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Research Article

A General Method for Module Automatic Testing in Avionics Systems

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Abstract: The traditional Automatic Test Equipment (ATE) systems are insufficient to cope with the challenges of testing more and more complex avionics systems. In this study, we propose a general method for module automatic testing in the avionics test platform based on PXI bus. We apply virtual instrument technology to realize the automatic testing and the fault reporting of signal performance. Taking the avionics bus ARINC429 as an example, we introduce the architecture of automatic test system as well as the implementation of algorithms in Lab VIEW. The comprehensive experiments show the proposed method can effectively accomplish the automatic testing and fault reporting of signal performance. It greatly improves the generality and reliability of ATE in avionics systems.

Keywords: ARINC429 bus, ATE, avionics systems, Lab VIEW, performance testing of modules, virtual instruments

INTRODUCTION

Along with the development of electronics and information technology, the avionics systems are becoming more and more complicated, leading to a much higher requirement of automatic testing for system reliability (Allen and McNeil, 1994; Craig, 2002; Ross, 2005; Dong and Li, 2009; Steadman *et al.*, 2002). There are two major directions for the automatic test system, the generality and the openness. The primary goals include the decrease of maintenance cost during its lifespan, the extension of applications, the improvement of adaptability and the improvement of fault diagnosis accuracy (Malesich, 2008; Michael and David, 2003; Droste and Guilbeaux, 2009).

The performance of the avionic equipments is easily affected by environmental factors because the particularity of working environment. If the temperature is high, low or changing rapidly, these equipments might lose accuracy. The environmental factors also include water vapor, rain, snow, wind, sandy dust, sunlight, vibration and corrosion etc. Therefore, the signal performance such as the rise time or fall time of impulse signal should to be tested thoroughly so as to increase the reliability of avionic equipments (Truebenbach, 2005).

So far, the three-level maintenance of avionics is evolving toward the new one with only two levels (Kornreich, 1989; Mullen and Wchter, 1993). The new maintenance imposes new requirements on the testing in all stages. The two-level maintenance not only brings the revolution of avionic technology, but also determines the trends of future automatic test equipments. The three-level maintenance is composed of the Organizational level (O-level), the Intermediate level (I-level) and the Depot level (D-level). The testing in O-level mainly targets at the isolation of system faults to the Line Replaceable Unit (LRU). I-level needs to isolate the system faults of LRU to the Shop Replaceable Unit (SRU). D-level should be able to isolate the faults of SRU to the shop replaceable sub-unit (SSRU) that makes use of much more accurate and specialized test equipments. In the two-level maintenance, the components that cannot be repaired in O-level are delivered to D-level, while bypassing I-level (Beat, 2002; Hu and Ying, 2006).

According to the philosophy of two-level maintenance, the LRU of avionics will be gradually replaced by the Line Replaceable Module (LRM). The modularized architecture requires that the ATE is capable of bus testing and systematic simulation (Beat, 2002; Hu and Ying, 2006; Michael, 1993). The main function of ATE transforms naturally from the testing of entire equipment to that of a module. It should isolate the faults to the components inside LRM or even smaller units and perform the fault diagnosis accordingly. Meanwhile, the avionic systems are more and more complex nowadays. The simulation and excitation of complex signals are inevitable. The arbitrary wave generation also becomes an important function of ATE (Ziomek and Jones, 2009).

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Under the three-level maintenance, the traditional automatic test equipments usually target at LRU. They are mainly used to test the entire equipment, instead of focusing on the testing of individual modules (Orlet and Murdock, 2002). Thus, it is very difficult to locate the faults into the components or even smaller units. Besides, the types of equipments that can be tested are limited.

Aiming at the insufficiency of ATE and the future trend of automatic test technology, we propose a generalized automatic test method for avionics modules, with application to the avionic test platform based on PXI bus. We utilize the virtual instrument technology to realize the automatic testing of signal performance in modules. Taking the avionics ARINC429 bus as an example, we build the automatic test system to test the signal performance of ARINC429 bus. This system has the merits of generality and reliability. It has reference significance in the future development of ATE of avionics systems under the two-level maintenance.

SYSTEM ARCHITECTURE

The general method of module automatic testing employs the virtual instrumental technology. It is applied in the avionics test platform based on PXI bus. The architecture of this method is shown in Fig. 1 which is composed of the embedded measurement and control computer module in the main testing box, the power control box, various testing resources, signal condition box and the interface of testing arrays.

The embedded measurement and control computer module is responsible of the management of testing resources. It provides the excitation signals for modules under test calling of testing resources by PXI bus; it collects, analyzes and records the output signals generated by module to test the performance of the signals. The testing resources mainly include the bus communication module, the digital oscilloscope module, the digital millimeter module, the arbitrary waveform generator module and the relay module.

The power control box is used to supply power for the modules and the signal condition box. It adopts relays to attach the output power to test array after isolation. The relay is controlled by PXI host computer. The voltage and the current of each channel of power are displayed by the digital watch.

The signal condition box is responsible for the condition of the original signals, such as the enlargement, the isolation, the filtering and the transformation. The signals generated by the tested resources are sent to the interface of test array via the signal condition box and are matched with the signals of the modules under test. It sends multi-channel signals to the oscilloscope and millimeter via matrix switch.

The test array interface supplies mechatronics of test unit and adapter, including test slot and signals connected to module under test and electric connection matched with test, control and power interface of test unit. Module under test is connected to the test platform via test adapter; test platform tests the performance of the same types of signals. It can connect to variant modules and test performance of multiple signals by replacing variant test adapters.

The digital signal test system, analog signal test system and all kinds of bus test systems can be built by replacing the bus communication module and signal condition box. The test system has the ability of automatic test, process and analysis of digital, analog and bus signals in the module under test. It has the generality of same type of signals in variant modules and no limitation to the type of module under test. It also improves the generality of ATE.

This system is concentrated on the performance testing of various signals in the modules. The gathering of signals and their analysis as well as simulation and excitation are the key technologies. In this study, we take the avionics bus ARINC429 as an example to construct a general automatic test system for ARINC429 bus signals. We target at the bus signals under test, gather the signals, analyze the input/output characteristics. The testing results are also presented in this study.

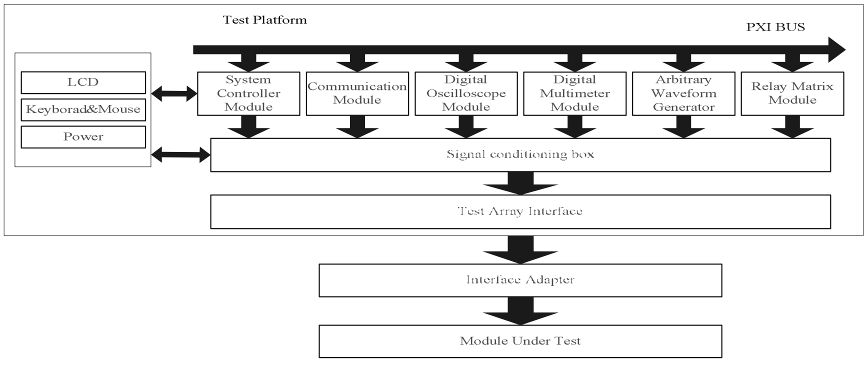


Fig. 1: Structure diagram of module automatic test system

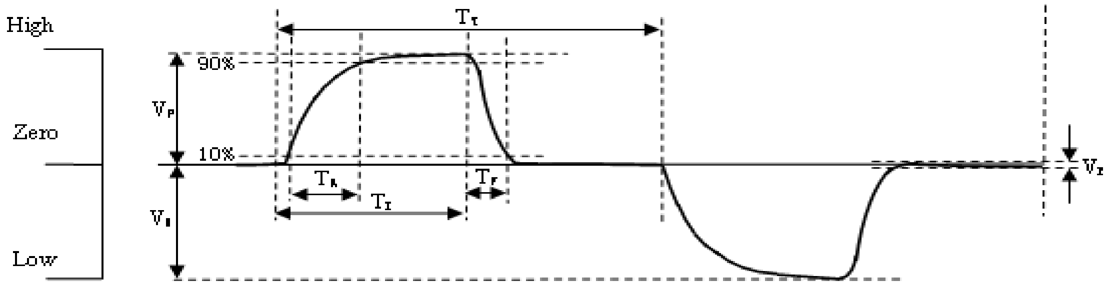


Fig. 2: Electrical characteristics of ARINC429 bus

Table 1: Test items and requirements of output electrical characteristics

Item name	Test condition	Requirements		
		Line A to line B	Line A to ground	Line B to ground
Positive output amplitude V_P	Measure the positive pulse amplitude of the output waveform	+10±1.0V	+5±0.5V	-5±0.5V
Negative output amplitude V_N	Measure the negative pulse amplitude of the output waveform	-10±1.0V	-5±0.5V	+5±0.5V
Zero level range V_Z	Measure the zero level range of the output waveform	0±0.5V	0±0.25V	0±0.25V

Table 2: Test Items and requirements of output time characteristics

Item name	Test condition	Requirements	
		High speed	Low speed
Bit rate R	Measure the items under following output conditions: • Absolute value of differential signal amplitude is 10V • 1~31 bits of the data word are respectively all 0, all 1, 0 alternating with 1 and 1alternating with 0 • Send the same data circularly to stabilize the waveform	100 kbps±1%	12~14.5 kbps±1%
Pulse rise time T_R		1.5 μs±0.5 μs	10 μs±5μs
Pulse fall time T_F		1.5 μs±0.5 μs	10 μs±5μs
Signal bit width T_Y		10 μs±2.5%	(1/R) μs±2.5%
Signal pulse width T_X		5 μs±5%	TY/2±5%

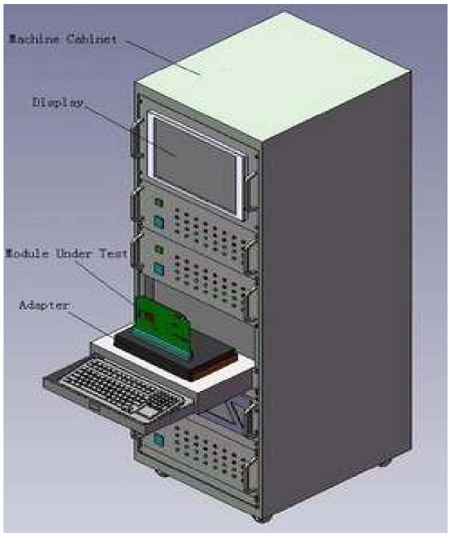
Requirements of performance test for arinc429 bus: The bus system is responsible for the information exchange and sharing of all sub-systems. Therefore, it is very important in the avionics systems. The reliability of the bus is the key factor to determine the stability of the whole system.

ARINC429 is one of the mostly used buses in the avionics systems. ARINC429 Digital Information Transmission Specification (DITS) is figured out by ARINC Aeronautical Radio Inc composed of American avionics manufacturers, the Airline Company, the airplane companies and other nation's Airline Companies. It stipulates the requirements of digital information transmission of avionics and the related sub-systems.

ARINC429 bus adopts bipolar return-to-zero code, as shown in Fig. 2. The basic information unit is composed of a 32-bit data word, transmitted through a twisted shielded pair of wires. The transmission rate has two types, a high speed one of 100 kpbs and a low speed one of 12.5 kpbs. According to statistics of substantial avionics tests, we choose the following electrical characteristics to test.

- **Signal amplitude:** The difference between positive (negative) level and zero level V_P (V_N), namely positive (negative) output amplitude.
- **Zero level range V_Z:** The level range of bus port with the state of bus waveform return to zero or no output data in the bus interface.
- **Pulse rise time T_R:** The time interval between the 10 and 90% voltage amplitude on the leading edges of the pulse.
- **Pulse fall time T_F:** The time interval between the 10 and 90% voltage amplitude on the trailing edges of the pulse.
- **Signal bit width T_Y:** The time width of logic "1" and logic "0" of signal waveform.
- **Signal pulse width T_X:** The signal pulse width excluding signal trailing.
- **Bit rate R:** Bit transmission rate of the bus.

The output electrical characteristics mainly include positive output amplitude, negative output amplitude and zero level range, the requirements is as shown in Table 1. Here, A and B refers to two terminals of



(a)

(b)

Fig. 3: Signal test platform of ARINC429 bus, (a) Schematic diagram of test platform, (b) Picture of test platform

differential signal. The output time characteristics include bit rate, pulse rise time, pulse fall time, signal bit width and signal pulse width. The requirements are shown in Table 2.

Signal test system of arinc429 bus: To test ARINC429 bus signals, we need to realize the automatic test and analysis of waveform parameters.

We also need to control and emulate variable electrical parameters of bus simulation signals. Common ARINC429 communication module can only test the bus function, including word message format, communication and process capability of invalid bus data. It cannot gather bus signal to test output electrical characteristics and time characteristics. It cannot change the level range dynamic to test input characteristics either. To satisfy the need of performance test, digital oscilloscope and arbitrary waveform generator of National Instruments (NI) are chosen. Digital oscilloscope is a very important tool of test and diagnoses in ATE. It gathers and analyzes ARINC429 bus signal sent by module under test (Kuenzi and Ziomek, 2007). ARINC429 bus signal that satisfies the amplitude and rate requirements can be generated by the arbitrary waveform generator and waveform editing software to realize signal imitation and stimulation of Unit Under Test (UUT). The signals are analyzed and processed to realize the performance test using Lab VIEW. The test platform of ARINC429 signal is shown in Fig. 3.

The test resources of ARINC429 bus module signal test system include ARINC429 bus communication module, digital oscilloscope module, digital multimeter module, arbitrary waveform generator module and relay module. PXI system controller uses the dual-core processor Intel Core2 Duo T7400, the dominant frequency is 2.16 GHz and the memory is 512MB.

The digital oscilloscope module with 8-bit resolution offers an input voltage range from ±0.8V~±30V, the sampling rate is 250 MS/s. The resolution of digital multimeter module is 7.5 bits with 20000 reading samples per second. The arbitrary waveform generator with 16-bit resolution offers an input voltage range from 0.564V~12V, the sampling rate is 100 MS/s, the band width is 43MHz and the buffer is 32MB.

IMPLEMENTATION OF ALGORITHM

The software is developed in Lab VIEW, the visualized virtual instrument integrated development environment of NI. Lab VIEW can integrate the development, analysis, visualization, simulation of many algorithms. It can also perform advanced signal processing, generator of applied programs, Signal Express software package, report generator for Microsoft Office and other functions. It is able to satisfy many performance requirements in the signal testing. Lab VIEW programs are called Virtual Instrument (VI). When a VI is run, values from controls flow through the block diagram, where they are used in the functions on the diagram and the results are passed into other functions.

The entire testing software is composed of seven modules, whose structure is shown in Fig. 4. The key techniques in the performance testing of bus signals include:

1. Signal gathering of ARINC429 bus by using the digital oscilloscope module
2. The testing of output characteristics
3. Testing of input characteristics
4. Analysis and display of test data

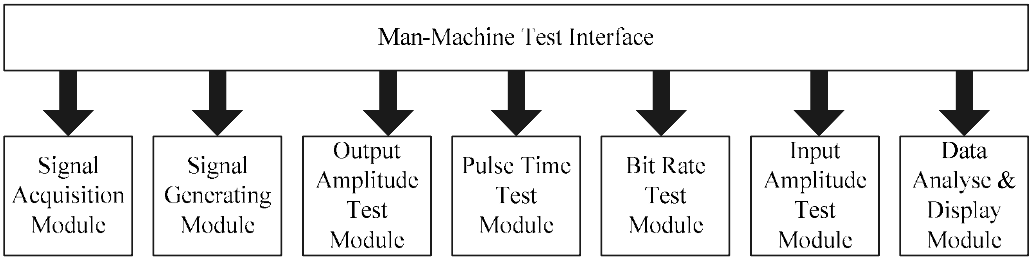


Fig. 4: Software structure diagram of module automatic test system

In 2), we test the signal amplitude, pulse rise time, pulse fall time, signal bit rate, signal bit width and signal pulse width etc. In 3), ARINC429 bus signal that satisfies the amplitude and rate requirements are generated by the arbitrary waveform generator along with waveform editing software. We use these signals to realize the signal imitation and stimulation of UUT, so that the input characteristics can be tested.

Signal acquisition: ARINC429 bus signal is classified as differential signal. Positive and negative signals are acquired by two channels of digital oscilloscope respectively. We obtain the differential signal from the positive and negative signals. The sampling rate of oscilloscope is set based on the incidence rate of bus signal. The vertical parameter, horizontal timing and trigger edge should be configured before signal acquisition. The positive and negative signals contain the time and scale information of waveforms. The time interval of two samples in the waveform acquired can be separated from positive and negative signals. The waveform signal Y can also be obtained from positive and negative signals. Time and waveform information yield the ARINC429 bus signal.

Output characteristics test: The key characteristics of ARINC429 bus signal include signal amplitude, zero level range, pulse rise time, pulse fall time, signal bit width, pulse width and bit rate. The signal processing VI in Lab VIEW performs the function of signal generating, digital filter and data windowing and spectrum analysis. Here, waveform measurement VI performs the function of time domain and frequency domain measurements, such as direct current, root mean square, frequency/amplitude/phase of single frequency, harmonic distortion, signal to noise and distortion ratio and average FFT measurement. The application VIs for the system has been developed using Lab VIEW-based graphical development environment to test the output characteristics and time characteristic of waveform.

Signal amplitude measurement: In our sub-VIs, the waveform signal is taken as the input signal. We define the measurement method of high level and low level of waveform in state setting. We choose “Peak” method to search maximum and minimum heights in the whole waveform and to measure amplitudes. We take the positive, negative and differential signal as the input signal of sub-VI to measure positive level amplitude, negative level amplitude as well as line-to-line amplitude and to output the corresponding amplitudes.

Pulse rise/fall time measurement: In our sub-VIs, we take the signal waveform under test as the input signal and set the polarity as a rising edge or a trailing edge. The rising or falling time can be obtained from the transient duration. ARINC429 is a differential signal that adopts bipolar return-to-zero code, which is different from the single end signal, e.g., RS232. The reference level must be set in the very beginning to configure the high, low and intermediate reference levels of transient interval. According to the characteristics of ARINC429 bus signal waveform, 90, 10 and 50% of the high level amplitude are chosen as the high, low and intermediate reference levels, respectively.

Signal bit rate measurement: ARINC429 bus signal is not a pure impulsive signal. It actually adopts bipolar return-to-zero code. In the actual application, “zero” always drifts, so that we increase the amplitude of differential signal properly. A set of zero-crossing points’ X coordinates of positive and negative signals are obtained, as shown in formula 1 and 2:

$$\begin{pmatrix} X_{P1} & X_{P2} & \dots & X_{PN} \end{pmatrix} \tag{1}$$

$$\begin{pmatrix} X_{N1} & X_{N2} & \dots & X_{NN} \end{pmatrix} \tag{2}$$

The maximum X coordinates of positive signal $X_{P\max}$, negative signal $X_{N\max}$ and minimum ones of positive signal $X_{P\min}$ and negative signal $X_{N\min}$ are got according to formula 1 and 2. Then, the maximum and minimum X coordinates, $X_{\max}$ and $X_{\min}$, are got via comparison. The rate is calculated by formula 3. The last bit is ignored so that we need to compensate $\Delta\delta$

for the number of signals. Here, I is time information, B is the bit number of one frame signal:

$$\left(X_{\max} - X_{\min} + \Delta\delta\right) \times I / B \times 10^{9} \tag{3}$$

The principle of measuring signal bit width is similar to measuring bit rate, where the details are omitted in this study.

Signal pulse width measurement: Figure 5 shows the diagram (code) of the pulse width measurement VI. We take the acquired positive or negative signal as input signal. The signal pulse width can be obtained from the pulse duration. Also, ARINC429 bus signal is a differential signal that adopts bipolar return-to-zero code. The high, low and intermediate reference levels are chosen to be 90, 10 and 50%, respectively of the high level amplitude.

Input characteristics test: Traditional ATE does not have the function of signal emulation. Thus, it is not able to produce complicated waveforms to carry out input characteristics test. To perform performance tests, we should generate more complicated waveforms so that arbitrary waveform generating is inevitable.

One important item of input characteristics test is to measure signal amplitude range. Generic ARINC429 communication module can only generate normal bus signal, while it cannot change output signal amplitude to test input characteristics. We carry out the simulation of signal waveform by using the arbitrary waveform generator. We develop a binary file format of ordinary ARINC429 signal that can be recognized by the arbitrary waveform generator. We then change the amplitude range and generate the waveform by the arbitrary waveform generator and finally output the ARINC429 bus signal with changeable amplitude in the

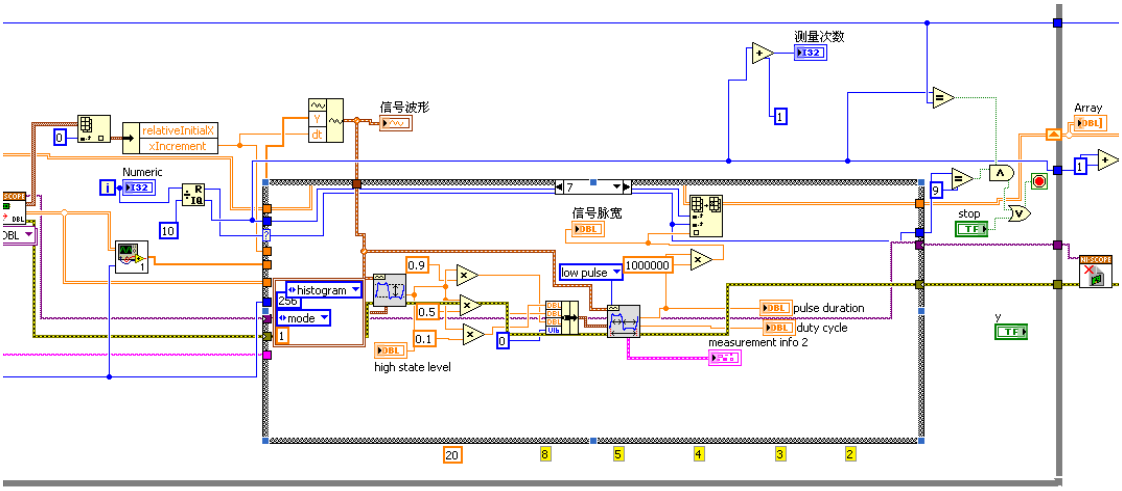


Fig. 5: Block diagram of pulse width measurement VI

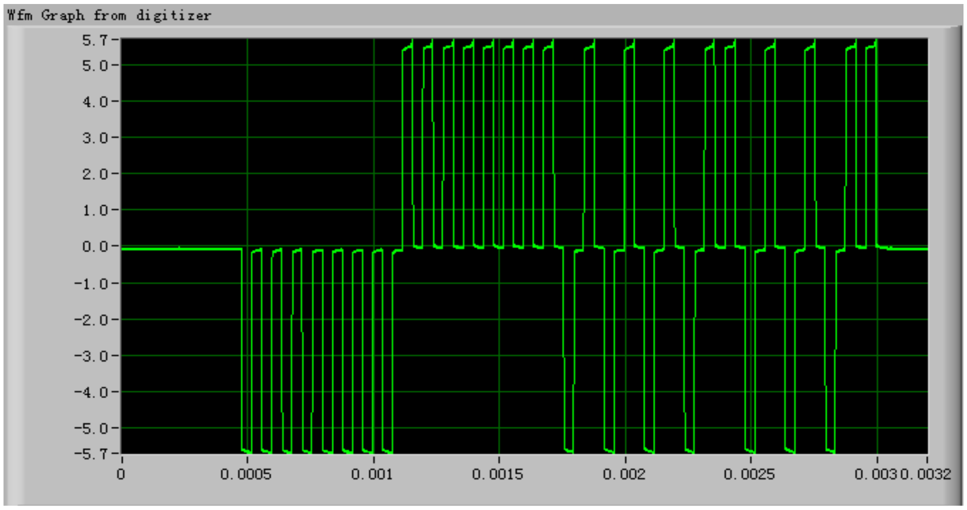


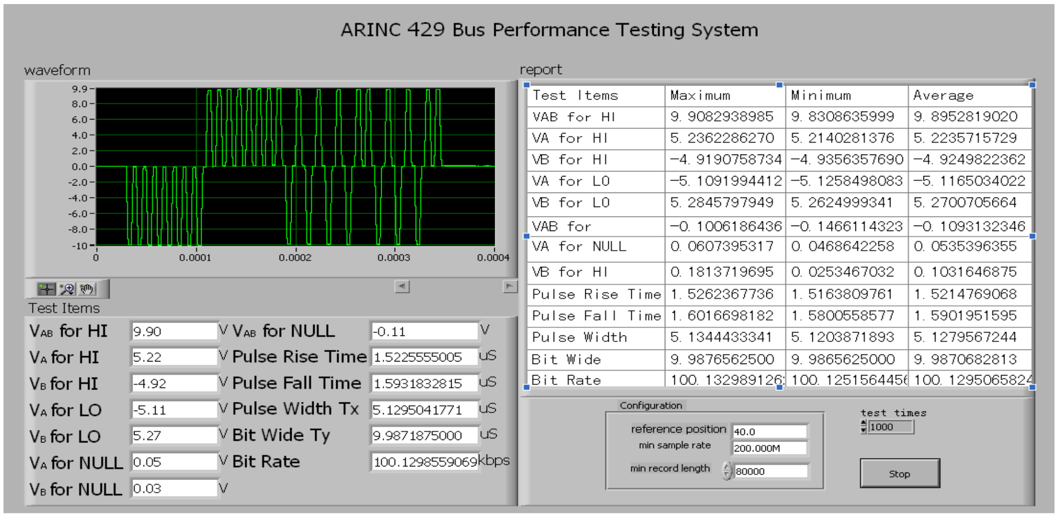
Fig. 6: ARINC429 signal generated by arbitrary waveform generator

I/O port. The arbitrary waveform generator only provides one output channel, leading to only output sing-end signals. So we transform single-end signal to differential signal in signal condition box and output it to module for testing the characteristics of input signal amplitude range. ARINC429 signal simulated by the arbitrary waveform generator is shown in Fig. 6. The high level range of output signal is +6.5~+13V, the zero level range is 2.5~-2.5V and the low level range is -6.5~-13V.

Data analysis and display: Lab VIEW contains a comprehensive set of tools for data analysis. It can analyze the gathered and measured data using various mathematical algorithms, including curve fitting and data model building, differential equation, internal interpolation and external interpolation, linear algebra, nonlinear system, optimization, rooting, mathematical statistics and random processing. Meanwhile, it affords multifarious report generating tool kits that acquire result and information from the data and generate test reports subsequently. With the help of tool kits in Lab VIEW, we analyze the data via a series of algorithms. The test report is generated and displayed on the front panel.

EXPERIMENT RESULT

We test various modules using signal test system of ARINC429 bus. The test report generated by data analysis and display modules gives the maximum, minimum and average values of 1000 test results. The test interface and the test data report are shown in Fig. 7 and 8. The left side of interface is the display window



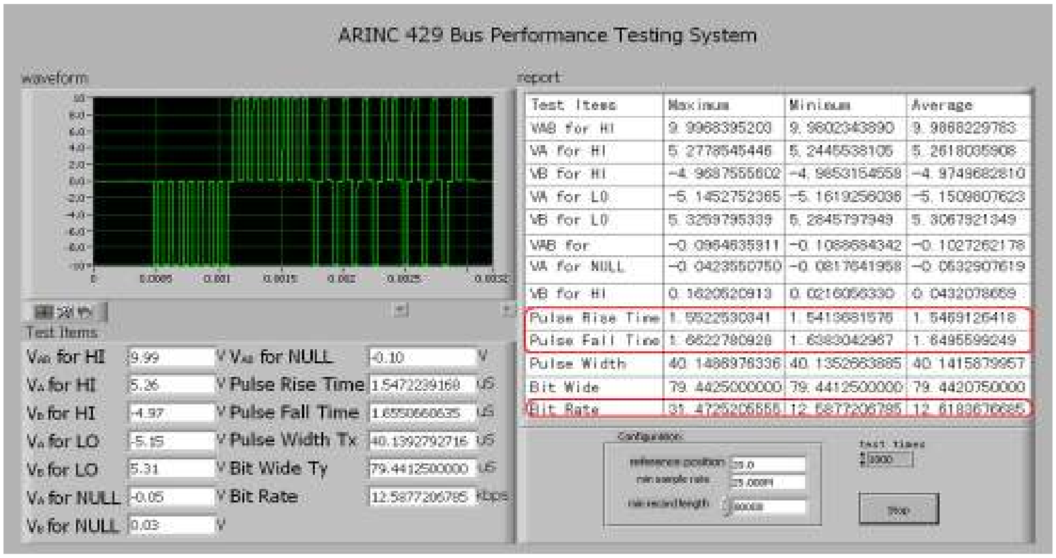
Test Items	Maximum	Minimum	Average
VAB for HI	9.9082938985	9.8308635999	9.8952819020
VA for HI	5.2362286270	5.2140281376	5.2235715729
VB for HI	−4.9190758734	−4.9356357690	−4.9249822362
VA for LO	−5.1091994412	−5.1258498083	−5.1165034022
VB for LO	5.2845797949	5.2624999341	5.2700705664
VAB for	−0.1006186436	−0.1466114323	−0.1093132346
VA for NULL	0.0607395317	0.0468642258	0.0535396355
VB for HI	0.1813719695	0.0253467032	0.1031646875
Pulse Rise Time	1.5262367736	1.5163809761	1.5214769068
Pulse Fall Time	1.6016698182	1.5800558577	1.5901951595
Pulse Width	5.1344433341	5.1203871893	5.1279567244
Bit Wide	9.9876562500	9.9865625000	9.9870682813
Bit Rate	100.132989126	100.125156445	100.129506582

Test Items

V_{AB} for HI	9.90	V	V_{AB} for NULL	-0.11	V
V_A for HI	5.22	V	Pulse Rise Time	1.5225555005	uS
V_B for HI	-4.92	V	Pulse Fall Time	1.5931832815	uS
V_A for LO	-5.11	V	Pulse Width Tx	5.1295041771	uS
V_B for LO	5.27	V	Bit Wide Ty	9.9871875000	uS
V_A for NULL	0.05	V	Bit Rate	100.1298559069	kbps
V_B for NULL	0.03	V			

Configuration
reference position: 40.0
min sample rate: 200.000M
min record length: 80000
test times: 1000

Fig. 7: Test report of ARINC429 bus signal with high speed



Test Items	Maximum	Minimum	Average
VAB for HI	9.9968395200	9.9802343890	9.9868229783
VA for HI	5.2778545446	5.2445538105	5.2618035908
VB for HI	−4.9687555602	−4.9853154558	−4.9749682810
VA for LO	−5.1452752365	−5.1619256036	−5.1509807623
VB for LO	5.3259795339	5.2845797949	5.3067921349
VAB for	−0.0964635911	−0.1069684342	−0.1027262178
VA for NULL	−0.0423550750	−0.0817641958	−0.0632907619
VB for HI	0.1620620913	0.0216056330	0.0432078659
Pulse Rise Time	1.5522530341	1.5413681576	1.5469126418
Pulse Fall Time	1.6622780928	1.6383042967	1.6495599249
Pulse Width	40.1488976336	40.1352663885	40.1415879957
Bit Wide	79.4425000000	79.4412500000	79.4420750000
Bit Rate	31.4725205555	12.5877206795	12.6183676685

Test Items

V_{AB} for HI	9.99	V	V_{AB} for NULL	-0.10	V
V_A for HI	5.26	V	Pulse Rise Time	1.5472239169	uS
V_B for HI	-4.97	V	Pulse Fall Time	1.6550660635	uS
V_A for LO	-5.15	V	Pulse Width Tx	40.1392792716	uS
V_B for LO	5.31	V	Bit Wide Ty	79.4412500000	uS
V_A for NULL	-0.05	V	Bit Rate	12.5877206795	kbps
V_B for NULL	0.03	V			

Configuration
reference position: 25.0
min sample rate: 25.000M
min record length: 80000
test times: 1000

Fig. 8: Test report of ARINC429 bus signal with low speed

of ARINC429 bus signal waveform and the test data; the right side is the test report. We control the output data of modules to the bus to be 0x55AAFF00 with high speed and low speed respectively, as shown in the waveform window in Fig. 7 and 8.

The high speed signal is the standard ARINC429 bus signal and the low speed signal is the nonstandard ARINC429 bus signal whose pulse rise time and pulse fall time are 1.5μs with alterable bit rate. Figure 7 shows the test result and report of high speed signal. The amplitude, pulse rise time, pulse fall time, signal pulse width, signal bit width and bit rate are all standard. Figure 8 shows the test result and report of low speed signal. The amplitude, signal pulse width, signals bit width are all standard, except that the maximum, minimum and mean pulse rise time are 1.552, 1.541 and 1.547μs, respectively. The maximum, minimum and mean pulse trailing time is 1.662, 1.638 and 1.650μs, respectively. They deviate from the standard by 10 us±5us obviously. Meanwhile, the range of bit rate is [12.588 31.473] kbps with an average 12.618 kbps. It deviates from the standard by 12~14.5kbps±1%. Experiment results indicate that this method can test the performance of ARINC429 bus signal in avionics modules accurately and provide the diagnosis report meantime.

CONCLUSION

The avionics systems are developing towards the direction of test and diagnosis ability of LRM and the even smaller units as well as signal performance. This study proposes a general method for module automatic testing. We use the avionics bus ARINC429 as a case study. The system architecture is presented and implemented based on Lab VIEW. We provide the tested data and the report. The testing results manifest that this system realizes the testing of input/output characteristics and the fault reporting. Based on the similar principle, we can build the automatic test system of digital, analog and bus signals in avionics modules. Thus, we can test the same signals in different types of modules. The general method for module automatic testing realizes the automatic testing of signal performance. It improves the generality of the automatic test system. The proposed method guarantees the reliability and the exchangeability of avionics systems. It has certain reference meanings for the development of two-level maintenance of ATE.

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