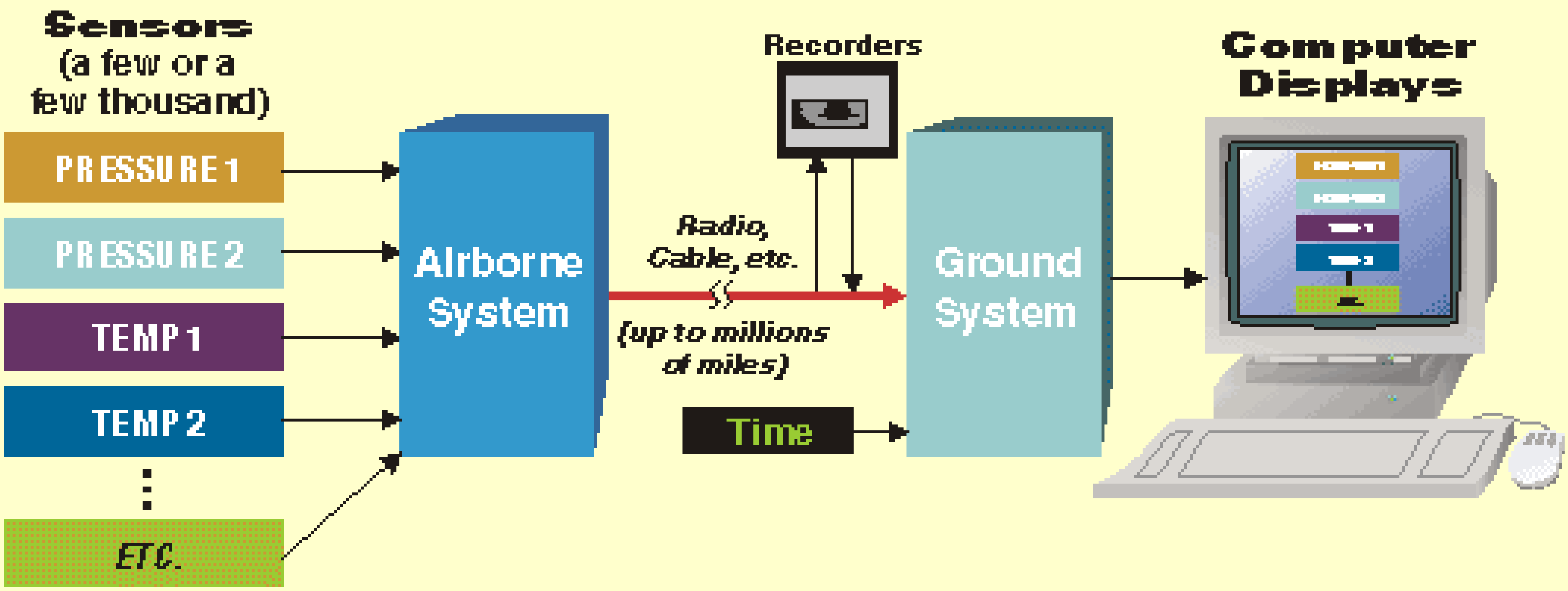
CHAPTER IV
TELEMETRY

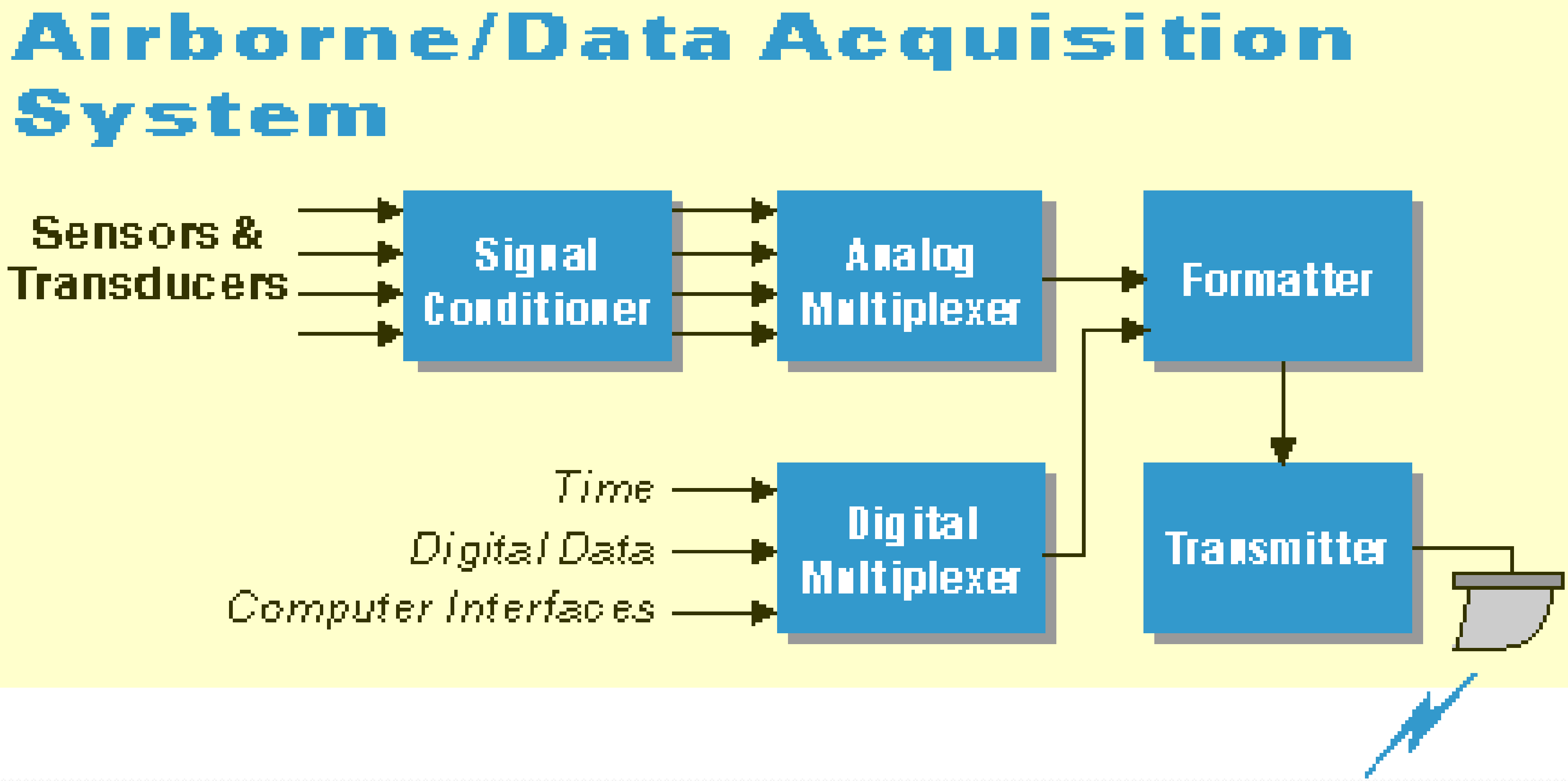
What is Telemetry?

- Telemetry is the process by which an object’s characteristics are ***measured***, and the results ***transmitted*** to a ***distant station*** where they are displayed, recorded, and analyzed.
- The transmission media may be air and space for satellite applications, or copper wire and fiber cable for static ground environments like power generating plants.
- Telemetry lets you stay in a safe (or convenient) location while monitoring what's taking place in an unsafe (or inconvenient) location.

Telemetry System



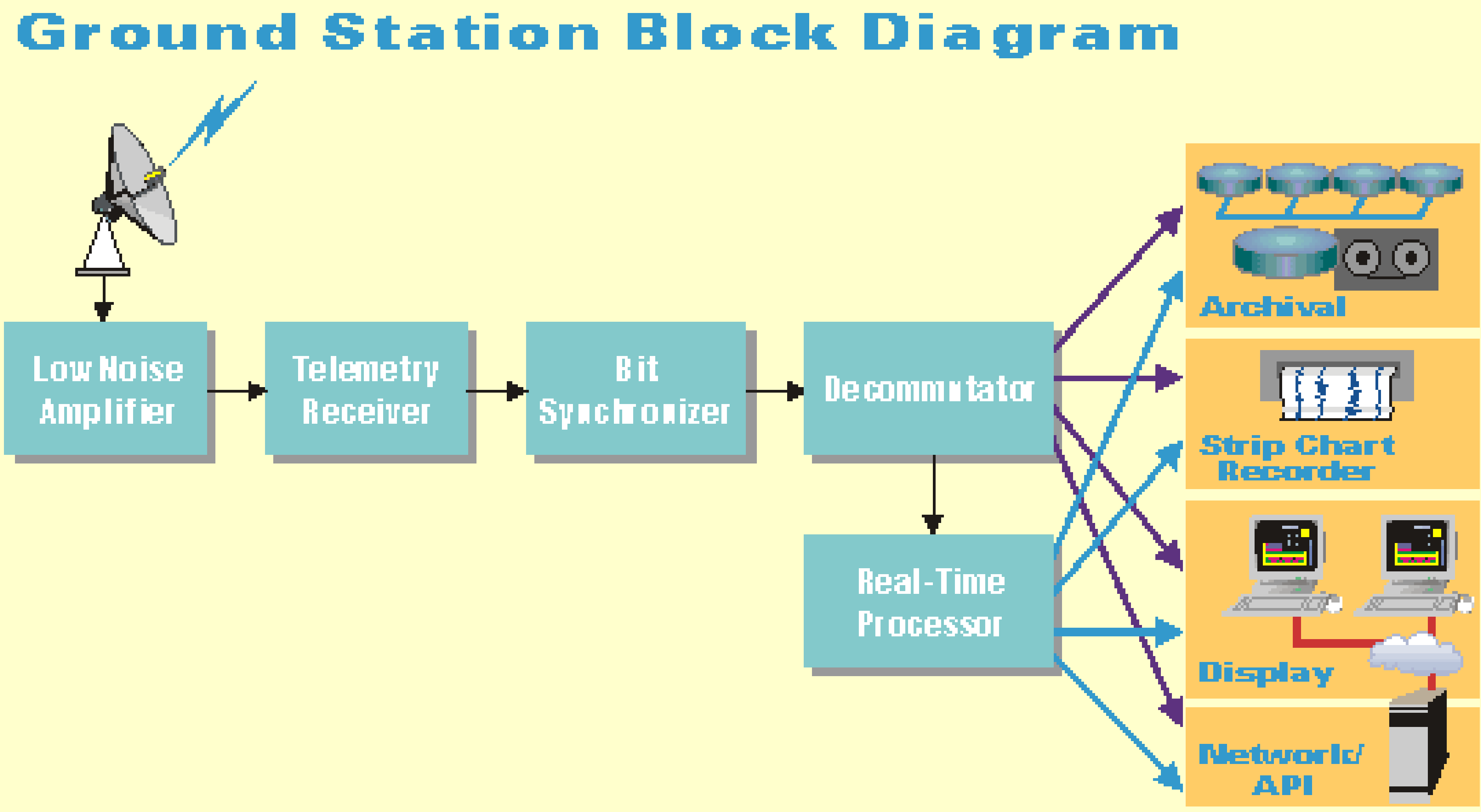
Telemetry System Overview



Telemetry System Overview

- ***Pulse Code Modulation (PCM)*** is today's preferred telemetry format for the same reasons that PAM is inadequate. ***Accuracy is high***, with resolution limited only by the analog to digital converter (ADC), and thousands of measurands can be acquired along with digital data from multiple sources, including the contents of the computer's memory and data buses.
- *The Output Formatter serializes the composite parallel data stream to a binary string of pulses (1's and 0's)* for transmission on copper wire, fiber cable, or "the ether."
- The output of the main ***encoder is filtered and transmitted*** via radio transmitter and antenna, coax cable, telephone line, tape recorder, etc.

Telemetry System Overview



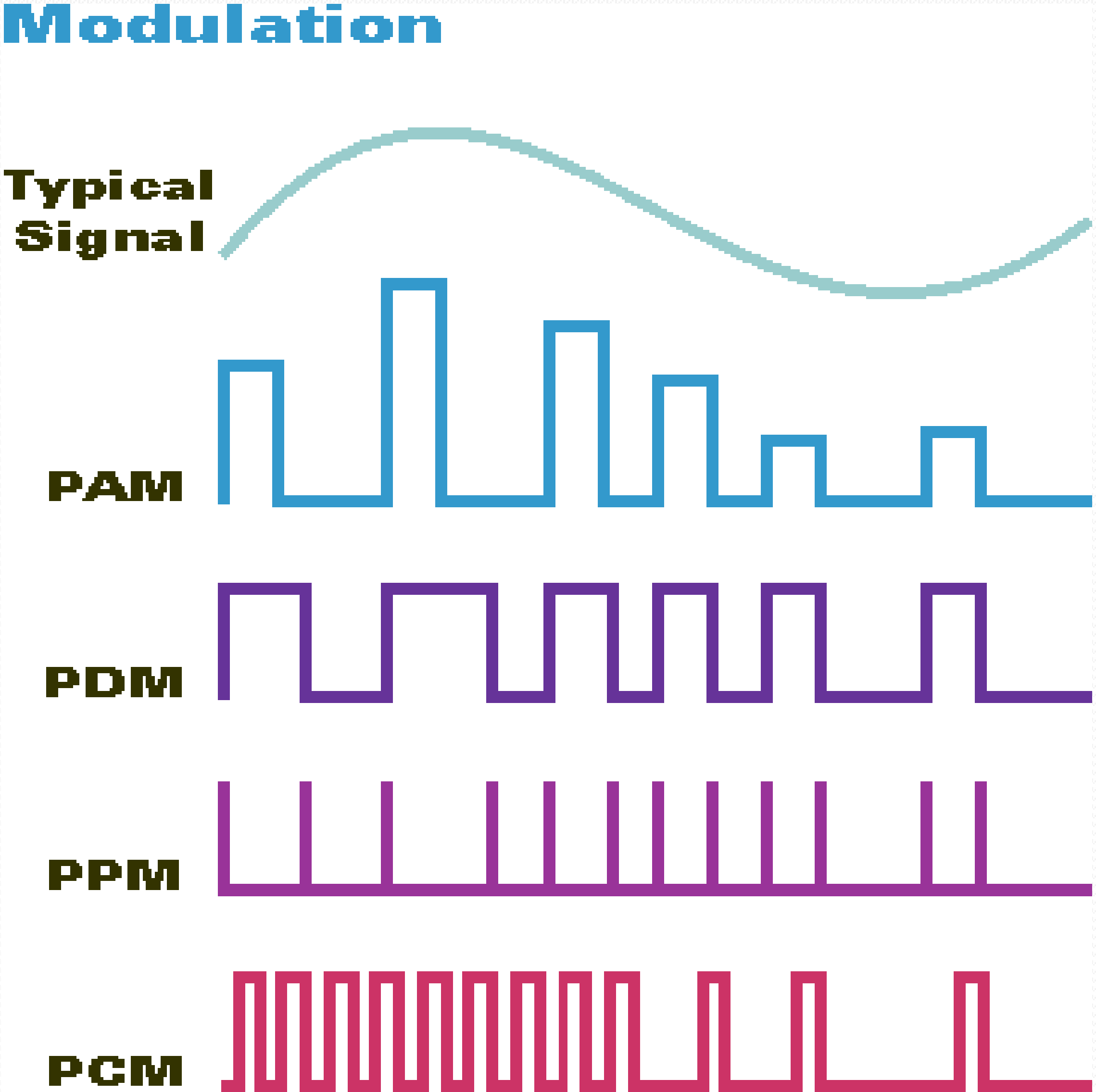
Airborne System – Data Acquisition

- In airborne data acquisition, sensor output characteristics must be transformed, filtered, or modified for compatibility with the next stage of the system.
- The absolute relationship between the output and the actual ***property value*** of the measurand ***may vary with time***, altitude, pressure, temperature, etc. Therefore, signal conditioners also incorporate calibration features to assist in defining the relationships.
- A system under test may be subjected to known physical characteristics and the output measured to ascertain and verify the relationship between the sensor and its output.

Airborne System – Data Acquisition

- Modulation is the technique where the value of each *sample* (i.e., the modulating signal) ***systematically changes the characteristics of a carrier signal*** (e.g., amplitude (height) or frequency (timing)).
- The resulting modulated wave "carries" the data. Conversely, removing the carrier signal results in the return of the original measurement.
- The *TDM stream* produced by the basic multiplexer scheme is accomplished via Pulse Code Modulation or PCM. Three other modulation forms are also used: Pulse Duration Modulation (PDM), Pulse Position Modulation (PPM), and Pulse Amplitude Modulation (PAM).

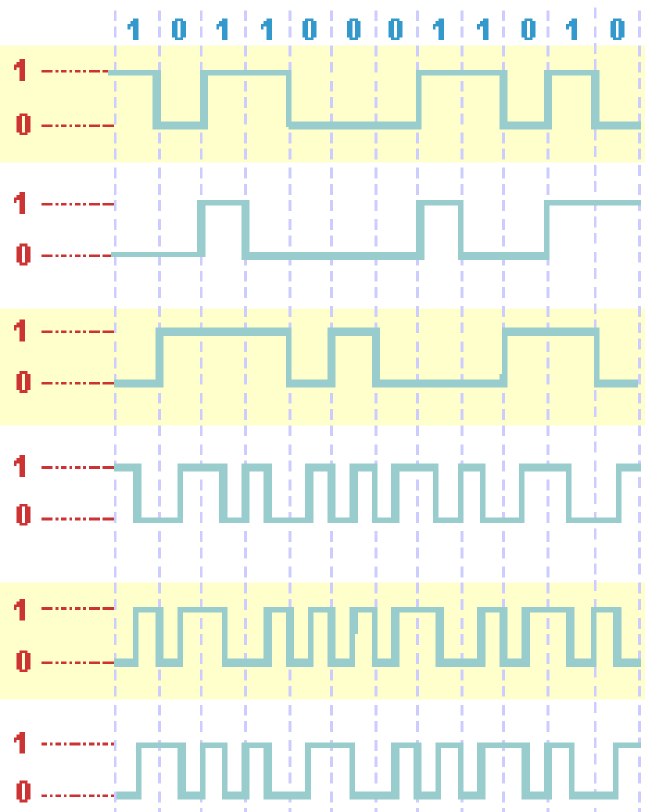
Airborne System – Data Acquisition



Airborne System – Modulation

- Over the years, a number of PCM codes have been designed to represent logic one and zero levels while achieving the greatest performance for a given application.

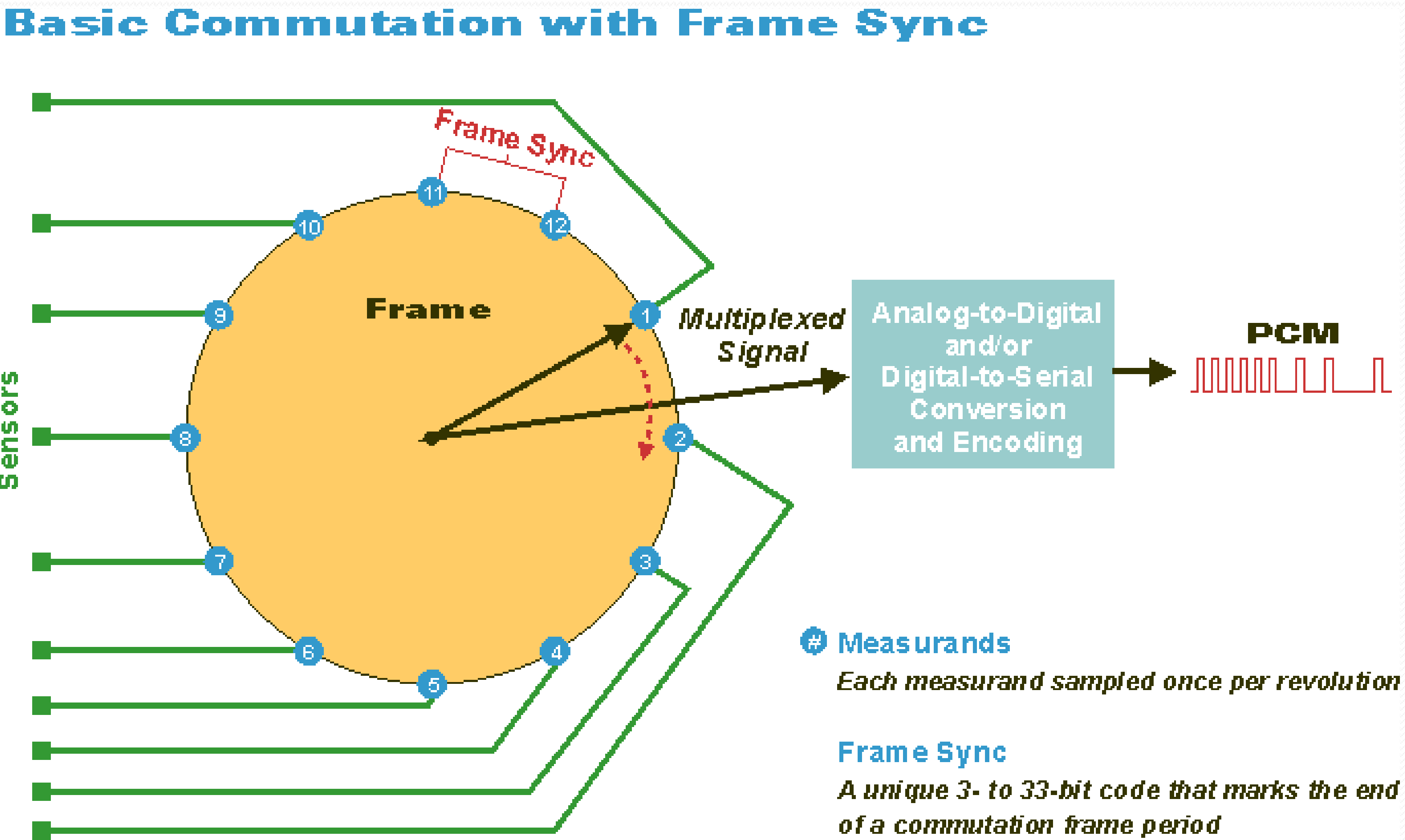
PCM Data Codes



- **NRZ-L Non-Return to Zero Level (also NRZ-C)**
  "One" is represented by one level
  "Zero" is represented by the other level
- **NRZ-M Non-Return to Zero Mark**
  "One" is represented by a change in level
  "Zero" is represented by no change in level
- **NRZ-S Non-Return to Zero Space**
  "One" is represented by no change in level
  "Zero" is represented by a change in level
- **BiΦ-L Bi-Phase Level Split-Phase Level change occurs at center of every bit period**
  "One" is represented by a 1 level with transition to 0 level
  "Zero" is represented by a 0 level with transition to 1 level
- **BiΦ-M* Bi-Phase Mark Level change occurs at center of every bit period**
  "One" is represented by no level change at the beginning of the bit period
  "Zero" is represented by a level change at the beginning of the bit period
- **BiΦ-S* Bi-Phase Space Level change occurs at center of every bit period**
  "One" is represented by a level change at the beginning of the bit period
  "Zero" is represented by no level change at the beginning of the bit period

** previously called "Differential BiPhase (DBΦ)"*

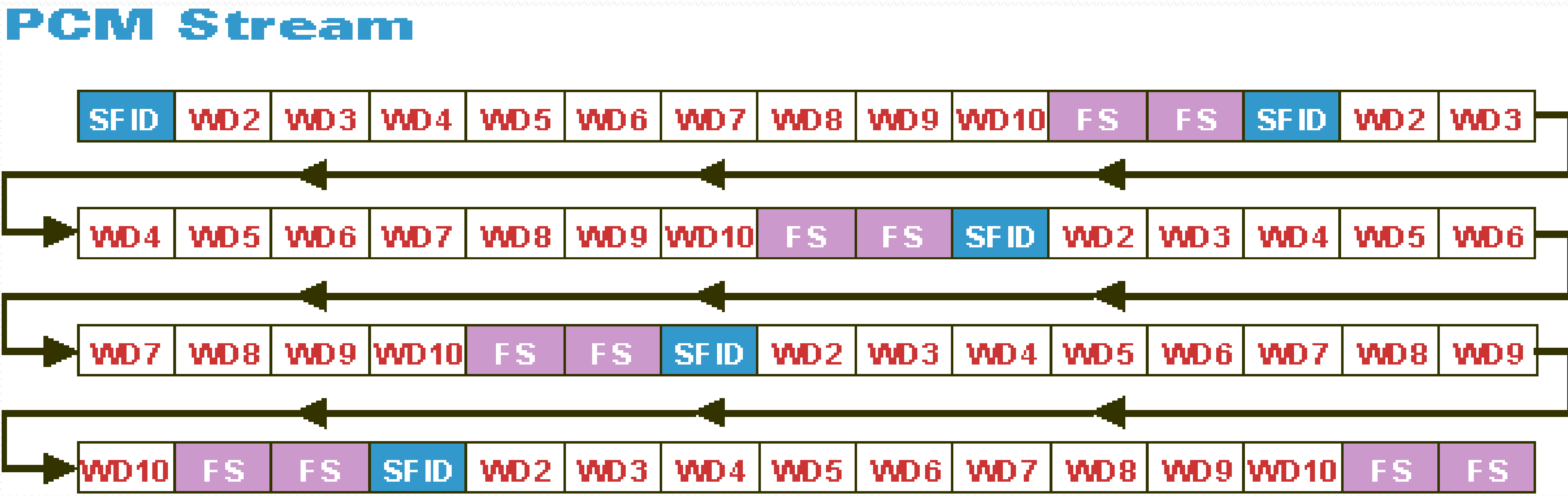
Airborne System – Commutation



Airborne System – Commutation

- A complete scan by the multiplexer (one revolution of the commutator) produces a frame of the stream of words containing the value of each measurand.
- Every scan produces the same sequence of words. Only the *value of a measurand is captured, not its address (name).*
- If only the measurand's data is captured, there is no way to distinguish the owner of one value from the next. Thus, a unique word called *the frame sync* is added at the end of each frame to serve as a reference for the process of decommutating the stream's data (i.e., extracting it into individual measurand values).

- Representing the telemetry stream as a continuous string of values in a diagram, while possible, is very cumbersome



- In addition to the *data words WD2 through WD10*, you will notice the *FS for frame synchronization*. Frame syncs mark the end of a frame so that the original data can be reconstituted in the ground station. As you can see, it can be cumbersome to visualize the simulated serial output data in this format.

Airborne System – Commutation

- An easier way to visualize data is presented in the table below. The standard includes both naming and numbering conventions of words and frames as seen below.

Data Words

	1	2	3	4	5	6	7	8	9	10	11	12
1	SFID	WD2	WD3	WD4	WD5	WD6	WD7	WD8	WD9	WD10	FS	FS
2	SFID	WD2	WD3	WD4	WD5	WD6	WD7	WD8	WD9	WD10	FS	FS
3	SFID	WD2	WD3	WD4	WD5	WD6	WD7	WD8	WD9	WD10	FS	FS
4	SFID	WD2	WD3	WD4	WD5	WD6	WD7	WD8	WD9	WD10	FS	FS
5	SFID	WD2	WD3	WD4	WD5	WD6	WD7	WD8	WD9	WD10	FS	FS

Data

A Supercommutated Data

Subframe Sync

Frame Sync

Airborne System – Data Words

- A **data word** is a *measurement, calculation, counter, command, tag, function, or other information entered into the frame position as a measurand*. A measurand is a uniquely identified source (e.g., temperature of location 256, cabin pressure, fuel consumption obtained from an avionics bus, or a dump of the flight computer's memory.) Each cell position in each frame contains the same measurand

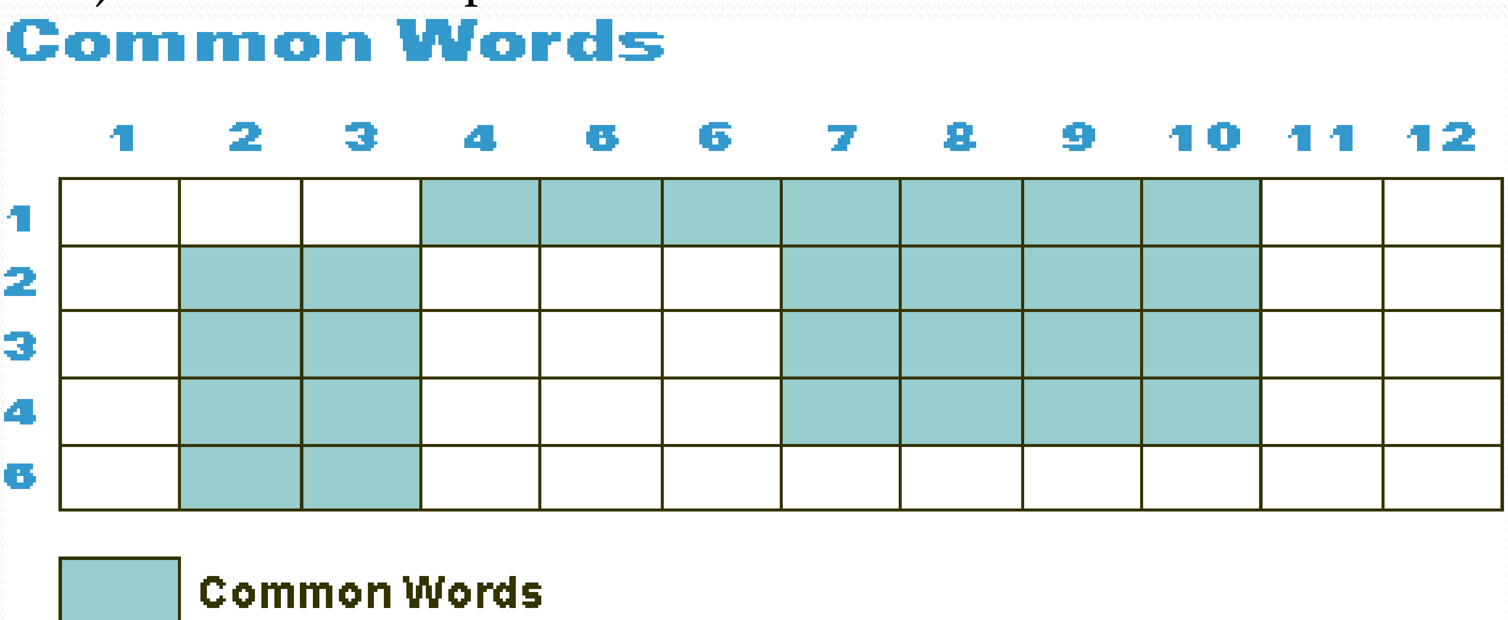
Data Words

	1	2	3	4	5	6	7	8	9	10	11	12
1	SF ID	WD2	WD3	WD4	WD5	WD6	WD7	WD8	WD9	WD10	FS	FS
2	SF ID	WD2	WD3	WD4	WD5	WD6	WD7	WD8	WD9	WD10	FS	FS
3	SF ID	WD2	WD3	WD4	WD5	WD6	WD7	WD8	WD9	WD10	FS	FS
4	SF ID	WD2	WD3	WD4	WD5	WD6	WD7	WD8	WD9	WD10	FS	FS
5	SF ID	WD2	WD3	WD4	WD5	WD6	WD7	WD8	WD9	WD10	FS	FS

Data | A Supercommutated Data | Subframe Sync | Frame Sync

Airborne System – Common Words

- ***Common words are filler words that do not contain a measurand and are filled with a common pattern.*** This pattern can be static, such as a hexadecimal word, or dynamic, such as the value of an input port or function generator.
- Common words are entered into all unused frame words. Encoders normally build a frame for transmission by first filling the entire frame with common words, then overwriting each word by the required data frame and subframe sync words, which are followed by measurands as the major frame is completed.



Airborne System–Frame Synchronization Pattern

- Identifying the end of each minor frame period is the synchronization (sync) word, which is a unique sequence of 1's and 0's. The pattern is generally a pseudo-random sequence that is unlikely to occur randomly in the acquired data and usually occupies two words (or more) in the minor frame.
- The length of the frame sync is longer than usual data words to reduce the probability of actual data matching it
- An identical pattern is repeated for every minor frame on the assumption that random data will not consistently match the defined pattern. The decommutator can then be programmed to lock onto this pattern to begin regenerating the original commutated measurands.

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

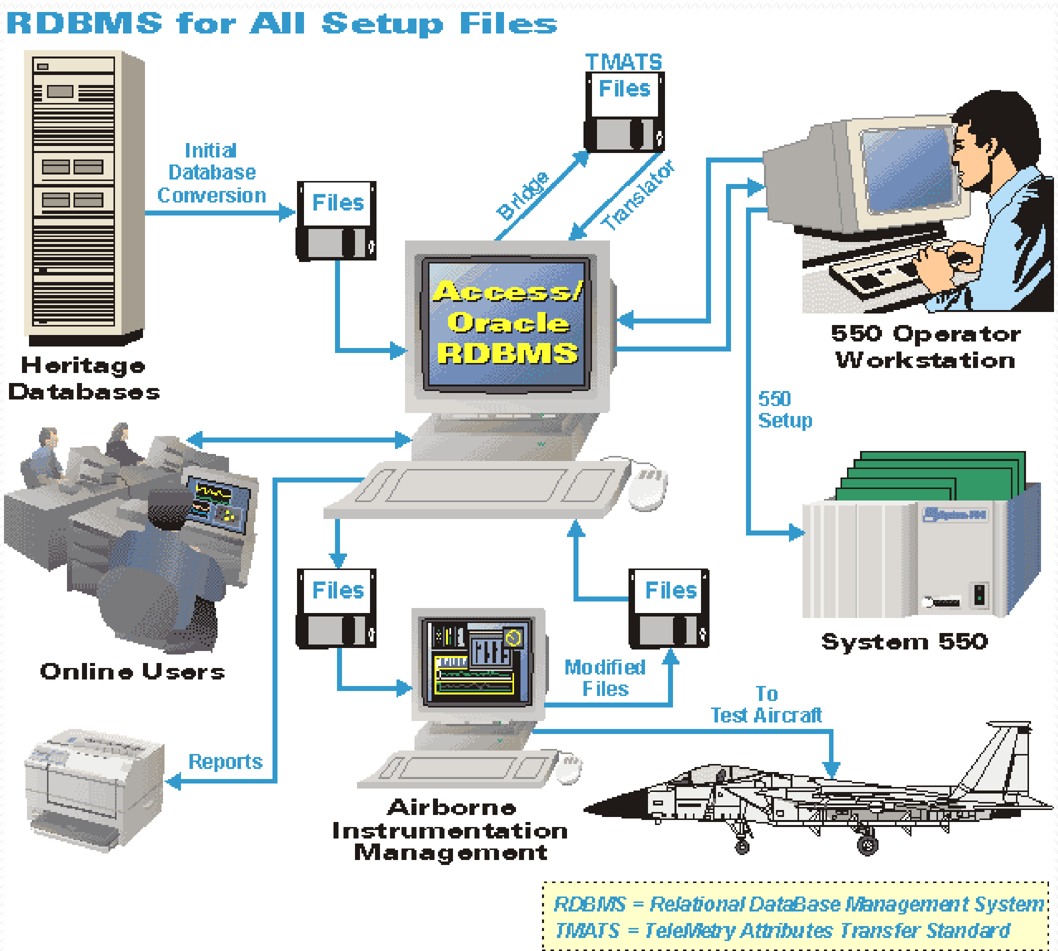
Ground System – Setup & Control

Setting up a telemetry ground station includes:

- ***Creating the definition for the data acquisition system***, including sensor characteristics and signal conditioners. Defining the telemetry frame(s) to accommodate sampling rate requirements as well as limitations of the acquisition hardware.
- ***Entering calibration information for every sensor if data will be evaluated in engineering units***, or using information from the airborne systems database Specifying, and where necessary, creating algorithms and their coefficients required for deriving parameters or engineering unit conversion. Creating displays for each display terminal, including objects, their size, attributes, and location, as well as measurands to be displayed. Defining data to be archived to disk.

Ground System – Setup & Control

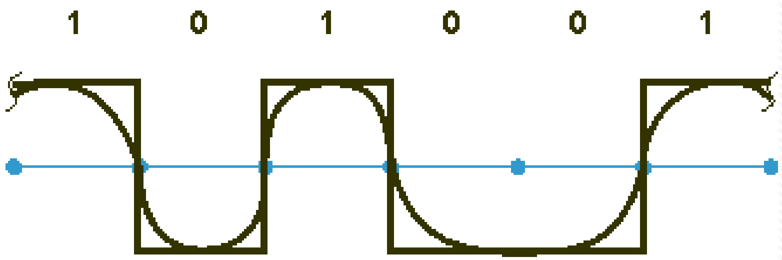
- The ***time*** required to set up and check out telemetry systems is significant. Since the setup files for both the airborne and ground system contain a large subset of common data it can be helpful to utilize ***file translation tools*** or a ***common database system.***



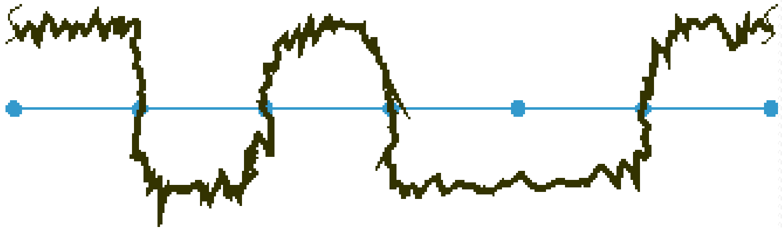
Ground System – PCM Stream Reconstruction

- At the ground station, the PCM stream, whether carried directly over wire or fiber, or ingested via an antenna and RF telemetry receiver, is ***reconstituted into the original raw measurands and data.***
- received PCM data signal must ***first be reconstructed***.
- The first signal processing function reconstructs the signal with a minimum number of symbol errors. Then the synchronous timing information is derived.
- This crucial signal processing function is called ***bit synchronization***. A bit synchronizer or "bit sync" is a device that ***establishes a series of clock pulses that are synchronous to an incoming signal***.

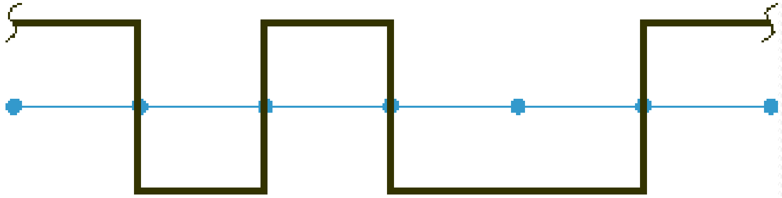
Bit Synchronization Steps



Idealized NRZ PCM Signal
at Airborne Encoder



Received PCM Signal

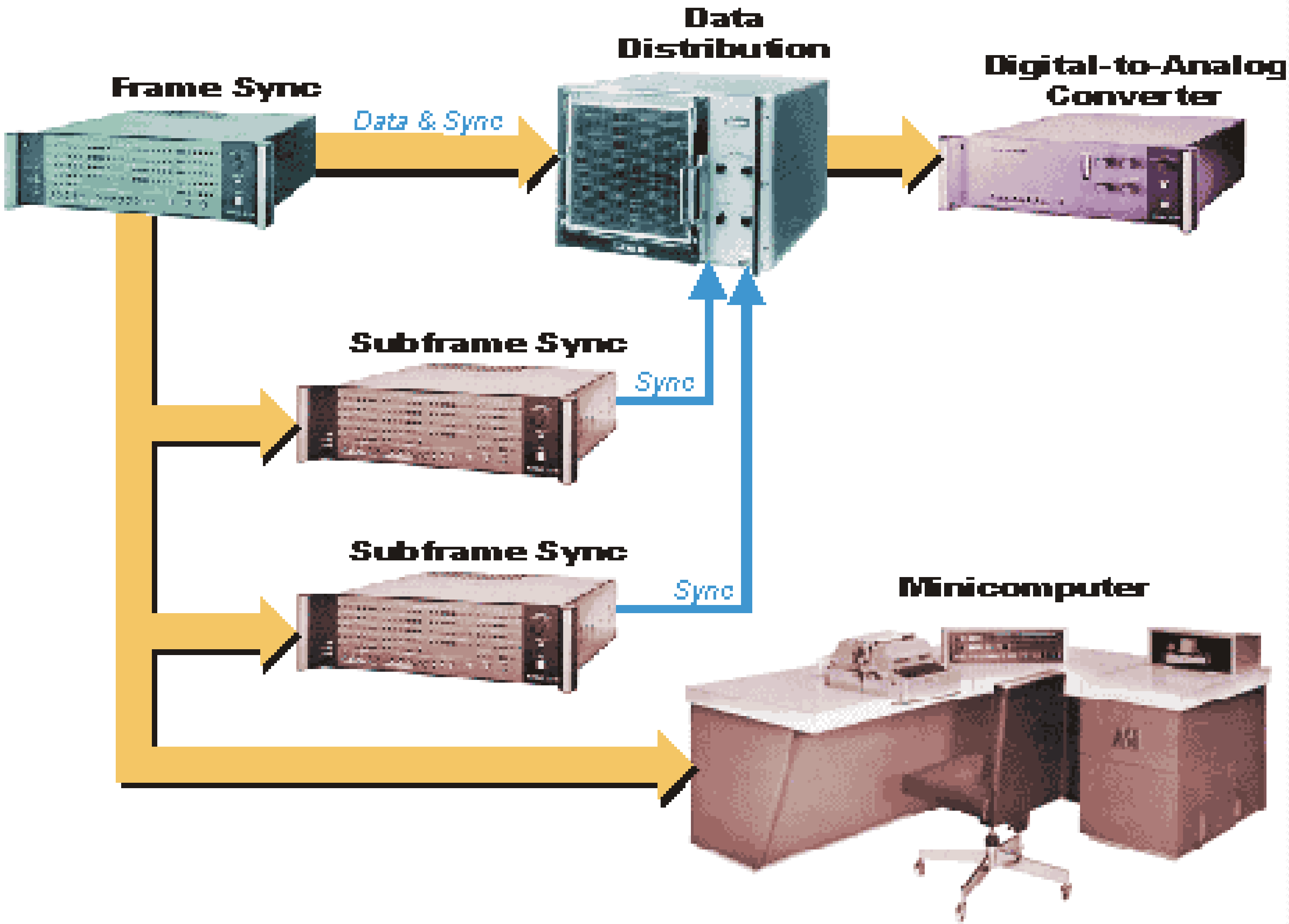


Reconstructed PCM Data
Out of Bit Synchronizer

Ground System – Frame Synchronization

- The reconstructed PCM telemetry stream remains a serial wave train of 1's and 0's. ***Before converting this serial stream into words containing characters, numbers, nibbles, and individual bits, the reference point or synchronization word must first be isolated.***
- This is the task of *frame synchronization*.

Heritage Telemetry Ground Station



Ground System – Frame Synchronization

- ***PCM streams are not always received with continuous complete errorless frames.*** Isolating the frame sync task is complicated by the presence of bit errors, slippage (undetected bit(s)), and random data sequences.
- Users can choose the number of valid frames before accepting data as well as the level of confidence that valid data is received by specifying the frame sync's ability to detect valid frame sync patterns. With respect to numbers of valid frames, four states or operational modes are considered in the definitions below:

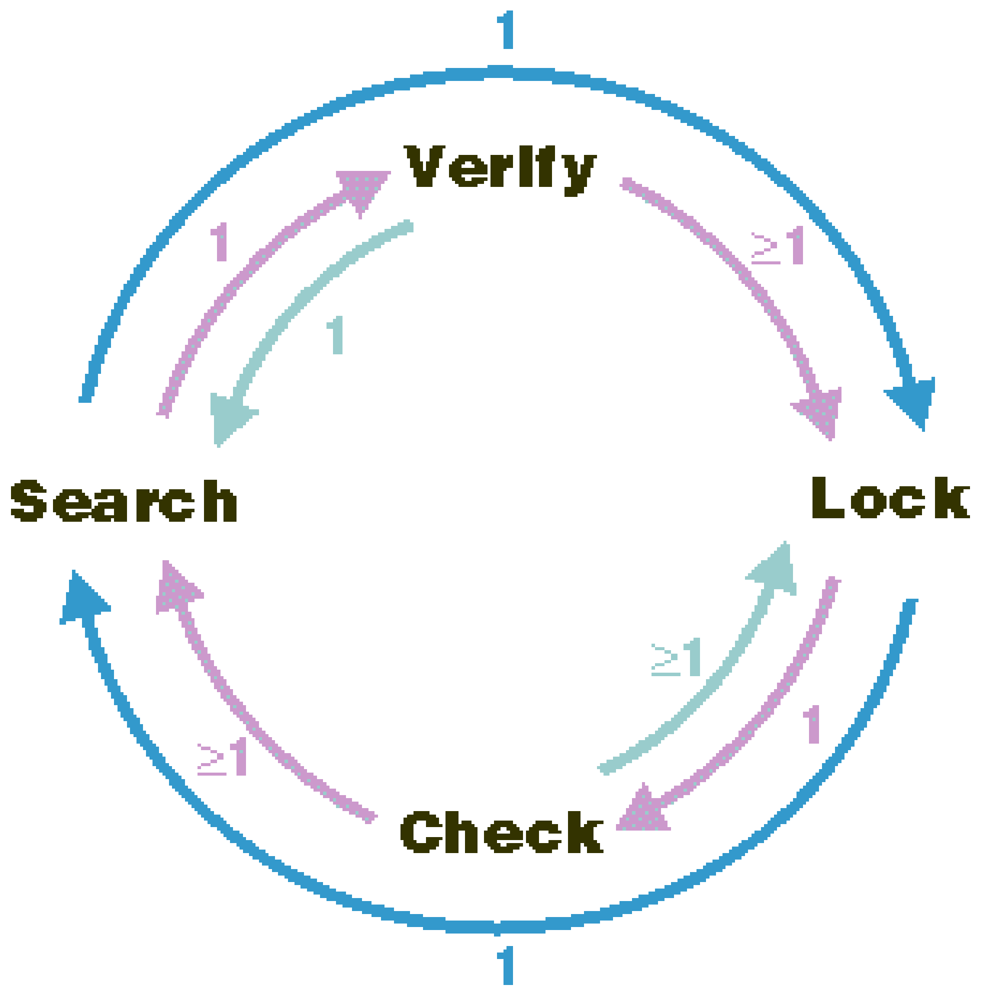
<u>Search</u> — ***The synchronizer looks for a possible sync pattern.***

<u>Verify</u> — ***A pattern is tentatively identified, a window is set at the predicted time of reoccurrence of the sync pattern, and the masked sync pattern is checked for several frames.***

<u>Lock</u> — ***The synchronizer continues to look for the frame sync pattern in the sync window and will only revert to a previous mode if the sync pattern fails to occur in the window for a given number of frames.***

<u>Check</u> — ***After being in lock, an expected frame sync pattern is not detected. This state is the converse of the "verify" mode.***

Frame Synchronization States



where: minimum numbers of valid frames to move right to next state;

minimum numbers of invalid frames to move left to next state

Ground System – Frame Synchronization

The conditions required to move between operational modes is also defined:

Search to Lock — ***Number of consecutive valid frame synchronization patterns that must be detected in the data stream before the decom advances from search to lock.***

Lock to Search — ***Number of consecutive invalid frame synchronization patterns that must be detected in the data stream before the decom goes into search mode.***

Sync Pattern Bit Errors — ***Calculates the number of correct bits in the synchronization pattern for a valid pattern.***

Bit Aperture — ***Allows or disallows bit slips in the frame synchronization pattern.***

Ground System – Decommutation

- After frame synchronization, individual measurands are identified according to the frame location.
- Another scheme rearranges measurands into a new format that is more appropriate for data manipulation, such as sorting the frame into arrays where each array is one or more instances of a single measurand.
- Another scheme maintains a current value table (CVT), including all or only those measurands of interest.

Ground System – Decommutation

- The advent of faster general-purpose front-end processors and computers offers a way to provide ***real-time software decommutation,*** but at slower data rates than a dedicated hardware decom.
- Software decommutation offers the ***advantage of handling the most complex formats and memory required to support instant switching between hundreds of frame formats.***
- Today's ground station management software includes a ***graphical user interface (GUI)*** to define telemetry stream decommutation content as in the database.
- ***Instant feedback*** occurs when data entry errors are detected

Ground System – Simulation & Encoding

- A data acquisition system or analog instrumentation recorder *may not always be available* at the telemetry station to produce PCM data streams for system checkout and operator training.
- Therefore, it is highly desirable to ***simulate identical PCM*** data streams produced by the acquisition subsystem.
- Measurands can be simulated *statically either as user-defined constants and wave shapes* via a CVT or *as multiple function generators* (square, sine, ramp, triangular) at different data rates and amplitudes. While the data changes, it is not considered dynamic.
- ***Dynamic simulation uses real-time data from external sources and measurand simulators as products of data bus, vehicle, or satellite constellation models***. These dynamically simulated streams are desirable for training and system test.
- A dynamic simulator is, in effect, a PCM encoder. *You can produce a new PCM stream by extracting words from incoming PCM stream(s)* or external data sources for applications such as commanding or forwarding data to another site.

Ground System – Real-Time Processing

- The result of decommutation is the reconstruction of sensor measurements, packed bus data, or computer words. To be more meaningful and easily comprehended, measurements are viewed in user-friendly formats like engineering units(EU) (miles per hour, degrees centigrade, or psi), not as raw counts from a transducer.
- *Real-time processing requires that data be converted/manipulated in real time to satisfy the immediate need to evaluate data and make decisions regarding safety, test continuation, controlling a satellite's movement, etc.*

Real-Time Processing Algorithms

Arithmetic

1750 to IEEE
absolute
convert
exp
exp 10
ln
log 10
mean
power
reciprocal
square root
standard deviation
trigonometric
variance

Compression

average over n
bit change
bit compress
bit swap
concatenation
conditional
constant value
delta
in limits
logical functions*
match bit
max over n
min over n
not match bit
nth word
out of limits
peak to peak
retag
rn average
rn steady state
steady state
sum over n
trig value
word rotate

Logical

gray code convert
logical functions
trigger on parameter

DSP

FIR

Engineering Unit (EU)

integer scale
polynomial eu convert
table look up
table look up 2D

System

loading

Telemetry

1 syllable to 2 syllable F
2 syllable to 1 syllable I
Frame sync alg
Frame sync sim
Idu format
Idu frame
Idu value
IRIG convert
IRIG oset
IRIG sync
setup retag
software decom
sub-frame alg
sub-frame sim
time stamp 1553
tm 1553

Ground System – Real-Time Processing

In addition to EU conversion, real-time processors serve other functions, including the following:

- **Alarm Checking** — Real-time processors continuously *check values against norms to ensure out-of-limits and caution boundaries are not exceeded* or to predict problems due to trending over time.
- **Bit Manipulation** — Telemetry frames are not always orderly with one measurand per word. When resources are at a premium, instrumentation engineers will combine unused bits from several word locations to form an additional measurand.
- **Derived Parameters** — A single meaningful attribute (e.g., air speed as a mach number) may be the result or derivation of multiple measurands (temperature, altitude, velocity) inhabiting multiple data streams.
- **Data Compression** — Often, data is sampled too frequently, producing too much data. This data is "compressed" using sampling or averaging algorithms.