Table 4 rms control surfaces motion

System	rms aileron position, deg	rms aileron velocity, deg/s	rms rudder position, deg	rms rudder velocity, deg/s
$\alpha-\beta$	4.33	14.3	3.60	17.3
$(z-0.85)^3$	1.41	4.45	1.74	8.11
$(z-0.8)^3$	2.41	8.17	2.73	13.2
$(z-0.75)^3$	3.42	11.4	3.30	16.0

Table 5
Wind response—position *Y*

System	rms aircraft position, m
$\alpha-\beta$	0.579
$(z-0.85)^3$	0.719
$(z-0.8)^3$	0.658
$(z-0.75)^3$	0.625

After much trial and error, three different observers with the characteristic polynomials $(z-0.85)^3$, $(z-0.8)^3$, and $(z-0.75)^3$, respectively, were chosen to be tested in the system. A comparison of the different systems response characteristics is given in Tables 1-5. These results were obtained by simulation which included the three nonlinearities of aileron servo limiting, rudder servo limiting, and bank autopilot input limiting. The four systems considered are the currently used system with the α-β filter, and the three systems based on the observers mentioned above.

Conclusions

Observers were designed to replace an α-β filter in an aircraft automatic landing system, in order to reduce the response of the system to radar noise while maintaining an acceptable wind response. The $(z-0.8)^3$ observer appears to offer the most advantages. The aileron servo saturation was reduced from 23% of the time to 2% of the time. The rms value of the aileron motion was reduced by 44%, and the rms value of aileron velocity was reduced by 43%. The rms value of the bank autopilot input was reduced by 26%. However, the rms value of the aircraft position response to wind was increased by 14%.

A slower observer $[(z-0.85)^3]$ reduces aileron motion further, but the wind response increases. A faster observer $[(z-0.75)^3]$ increases aileron motion, but reduces the wind response.

It is concluded that the use of an observer in the automatic landing system to replace the α-β filter enhances system operation, without appreciably increasing wind response or appreciably degrading the system stability margins.

Acknowledgment

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References

[1] Wigginton, R.F., "Evaluation of OPS-II Operational Program for the Automatic Carrier Landing System," Project 70-65, Naval Electronics Systems Test and Evaluation Facility, Saint Inigoes, Md., Feb. 1971.

[2] "AN/TPN-22 Model 1 Final Report," ITT Gilfillan, Van Nuys, Calif., Contract N00039-75-C-0021, Aug. 1979.

[3] Luenberger, D.G., "An Introduction to Observers," *IEEE Transactions on Automatic Control,* Vol. AC-16, Dec. 1971, pp. 416-426.

[4] Benedict, T.R. and Bordner, G.W., "Synthesis of an Optimal Set of Radar Track-While-Scan Smoothing Equations," *IEEE Transactions on Automatic Control,* Vol. AC-7, July 1962, pp. 27-32.

[5] Schust, A.P. Jr., "Determination of Aircraft Response Characteristics in Approach/Landing Configuration for Microwave Landing System (MLS) Program," Naval Air Test Center, U.S. Naval Air Station, Patuxent River, Md., Oct. 1973.

ARINC 429 Digital Data Communications for Commercial Aircraft

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Introduction

THE ARINC 429 Digital Information Transfer System (DITS) broadly defines a digital data transmission format for avionics subsystems used in the new generation of commercial aircraft (Boeing 757, 767, Airbus A310) avionics applications. This standard specifies serial data transmission at a low rate (12-14.5 kHz) or a high rate (100 kHz) via a 75 Ω, shielded, twisted-pair cable using a series bus termination at the transmitter only. Advantages of using ARINC 429 are less cabling, reduced weight, enhanced reliability, minimal size, weight, and power of the interface electronics, a very simple bus protocol, and lower installation and maintenance costs. A disadvantage is the increased software overhead.

Background

Usage of digital data buses on commercial aircraft has developed by an evolutionary process to meet the requirements of each generation of commercial aircraft. Present generation commercial aircraft utilize digital data buses on an individual system basis, i.e., Inertial Navigation System, digital air data, etc. The next generation of commercial aircraft will make extensive use of data buses on an aircraft wide, architectural basis.[1] The ARINC 429 interface standard is issued by Aeronautical Radio, Inc. (ARINC) in which the United States airlines are the principal stockholders. Hence, it is a consensus given to one set of interface specifications, rather than an optimal, more general solution to data communications interface problems.

Prior to ARINC 429, 8 to 10 different digital data transmission standards existed using different word labels, for-

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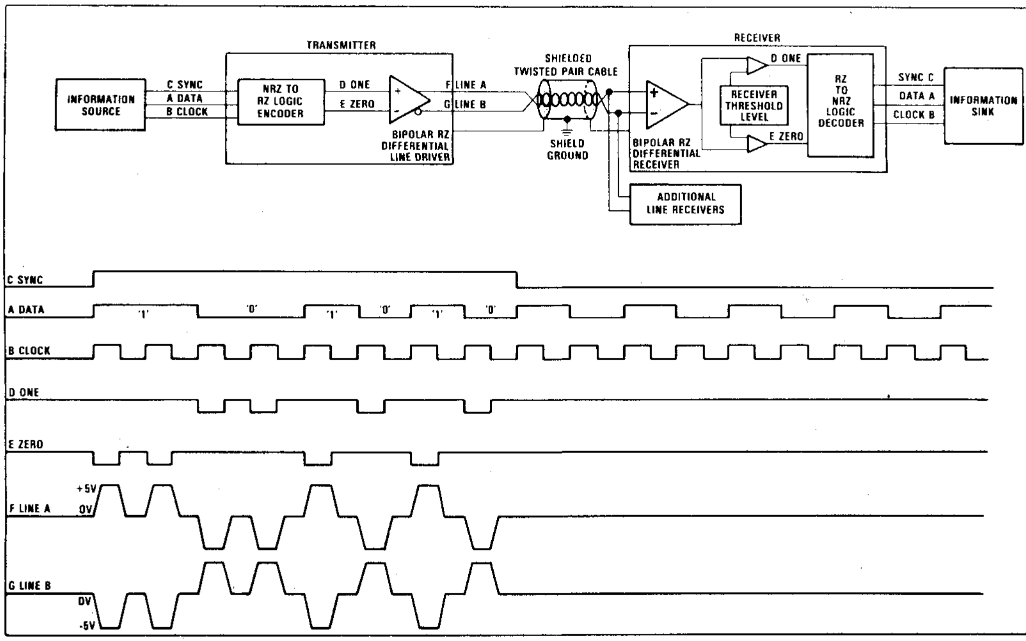

Fig. 1 ARINC 429 data transmission system.

mats, and electrical characteristics. In addition, previous digital avionics systems (e.g., ARINC 575) did not require data transmission frequencies of 100 kilobits/s (KBPS). Due to the new generation of digital avionics subsystems, a 100 KBPS data transmission frequency is required to support new sensors, controls, and instruments. Thus, ARINC 429 was adopted. Examples of subsystems which require 100 KBPS data rates are new compass displays and electronic attitude director indicators (EADI) which utilize cathode ray tube (CRT) displays. The prior art uses analog synchro signals to drive these displays. The historical development of the ARINC 429 Digital Information Transfer System (DITS) is described in Ref. 1.

ARINC 429 Data Bus System

A typical ARINC 429 data bus and waveforms are illustrated in Fig. 1. Direct coupling of the transmitter and receiver(s) to the data bus is normally used but it is not a requirement. ARINC 429 specifies a simplex distribution mode (i.e., broadcast) which means that data flow is unidirectional and nonreversible from a single transmitter to the receiver(s). A separate bus for each direction must be used if data are required to flow both ways (i.e., half-duplex). Data flow from a single source over a shielded twisted-pair cable to data sinks which, upon decoding the 8-bit word label, accepts or rejects the word.

Transmission is asynchronous with self-clocking "bipolar return-to-zero" (BPRZ) encoding logic used to represent the digital information. Between each word transmission, a minimum time gap sync of 4-bit time intervals is inserted by the source. This allows the sinks to detect the receipt of bit 1 of each 32-bit word and synchronize the receive logic to decode the message. The ARINC 429 transmitter device performs the functions of a serial, nonreturn to zero (NRZ) to BPRZ data, clock and sync logic encoder and power line driver. The receiver device interfaces to the data bus and converts BPRZ inputs to serial NRZ data, clock and sync signals.

No transmission line termination is provided by the receiver. However, the transmitter's source impedance (75 Ω) is matched to the transmission line's characteristic impedance (75 Ω) and thus provides the means for a source-terminated system. Since the transmitter terminates the bus, only one transmitter per bus is allowed. A maximum of 20 receivers may be connected to each bus.[2] Rise and fall times of the transmitter's output pulse are controlled per ARINC 429 to minimize electromagnetic interference (EMI) radiated by the

FUNCTION	PARITY (ODD)	SIGN/STATUS MATRIX	DATA	SOURCE/DESTINATION IDENTIFIER (SDI)	LABEL
			MSB LSB		LSB MSB
BIT NO.	32	31 30	29 28 27 26 25 24 23 22 21 20 19 18 17 16 15 14 13 12 11	10 9	8 7 6 5 4 3 2 1

Fig. 2 Basic ARINC 429 data word.

transmission line cable from adversely affecting other electronic systems.

A 32-bit digital word is the basic information unit, shown in Fig. 2. Each word consists of: 1) an 8-bit label to define the type of data (e.g., ILS frequency, DME distance); 2) a source/destination identifier (SDI) specifies one of four sources/destinations for words; 3) a sign/status matrix indicates the sign (plus, minus, east, west, etc.) of the data and the status of the transmitter hardware; 4) a parity bit (odd); and 5) data.

ARINC 429 System Performance

ARINC 429 does not specify the required performance of the data bus but only general characteristics, such as waveform and data rates. For example, bit error rate requirements are omitted, cable parameters, except for characteristic impedance (75 Ω), are not controlled, and no formal requirement is placed on the number or length of stubs.

However, typical Boeing 747 installation requirements (i.e., the largest commercial transport aircraft) are informally stated as guidelines for maximum bus length (approximately 300 ft) and stub length (approximately 20 ft). Hence, ARINC specifications (e.g., 429) are form, fit, and function standards for aircraft equipment design. These standards alone do not insure satisfactory performance, albeit they are based on experience and good engineering judgment.

Factors Affecting System Performance

ARINC 429 has resulted in a large increase in the number of data buses, an almost complete change from analog to digital signal processing and interfaces, and an increase in the maximum data rate carried on uncontrolled impedance wires. The performance of the ARINC 429 DITS is judged by the accuracy with which data on the bus is decoded by the receiving equipment. The primary factors that affect the accuracy of the decoded data are: 1) the degree of common-mode rejection at the receiver input, and 2) the filtering operations performed prior to data detection.

Electromagnetically coupled interference from electrical transients in adjacent circuits is the major potential source of errors in an ARINC 429 system. Balanced transmission on shielded, twisted-pair wires is employed to minimize the effect of this electromagnetic interference. In order to realize the full advantage afforded by balanced transmission, the receiver must have a high common mode rejection ratio (CMRR). This is accomplished by having large and/or nearly equal impedances on each receiver input line and equal gain through each differential amplifier input. A minimum CMRR of 40 dB is recommended.

The receiver filter characteristic also affects the ARINC 429 error rate. In general, the receiver filter characteristic should be chosen to maximize the output signal-to-noise ratio at the sampling instant. Usually, a low-pass RC filter yields adequate performance in most applications. Hysteresis in the line receiver can also improve relative noise immunity.

If an ARINC 429 bus failure should occur, continued satisfactory system operation depends upon the proper operation of the remaining data buses. Hence, prevention of failure propagation between redundant or independent data buses is essential. To insure the integrity of these buses, multiple transmitters and receivers within the same system should be electrically and thermally isolated. This isolation must be adequate to prevent a failure of any one bus (possibly induced by a short circuit to a damaging voltage level) from affecting the successful operation of any other bus.

Control of bit errors within an ARINC 429 word depends upon the error detection strategies employed. A single-bit error within each 32-bit word can be detected by a parity check and the word can be discarded. However, any even number of errors within the 32-bit word will escape detection by the parity check and be passed on to the system that uses the data. Hence, to enhance the validity of the parity test, received data words which do not contain exactly 32 data bits (as detected by threshold crossings) are rejected. In order to minimize data errors, the receiver described herein is designed with a minimum CMRR of 40 dB and hysteresis. Failure propagation is minimized by separate power and ground pins for electrical isolation between the dual receivers in the same package. In order to minimize impulse noise effects, the receiver's differential input stage has a frequency response that limits the signal bandwidth to approximately 233 kHz. This bandwidth is consistent with the 1.5 μs rise and fall times of the 100 kHz waveform. Favorable EMI test results on a hybrid receiver described herein have verified the validity of this design approach.

757/767 Flight Management System Architecture

The 757/767 Flight Management System (FMS) represents the first application of a digital avionics system in commercial transport aircraft that has used the ARINC 429 bus interfaces to integrate almost all avionics data transmission. The FMS is a network of subsystems that communicate via a system of approximately 122 ARINC 429 data buses. Each subsystem interface uses a separate bus. In addition, a 1-MHz ARINC 453 bus is used between the weather radar receiver/transmitter and the Electronic Flight Instrument System (EFIS) symbol generators.

The architecture of the FMS is partitioned by functional capabilities into separate computer subsystems with different levels of redundancy. Its capabilities comprise four main functions: automatic flight control; performance management, navigation and guidance; advisory warning and caution; and controls and displays for crew operations. These subsystems can be operated in selective degrees of automation at the pilot's option.

Description of Hybrid Transmitter/Receiver

Because of the large number of transmitters and receivers required by the 757/767 avionics architecture, a packaging technology that could achieve the required miniaturization and reliability is essential. Various suppliers of such circuits for the 757/767 subsystems have used hybrid, custom LSI and combinations of these technologies. For the design described in this Note, the hybrid approach was selected because of development time, worst-case power dissipation, and component optimization considerations. In order to optimize power, speed, and versatile interface compatibility, a mix of CMOS (logic) and bipolar (linear) technology was chosen. The transmitter and dual-receiver hybrid packages each measure 1.2×1.2 in. and the single-receiver package measures 0.6×1.2 in. (Ref. 3).

Only the basic transmitter and receiver functions are implemented in the subject ARINC 429 hybrids, because they are intended for use as universal interface components and the utility of extra functions is application dependent. As a result, users have more flexibility to optimize their interface design, and the advantage of reduced cost for a basic device usually results in a lower system cost.

During the receiver development, an optically coupled line receiver was considered. However, the idea was dropped because at low input currents, reliably switching the optical-isolation LEDs currently available was considered marginal under worst-case conditions. Optoisolation receivers have the advantage of dielectrically isolating the receiver unit from the data bus. This feature is useful in a high level, common mode environment due to severe EMI conditions. Direct coupling of the transmitter and receiver(s) to the data bus was chosen as opposed to transformer or capacitive coupling. Direct coupling precluded buildup of residual voltage offsets on an isolation transformer or capacitor during continuous transmission of long messages required by some applications.

A worst-case analysis was also performed on the transmitter and receiver with a goal of conforming to ARINC 429 specification limits after a 20-yr end-of-life service. This was achieved by passively ratio trimming critical resistors to optimum start-of-life values. The use of hybrid microelectronics packaging has reduced the physical package size of the transmitter by at least 4:1 for the transmitter and 6:1 for the receiver, while also achieving estimated reliability figures for mean time between failure (MTBF) of 300,000 h for the receiver and 270,000 h for the transmitter.

Transmitter/Receiver Development and Testing

During testing of ARINC 429 data buses it was determined that some receivers would continue to accept data when one of the input lines (line A or B) was either disconnected or shorted to ground. The receiver appears to operate normally, but the performance is potentially degraded because in either condition the common mode rejection is lost and the effective input signal amplitude is reduced. In the case of the open fault, either the high or low line acts as an antenna, and can induce noise spikes into the system because all common mode rejection is lost, which can cause intermittent conditions on the receiving system that are very difficult to detect. This type of failure could cause boxes to be removed from the aircraft when actually the failure is in the aircraft cable and not in a line replaceable unit (LRU).

In order to correct this problem, ARINC 429 was revised and the subject receiver was modified to incorporate an input threshold of ± 6 V. Since the transmitter will output only 5 V on a single line, a single wire (line A or B) open-circuit or ground fault will cause the receiver to cease functioning, thereby indicating the fault and allowing switchover to a backup unit. For the subject receiver, raising its input threshold was deemed to be the simplest and most inexpensive way to enable the receiver to detect a transmission line fault. However, other implementations of fault detection and anunciation are possible.

The hybrid transmitter and receiver, and receivers from other suppliers, were tested in the ARINC 429 system to determine if the data bus will operate properly in the aircraft electromagnetic environment with a shield ground wire longer than 6 in. Results of the testing concluded that an ARINC 429 data bus should use twisted, shielded wire with the shield grounded at both ends and a 6-in. shield ground is recommended; however, shield grounds up to 18 in. can be utilized in areas where the shorter ground is impossible to achieve. During EMI testing, the subject receiver functioned properly without loss of data, even during an inductive transient when using a 6- or 18-in. shield ground.

Conclusion

The ARINC 429 digital data bus is the key integrating element of the 757/767 aircraft's digital avionics system. Although ARINC 429 defines a standard interface specification, the implementation of the required receiver/transmitter circuitry involves considerations of performance which are not necessarily apparent to the reader of that specification.

References

[1] Small, V.J., "Use of Digital Data Buses on Commercial Aircraft," *Proceedings of the 2nd AFSC Multiplex Data Bus Conference*, Aeronautical Systems Division, ASD-TR-78-34, Vol. 2, Nov. 1978, pp. 381-388.

[2] Airlines Electronic Engineering Committee, "ARINC Specification 429-4 MARK 33 Digital Information Transfer System (DITS)," Aeronautical Radio Inc., Annapolis, Md., Aug. 1980.

[3] Chun, R.K.B. and Larsen, D.E., "Digital Data Communications System," U.S. Patent 4,280,221, July 1980.

Nonlinear Filter for Pilot's Remnant Attenuation

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Introduction

THE pilot's response in the performance of a closed-loop compensatory control task can be modeled as being composed of a signal that is linearly related to the input signal (system error) and a random noise (remnant). The remnant contains high-frequency components that increase the error in compensatory control. Thus, a filter with a sharp high-frequency roll-off, no resonance peaks, and an ideally zero phase shift in the frequency range of interest will increase tracking accuracy. In other words, such a filter imposes a rate limit on the pilot's control signal output without any delay introduced in the process. This, in turn, will enable smooth maneuvers and lower attitude rates. Such a filter type will be particularly useful in fly-by-wire systems. Research on the desired filter was initiated by Adams[1] with a fixed-base simulator. His results show that a nonlinear filter of the type he has used eliminates enough of pilot's remnant so that smoother maneuvering with smaller pitching velocity peaks in longitudinal tracking can be obtained. However, some stability problems in the pilot/aircraft system were observed because of the phase shifts introduced by the filter, which was of first order using an integrator with an input limiter.

The work reported here proposes an alternative approach, wherein the rate of change of pilot's output (i.e., stick rate) itself can be used to obtain the remnant attenuation, with no phase shift being introduced.

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Proposed Filter

The configuration of the proposed filter was developed using an analog computer and a pilot model—aircraft simulation with realistic data. For actual implementation, it is assumed that the rate signal from the pilot's control stick will be available if an appropriate transducer is used.

A block diagram representation of the proposed filter is shown in Fig. 1. Essentially, the filter generates a variable coefficient q with which the pilot's output signal $\delta(t)$ is multiplied before it is used for the control surface actuation, as shown in Fig. 1a. It can be observed from Fig. 1a that under no circumstances can there be any phase shift in the $\delta(t)$ signal, as q is a variable coefficient and will be unity in the passband of the filter, as will be explained below. The filter is implemented by first generating the absolute values of the control stick rate and positions as shown in Figs. 1b and 1c. A cutoff frequency for the low-pass filters of about 3-5 times the desired bandwidth of the nonlinear filter was found to be satisfactory. Hence, for the 10 rad/s bandwidth selected, the cutoff frequency of the low-pass filters was set at 30 rad/s to make the absolute values "smooth." As shown in Fig. 1d, after obtaining the signal proportional to the reciprocal of the frequency content, it is squared and passed through a threshold circuit after subtracting it from a reference. The break point V_B is adjusted to obtain the desired bandwidth. The output of the threshold circuit V_d is again subtracted from a reference to obtain the coefficient q, as shown in the figure.

Pertinent relationships describing the voltages at various points in Fig. 1d are given below, where ω_i represents the input frequency and ω_c the desired cutoff frequency of the nonlinear filter,

$$V_a = V_L \qquad \text{for} \quad \omega_i \leq 0.1 \text{ rad/s}$$

$$= K_1/\omega_i \qquad \text{for} \quad \omega_i > 0.1 \text{ rad/s}$$

The switching point at $\omega_i = 0.1$ rad/s was selected because below this frequency it is unlikely that any attenuation will

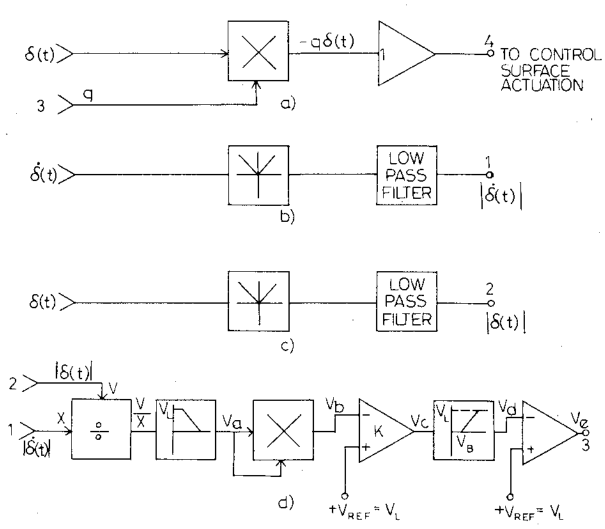

Fig. 1 Block diagram of the proposed nonlinear filter.