Data loss fail
CTP	ERROR	Heartbeat gain lost	
CBIT	ERROR	Link Status failed	Data transmit /receive error
Persist	ERROR	KV import failed	Display data status error
HW	ERROR	GPS time out	GPS operation error
HW	ERROR	Com1 Tx time out	Communication error
CBIT	INFO	CORE RESET	Display abnormal

By conducting detailed data analysis, we observed warning codes, such as data synchronization failure (data bus overflow) and data loss (heartbeat lost), and error codes, including data transmission/reception error (link status error) and display data status error. These error codes usually occur when there is an interference in transmitting/receiving Byteflight data. It is determined that when these data error codes occur, abnormal operations are triggered such as GPS operation error, communication loss (Com Tx time out), and blank/flickering displays (CORE RESET).

2.3 Analysis of Main Causes

By performing fault tree analysis (FTA), as shown in Fig. 3, we examined the effects of main factors that cause Byteflight data communication errors such as avionic units that use Byteflight signals (integrated display unit, communication unit, and flight control unit), instability of input voltage, and wire harness (W/H) path of Byteflight data bus connected between avionics units.

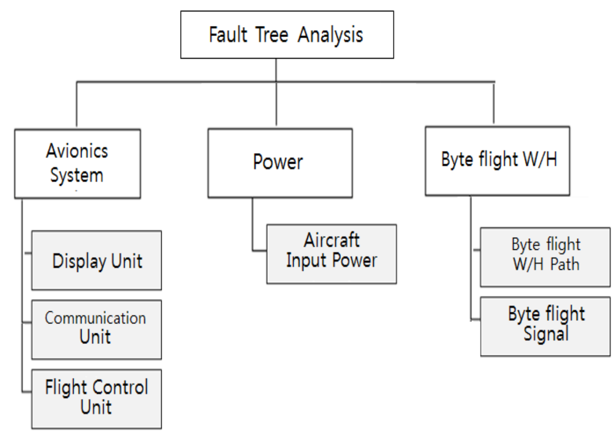

Fig. 3 Fault tree analysis for abnormal phenomenon.

Initially, in the event of an abnormal phenomenon due to Byteflight data communication error in the aircraft, we performed inspection by sequentially replacing the main avionics units of the integrated avionics system. However, we determined that the abnormal phenomenon occurred continuously. This confirmed that there is no effect of the avionics units as shown in Table 3.

Table 3 Inspection result after changes in Avionics unit.

Category	Abnormal phenomenon
Display Unit	Occurred
Communication Unit	Occurred
Flight Control Unit	Occurred

Furthermore, as shown in Fig. 4, we confirmed the instability effect on the input voltage in the avionics system due to inrush voltage and vibration that occurs when the engine starts.

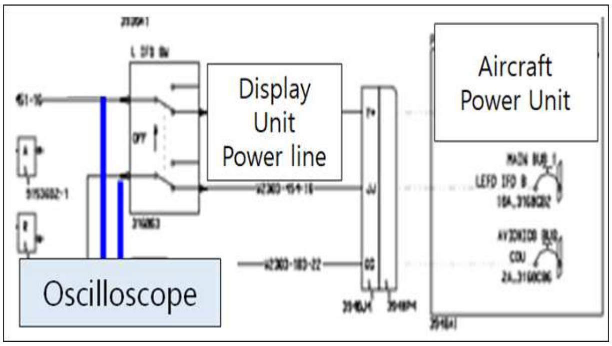

Fig. 4 Measurement method for input power of the avionics unit.

The input power in the avionics system is measured with an oscilloscope as shown in Fig. 5. It was observed that the input power had no effect because stable voltage was measured in the input power based on the criteria (about 2X V) of power standard (MIL-STD-704F) under various conditions (battery, engine start, and ground equipment) [6].

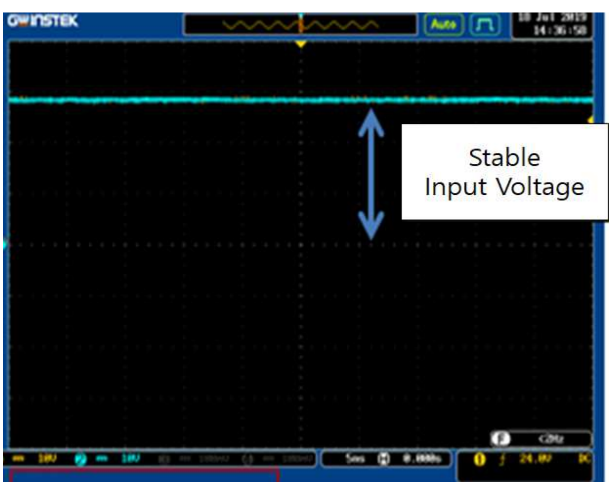

Fig. 5 Measurements of input power in the avionics unit.

Therefore, we analyzed the causes based on the phenomena and log data of the data bus for the Byteflight in the avionics system. The main causes of data communication errors between avionics units were determined as weak signal strength and data signal reflection and distortion due to impedance mismatch. This implies that data interpretation errors can occur in the avionic units receiving the data. We reviewed improvement methods by examining the workability, stub-point length, and W/H path when installing the W/H of the Byteflight data bus installed in the aircraft[7].

3. Review of Improvement Methods

3.1 Review of Byteflight Stub Point

Impedance mismatch refers to a phenomenon of reflected waves that are generated due to the difference in the impedance of the output unit and reception unit when they are connected. This can lead to data communication errors. First, to check the bonding and ground adequacy of the avionics units that use Byteflight, we measured the bonding and ground parts of the integrated display unit, communication unit, and flight control unit by using a bonding meter and multi-meter. As shown in Table 4, bonding and ground were within the reference values. This implies that they had no impact.

Therefore, we examined the W/H path of the Byteflight data bus. The W/H path is connected in a structure of two parallel lines for each avionics unit. The parallel-line part has a structure of parallel transmission lines consisting of the red lead and blue lead of the solder sleeve as shown in Fig. 6 [4].

Table 4 Measurement results for bonding and ground.

Category	Measurement point	Result
Bonding (Less than 2.X mΩ)	Display Unit Chassis	1.X mΩ (Good)
	Communication Control Unit Chassis	2.X mΩ (Good)
	Flight Control Unit Chassis	1.X mΩ (Good)
Ground (Less than 1Ω)	Display Unit	0.X Ω (Good)
	Communication Control Unit	0.X Ω (Good)
	Flight Control Unit	0.X Ω (Good)

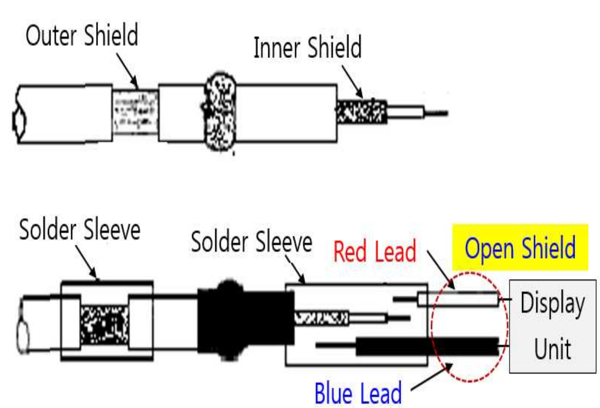

Fig. 6 Lead configuration of two parallel lines.

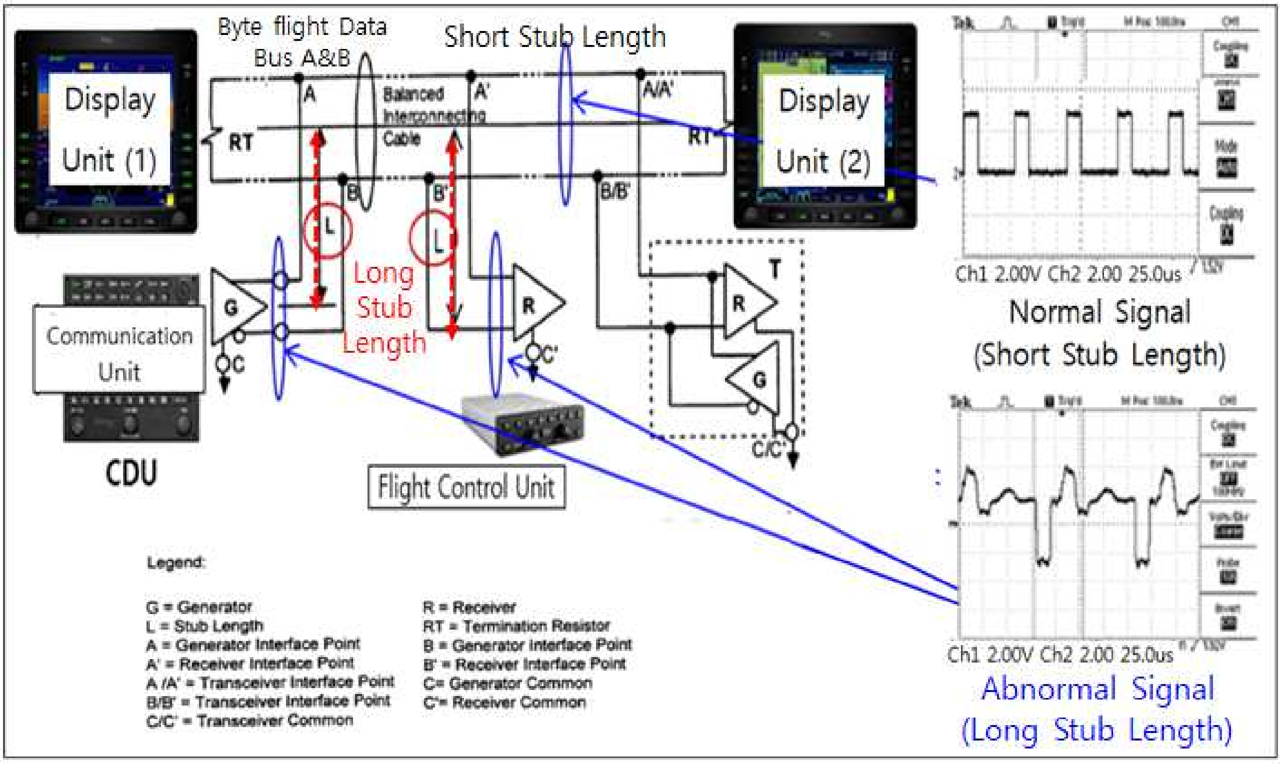

Fig. 7 Analysis of the TIA/EIA-485-A.

The outer and inner shields are applied, and the shielded part is shielded once more through the solder sleeve. This leads to effective properties for inner/outer noise and interference. However, if there is a factor that can induce video signal interference or attenuation in the W/H path, then it can lead to a conductive loss, a dielectric loss, and an increase in signal-to-noise ratio (SNR). Therefore, we examined them in detail [7].

We determined that the stub point part of the Byteflight data bus installed in the avionics system exhibited an open-shield structure. If the length increases in the stub point part, which has a shield structure, then it is vulnerable to external noise elements, and distortion can occur due to signal interference and loss. Given that high-frequency energy propagates along the surface of the conductor, the inner conductor's outer diameter and outer conductor's inner diameter are important variables. If the length of the open shield is not adequate, a characteristic impedance mismatch occurs due to the difference in the characteristic impedance. Hence, the energy is transferred only partially, and the remaining energy is reflected. This in turn generates standing waves inside the cable, which can lead to signal interference and loss [8].

Furthermore, as shown in Fig. 7, we confirmed the content related to RS-485, which is the basis of Byteflight data communication in the standard specifications (TIA/EIA -485-A). As per the standard specifications, the connection should be made with the shortest possible stub length (L) such that a signal can be normally recognized from the main cable. Furthermore, in signals of a short stub length, linear and normal signals are measured. However, in a long stub length, non-linear signals are measured. Hence, Byteflight data communication errors can occur due to interferences and distortions of signal waveforms [4]. Specifically, a parallel-line structure exhibits a characteristic impedance as shown in Eq. (1) and Fig. 8 [9]. Therefore, a variety of characteristic impedance ranging from 100 Ω to 300 Ω can occur. This leads to impedance mismatch based on the gap, length, and conditions of the red and blue lead lines at the stub point in the signal cable [10-11].

$$Z_O = 120 \in \frac{2D}{d} = 276 \log_{10} \frac{2D}{d} \qquad (1)$$

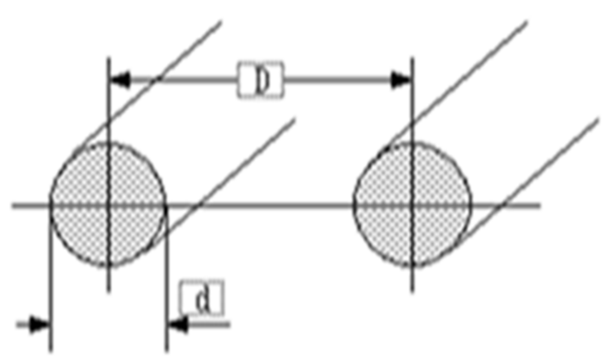

Fig. 8 Characteristic impedance of two parallel lines.

Based on the examination results, the Byteflight data bus W/H is connected to various avionics system units of the integrated avionics system, and a variety of large amount of data is transmitted/received between the avionics units in real-time via each stub point. Hence, an open shield structure with a moderately long length is observed at the harness stub point of the avionics system units. Given the mismatch at each stub point of the W/H, signal interference and impedance mismatch can occur in transmitted/received data. Therefore, we measured actual impedance signals by using a time domain reflectometry (TDR) device. This device verifies impedance signals by measuring the reflected waves that are returned after providing step pulses to the stub point. In the measurement results, impedance mismatch signals are intermittently observed at the stub point as shown in Fig. 10. Therefore, we examined the method of minimizing the open shield part by applying the same short length at the stub points of the Byteflight data bus W/H.

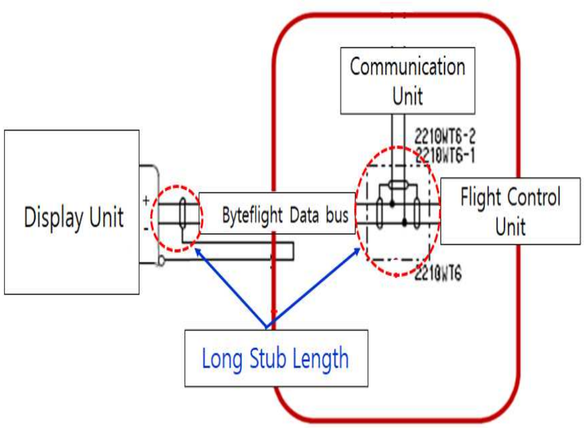

Fig. 9 Measurement result of Byteflight data bus stub.

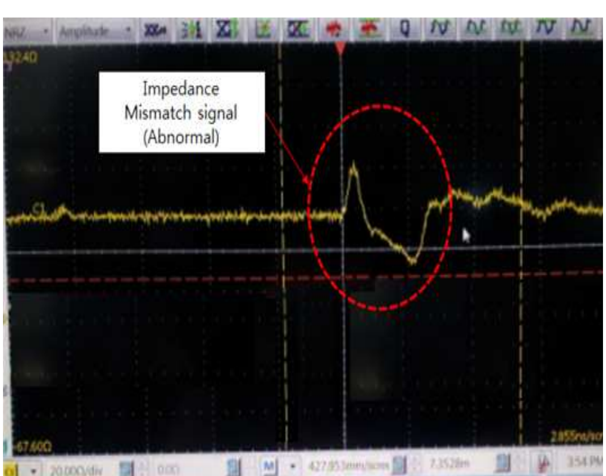

Fig. 10 Measurement results of disconnection point.

3.2 Review of Wire Harness Path of Byteflight Data Bus

In addition to signal interference between the output unit and reception unit and inadequate length of the connected line, impedance mismatch can occur due to stub points between the W/H path. Therefore, we examined the Byteflight W/H path and length between the avionics units. As shown in Fig. 11, given various types of transmitted/received signals between the avionics units, the Byteflight W/H is designed to branch with a W/H matrix as opposed to directly connected between the avionics units such that each signal can be provided to each device. This design method involves applying separate W/H paths by adding W/H matrix to improve the maintainability based on ease of removing/mounting wires when Byteflight wires are deteriorated or damaged [12]. However, as stub points are added due to the W/H matrix of the Byteflight data bus cable paths, signal interference and distortion occur because of the impedance mismatch characteristics. This implies that improvements are required. Furthermore, given that the stub points connected to the W/H matrix exhibit an open shield structure, internal/external interference signals can lead to screen flickering. Therefore, it was necessary to examine the effect via signal measurement.

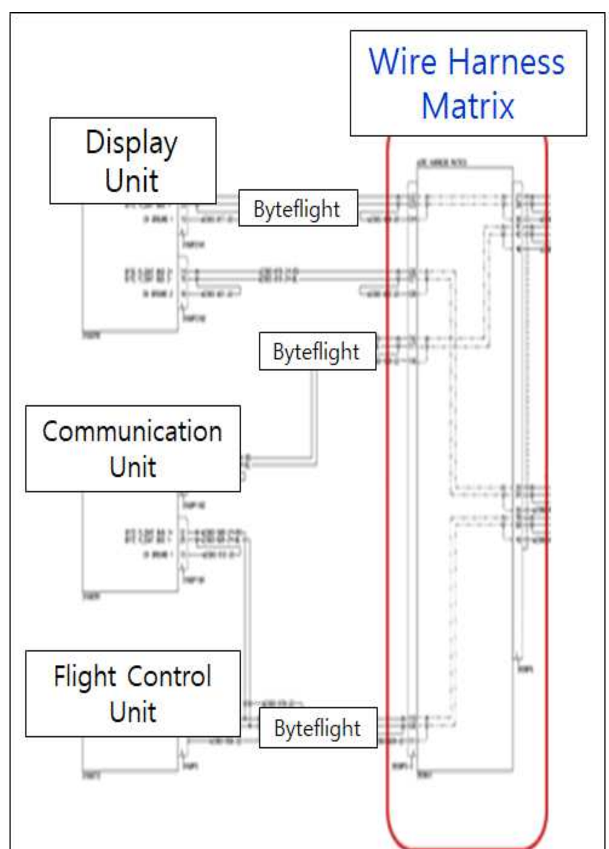

Fig. 11 Avionics unit and W/H matrix disconnection.

3.3 Byteflight Data Bus Signal Measurement

We examined signals at the stub points of the Byteflight data bus with the open shield, a long length condition, and W/H path matrix. As shown in Fig. 12, weak signal strengths, unstable amplitudes, reflections, quality degradation, signal collisions, and high impedances were measured because of signal loss and impedance mismatch.

Furthermore, when linear and normal signals are measured, as shown in Fig. 13, interference signals are continually measured at the end of the signals. This implies that improvements are required.

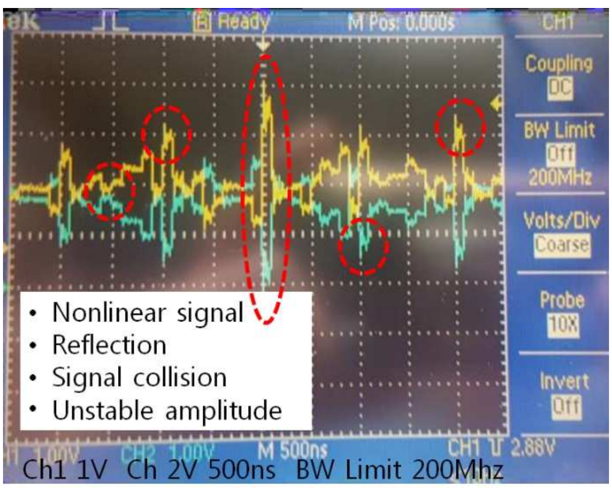

Fig. 12 Measurement results of Byteflight impedance mismatch signal.

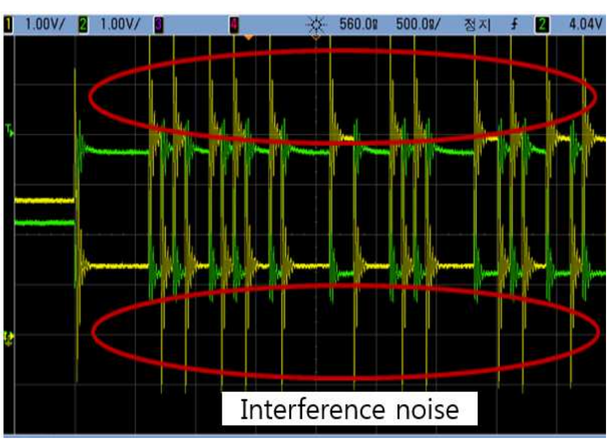

Fig. 13 Measurement results of Byteflight interference signal.

Therefore, we analyzed the impedance mismatch improvement by adding a π section filter, which has high insertion loss (60 dB/decade) in the circuit exhibiting high source and load impedances, as shown in Fig. 14 and Eq. (2).

$$IL(f) \cong 20\,log\cdot[\omega^2 \cdot LC + (LC^2 \cdot \omega^2 + 2\omega C)\cdot \frac{Z_S \cdot Z_L}{Z_S + Z_L}]; dB \quad (2)$$

$$(\frac{1}{\omega C} < Z_S \text{ and } \frac{1}{\omega C} < Z_L \text{ and } \omega L > \frac{1}{\omega C})$$

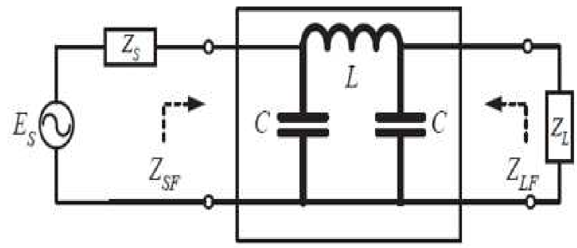

Fig. 14 π section circuit.

According to the analysis results, the work method and scope are quite limited when a filter is added in the Byteflight W/H path, and it requires a long time. Furthermore, the additional stub point at the end of the filter-added W/H path is open-shielded. This leads to signal interference due to the inflow of noises. Therefore, we proposed a method of improving signal interference by considering the operating rate maintenance of the aircraft under operation.

4. Application of Improvement Method

4.1 Improvement of Byteflight Stub Point

As shown in Fig. 15, we change the stub length of the Byteflight data bus to a short length of approximately 1 in, which is the minimum length recommended in the standard specifications. Furthermore, approximately a length of 1 in was applied for the splice and approximately a length of 2.X in was applied for shielding. These design changes were applied to the aircraft to resolve the impedance mismatch by minimizing the open shield part [4, 10-12].

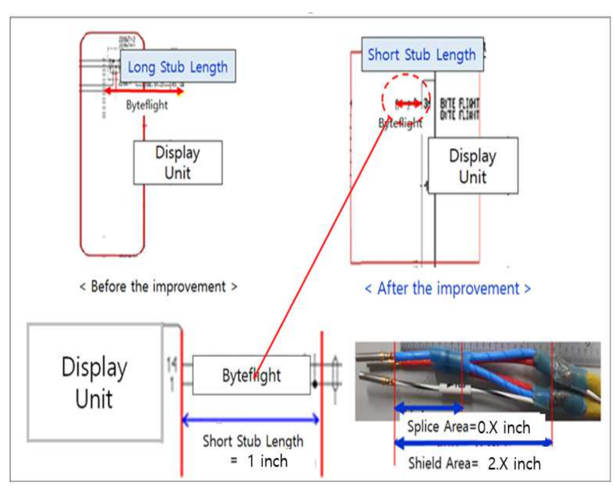

Fig. 15 Improvement in the Byteflight data bus via the application of short stub length, splice, and shielding area.

4.2 Byteflight Data Bus W/H Improvement

To improve the signal interference and impedance mismatch between the Byteflight data bus paths, we connected the Byteflight data bus W/H directly between the avionics units without passing through the W/H matrix as shown in Fig. 16. Furthermore, we designed a short W/H length to minimize signal losses, as shown in Table 5, and applied it to the aircraft.

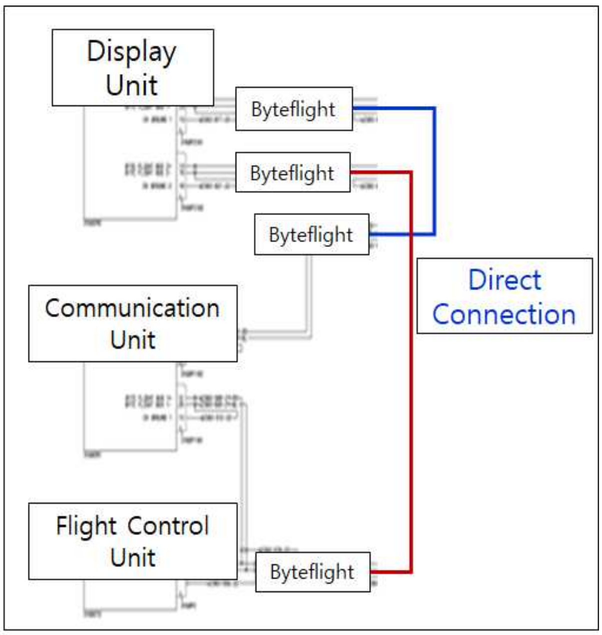

Fig. 16 Configuration of avionics unit with direct connection.

Table 5 Comparison of Byteflight data bus W/H length before/after improvement.

Byteflight			Before (m)	After (m)
Data Bus	From	To		
A	Display unit 1	Flight Control Unit	4.X	1.X
	Display unit 2	Communication Unit	3.X	1.X
B	Display unit 1	Flight Control Unit	4.X	1.X
	Display unit 2	Communication Unit	2.X	1.X
	Flight Control Unit	Communication Unit	4.X	1.X
Total length			1X.X	7.X

4.3 Measurement and Validation of Improvements

We applied short stub lengths for the Byteflight data buses in the aircraft where abnormalities of the avionics system occurred. Then, after performing improvements with the method of directly connecting the W/H paths, we measured Byteflight signals. As shown in Fig. 17, waveforms of linear Byteflight voltage signals without interference and noise and with impedances of strong and weak signal strengths were continuously measured.

Additionally, we used the TDR device to measure the impedance signals, and as shown in Fig. 18. Furthermore, normal impedance signals were continuously measured.

Fig. 17 Measurement result of Byteflight data bus signal after improvement.

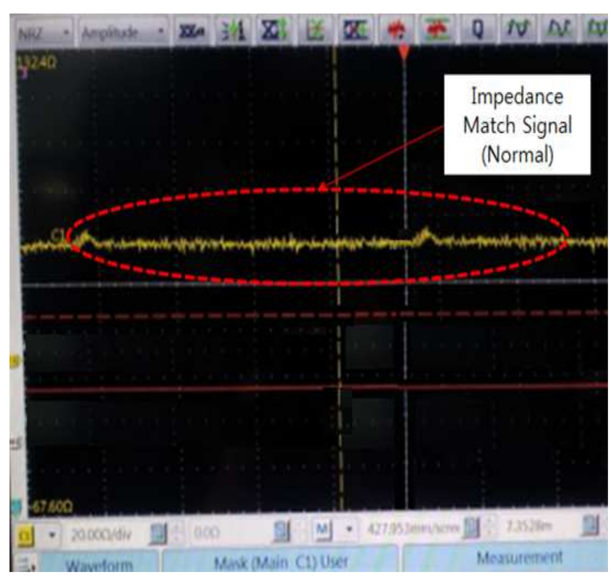

Fig. 18 Measurement results of impedance match.

In the comparison results of signal characteristics before and after improvements, we observed that the signal interference and impedance mismatch phenomena are resolved owing to strong signal strength, stable amplitude, and low impedance after improvement as shown in Table 6.

Table 6 Comparison of Byteflight data bus characteristics.

Configuration	Volts characteristics	Detailed characteristics
Long Length & W/H Matrix (Before)	Nonlinear Volts	Weak signal Nonlinear signal Reflection Signal collision High impedance Unstable amplitude
Short Length & Direct connect (After)	Linear Volts	Strong signal Linear signal No signal collision Low impedance Stable amplitude

Usually, blank screens, communication losses, and GPS faults due to signal interference can occur intermittently during flights, and more data are transmitted/received on the Byteflight data buses under various types of conditions during flights as opposed to those on the ground. Therefore, improvements should be verified via flight inspection. We applied the improvement method to the Byteflight data bus of the integrated avionics system inside the aircraft where abnormalities occurred frequently. Then, we conducted continuous ground and flight inspections based on the procedure in the flight manuals. The inspection revealed that no abnormal phenomena, such as blank screens, communication losses, and GPS faults, occurred as shown in Table 7. Furthermore, interviews with actual operators confirmed no occurrence of abnormalities and any other unusual events.

Table 7 Test Results after improvement in Byteflight

Aircraft	Result	
	Before Improvement	After Improvement
A	· Intermittent Flickering · GPS Fault · Uncommunicative & Fault	Normal
B		
C		

By analyzing the flight data after applying the improvement method, we confirmed that various types of Byteflight data-related error and warning codes, which occurred as effects of signal interferences before the improvement, did not occur. Furthermore, no abnormalities were observed when the W/H paths and stub points were checked after the ground/flight operation. As listed in Tables 8 and 9, the functions of the integrated display unit, communication unit, and flight control unit exhibited no abnormalities.

Table 8 Event data log analysis for normal message.

Code	Type	Normal message	Remark
CBIT	INFO	Versions ok	Normal Operation
LINK	INFO	Server Install Successful	Data sync normal
CBIT	INFO	Link Status	
CTP	INFO	CTP Receive	Data transmit /receive normal
CTP	INFO	CTP Transmit	
CBIT	INFO	GPS Track	GPS operation normal
CBIT	INFO	Com1 Tx on	Communication normal
CNS	INFO	Com1 Actv frequency change	
CBIT	INFO	Node Kbd1	Display normal
CBIT	INFO	Node Status	

Table 9 Test results with respect to the display & function.

Avionics Unit	Display & function
Display Unit	 Normal
Communication Control Unit	Normal
Flight control Unit	Normal

5. Conclusion

Abnormal phenomena, such as flickering screens, communication losses, and GPS faults, occurred in an integrated avionics system, which uses Byteflight data buses in an aircraft, because of communication errors in the Byteflight data buses. The main causes of data communication errors in the avionics system are as follows: long length of the open-shielded part at the stub point in the Byteflight data bus W/H path; long stub and W/H lengths due to the W/H matrix, which occurred cause impedance mismatch resulting in signal interferences and distortions in Byteflight data communication and weak signal strength, which causes data interpretation error resulting in abnormal phenomena. Therefore, we examined the characteristics of the Byteflight data bus used in the avionics system. Based on this, we modified the stub length of the Byteflight W/H to a short length corresponding to the minimum length recommended in the standards. Furthermore, by connecting the Byteflight data buses directly with a short path between the avionics units that used Byteflight, we improved the signal interference. Hence, factors that hindered the ground and flight operations were eliminated. We expect that aircraft operability can be improved by performing failure investigation and cause analysis cases for signal interference, which can occur when designing and operating similar models of aircraft wherein Byteflight data bus is applied.

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