PCM
&
Airborne Instrumentation Systems

Introduction

The characteristics of a PCM stream are defined in Chapter 4 of the IRIG-106 Standard.

Two classes of PCM formats are discussed in Chapter 4. Class I is the basic simpler type, Class II is more complex, and usually involves more interaction with the ground station.

The PCM streams we utilize contain some of the Class II attributes.

Pulse Code Modulation (PCM)

Patented in 1938

- ITT/France, by Sir Alec Reeves

Benefits

- High Accuracy
- Digital Implementation means easy interface to computers
- Today's Major Market

Weaknesses

- High cost for a low number of channels
  (but that's changing with market trends)

What is PCM?

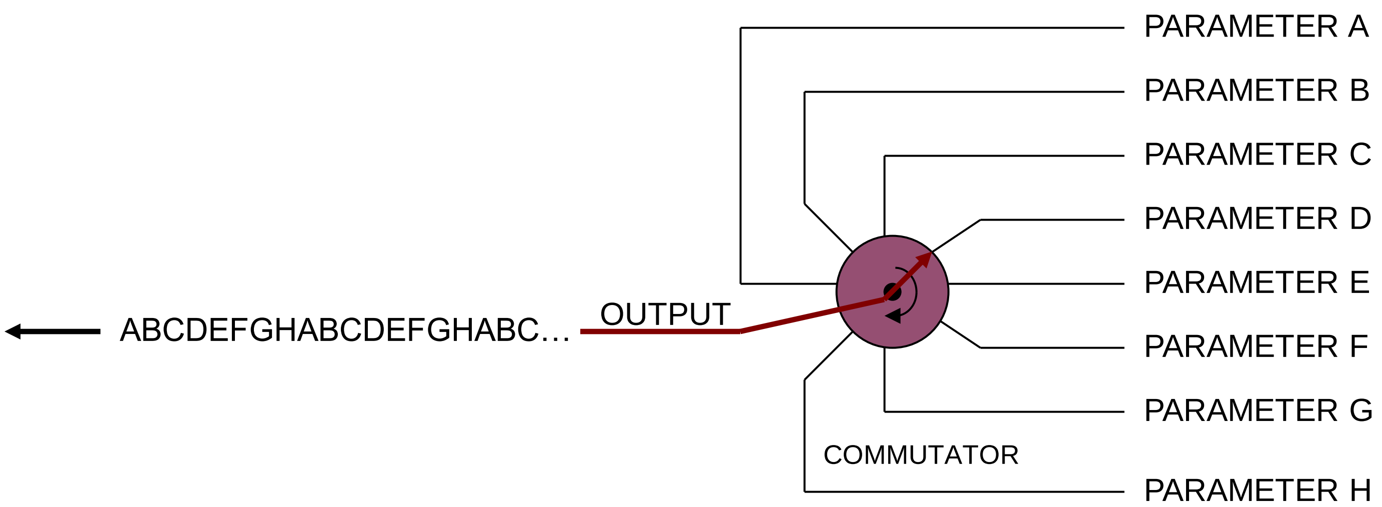
PCM stands for **P**ulse **C**ode **M**odulation, and it is a method of encoding analog parameters to a digital quantity.

Chapter 4 of the IRIG-106 Standard defines PCM as the serial bit stream of binary-coded time-division multiplexed words.

This definition will not have any meaning until we define some of the terminology and describe how this serial bit stream is created.

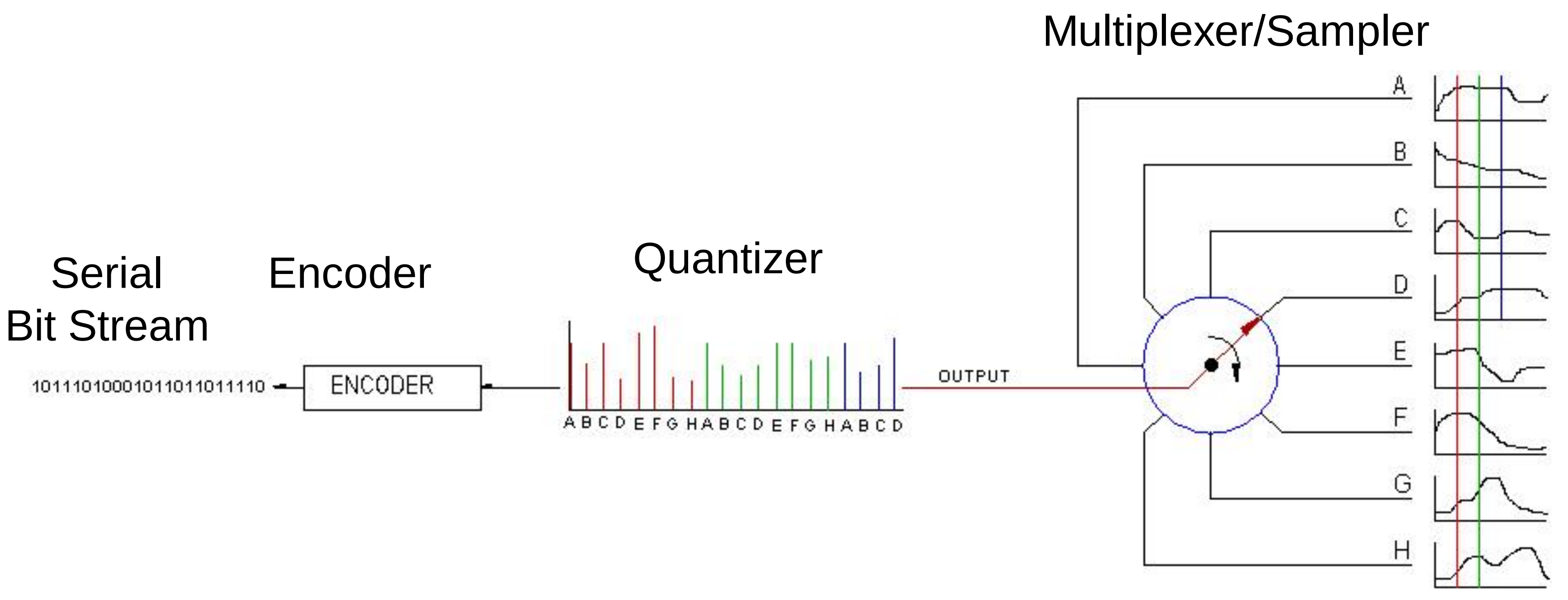
The Multiplexer/Sampler

A Multiplexer/Sampler can put several quantitative measurements over a single output line. The Commutator (shown below) is a mechanical model used to illustrate how a multiplexer/sampler works. As the arm rotates, each parameter is output within in a certain time period. This is known as Time Division Multiplexing (TDM).



The Entire System

This diagram shows each of the components as a system. The multiplexer/sampler samples each of the signals, the quantizer assigns values to the amplitude of the pulses, and the encoder converts the amplitude value to a binary number, all which are output as a serial bit stream.



Class I PCM Stream

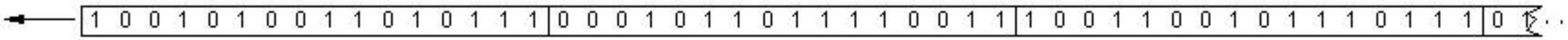
A PCM stream is defined as the serial bit stream of binary-coded time-division multiplexed words (or parameters).

This definition should make more sense now that the process of creating the PCM stream has been explained.

Serial Bit Stream

← 001101100110 011101010110 111001110100 011001001110

Bit Rate



The Bit Rate is the rate at which bits of the PCM stream are output within a second. Its units are bits/sec or bps.

For a Class I PCM Stream, the bit rate must be a minimum of 10 bps and maximum of 10 Mbps.

So a PCM stream with a bit rate of 2 Mbps outputs two million bits within a second.

PCM Words

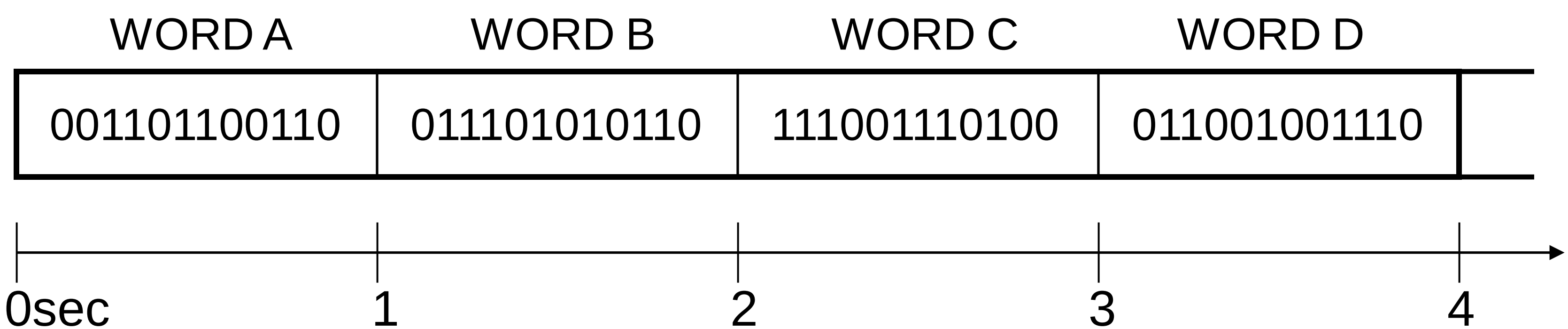
When this serial stream of bits is divided into bit-groups called words, they convey information. Each word is the encoded sample of the parameters.

001101100110	011101010110	111001110100	011001001110

PCM Word

Time Division Multiplex (TDM)
in Reference to the PCM Stream

As shown earlier, only one word in the PCM stream is output at a time. For example, the information from Word B is output in the time period of 1 to 2 seconds and the information from Word C is output in the time period of 2 to 3 seconds. This is known as time division multiplexing as the parameters are output one at a time, not simultaneously.



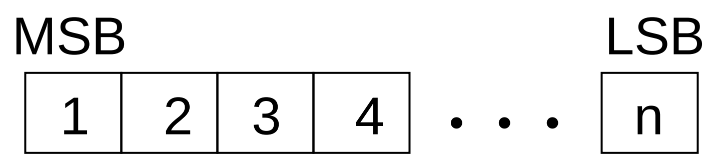
Word Length

The Word Length is defined as the number of bits per word (bpw).

For a Class I PCM Stream, this can vary from 4 to 32 bits.

Bit Numbering Within a Word

The most significant bit of a PCM word is bit position 1. Subsequent bits are numbered consecutively.



Be aware that when monitoring other systems and placing their data in a Chapter 4 PCM Stream, their bit numbering may not be the same. You will have to make a conversion chart which maps their numbering to Chapter 4's numbering. Not properly doing so will cause you to monitor the wrong bits.

Frame Synchronization Patterns

- Frame Synchronization (or Frame Sync) patterns are used to define the *beginning* of the PCM frame.
- Without a sync pattern, there is no reference to locate the beginning or end of a PCM stream. It just looks like an unending stream of 1's and 0's.
- The frame sync pattern length may vary from 16 to 33 bits. In practice, sync words are usually two PCM words in length in order to achieve frame sync patterns greater than 16 bits.

111110101111	001100100000	111001110100	011001001110
FRAME SYNC PATTERN		PCM Word	PCM Word

Frame Synchronization Patterns

- Frame sync patterns must be unique, such that two consecutive data words in your PCM stream don’t look like the assigned frame sync pattern.
- defined patterns of 1’s and 0’s called Barker Codes are used within frame sync patterns to get various lengths.
- Barker codes come in lengths of 2, 3, 4, 5, 7, 11, and 13 bits.
- Barker Codes were chosen because they are statistically less likely to appear as consecutive data words within the PCM stream.

Codes Assigned as Frame Sync Patterns

Table A-1. Optimum Frame Synchronization Patterns for PCM Telemetry											
Pattern Length	Patterns										
16	111	010	111	001	000	0					
17	111	100	110	101	000	00					
18	111	100	110	101	000	000					
19	111	110	011	001	010	000	0				
20	111	011	011	110	001	000	00				
21	111	011	101	001	011	000	000				
22	111	100	110	110	101	000	000	0			
23	111	101	011	100	110	100	000	00			
24	111	110	101	111	001	100	100	000			
25	111	110	010	110	111	000	100	000	0		
26	111	110	100	110	101	100	110	000	00		
27	111	110	101	101	001	100	110	000	000		
28	111	101	011	110	010	110	011	000	000	0	
29	111	101	011	110	011	001	101	000	000	00	
30	111	110	101	111	001	100	110	100	000	000	
31	111	111	100	110	111	110	101	000	010	000	0
32	111	111	100	110	101	100	101	000	010	000	00
33	111	110	111	010	011	101	001	010	010	011	000

Table A-1 of Appendix 4-A of the IRIG-106 Standard

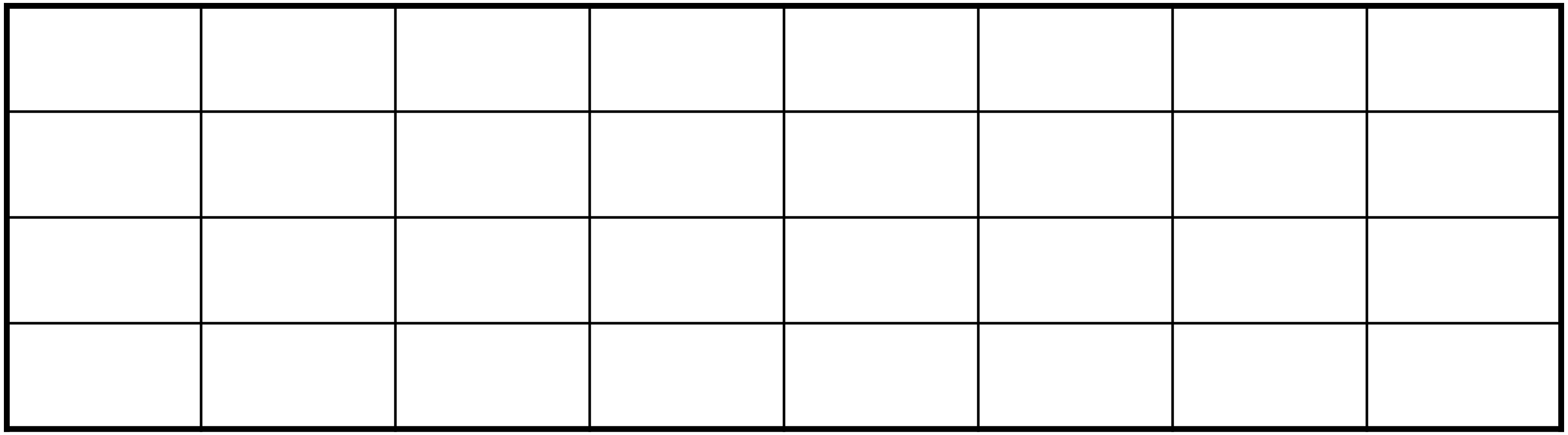
Common Frame Sync Patterns

Word Lengths	Bit Pattern	Hex Equivalents
12 BITS/WD	1111 1010 1111 0011 0010 0000	FAF 320
16 BITS/WD	1111 1110 0110 1011 0010 1000 0100 0000	FE6B 2840

Because our data acquisition systems primarily use 12 and 16 bits, these are the codes most commonly used.
Chapter 8, which has 24-bit words, utilizes FAF 320.

PCM Map

The PCM Map graphically shows the layout of the words within the PCM stream. It is laid out in a grid as shown below. Each block is a PCM word sample.



Minor Frame

A Minor Frame is the row of words from the beginning of a minor frame sync pattern to the beginning of the next minor frame sync pattern. This particular PCM map has 4 minor frames.

FRAME SYNC 1	FRAME SYNC 2						
FRAME SYNC 1	FRAME SYNC 2						
FRAME SYNC 1	FRAME SYNC 2						
FRAME SYNC 1	FRAME SYNC 2						

Each row is a minor frame in the PCM map.

Major Frame

A Major Frame contains the number of minor frames required to include one occurrence of every word in the format.

FRAME SYNC 1	FRAME SYNC 2						
FRAME SYNC 1	FRAME SYNC 2						
FRAME SYNC 1	FRAME SYNC 2						
FRAME SYNC 1	FRAME SYNC 2						

No Minor Frames?

Some PCM streams have a single minor frame. Therefore the major frame and the minor frame is the same. Although usually it is described as a PCM map that does not have any minor frames.

FRAME SYNC 1	FRAME SYNC 2						

Minor Frame Numbering

The first minor frame in a major frame shall be identified as minor frame 1. The remaining minor frames are numbered sequentially within the major frame.

For a Class I PCM stream, there are at most 256 minor frames in a major frame.

1	FRAME SYNC 1	FRAME SYNC 2						
2	FRAME SYNC 1	FRAME SYNC 2						
3	FRAME SYNC 1	FRAME SYNC 2						
4	FRAME SYNC 1	FRAME SYNC 2						

Subframe Identification

To identify between each of the minor frames within the major frame, a sub frame ID counter is used. It is usually the first word after the frame sync pattern. Depending on the system, this counter can start counting from 0 or 1. The equipment used at AID begins its count at 0.

1	FRAME SYNC 1	FRAME SYNC 2	SFID = 0					
2	FRAME SYNC 1	FRAME SYNC 2	SFID = 1					
3	FRAME SYNC 1	FRAME SYNC 2	SFID = 2					
4	FRAME SYNC 1	FRAME SYNC 2	SFID = 3					

A sub frame will be described later in this training.

Identification

The first word after the frame sync pattern shall be word number one. Each minor frame has the same word numbering with each individual word identified by its minor frame location (ex: word 4, minor frame 3). Do not get confused by identifying the location by the sub frame ID counter.

			1	2	3	4	5	6
1	FRAME SYNC 1	FRAME SYNC 2	SFID = 0					
2	FRAME SYNC 1	FRAME SYNC 2	SFID = 1					
3	FRAME SYNC 1	FRAME SYNC 2	SFID = 2			X		
4	FRAME SYNC 1	FRAME SYNC 2	SFID = 3					

Word Numbering

Because the first word after the frame sync pattern is designated as word 1, the PCM map is normally shown in this form in data acquisition software. This makes it easier for the person programming the hardware and creating the PCM map.

	1	2	3	4	5	6	7	8
1	SFID = 0						FRAME SYNC 1	FRAME SYNC 2
2	SFID = 1						FRAME SYNC 1	FRAME SYNC 2
3	SFID = 2						FRAME SYNC 1	FRAME SYNC 2
4	SFID = 3						FRAME SYNC 1	FRAME SYNC 2

This is a PCM map that is represented from the hardware point of view. While in actuality the frame sync word comes first just keep in mind that we say it comes last so the first word represented is word 1.

Minor Frame Length

Minor Frame Length is defined as the number of words (including the frame sync pattern) within each minor frame.

For a Class I PCM Stream, the minor frame can be no longer than 8192 bits. For a 12-bit system that is 682 words, and for a 16-bit system that is 512 words. Additionally, no minor frame shall exceed 1024 words.

For our example, the minor frame length is 8 words/minor frame.

	1	2	3	4	5	6	7	8
1	SFID = 0						FRAME SYNC 1	FRAME SYNC 2
2	SFID = 1						FRAME SYNC 1	FRAME SYNC 2
3	SFID = 2						FRAME SYNC 1	FRAME SYNC 2
4	SFID = 3						FRAME SYNC 1	FRAME SYNC 2

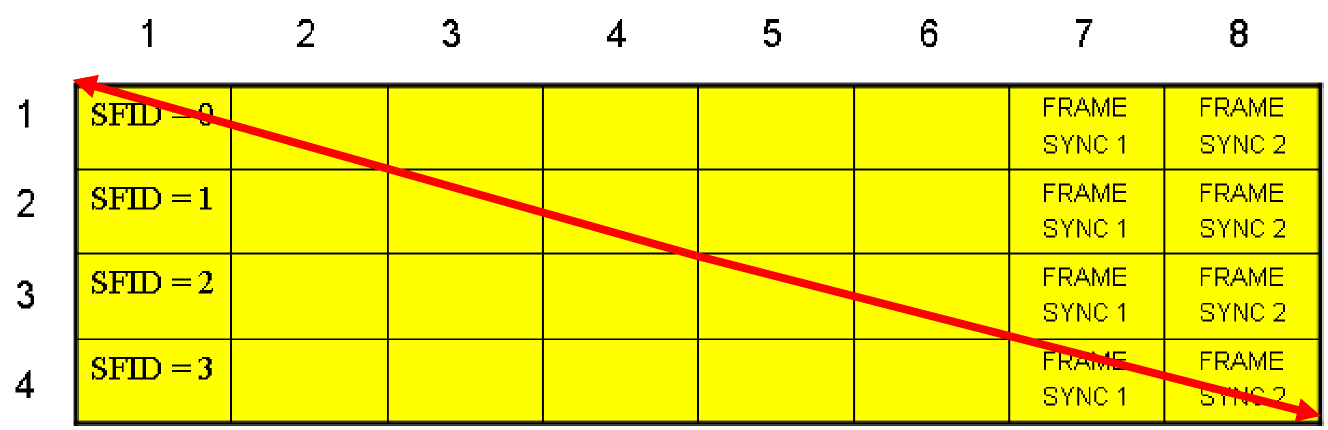
Major Frame Length

Major Frame Length is defined as the minor frame length multiplied by the number of minor frames in the major frame.

In our example, the major frame length is

8 words/minor frame x 4 minor frames/major frame or

32 words/major frame.



Super Commutation

A super commutated word is one which appears more than once in a minor frame. This word *must appear in even word intervals*. Word D is a super commutated word appearing twice per minor frame in even intervals of 4 word positions.

	1	2	3	4	5	6	7	8
1	SFID = 0	D	E	X	X	D	FRAME SYNC 1	FRAME SYNC 2
2	SFID = 1	D	E	X	X	D	FRAME SYNC 1	FRAME SYNC 2
3	SFID = 2	D	E	X	X	D	FRAME SYNC 1	FRAME SYNC 2
4	SFID = 3	D	E	X	X	D	FRAME SYNC 1	FRAME SYNC 2

4 1 2 3 4 1 2 3

Sub Frame

A Sub Frame is defined as a group of words in a column which occupy the same minor frame word in each of the minor frames. In this example, the sub frame occupies word 4.

	1	2	3	4	5	6	7	8
1	SFID = 0	D	E	X	X	D	FRAME SYNC 1	FRAME SYNC 2
2	SFID = 1	D	E	X	X	D	FRAME SYNC 1	FRAME SYNC 2
3	SFID = 2	D	E	X	X	D	FRAME SYNC 1	FRAME SYNC 2
4	SFID = 3	D	E	X	X	D	FRAME SYNC 1	FRAME SYNC 2

Sub Commutation

A Sub Commutated word is one which is sampled at evenly spaced sub multiple rates of the minor frame rate.   Parameters F and H are sampled ¼ of the minor frame rate and G is sampled ½ the minor frame rate. A parameter appearing 4 times would be considered to be a minor frame word (parameter E).

	1	2	3	4	5	6	7	8
1	SFID = 0	D	E	F		D	FRAME SYNC 1	FRAME SYNC 2
2	SFID = 1	D	E	G		D	FRAME SYNC 1	FRAME SYNC 2
3	SFID = 2	D	E	H		D	FRAME SYNC 1	FRAME SYNC 2
4	SFID = 3	D	E	G		D	FRAME SYNC 1	FRAME SYNC 2

Class II PCM Stream Differences

- Bits Rate higher than 10 Mbits/sec
- Word Lengths greater than 32 bits, but less than 64 bits.
- Fragmented words
- More than 8,192, but less than 16,384 bits/minor frame
- Unevenly spaced super commutation
- Cyclic Redundancy Checks (CRC)
- Format changes
- Asynchronous embedded formats
- Tagged data formats
- Asynchronous data merging

Why Make This So Complex?

This is done so you can have multiple sampling rates to most efficiently utilize the PCM Frame and keep the Bit Rate as low as possible. Vibration measurements require high sample rates, temperature measurements require low sample rates.

- Super Commutation - for high sample rates
- Minor Frame words - for upper medium sample rates
- Super Sub Commutation - for lower medium sample rates
- Sub Commutation - for lower sample rates

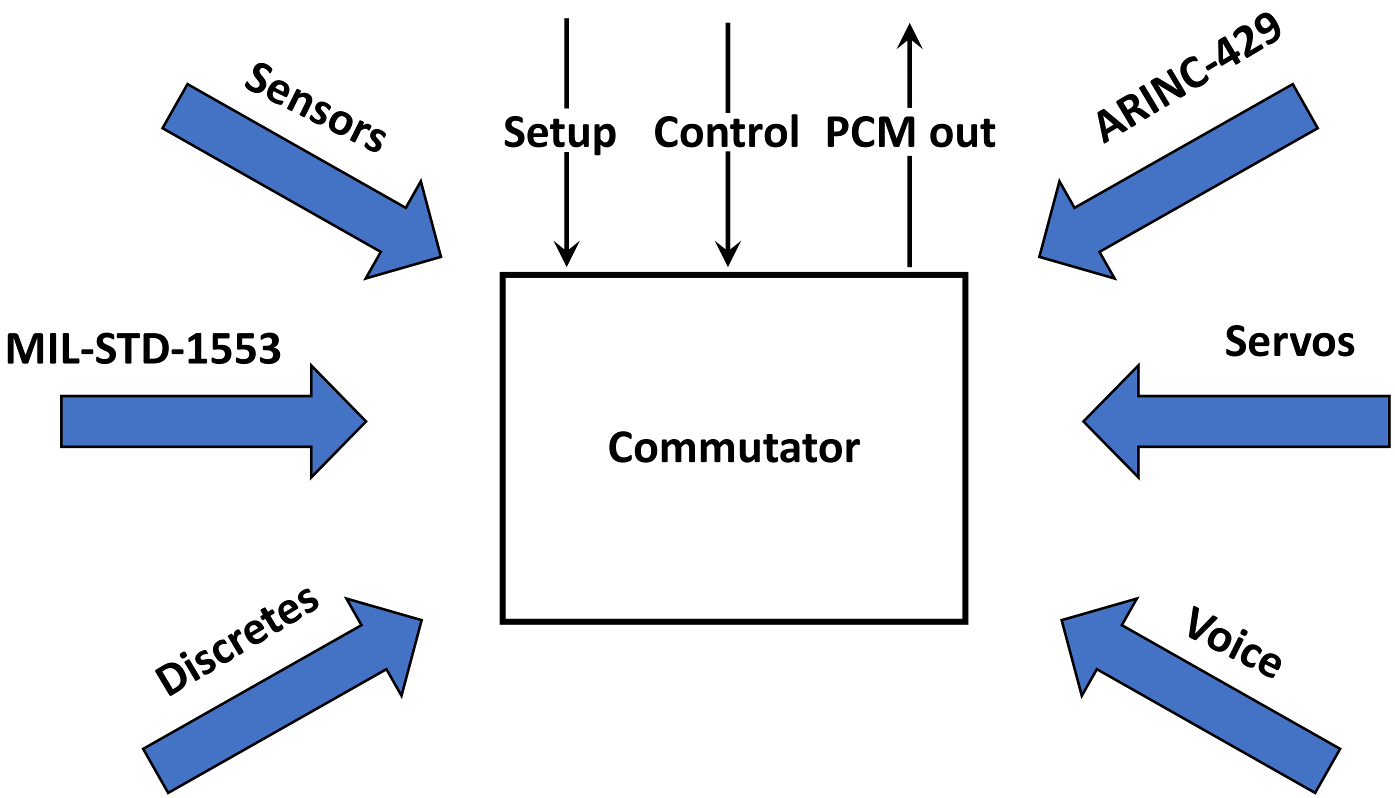
Airborne Instrumentation

Many vendors, both US and international

Two system level architectures

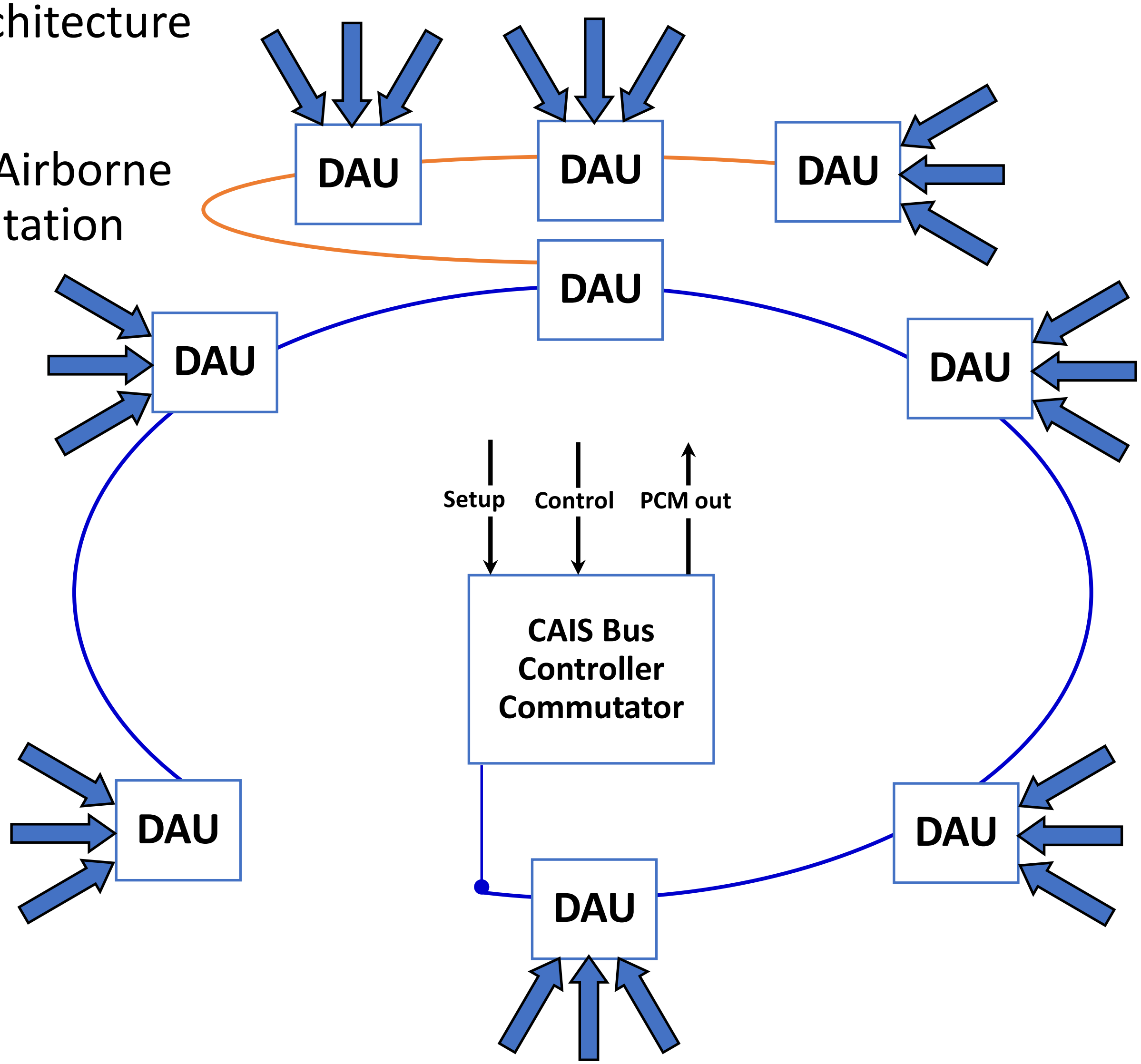
Central

Distributed



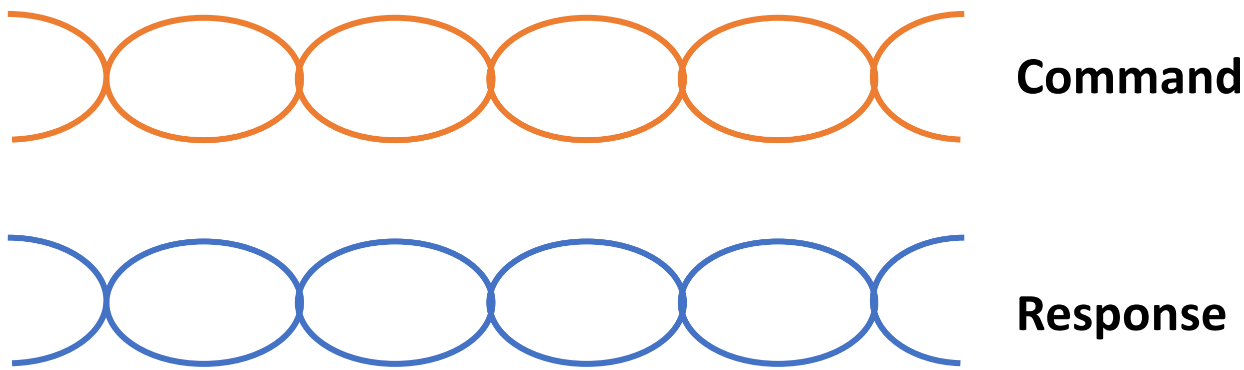
Airborne Instrumentation, cont.

- Distributed architecture
- CAIS
  - Common Airborne Instrumentation System



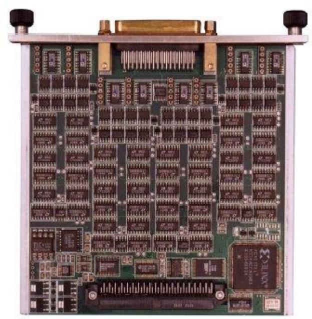
Airborne Instrumentation, cont.

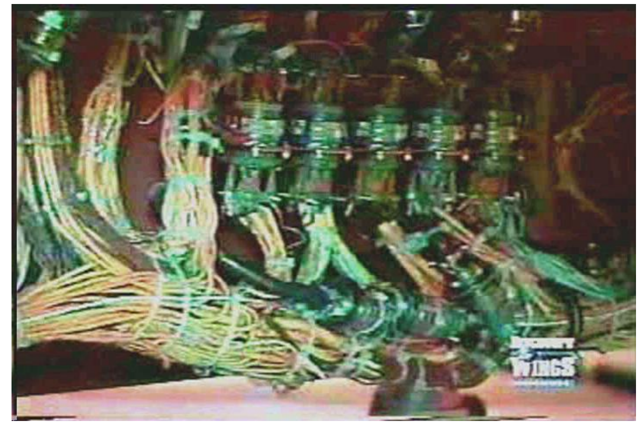
CAIS Party Line (Control Bus)



- **10 Mbps — Differential**
- **up to >400,000 sps**
- **up to 63 DAU's supported**
- **Uses Manchester II Bi-Phase PCM to XMIT instruction and data**

Airborne Instrumentation, cont.





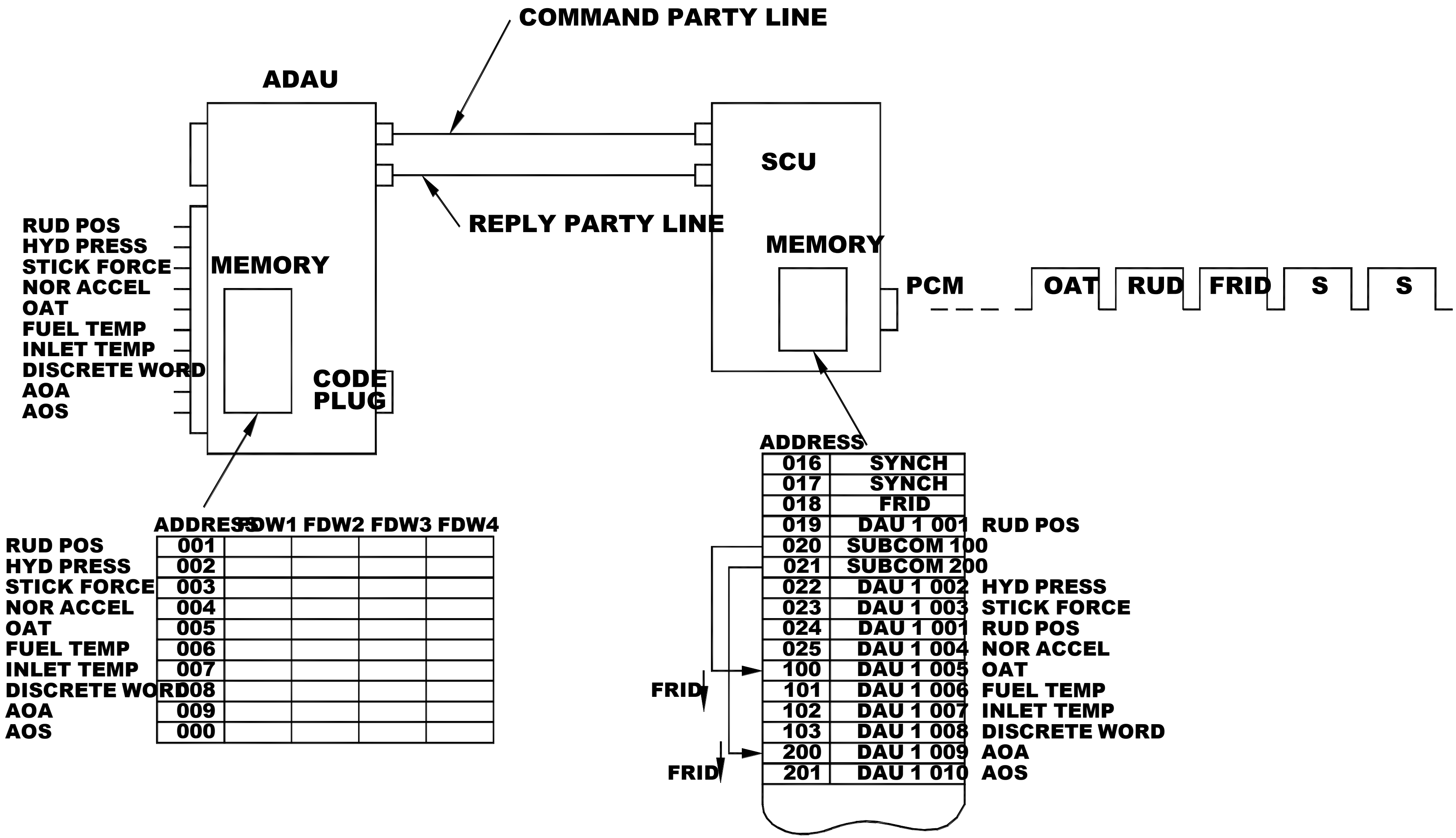
Airborne Hardware (PCM)

- CAIS Hardware is a family of modular data acquisition, processing and control units and related support equipment
  - The modular design allows the system to be tailored for size, cost and test requirements.
  - The basic system consists of a programmable system controller which communicates to both analog and digital units via the high speed communication bus (CAIS party line)
  - The remote devices interface to a wide variety of transducers
  - State of the art multiplexing techniques, standard components, and proven designs are combined to make instrumentation systems.

Airborne Hardware (PCM)

- System Controller
  - Uses CAIS Party line to control and communicate to remote units.
  - Maintains time coherence by filling all unused words with filler pattern
  - The system controller is responsible for all format synchronization
  - Provides PCM out to multiple devices including recorders and TM Links.
  - Typically can store up 16 different formats selectable through software or discrete control lines.
- Remote Units
  - Accepts analog data from transducers and signal conditioning.
  - Remote Units sample, amplifies and encodes the data.
  - Amplification occurs through two stage process.
  - Signal can have an offset applied to correct range requirements.

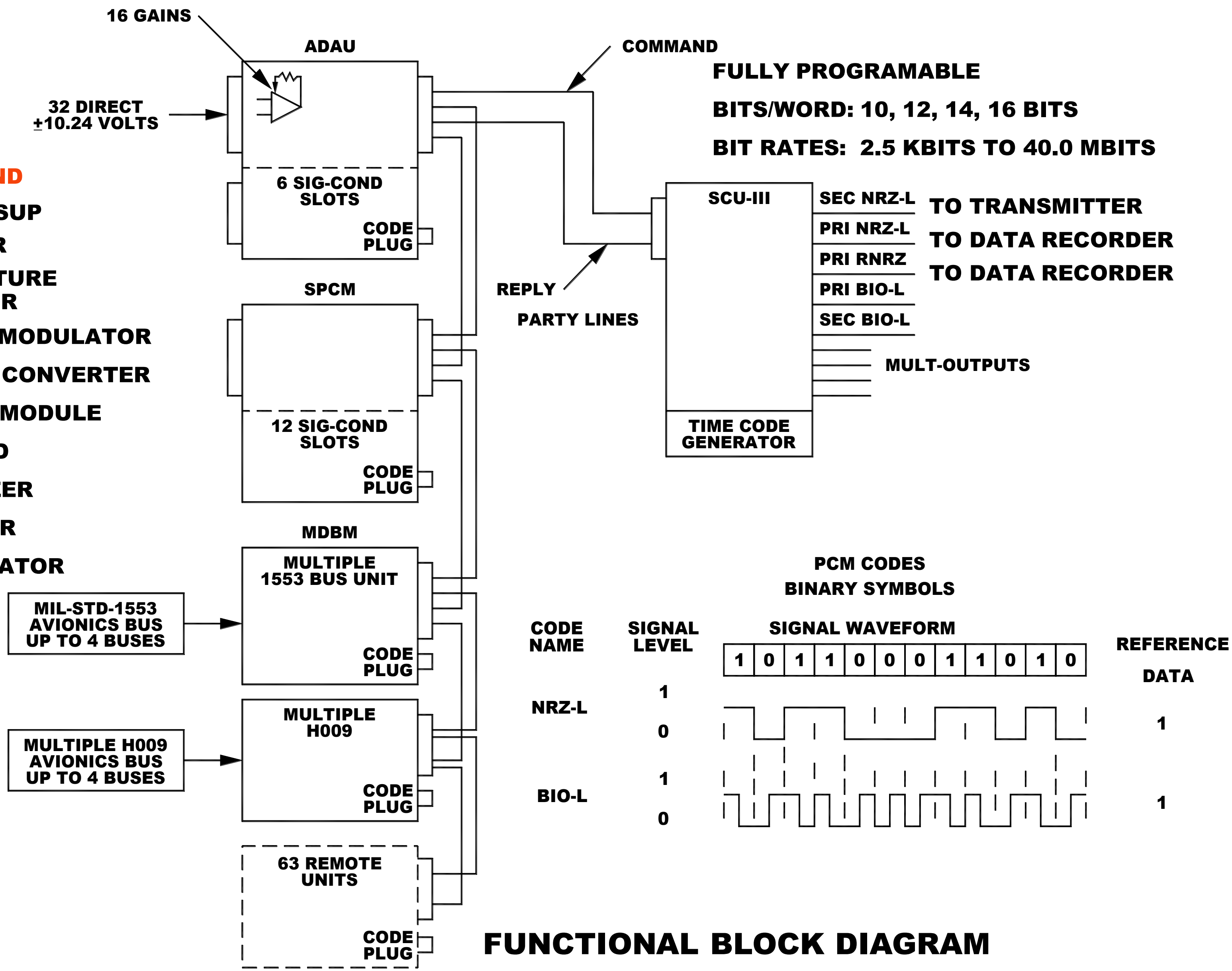
AIRBORNE INSTRUMENTATION SYSTEM



AIRBORNE INSTRUMENTATION SYSTEM

FAMILY SIG COND

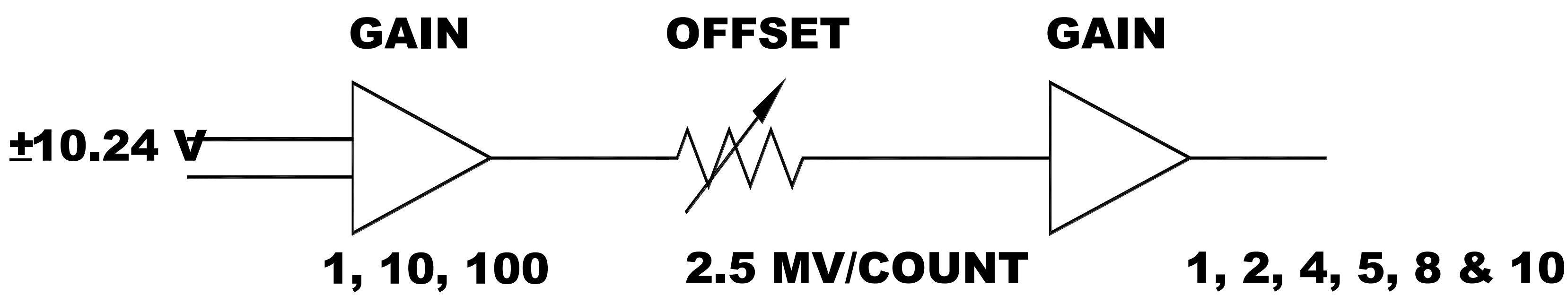
- TRANSDUCER EXCIT SUP
- ANALOG DATA FILTER
- RESISTIVE TEMPERATURE SENSOR CONDITIONER
- PHASE SENSITIVE DEMODULATOR
- SYNCHRO/RESOLVER CONVERTER
- PARALLEL DISCRETE MODULE
- SERIAL DIGITAL COND
- FREQ/PULSE TOTALIZER
- ANALOG ATTENUATOR
- CONTROL SIG GENERATOR



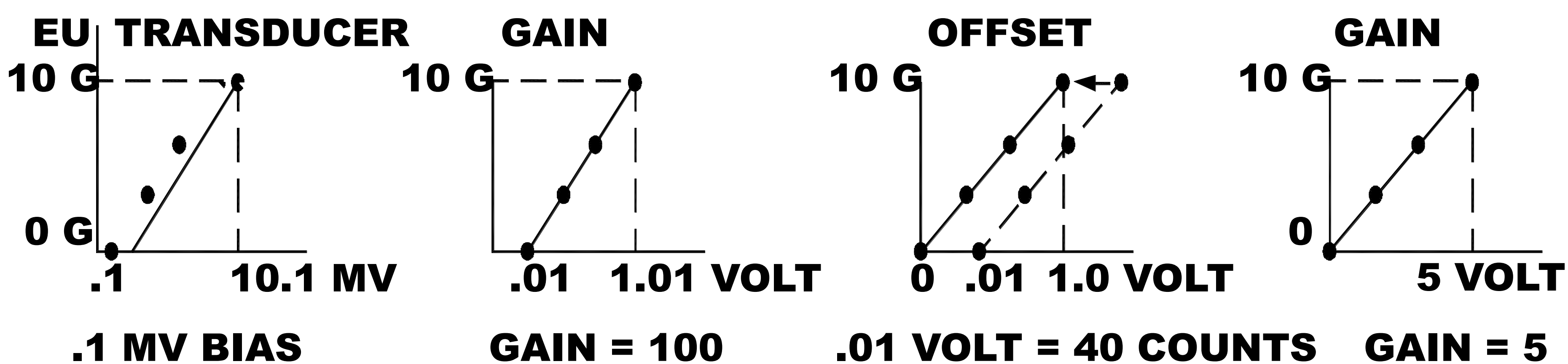
FUNCTIONAL BLOCK DIAGRAM

DIRECT ANALOG CHANNELS

EXAMPLE: GAIN & OFFSET



ASSUME: 10 BITS/WORD
5 VOLTS = 1000 COUNTS



PCM FORMAT LAYOUT

SUPERCOM

WORD →

FRAME ↓	0	1	2	3	4	5	6	7	8	9
0	SYNCH	SYNCH	FRID	RUD POS	OAT	AOA	HYD PRESS	STICK FORCE	RUD POS	NOR ACCEL
1					FUEL TEMP	AOS				
2					INLET TEMP					
3					DISCRETE WORD					

→ BIT RATE MINOR FRAME

MAJOR FRAME

SUBCOM

PARAMETER LOCATION

	WORD	FRAME	BIT
RUD POS	3, 8	0	
OAT (OUTSIDE AIR TEMP)	4	0	
FUEL TEMP	4	1	
INLET TEMP	4	2	
AOA (ANGLE OF ATTACK)	5	0	
AOS (ANGLE OF SIDESLIP)	–	–	
HYD PRESS	–	–	
STICK FORCE	–	–	
NOR ACCEL	–	–	
DISCRETE WORD	4	3	
GEAR DOWN	4	3	1
TAPE RECORDER OFF	4	3–	2

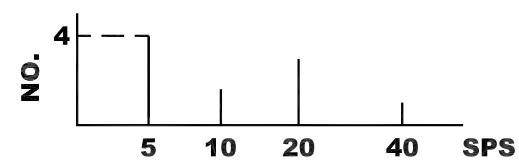
TAPE RECORDER OFF

GEAR DOWN

10	9	8	7	6	5	4	3	2	1

DISCRETE WORD

HOW TO DETERMINE BIT RATE
ASSUME 10 BITS/WORD
DATA RATE:
RUD POS 40 SPS
HYD PRESS, STICK FORCE, NOR ACCEL, 20 SPS
OAT, FUEL TEMP, INLET TEMP, DISCRETE WORD, 5 SPS
AOA, AOS 10 SPS



1 PAR X 40 SPS X 10 BIT/WORD = 400 BPS
3 PAR X 20 SPS X 10 BIT/WORD = 600 BPS
4 PAR X 5 SPS X 10 BIT/WORD = 200 BPS
2 PAR X 10 SPS X 10 BIT/WORD = 200 BPS
2 SYNCH X 20 SPS X 10 BIT/WORD = 400 BPS
1 FRID X 20 SPS X 10 BIT/WORD = 200 BPS

2000 BPS

AIRBORNE INSTRUMENTATION SYSTEM

FIXED WORDS

FORMAT REQUIREMENT:

177 PARS @ 100 SPS
30 PARS @ 10 SPS

10 BITS/WORD

AATIS BIT RATE

KB/SEC
227.273
200.00
178.571

COMPUTE BIT RATE:

177 PARS X 10 BITS/WORD X 100 SPS = 177,000 BPS
30 PARS X 10 BITS/WORD X 10 SPS = 3,000 BPS
2 SYNCH X 10 BITS/WORD X 100 SPS = 2,000 BPS
1 FRID X 10 BITS/WORD X 100 SPS = 1,000 BPS

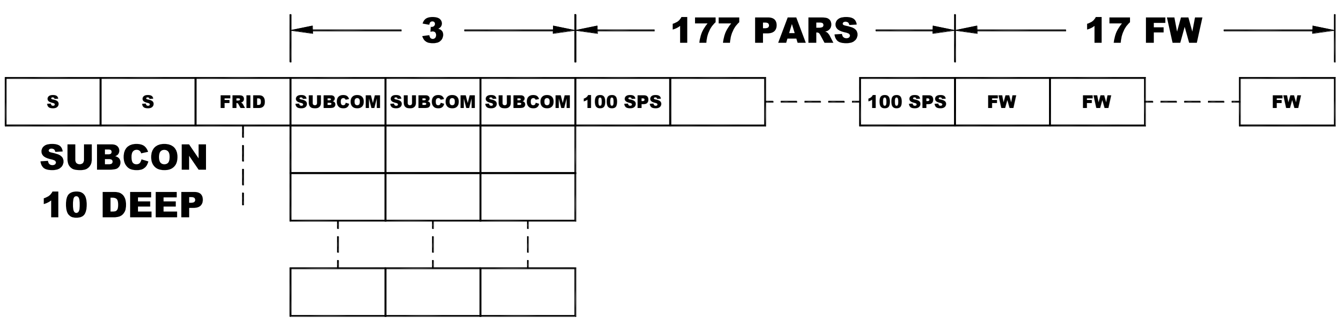
183,000 BPS

COMPUTE FIXED WORDS

183W X 10 B/W X 100 SPS + FW X 10 B/W X 100 SPS = 200,000

$$FW = \frac{200{,}000 - 183{,}000}{1000}$$

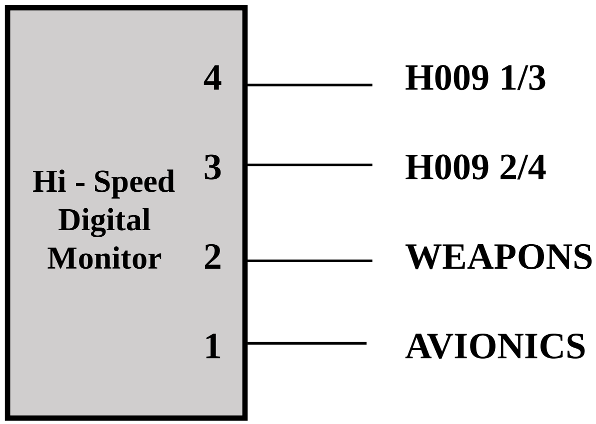
FW = 17



PCM FORMAT LAYOUT

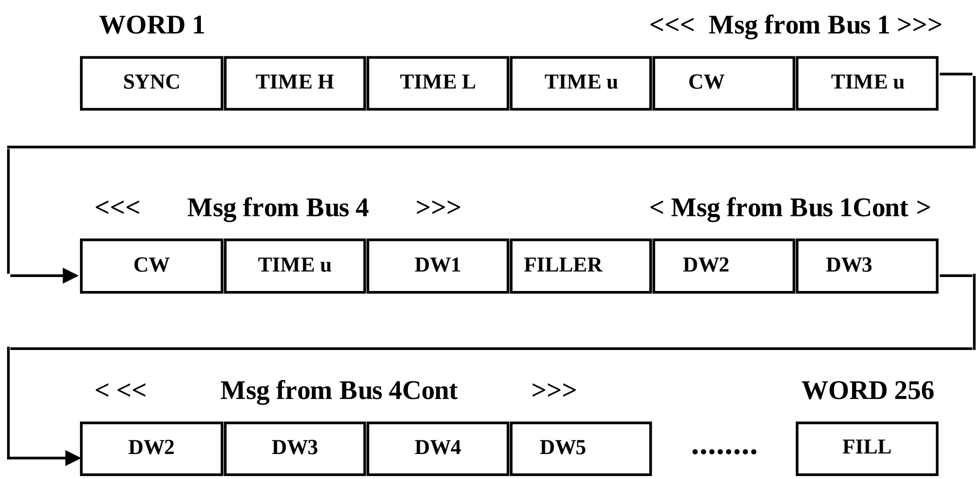
IRIG 106 Ch. 8 Total Bus Capture

- FRAME STRUCTURE
  - 256 Words x 1 Frame
  - 24 Bits / Word
  - Sync = FAF320
  - Programmable Bit Rate
- DATA ORDER
  - Word 1 = Sync
  - Word 2-4 = Embedded Time
  - Data = FIFO
- WORD STUCTURE
  - 24 Bits
  - First 8 bits Identify Word Type and Bus
  - Command, Status, Data, Time, Filler



CONFIGURATION

PCM STREAM



Questions?