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A PRIMER OF AIRCRAFT MULTIPLEXING

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1. INTRODUCTION

Today's sophisticated aircraft are required to effectively perform a variety of missions. With the advent of micro-miniaturization in electronics and advanced digital computers, a new generation of avionics equipment and systems can be utilized to increase the capabilities of the aircraft. As the quantity and variety of equipment and functions increases, the problems of inter-connecting these equipments with wires presents a constraint on size, weight, signal conditioning, reliability, maintainability and electromagnetic control. Conventional wiring has resulted in large bundles of wires and many connectors which adds excessive weight and reduces the space available for the pilot and other vital elements. This limitation can be relieved significantly by the application of w proven multiplexing techniques.

2. WHAT IS MULTIPLEXING?

Interior communications (signal flow) in an aircraft is conventionally accomplished by point to point wiring between the various electronic and electrical equipment. Multiplexing provides a means of increasing the number of signals transmitted between units while decreasing the number of signal paths. The result is a significant reduction of wire bundles and weight in the aircraft. With the extensive application of multiplexing techniques, it is conservatively estimated that 300 to 500 pounds of wire and associated hardware can be saved on a typical military fighter aircraft. For a large multi-engine aircraft this figure is expected to quadruple. Application of remote multiplexing in the instrumentation (data acquisition) system of a military missile system has demonstrated a savings of 2,000 pounds of wire.

3. WHAT ARE THE ADVANTAGES?

The rapid advance in solid state technology has provided reliable micro-miniaturized components which are directly applicable in multiplexing systems. These systems, when applied to the design of future aircraft may result in higher reliability and improved aircraft performance. The following is a summary of the major advantages which may possibly be gained by the application of multiplexing to aircraft systems.

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|-------------------|--|
| • Weight | Significant reduction of wire weight due to sharing of data transmission line. |
| • Volume | Significant reduction in wiring harness sizes. |
| • Maintainability | Self-test and built-in-test functions are incorporated for malfunction detection and fault isolation. Complete cabling network and all system components can be tested and fault isolated by use of simple Ground Support Equipment (GSE). |
| • Vulnerability | Less vulnerable to battle damage in military aircraft. |
| • Cost | Large life-cycle cost savings due to improved maintenance and less costly changes. |

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- Survivability Redundancy techniques are employed to provide higher survivability (immunity to damage). Self-test and automatic switchover to redundant lines and equipment is provided.
- Flexibility Easily reconfigured due to modularity and compatible interface.
- Electromagnetic Compatibility Data signals are well controlled over a shielded transmission link. Provides more room in cable raceway for ideal spacing of handwired bundles per EMIC specifications.

The following paragraphs relate the basic principles of multiplexing and the significant areas of aircraft systems where multiplexing techniques may be applied.

4. HOW DOES MULTIPLEXING WORK?

- 4.1 Multiplexing is basically a technique providing efficient utilization of a transmission medium for transfer of information between remotely located points. If information is required to be transmitted from one point and received at another, then a communication link must be established. Communicated information exists in many forms; voice, on-off, voltage, current, high frequency (video), codes and tones are a few of the common forms. A basic form of communications applicable to the electrical system on an aircraft is the on-off function initiated by a switch to activate a relay coil which furnishes power to a load. This is the case of a simple control function and, if accomplished in the conventional way, requires a pair of wires or single wire if common return is used, as the communication medium for each required function. On a typical small high performance aircraft, as many as 1,000 of these functions are required. Multiplexing reduces the 1,000 - 2,000 inter-connections to a single pair of wires. A typical requirement for the application of multiplexing in aircraft avionics is to inter-connect equipment such as radios to intercoms, control panels, display panels and a central computer.
- 4.2 Two basic types of multiplexing are used for communication systems in industrial, aircraft and aerospace applications. These two types of multiplexing are (1) Frequency Division Multiplexing (FDM) and (2) Time Division Multiplexing (TDM). Frequency Division Multiplexing is a technique in which the bandwidth capability of the communication medium is utilized by assigning a separate frequency for every information channel to be carried over the medium. Separation of information channels is accomplished in the frequency domain by separating the assigned frequencies by a specific number of cycles (guard band) dependent on channel capacity, bandwidth and cross-talk requirements. Time Division Multiplexing achieves signal separation by sampling the data channels one at a time. The FDM techniques are most effectively used where a small number of channels with wideband signals are required to be transmitted. TDM is most efficiently applied to transfer of a large number of low frequency signals. A combination of FDM and TDM can be implemented if the advantages in the particular application outweigh the disadvantage of additional complexity. Table I is a comparison chart of the two multiplexing types showing the major features of each assuming the simplest form of modulation for each case.

TABLE I
SUMMARY COMPARISON OF MULTIPLEXING TYPES

<u>Characteristic</u>	<u>FDM</u>	<u>TDM</u>
Preferred Signal	High Frequency	Low Frequency
Channel Capacity	Low	High
Bandwidth Required	High	Relatively Low
Analog Accuracy	$\pm 1\%$	$\pm 1\%$ (PAM, PDM)
Complexity	High	Low (PAM, PDM)
Phase Distortion	Low	High
Large Scale Integration (LSI)	Low	High
Cost	High	Low



5. MODULATION METHODS

- 5.1 In the design of any communication link, after the multiplex type has been chosen, a modulation method must be considered.
- 5.2 A common form of modulation used in FDM telemetry and other systems is Frequency Modulation (FM). Further modulation is required depending on the character of the communication link. For instance, a Radio Frequency (RF) Link requires further translation of the composite signal to an RF carrier which may result in an additional frequency modulation.
- 5.3 Inherent to the TDM system is a modulation called Pulse Amplitude Modulation (PAM). The signal in each channel is sampled on a regular basis for a period of time which is the same for each sample. The resulting output of the commutator is a PAM wavetrain with the samples of each input signal interleaved in time depending on the sampling sequence. In the case of TDM, the final modulation and link characteristics depend to some extent on the nature of the signals being transmitted. For instance, the sampled data may be discrete (on/off) signal which normally has two states. This is the case for most of the electrical (power) functions on an aircraft. Or the data may be analog (continuous) data which must be maintained in linear form through the communication system.
- 5.4 In the case of analog data discussed above, where amplitude modulated pulses (PAM) are transmitted, the system is subject to noise and distortion which results in error. For systems where data accuracy is not a major factor, such as intercom (voice), PAM may be used as the final signal form. If greater accuracy is necessary then coding of the signal may be used. This technique is referred to as Pulse Code Modulation (PCM). Each analog signal is sampled in a commutator and converted to an equivalent digital code in an analog-to-digital converter (ADC). Digital inputs in discrete (on-off) form are sampled in the digital multiplexer and formatted into the output. The advantages of PCM for use in aircraft multiplexing are:
- Immunity from noise and distortion
 - Simplified communication medium due to on/off characteristics of signal
 - Compatible with digital computer
 - Compatible with discrete (on/off) data
- 5.5 The major disadvantage of PCM is the cost and complexity of analog-to-digital converters (ADC) and digital-to-analog converters (DAC). Due to the advantages listed above and the fact that a large portion of the signals in aircraft are in digital form, PCM is considered a very attractive technique for multiplexing.

Additional conditioning of the signal in the form of Amplitude Modulation (AM) or BI-Phase Modulation (BI-Ø) is implemented to drive the transmission line.

6. WHAT KIND OF SIGNALS WILL MULTIPLEXING HANDLE ?

The signals which are present in the electrical/avionics system on a typical high performance aircraft cover a wide spectrum of frequencies. Video, audio, medium and low frequency analog and discrete (on/off) are required to be processed. The listing of Table II shows the percent population and the preferred criteria for handling the signals in the various categories.