Introduction to Instrumentation

Instrumentation

- Instrumentation is a varied field that contains many specialties. This training provides an overview of the many components that make up an aircraft instrumentation system.

- The goal of this training is to provide an understanding of the equipment used to make measurements and the technical decisions made to condition, filter, and digitize the signals.

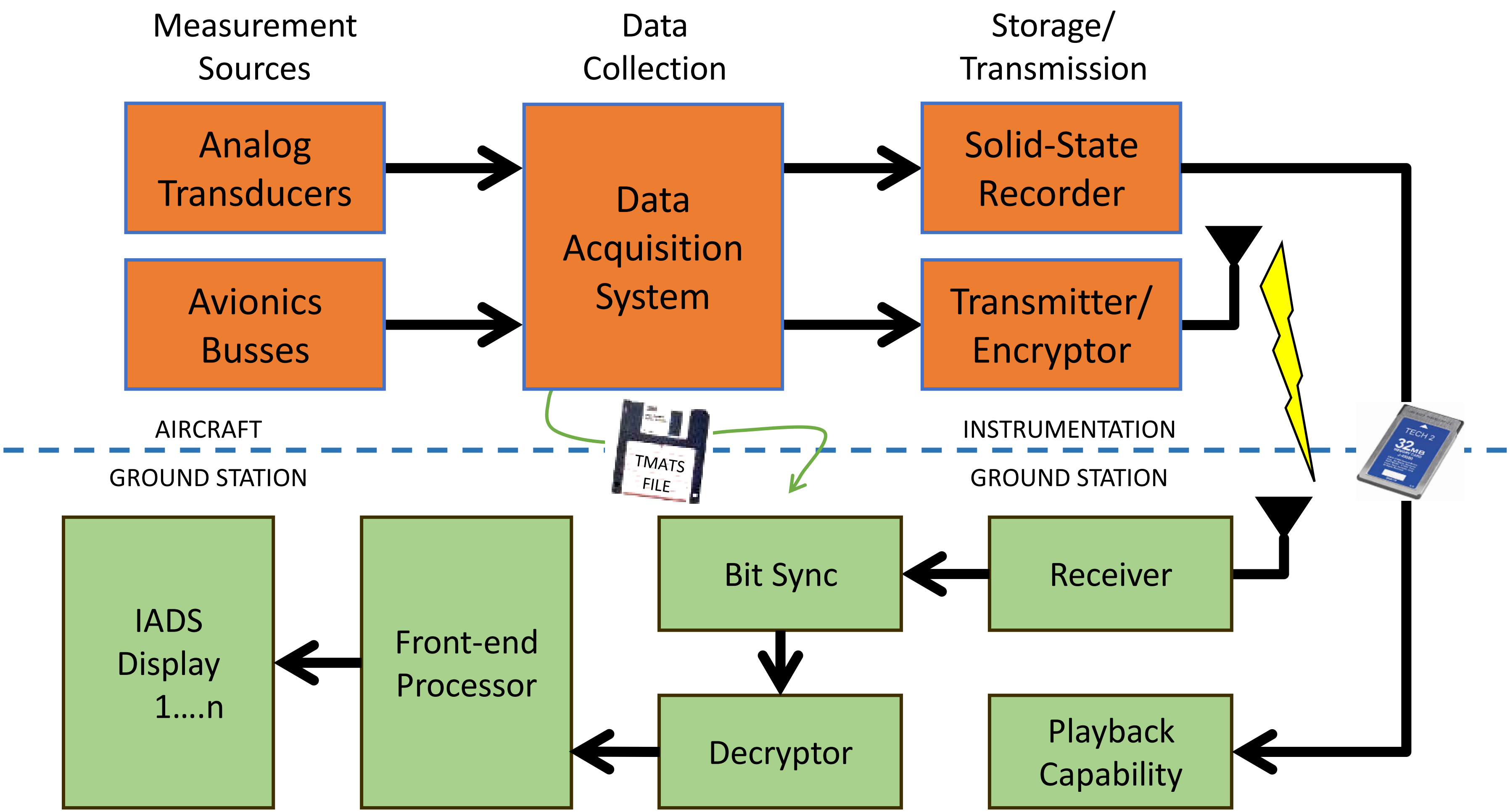
Decision Quality Data

Decision Quality Data is data produced using sound technical and analytical methods that: meets customer defined decision criteria, is repeatable, and has documented and verifiable uncertainty.

You may not think of it, but the product being delivered to your customer is data. The instrumentation system is the means of creating that data.

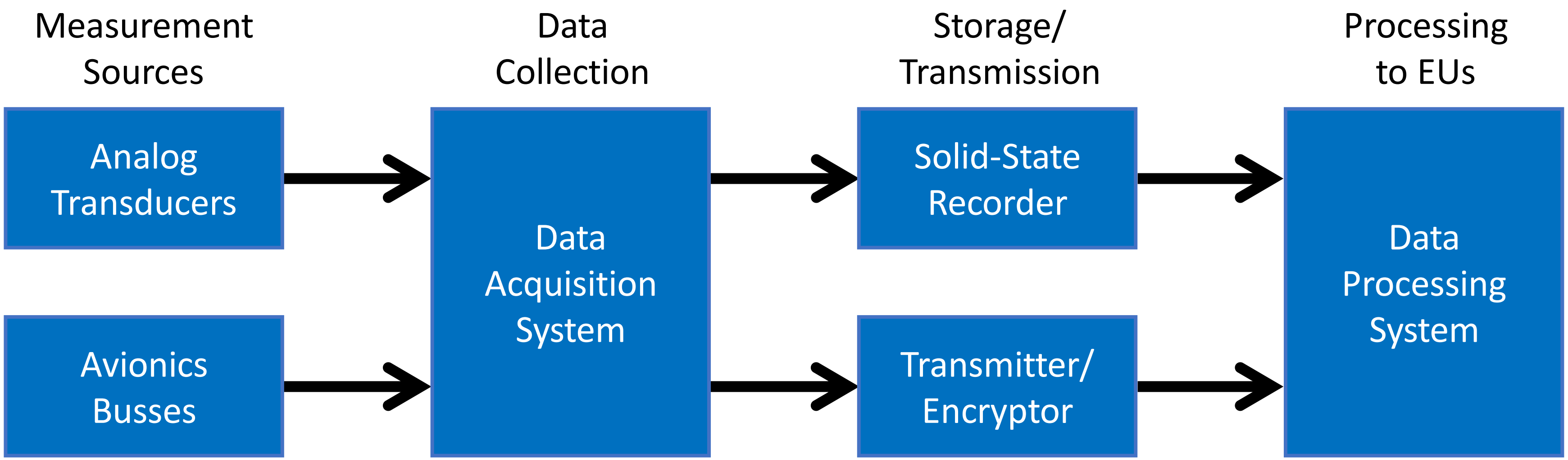
Telemetry: The Remote Sensing of Measurements

- This is the block diagram of the instrumentation system and the receiving ground station.



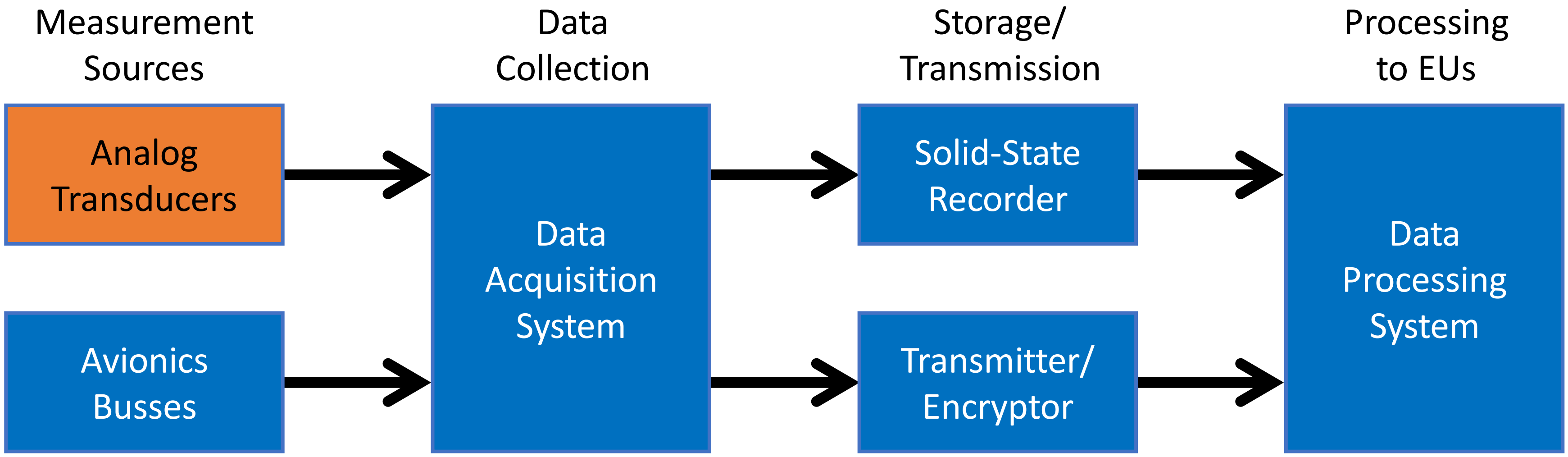
Block Diagram of an Instrumentation System

- All data starts off as an analog signal. All measurements on the avionics busses were at one time an analog signal. The data acquisition system converts analog signals or formats digital data to a standard form such that it can be stored to solid state media or transmitted to a ground station. The final step is the data processing system where digital data is converted back into Engineering Units (EU) for display to the flight test engineer.



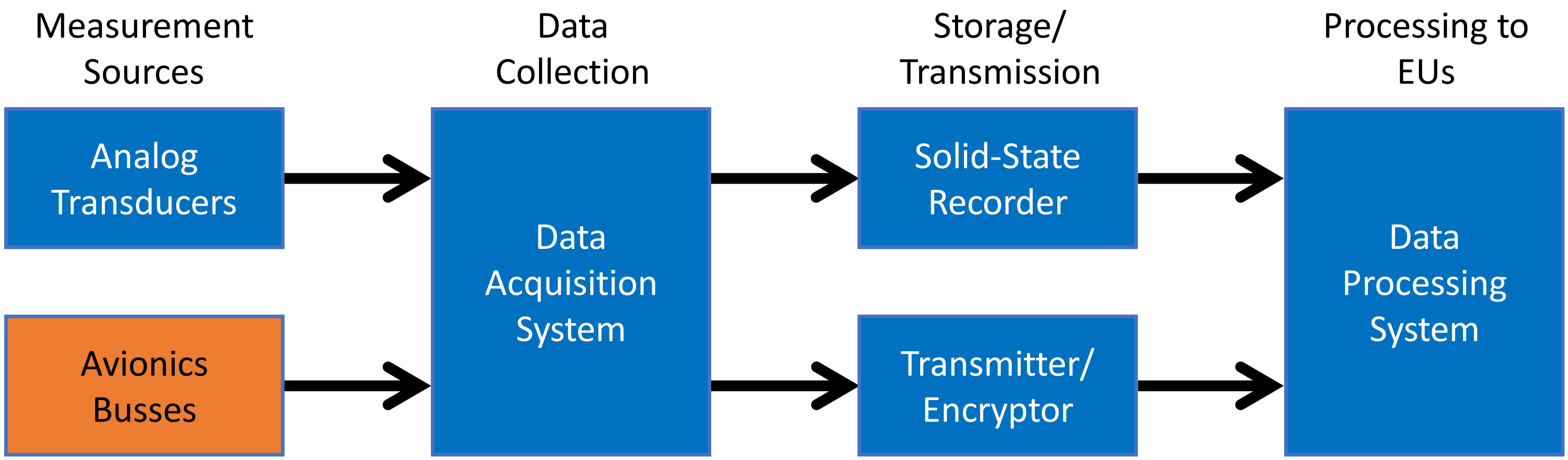
Analog Transducers

- Internal to a transducer is a sensing element which responds to the physical phenomena being measured. Electronic circuitry (the transducer) then converts the changing properties of the sensor to an electrical signal that can be measured within the data acquisition system. Simply stated, a transducer converts a physical quantity to an electrical signal.



Avionics Busses

- Avionics busses are production-installed communication busses on an aircraft which connect the various avionics systems. Many times, these busses are monitored by the Data Acquisition System. When doing so, a document known as an Interface Control Document (ICD) or bus catalog is needed to decode the information on the bus. Without it, the data is useless.



Basic Definitions

- **Instrumentation** is defined as the art and science of *measurement* and *control*".
- **Instruments** are devices which are used in measuring our physical world. The variable/measured can include practically any measurable event related to the physical sciences. These physical events include:
    - Pressure
    - Flow
    - Temperature
    - Level
    - Current
    - Voltage
    - Frequency
    - Chemical properties
    - Etc...
- Instruments can often be viewed in terms of a simple input-output device. For example, if we "input" some temperature into a thermocouple, it "outputs" some sort of signal. (Which can later be translated into data.) In the case of this thermocouple, it will "output" a signal in millivolts.

Basic Definitions, cont.

- **Instrumentation Engineering** is the engineering specialization focused on the design, configuration and maintenance of automated systems.

- **Instrumentation Engineers** usually (but not always) have degrees in Instrumentation Engineering, Electrical Engineering, Mechanical Engineering, Chemical Engineering, Physics, and sometimes even in Aerospace Engineering. Ok any engineer who likes to work with manufacturing and maintenance personnel could become an Instrumentation Engineers.
  - Typically work for industries with automated processes, such as chemical or manufacturing plants, with the goal of improving system productivity, reliability, safety, optimization and stability.
  - Integral Partner with the other test engineers and analyst on any test and evaluation test project

- **Instrumentation Technicians** specialize in the installation, troubleshooting and repairing instruments and instrumentation systems. This trade is so intertwined with electricians, pipe-fitters, power engineers, and engineering companies, that they could find him/herself in extremely diverse working situations.

Basic Definitions, cont.

- **Digitizing** or **digitization** is representing an object, an image, or a signal (usually an analog signal) by a discrete set of its points or samples.
- **Analog-to-Digital converter** (abbreviated ADC, A/D or A to D) is an electronic circuit that converts continuous signals to discrete digital numbers. The reverse operation is performed by a digital-to-analog converter (DAC).
  - Typically, an ADC is an electronic device that converts an input analog voltage to a digital number. The digital output may be using different coding schemes, such as binary and two's complement binary.
  - Resolution can also be defined electrically and expressed in volts. The voltage resolution of an ADC is equal to its overall voltage measurement range divided by the number of discrete values. One example:
  - Example 1
    - **Full scale measurement range = -10.24 to 10.24 volts**
    - **ADC resolution is 12 bits: 2^{12} = 4096 quantization levels**
    - **ADC voltage resolution is: (10.24V-(-10.24V)/4096 count = 0.005 V/count = 5 mV/count**

Basic Definitions, cont.

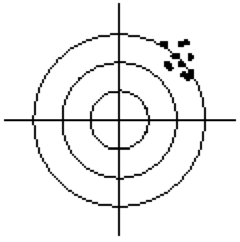
- **Measurement** is the estimation of a physical quantity such as length, temperature, or time.
  - Measurements are the ratio of some physical quantity to a standard quantity of the same type, thus a measurement of length is the ratio of a physical length to some standard length, such as a standard meter.
  - Measurements are usually given in terms of a real number times a unit of measurement, for example 2.53 meters.
  - Measurements always involve some error, and so in science measurements are often accompanied by error bounds, as in 2.53 meters plus or minus .01 meters. The study of measurement is called metrology.

- **Uncertainty** of a measurement is found by repeating the measurement enough times to get a good estimate of the standard deviation of the values. Then, any single value has an uncertainty equal to the standard deviation. However, if the values are averaged and the mean is reported, then the averaged measurement has uncertainty equal to the standard error which is the standard deviation divided by the square root of the number of measurements.

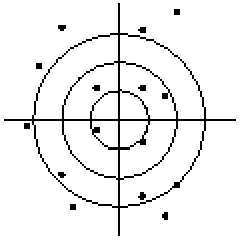
Basic Definitions, cont.

Accuracy versus Precision - What is the Difference?

An **accurate** measurement is one that is very close to the true value of the event you are monitoring. A **precise** measurement is one that has very little scatter: repeat measurements give essentially the same value. If the measured data has high precision but poor accuracy, one may suspect that a systematic bias has been introduced: you are using an instrument where the zero position has not been set properly.



PRECISION



ACCURACY

Precision is a measure of repeatability while accuracy refers to how close the average value is to the "true" value.

If you do not know the expected value of a phenomenon but are trying to determine just that, it is obviously better to have accurate observations with poor precision than very precise, but inaccurate values. Why? The former will give a correct, but imprecise estimate while the latter will give a wrong, but very precise result!

Why do we instrument our World?

History

- Units of measurement was among the earliest tools invented by humans. Primitive societies needed rudimentary measures for many tasks: constructing dwellings of an appropriate size and shape, fashioning clothing, or bartering food or raw materials.

- The earliest known systems of weights and measures seem to have all been created sometime in the 4th and 3rd millennia BC among the ancient peoples of Mesopotamia and Egypt. The most astounding of these ancient systems was perhaps that of the Indus Valley Civilization (Iran) (ca. 2600 BC). The Indus Valley peoples achieved great accuracy in measuring length, mass, and time. Their measurements were extremely precise (a unit was 1.704mm).

Why do we instrument our World?

Why we are instrumenting our world today:

- We design, develop and manufacture instrumentation systems for several reasons

  - Process and industrial monitoring
  - Control and factory automation
  - Real time information systems
  - Test and measurement (including calibration)

- **Flight Test Instrumentation (FTI) is used to support the test and evaluation of air vehicles and therefore at times all parts of the instrumentation discipline are required.**

Why do we instrument our World?

- Do you need flight test instrumentation equipment installed on your air vehicle?
  - You should consider the risks and operational environment!
  - If you are interested in what an aircraft is doing, but it departs from flight or simply crashes, is it the “end of the world”? Can the data be recorded “on-board” and be “recovered from the scene”?
  - What is the complexity of the aircraft and data? Boeing 777 has tens of thousands of parameters …. Can a pilot monitor that much information and accurately report back?
  - What is the risk to the platform? If a missile explodes, can you figure out what happened without the data?
  - If an aircraft is flying, does the data need to be monitored on the ground?

Delta 2

Fleet Ballistic Missile

Commercial Aviation

And even when things go right …

- Do you think knowing the stresses on the launcher is important, what corrections occurred in flight on the missile, and what was the overall result of the test?

- **If everything is destroyed, we are simply guessing at what happened?**

This does not cut it!

Instrumenting an Aircraft

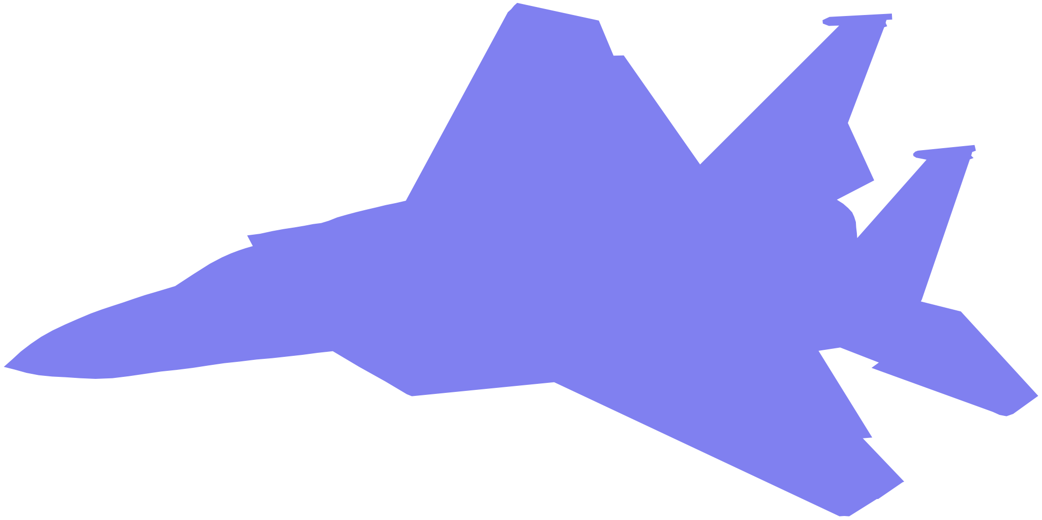
- OBSERVATION: Most test programs underestimate the cost and schedule required to properly plan, design, document, install and checkout the instrumentation needed by a flight test program.

- Remember the 5 p's of being a boy scout

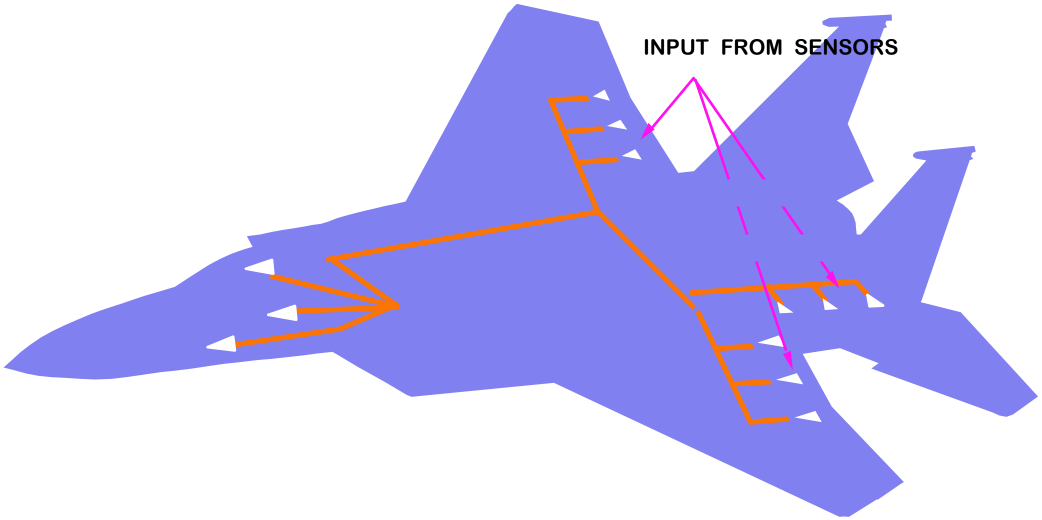
  (proper planning prevents poor performance)

- The four simple steps required to instrument any aircraft are:

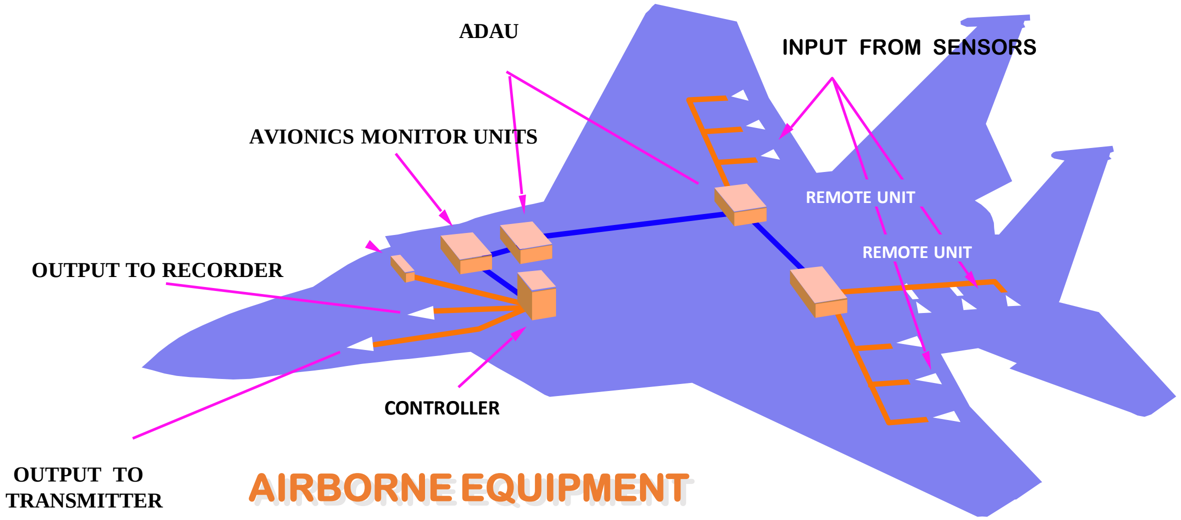
Step 1. Get an aircraft that can fly



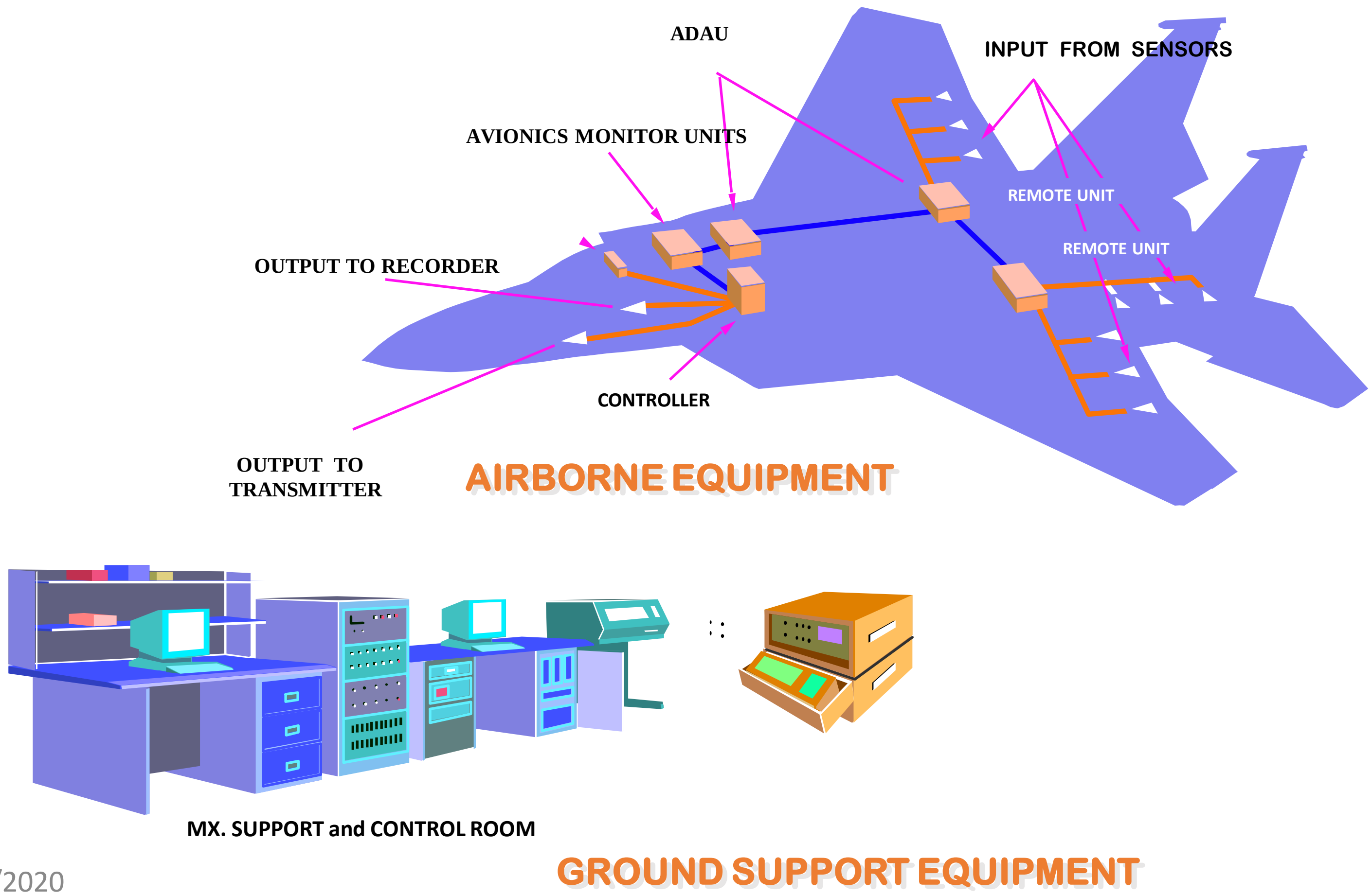
Step 2. Install up to 200,000 feet of orange wires, and a whole lot of transducers.



Step 3. Connect all the wires to a bunch of Orange boxes in the aircraft.



Step 4: Obtain Ground Support Equipment to support and process the information recorded by the orange boxes.



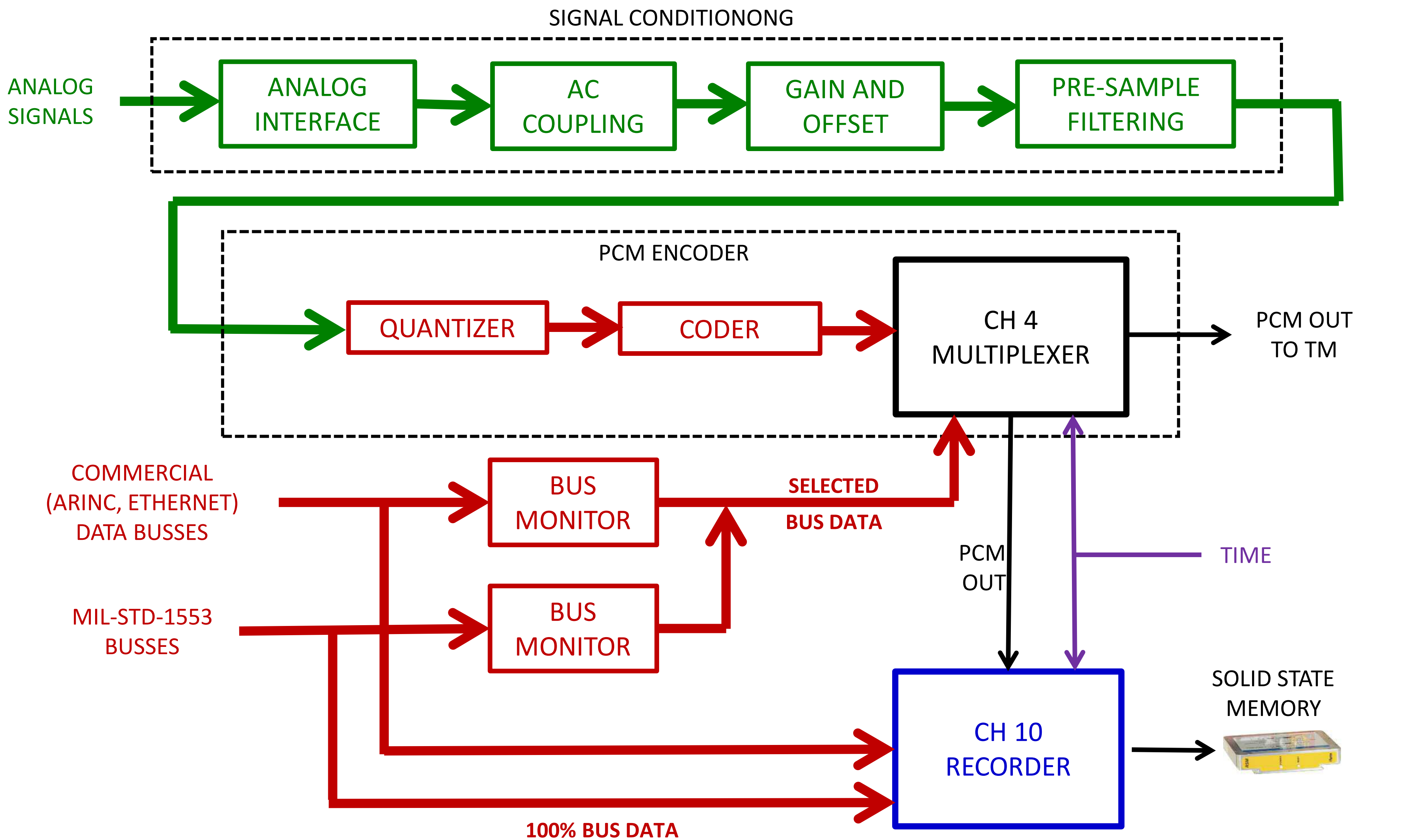
Instrumenting an Aircraft

- Design of an instrumentation system requires a measurement list from the test engineers as early as possible which is based on the current test program requirements.
- The measurement list should contain at a minimum the following:
    - Test Item: Measurement nomenclature (Parameter Name)
    - Range: nominal full-scale value of the parameter of values expected
    - Accuracy: What is an acceptable uncertainty (%)
    - Resolution:
    - Frequency Response
    - Location on Aircraft
    - Environmental Conditions
    - Measurement Priority (Go/No Go requirement for different stages of test program)
    - Any additional Notes
- The Instrumentation Engineer should work with the test engineer to validate the measurement list requirements in order to prevent excesses that cost the test program unnecessary cost and schedule.
- Based on the finalized measurement list, the Instrumentation engineer should organize the data requirements by frequency response and accuracy requirements. Once this occurs a basic instrumentation block diagram can be generated.

Aircraft Data Acquisition System

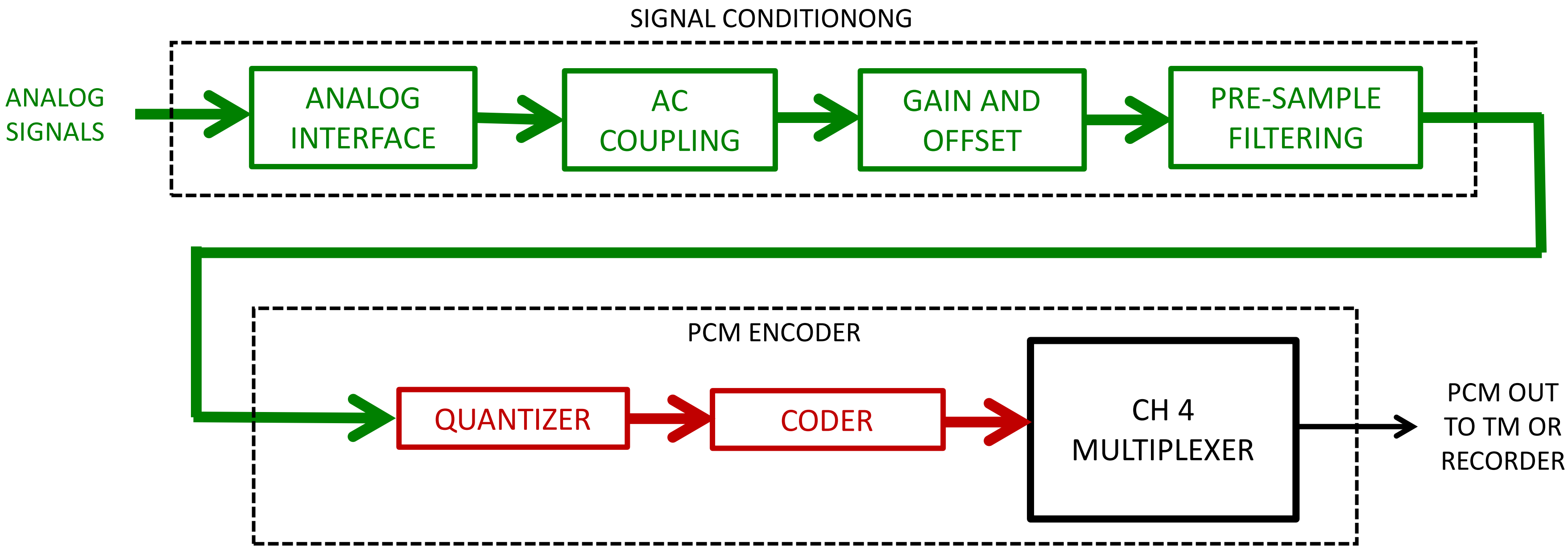
- The basic building blocks to any aircraft data acquisition system are:
  - Transducers
  - Signal Conditioning
  - Encoder/Controllers
  - Time & Position Reference Systems
  - Data Recorders
  - Telemetry Transmitters and Receivers

Detailed Block Diagram of a Data Acquisition System



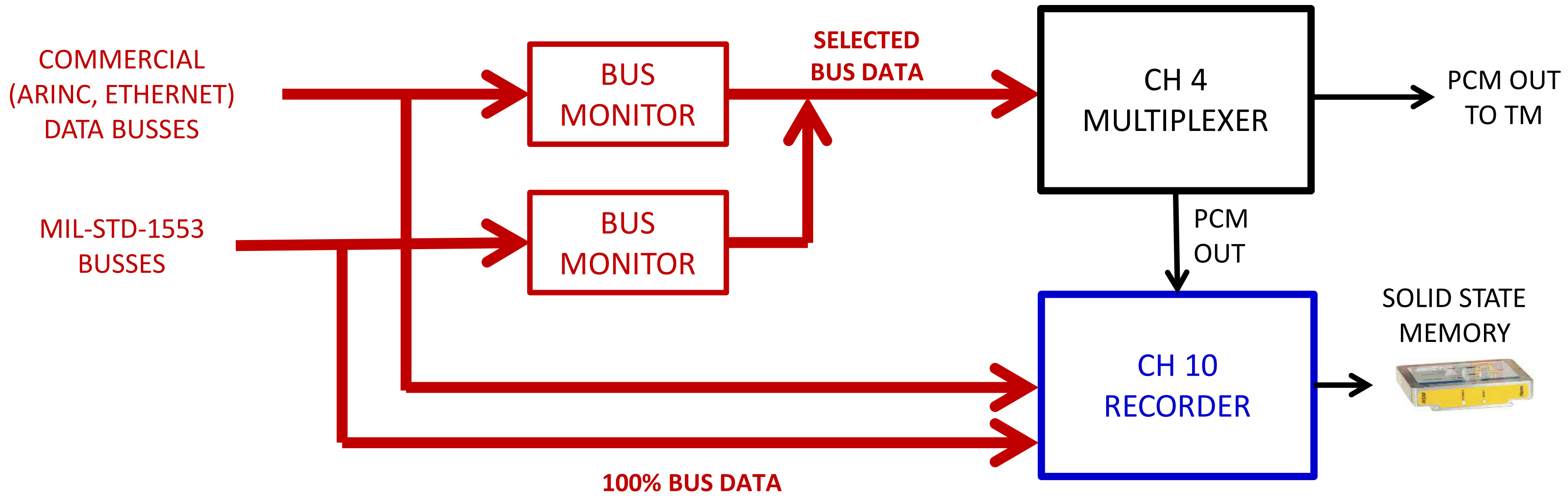
Data Acquisition System Block Diagram
Analog Conditioning

- Analog signals need a variety of signal conditioning to provide the correct EU ranges and frequency response for the measurement. The analog signal then is sampled and digitized before being multiplexed with other signals. The output is a serial Pulse Code Modulation (PCM) bit stream of ones and zeros.

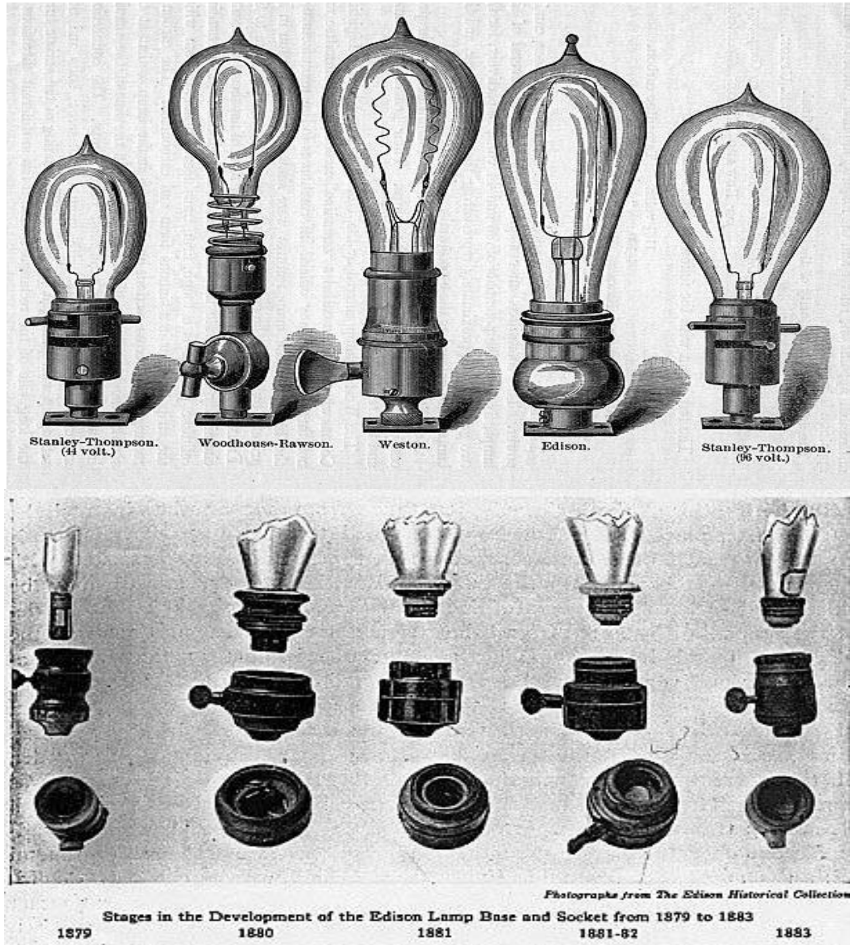


Data Acquisition System Block Diagram
Avionics Busses

- Avionics busses already have their data digitized. The data acquisition system formats the avionics busses such that it can be merged into a PCM stream. The data acquisition system can also capture 100% of the Commercial-type busses, 1553, and ARINC messages.



Why Do We Need Standards?



Too many solutions to a universal need

Range Commanders Council

The Range Commanders Council (RCC) was founded in August 1951 upon the recommendation of the Commander, Naval Air Missile Test Center, Point Mugu, California, to the Commanding General, White Sands Proving Ground, New Mexico, and the then Commander, Patrick Air Force Base, Florida. It began as the Range Commanders Conference and later became the RCC in 1963.

The RCC structure consists of the Range Commanders, Executive Committee (EC), *standing and ad hoc groups*, as may be established, and the Secretariat.

The RCC is dedicated to serving the technical and operational needs of U.S. test, training, and operational ranges._

The responsibilities and relationships of the RCC are to proactively share insights and products with various services and DOD organizations. _

RCC Goals/Functions

- The RCC provides a framework wherein:
  - Common needs are identified, and common solutions are sought
  - Technical standards are established and disseminated
  - Joint procurement opportunities are explored
  - Technical and equipment exchanges are facilitated
  - Advanced concepts and technical innovations are assessed, and potential applications are identified
- The Range Commanders Council was organized to preserve and enhance the efficiency and effectiveness of member ranges, thereby increasing their research and development, operational test and evaluation, and training and readiness capabilities. The scope of the Range Commanders Council is to:
  - Resolve common problems
  - Discuss common range matters in an organized forum
  - Exchange information thereby minimizing duplication
  - Conduct joint investigations pertaining to research, design, development, procurement, and testing
  - Coordinate major or special procurement actions
  - Develop operational test procedures and standards for present and future range use
  - Encourage the interchange of excess technical systems and equipment

What is “IRIG”

- *Inter-Range Instrumentation Group (IRIG):* The IRIG was formed by the Conference to do the work (standards …). Today only a few RCC standards documents retain the IRIG designation, while the others changed to the RCC designation .
- *Telemetry Group:* The RCC Telemetry Group (TG) formed in 1953 as part of the IRIG. The TG has four active committees (Data Multiplex, Recorder Reproducer, RF Systems and Vehicular Instrumentation and Transducer). The TG supports several documents IRIG 106, RCC 118,119,120 and 121. IRIG 106-xx Parts 1 and 2 (the telemetry (TM)standards) is the only document that retains the IRIG designation. The RCC TG maintains the TM system standards that are used by member ranges of the RCC. They contain many of the standards used in the flight test telemetry industry.

IRIG-106 Telemetry Standards Part 1

Chapter 1: Introduction

Chapter 2: Transmitter and Receiver Systems

Chapter 3: Frequency Modulation

Chapter 4: Pulse Code Modulation

Chapter 5: Digital Audio Telemetry

Chapter 6: Tape Recorder Standards

Chapter 7: Packet Telemetry Downlink

Chapter 8: Digital Data Bus Acquisition Formatting Std.

Chapter 9: Telemetry Attributes Transfer Std. (TMATS)

Chapter 10: Digital On-board Recorder Standard

Chapter 11: Recorder Data Packet Standard

IRIG-106 Telemetry Standards Part 2

Chapter 21: Telemetry Network Standard Introduction

Chapter 22: Network-Based Protocol Suite

Chapter 23: Metadata Configuration

Chapter 24: Message Formats

Chapter 25: Management Resources

Chapter 26: TmNSDataMessage Transfer Protocol

Chapter 27: Radio Frequency Network Access Layer

Chapter 28: Radio Frequency Network Management

IRIG-106 Telemetry Standards

Appendix

- A Frequency considerations
- B Use Criteria for Frequency Division Multiplexing
- C Pulse Code Modulation
- D Magnetic Tape Recorder Use Criteria

  this appendix just picked up lots of old Chapter 6 and Chapter 7 items
- E Transducer Documentation
- F Continuously Variable Slope Delta Modulation
- H, I and J Telemetry Attributes Transfer
- K Pulse Amplitude Modulation
- List of Tables

IRIG-106 Telemetry Standards, cont.

- Part 1 is the traditional telemetry as outlined previously
- Part 2 discusses new telemetry networks.
- IRIG standards are available on-line at https://www.wsmr.army.mil/RCCsite/Pages/Publications.aspx also https://irig106.org
- See also: http://www.telemetry.org

Questions?