communications

Telemetry-West

Telemetry Tutorial

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ML1800 Rev. A

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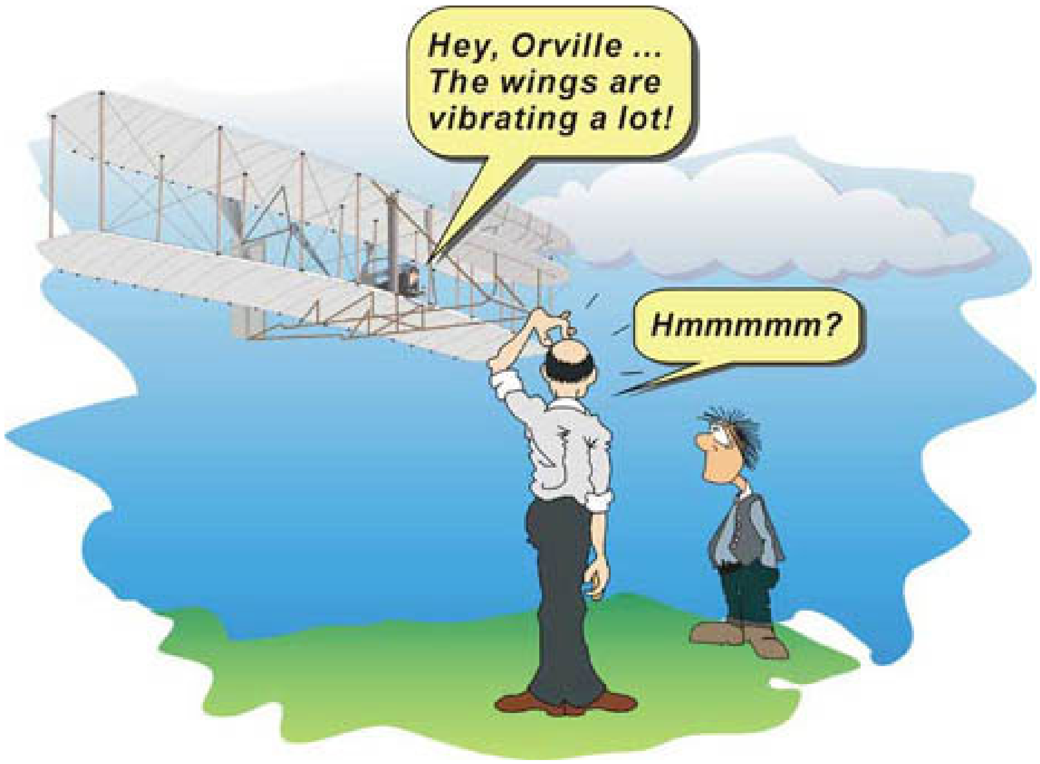
Preface

Getting Started

Welcome to L-3 Telemetry-West's Web-based Telemetry Tutorial. This basic course covers the entire telemetry process — everything from taking measurements to displaying and archiving results to analyzing data for mission-critical applications. While this tutorial is structured to flow sequentially, we encourage you to jump around to your areas of interest.



A Word on Telemetry Definitions

Telemetry sure would have come in handy for the Wright brothers at Kitty Hawk, North Carolina back in 1903. But engineers from different disciplines and industries didn't pioneer it until some years later. As fate would have it, each deployed their own unique set of telemetry nomenclature. Even today, definitions used in airborne, ground, space, flight test, or industrial applications may differ.

L-3 Telemetry-West's heritage is in aircraft ground systems, so the definitions used in this tutorial will be ground oriented. Click on the Glossary for a comprehensive summary of telemetry definitions. You can also jump to the Additional Sources section to get even more information on Telemetry.

Help Us Help Others!

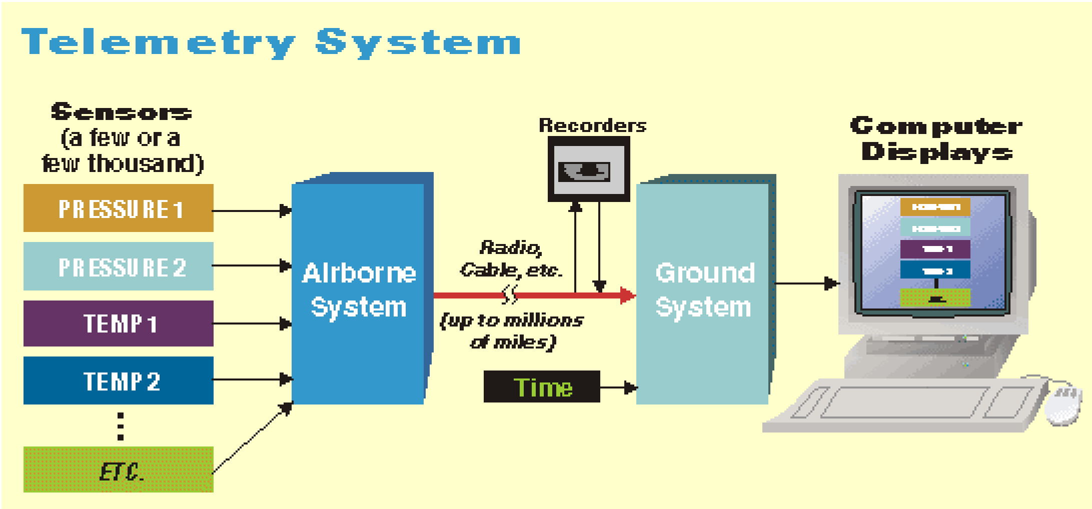
Your comments regarding this tutorial are essential to keeping it relevant and up-to-date. We are also very interested in your suggestions for additional topics, as well as your ideas on which areas to elaborate on and/or modify. Please e-mail your feedback to webmaster@ti.l-3com.com.

Thank you!

Introduction

What Is Telemetry?

Telemetry is the process by which an object's characteristics are measured (such as velocity of an aircraft), 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.



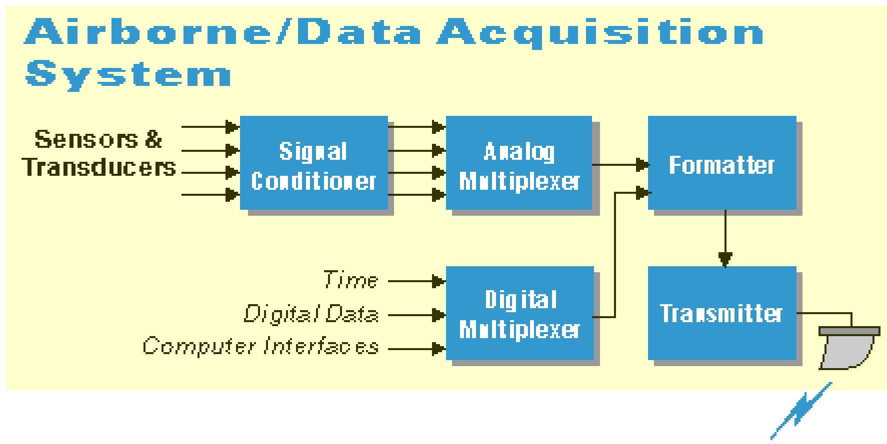
In today's telemetry applications, which support large numbers of measurands, it is too costly and impractical to use separate transmission channels for each measured quantity. The telemetry process involves grouping measurements (such as pressure, speed, and temperature) into a format that can be transmitted as a single data stream. Once received, the data stream is separated into the original measurement's components for analysis.

Telemetry lets you stay in a safe (or convenient) location while monitoring what's taking place in an unsafe (or inconvenient) location. Aircraft development, for example, is a major application for telemetry systems. During initial flight testing, an aircraft performs a variety of test maneuvers. The critical flight data from a maneuver is transmitted to flight test engineers at a ground station where results are viewed in real time or analyzed within seconds of the maneuver. Real-time monitoring allows the "safety officer" to make instant decisions on whether to proceed with or terminate a test. With real-time analysis, the flight test engineer can request a maneuver be repeated, the next maneuver be performed, or test plan alternatives be substituted. Real-time data is also captured to storage media, such as disk and tape, for later analysis and archiving.

Telemetry Systems Overview

Today's telemetry systems are built from commercial-off-the-shelf (COTS) products. But while they all have many common elements, they are each uniquely configured to meet specific application requirements.

A telemetry system is often viewed as two components, the Airborne System and the Ground System. In actuality, either or both may be in the air or on the ground.

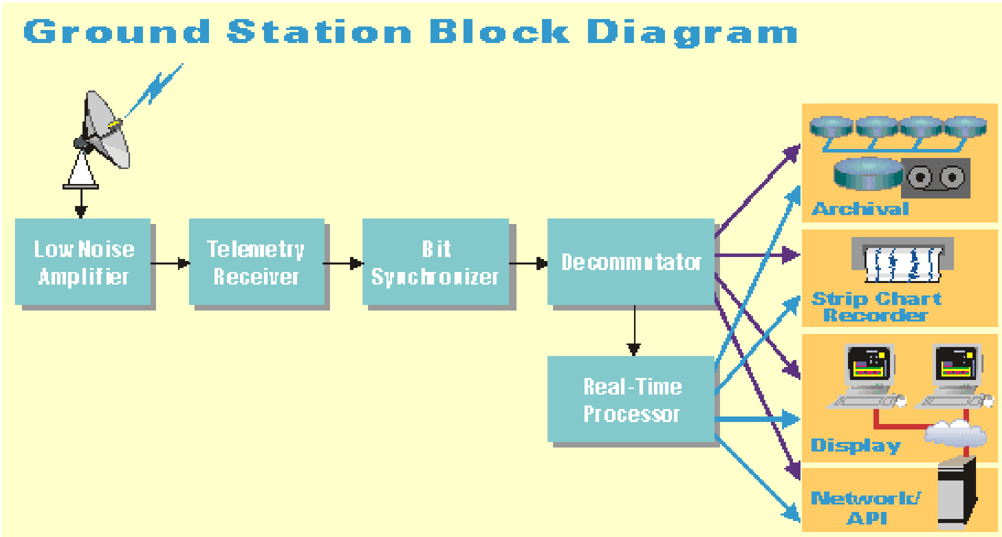


Data acquisition begins when sensors (aka, transducers) measure the amount of a physical attribute and transform the measurement to an engineering unit value. Some sensors produce a voltage directly (thermocouples for temperature or piezoelectric strain gages for acceleration), while others require excitation (resistive strain gages, potentiometers for rotation, etc.). Sensors attached to signal conditioners provide power for the sensors to operate or modify signals for compatibility with the next stage of acquisition. Since maintaining a separate path for each source is cumbersome and costly, a multiplexer (historically known as a commutator) is employed. It serially measures each of the analog voltages and outputs a single stream of pulses, each with a voltage relative to the respective measured channel. The rigorous merging of data into a single stream is called Time Division Multiplexing or TDM.

The scheme where the pulse height of the TDM stream is proportional to the measured value is called Pulse Amplitude Modulation (PAM). A unique set of synchronization pulses is added to identify the original measurands and their value. PAM has many limitations, including accuracy, constraints on the number of measurands supported, and the poor ability to integrate digital data.

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. In a PCM-based system, the original PAM multiplexer's analog output is digitized to a parallel format. The Output Formatter along with synchronization data for measurand identification merges this, plus other sources of digital data. 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." All components from after the sensor to the formatter comprise the encoder (see figure below}. Other, often remote encoders are used to multiplex additional sensor data into the main encoder's output. Not only does this expand the number of measurands to thousands per stream, but it also eliminates the weight of cables required for each sensor.

The output of the main encoder is filtered and transmitted via radio transmitter and antenna, coax cable, telephone line, tape recorder, etc. Filtering rounds or smoothes the square data pulses to reduce frequency content and thus the required transmitter bandwidth. At the Ground Station, the received data stream is amplified. Since the transmission path often distorts the already rounded signal, a bit synchronizer reconstructs it to the original serial square wave train. Then, a decommutator or decom (similar to that found in L-3' Visual Test System or System 550) recognizes the synchronization pattern and returns the serial digital stream to parallel data. The decom also separates the PCM stream into its original measurands (also known as prime parameters) and data.



The computer (in the Visual Test System) or the telemetry front end (System 550) selects prime parameters for real-time processing; archiving to disk or tape; display; output to strip chart recorders and annunciators; or distribution to other computing resources according to the test plan.

L-3 Telemetry-West and its sister divisions manufacture virtually the entire telemetry system — from signal conditioners to antennas for the Airborne System and from antennas to telemetry receivers for the Ground System. The following table breaks down which L-3 divisions provide what for today's telemetry system requirements. Just remember that when you need to put everything together, L-3 Telemetry-West will help specify, integrate, and install all L-3 and third-party components for a total telemetry solution..

Telemetry System Components	**L-3 Supplier**
Airborne Encoders	Telemetry-West, Telemetry-East
Airborne Storage (Data Archiving)	Communication Systems-East, Telemetry-East
Airborne Transmitters	Telemetry-West, Southern California Microwave, & Telemetry-East
Airborne Antennas	Randtron
Ground Antennas	EMP, ESSCO, & Microdyne
Ground Receivers	Microdyne
Ground Systems	Telemetry-West
Rugged Displays	Display Systems
Telemetry Systems	Telemetry-West

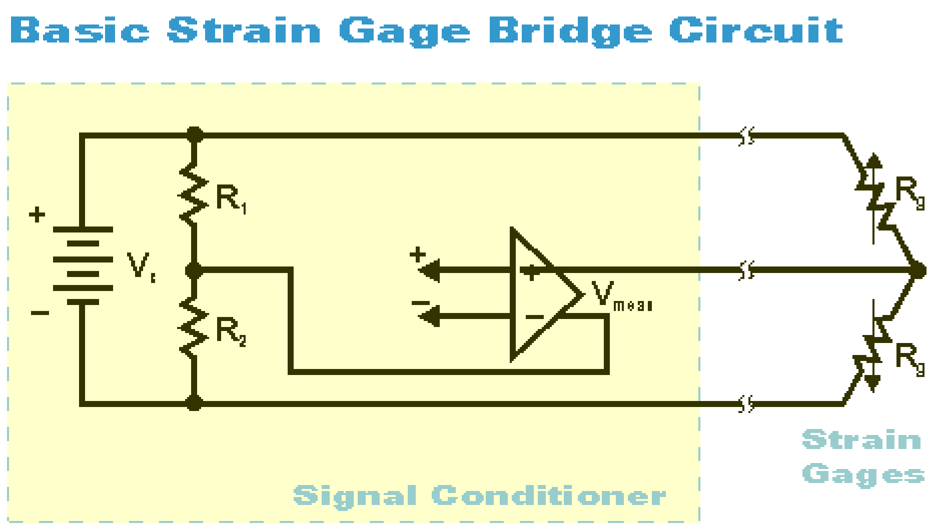
Airborne Systems

Data Acquisition

A wide variety of sensors (also known as transducers) are used to measure and acquire a physical property's value. It is up to the instrumentation engineer to select the device to meet the environmental, response, accuracy, size, and cost specifications for the application. Signal conditioners serve as the interface of the data acquisition system from the transducers. Many transducers require ac or dc power (e.g., thermistors, strain gages, and linear variable differential transformers - LVDTs) while others generate signals (tachometers, thermocouples, and piezoelectric strain gages). They provide excitation (power), network calibration, signal amplification, and filtering.

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.

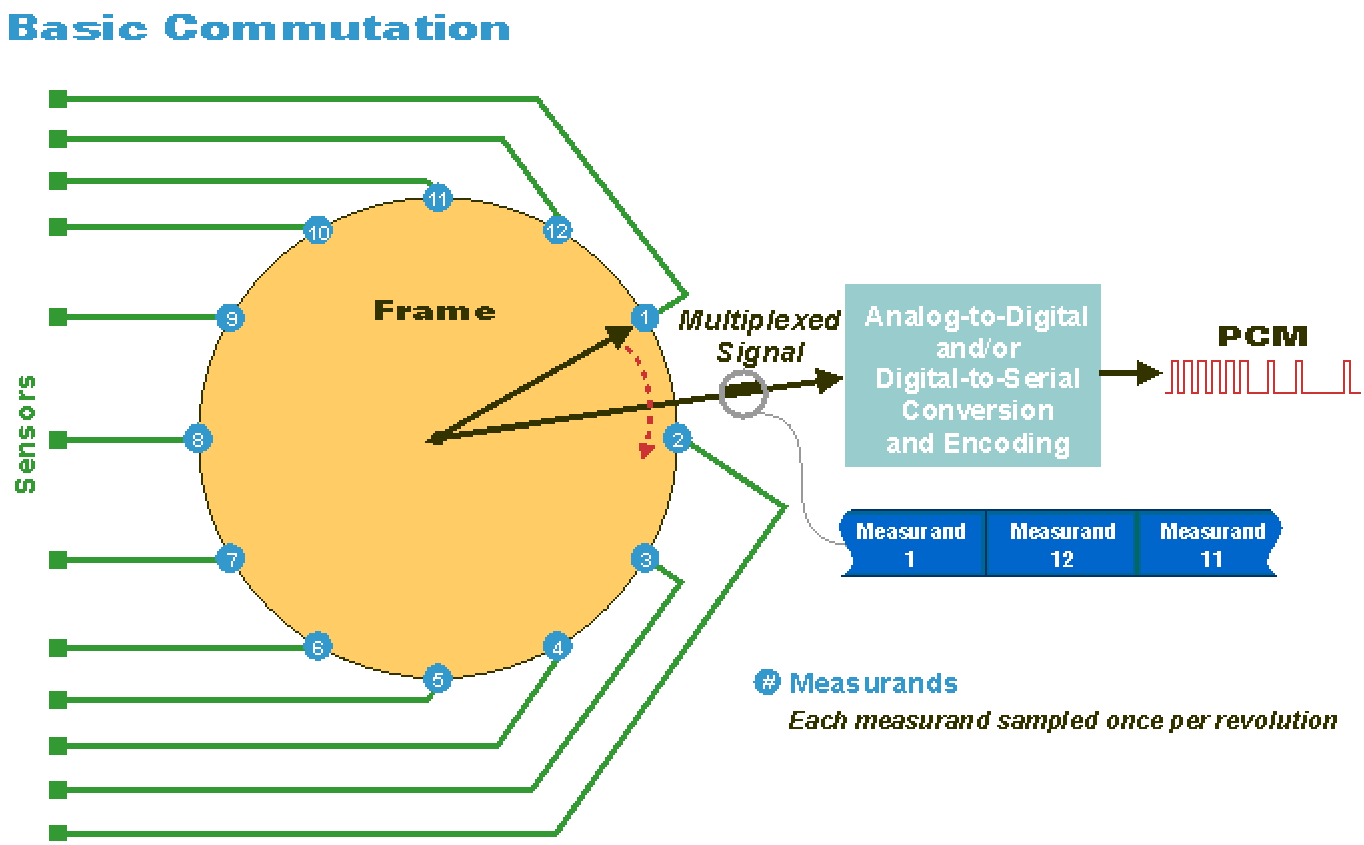
A system under test may be subjected to known physical characteristics and the output measured to ascertain and verify the relationship between the sensor and its output. For example, when on the ground, an airplane's flaps may be moved at known angles, while measurements are taken on sensor or airborne system output. The plot of angle vs. output will be used by the ground system for real-time data display in engineering units.



Multiplexer

Whatever the quantities monitored at the data source (whether electrical or physical), the cost to transmit each quantity through a separate channel would be prohibitive. Think of the equipment and cables or frequency spectrum required to monitor and transmit several hundred or thousands of measurands! One way to conserve resources is to share time or frequency spectrum with techniques such as Time-Division Multiplexing (TDM) and Frequency Multiplexing (FM), respectively.

Today, the most popular form of telemetry multiplexing (originally called commutation, as in an electric motor's commutator) is TDM. Here, each channel is serially sampled for an instant by the multiplexer (see figure below).



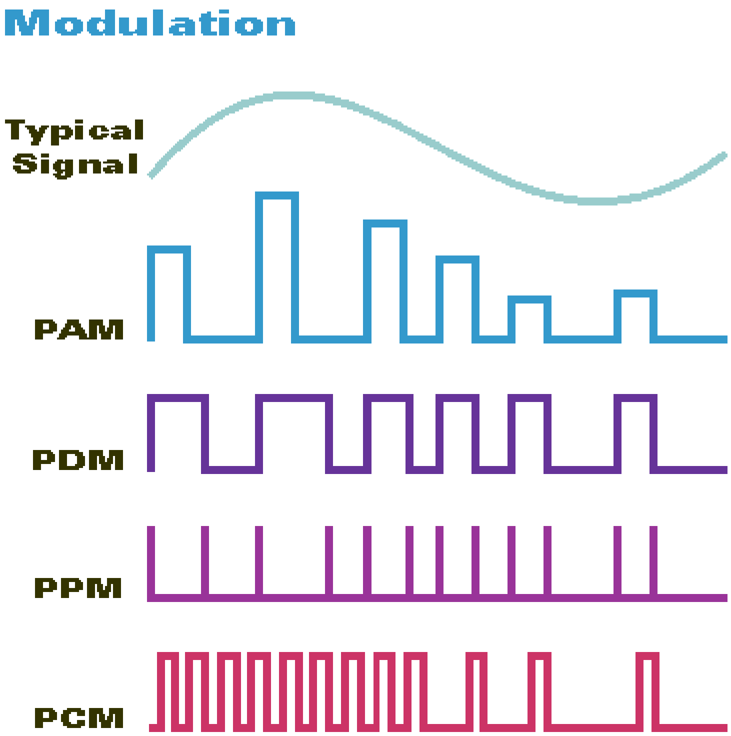
When all channels have been sampled, the sequence restarts at the first channel. Thus, samples from a particular channel are interleaved in time between samples from all of the other channels. An example of a simple interleaved data stream is shown below as the output of the commutator:

Since no measurand is monitored continuously, sampling must be accomplished fast enough so that the value of each measurand does not change significantly during intervals. In practice, each parameter is measured at a rate of three to five times the highest frequency of interest. There's a definite science to selecting efficient sampling rates and measurand positions!

Modulation

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 PAM. Three other modulation forms are also used: Pulse Duration Modulation (PDM), Pulse Position Modulation (PPM), and Pulse Amplitude Modulation (PAM). The resulting waveforms from these modulation techniques for a simple analog data signal are shown below.



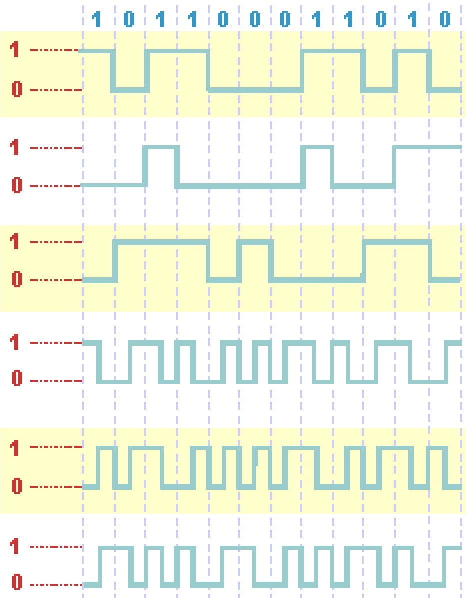
The PAM data stream signal is transmitted from the multiplexer in a uniformly spaced sequence of constant-width pulses. The intensity of each pulse is modulated by amplitude. This is similar to AM radio broadcast, except the carrier is a pulse rather than a sine wave.

Since amplitudes are degraded by noise, the multiplexed data stream is usually converted to a constant-amplitude pulse modulation scheme. PDM carries the information in the pulse width, which varies directly to the amplitude of the signal. PPM results if the PDM waveform is differentiated, then rectified. The distance between the two pulses represents the sampled amplitude of the sine wave, with the first pulse as the zero time reference. Average system power for PPM is much lower than that required for PDM, but at the expense of greater bandwidth.

Both PDM and PPM use constant-amplitude pulses, but are still analog representations of an analog signal. In a PCM system, each pulse is encoded into its binary equivalent before transmission. During PCM encoding, the serial output stream is conditioned for the communication link. In many cases, PCM data is not only transmitted, but also stored. When considering recording or transmitting requirements, you must establish the patterns used to represent logical one and zero values.

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. These are shown below.

PCM Data Codes

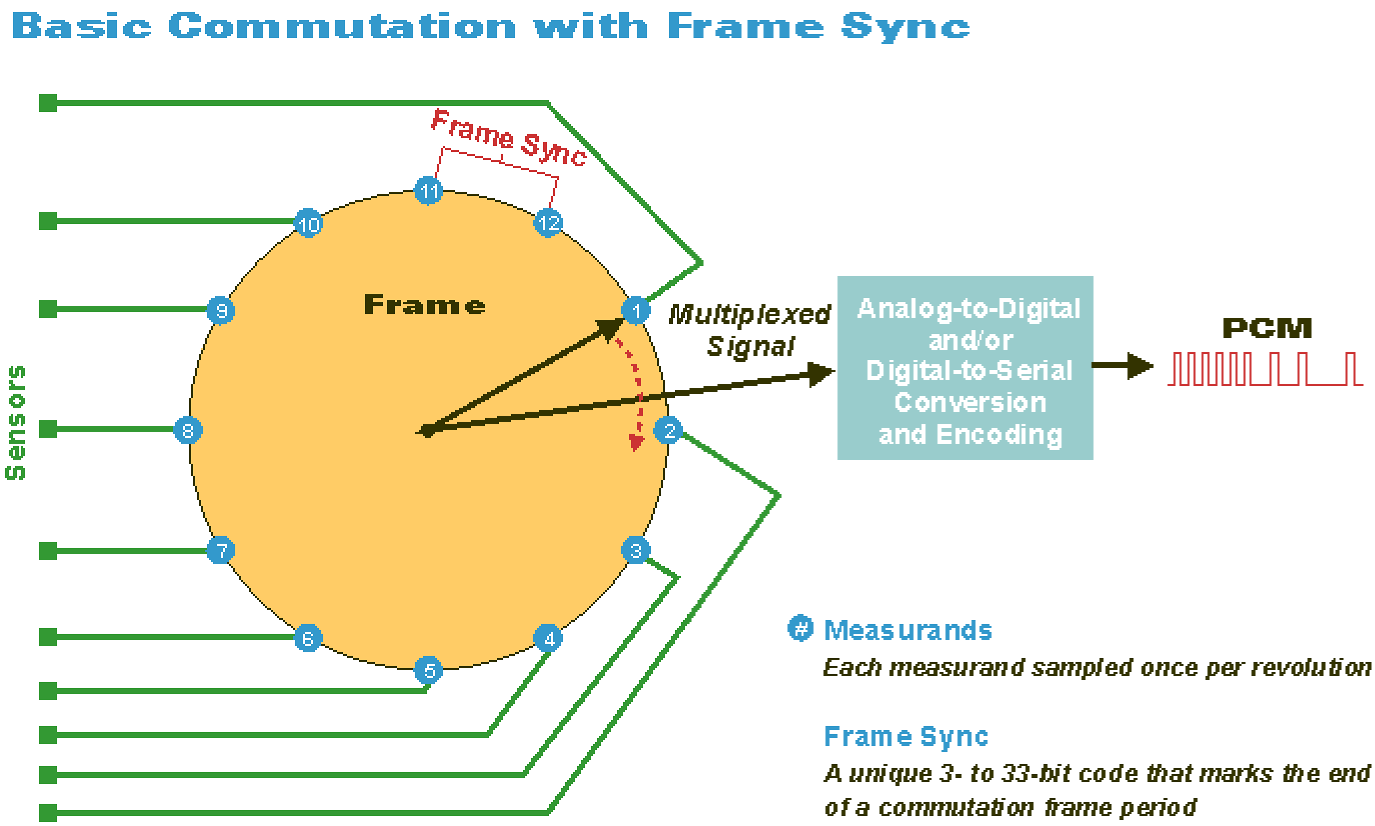


- **NRZ-L Non-Return to Zero Level (also NRZ-C)**
  "One" is represented by one level
  "Zero" is represented by the other level
- **NRZ-M Non-Return to Zero Mark**
  "One" is represented by a change in level
  "Zero" is represented by no change in level
- **NRZ-S Non-Return to Zero Space**
  "One" is 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)"*

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).



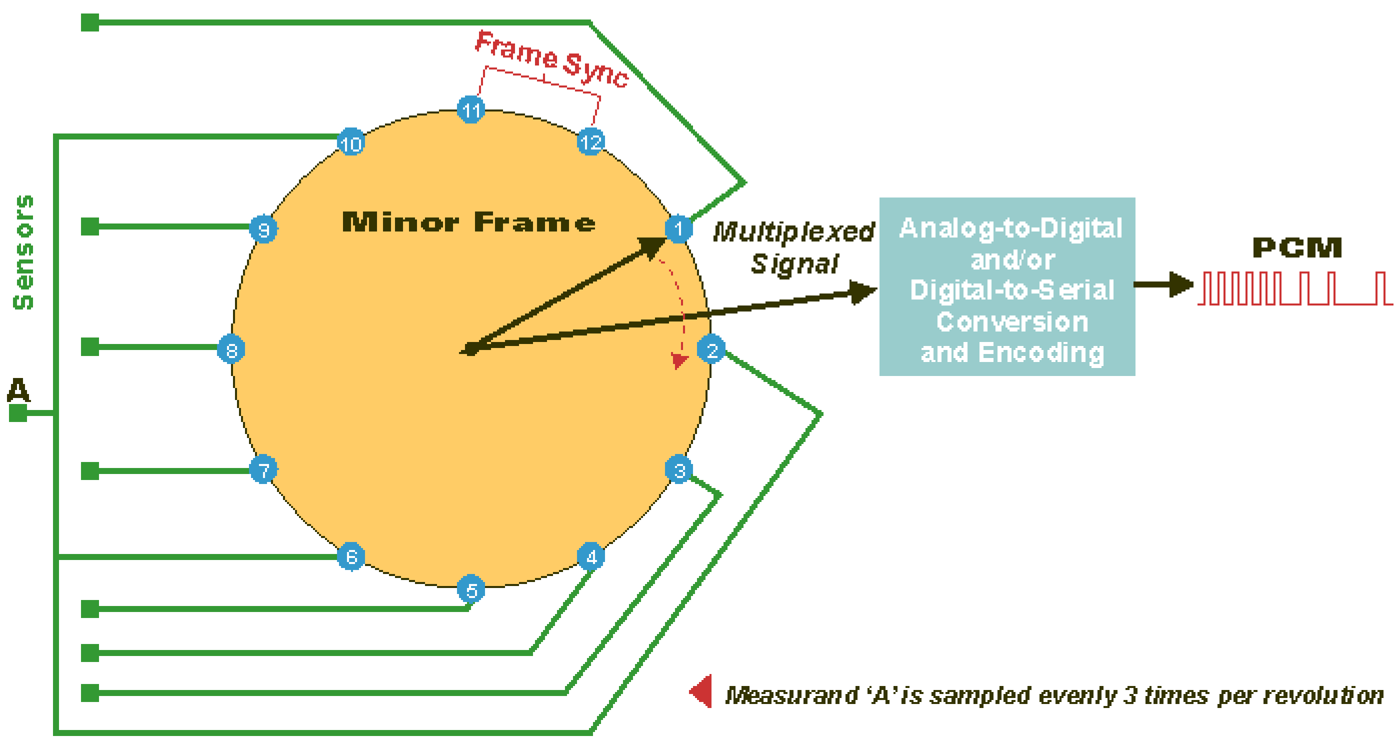
The example above shows a frame sync word for only 10 data words. In practice, the frame may incorporate hundreds or thousands of measurands. While this reduces overhead, it increases the amount of data lost if the frame sync is corrupted or bits of the frame are lost and the location of measurands cannot be guaranteed.

In a simple commutator, each data word is sampled once per revolution at a rate compatible with the measurand with the fastest changing data. Since the rate of change of a measurand's value varies tremendously, the sampling frequency rate must accommodate it. As an example, to characterize vibration requires many more samples per second (thousands) than temperature (fractions).

According to the Nyquist Theorem, you must sample data at twice the maximum frequency component for the signal to be acquired. Sampling rates of 5 times the maximum frequency component are typical. A low pass filter is used to eliminate any frequencies that you cannot accurately digitize to prevent aliasing.

If we were to take a worst-case approach to sampling all measurands at the highest rate, we could expect much waste in carrier frequency spectrum and power. Sampling rates should therefore vary with respect to frequency content and be somewhat independent of other measurands with different periodic acquisition rates. Highly sampled measurands are super-commutated with multiple occurrences of the measurand in each frame.

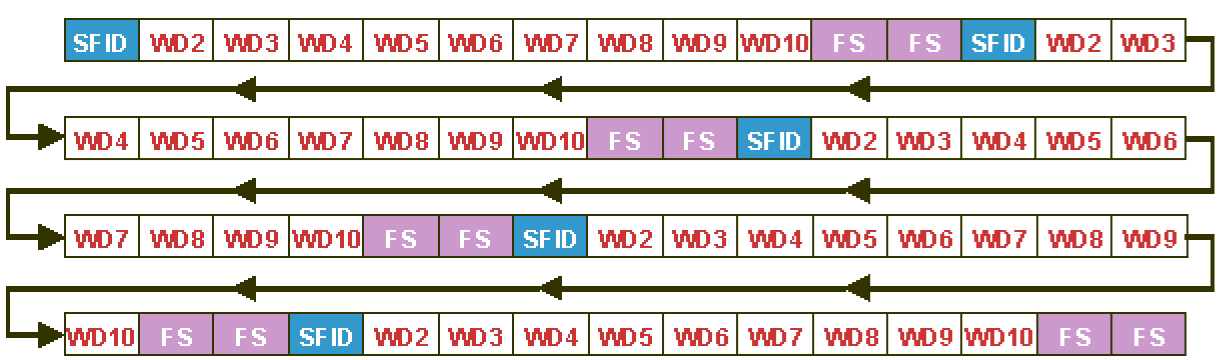
Supercommutation



The opposite scheme occurs in subcommutation and embedded asynchronous data streams, where one position over time has multiple meanings. More on these commutation schemes appears later.

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

PCM Stream



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.

An easier way to visualize data is presented in the table below and is defined in Chapter 4 of the IRIG-106 Standard. The standard includes both naming and numbering conventions of words and frames as seen below.

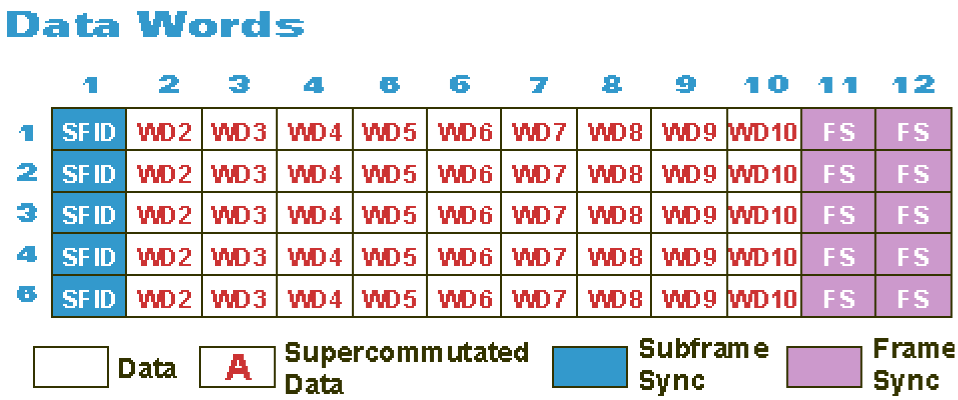
Data Words

	1	2	3	4	5	6	7	8	9	10	11	12
1	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

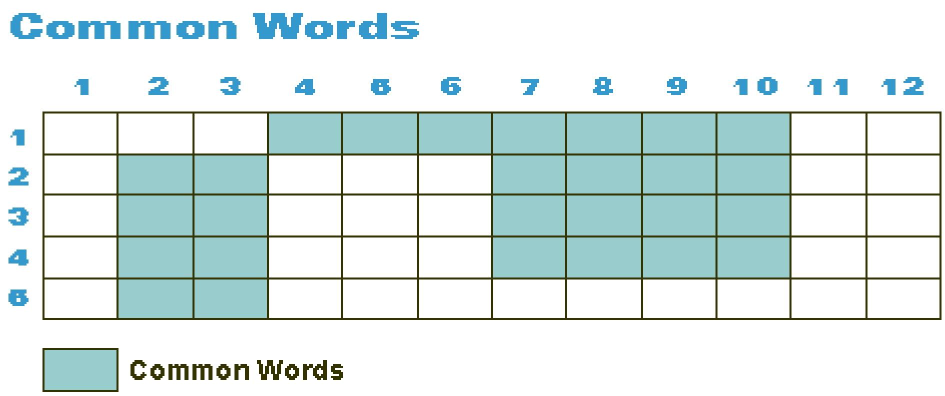
Data Words

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 (subframes and embedded asynchronous frames may appear to be an exception, but are not; they are discussed later).



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.



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 IRIG-106 Standard lists recommended patterns for lengths 16 through 33 bits. The first three bits transmitted in a frame sync pattern are always a "1," regardless of LSB or MSB alignment.

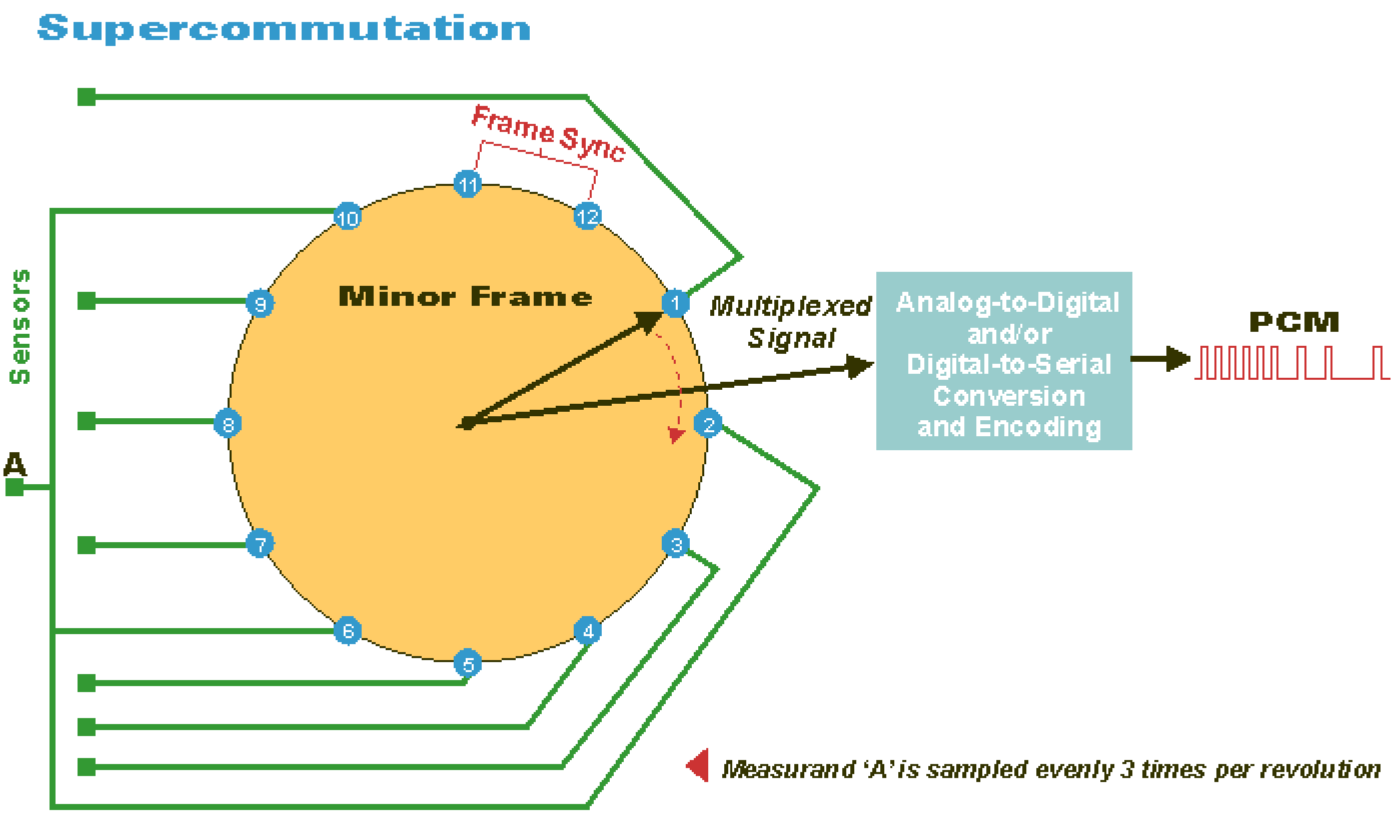
Optimum Frame Synchronization Patterns for PCM Telemetry

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

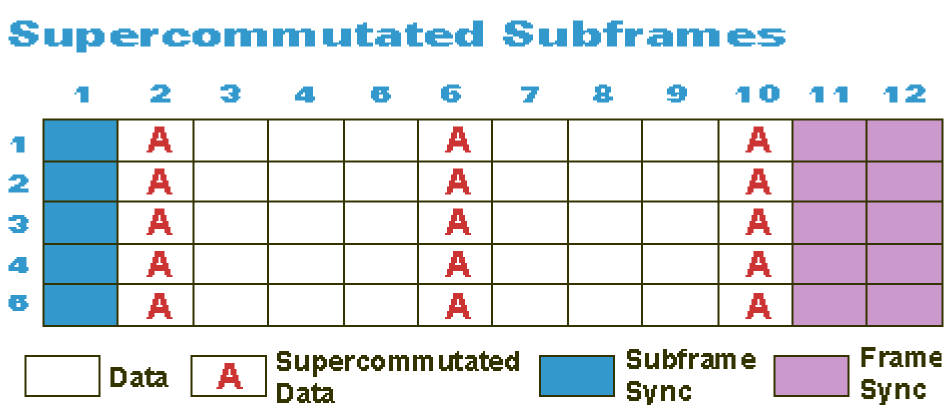
The length of the frame sync is longer than usual data words to reduce the probability of actual data matching it. The frame sync should also be commensurate with the number of words in the minor frame (typically, it occupies 1 to 5 percent of the total minor frame). An identical pattern is repeated 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.

Supercommutation

Measurands containing higher frequency content information are sampled multiple times per minor frame.

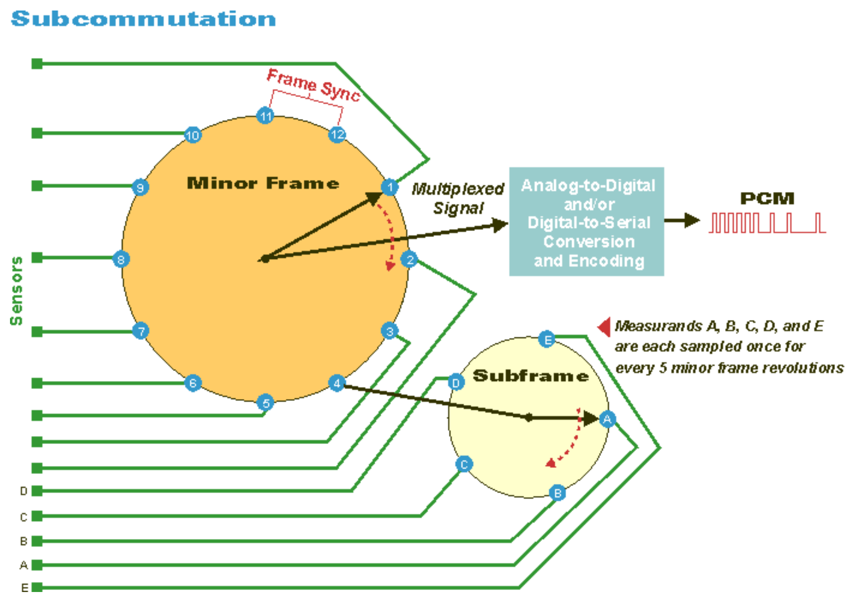


Usually, the number of words between the supercommutated measurands are equal to accommodate the regular sampling schemes required for Fast Fourier Transfer (FFT) spectral analysis of transducer output. When designing the frame, instrumentation engineers must work around the fixed positions of synchronization words. In the example below, the fastest supercommutation is only every fourth word. You could sample every third word and achieve faster results by moving the subframe sync to ensure both sync words are not contiguous.



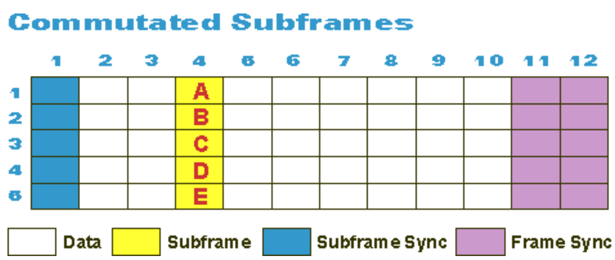
Subframe Commutation and Frame Structure

In most telemetry applications, measurand values change at different rates, often by several orders of magnitude. There is no need to sample slowly changing measurands as frequently as quickly changing measurands. The slowest changing data may not even require sampling once per frame. The concept of a major frame was therefore developed to include multiple frames, each called a minor frame.



Multiple slow changing measurands can share a single frame word (word 4 in the above illustration). This slower sampling rate is called subcommutation. To distinguish between the meaning of this shared position between minor frames, a subframe synchronization scheme is required. The value of the contents of another word in the frame is assigned the task of identifying the current minor frame. Details of subframe synchronization appear later.

The figure below illustrates subcommutation with the symbolic representation of four sub-commutated channels, which share the sixth channel of the main commutator frame. The makeup of each frame is different.



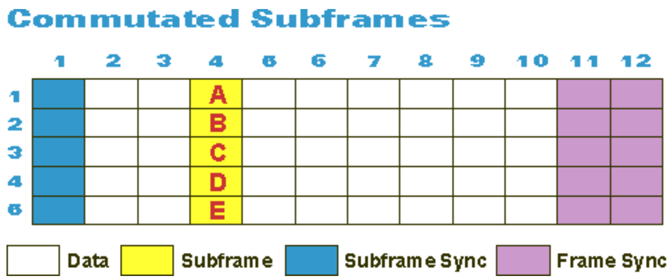
It takes five revolutions of the main commutator to sample every sensor at least once. These five frames together are called the major frame. Each pass of the main commutator produces a minor frame.

The wheel shown here is a rather simplistic example. In a typical operation, it is not uncommon to use 64 minor frames per major frame, with 512 words per minor frame. The size is not to accommodate a large number of different measurands, but to satisfy a large disparity of sampling rates (e.g., temperature versus an accelerometer).

Paragraph 4.3.2 of the IRIG-106 Standard illustrates the major frame as a two-dimensional matrix with the minor frame as one row.

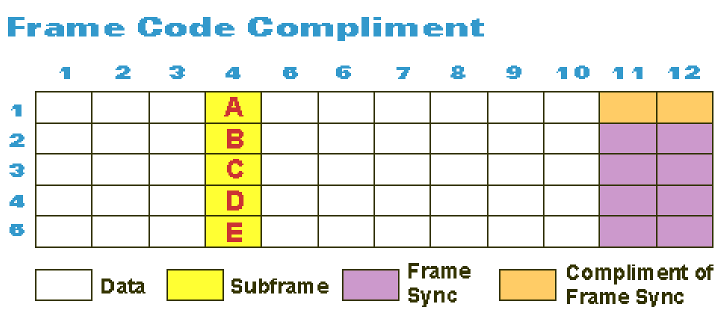
Subframe Synchronization Pattern

A subframe or major frame synchronization pattern is added to the minor frame so the decommutator can distinguish subframe words, i.e., those words that have a unique meaning in each minor frame. The figure below shows that word 4 of each minor frame has a different meaning (measurands A through E). Several methods are frequently employed to distinguish a unique single position (word) in the major frame, or, in other words, to identify the subframe.



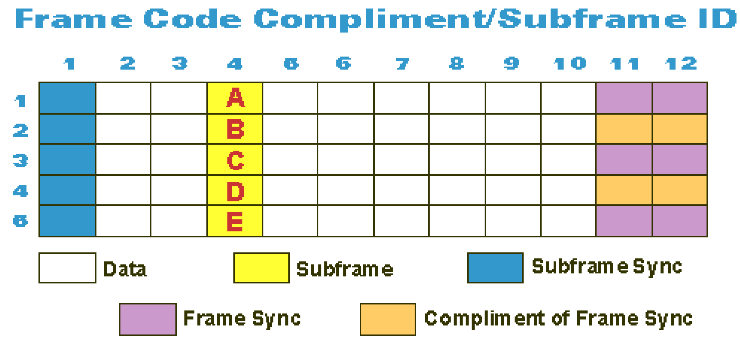
The most common subframe sync method is SubFrame IDentification (SFID). This sync pattern occupies a word in each minor frame (typically, the first word — see diagram above). The SFID sync acts as a counter for all frame samples. The pattern increments or decrements to a specified value and then resets itself, indicating that the last minor frame was generated. The decommutator can thereby locate the start of the next subframe sampling.

Another minor frame identification method inverts the frame sync pattern of the first minor frame in a subframe. This major frame synchronization scheme is known as Frame Code Complement (FCC). Since the complementary pattern exhibits the same correlation properties as the true pattern, minor frame sync lock will not be compromised. Minimum sync overhead regarding the number of words is also attained using the FCC method, although it requires a longer time before you are assured correct data. The figure below illustrates the FCC replacing the frame sync in words 11 and 12 of frame 1.

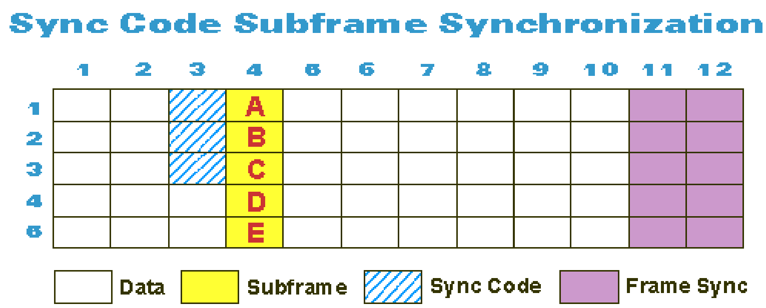


The Unique Recycle Code (URC) major frame synchronization technique is similar to FCC except that the first sync word is not related to the standard sync word. Of course, a hardware decommutator becomes more complicated because it requires the ability to correlate two different sync words.

Frame Code Complement/Subframe Identification (FCC/SFID) seen in the next figure uses the SFID word plus an alternating FCC frame sync word. The frame sync pattern is placed in the usual location in the first minor frame and its complement is placed in the second minor frame. This cycle repeats. A normal SFID word occupies its position in every minor frame.



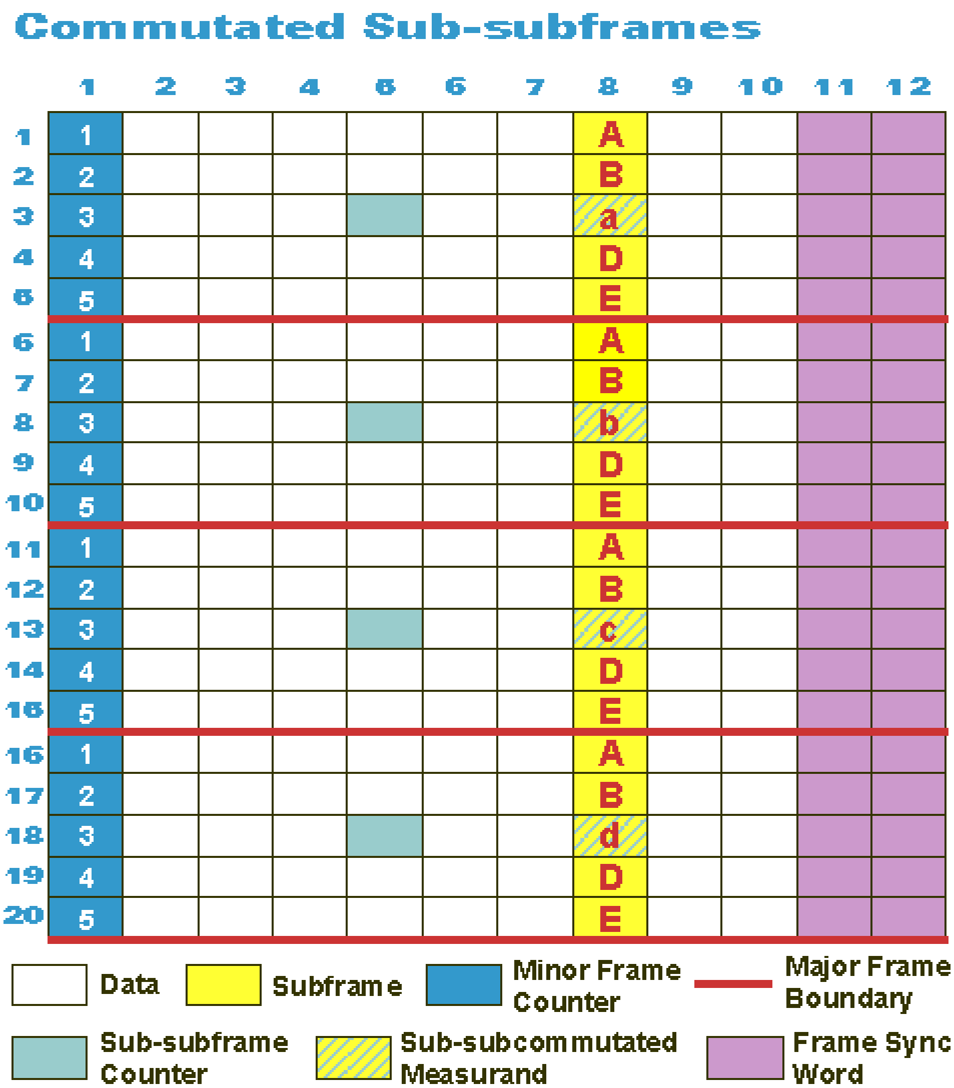
In Sync Code subframe synchronization, a single sync word occupies several data words. This method has the latency drawback of FCC, plus it requires processing to extract the subframe sync from the data frame (unless the hardware decommutator incorporates this feature).



Sub-Subframes

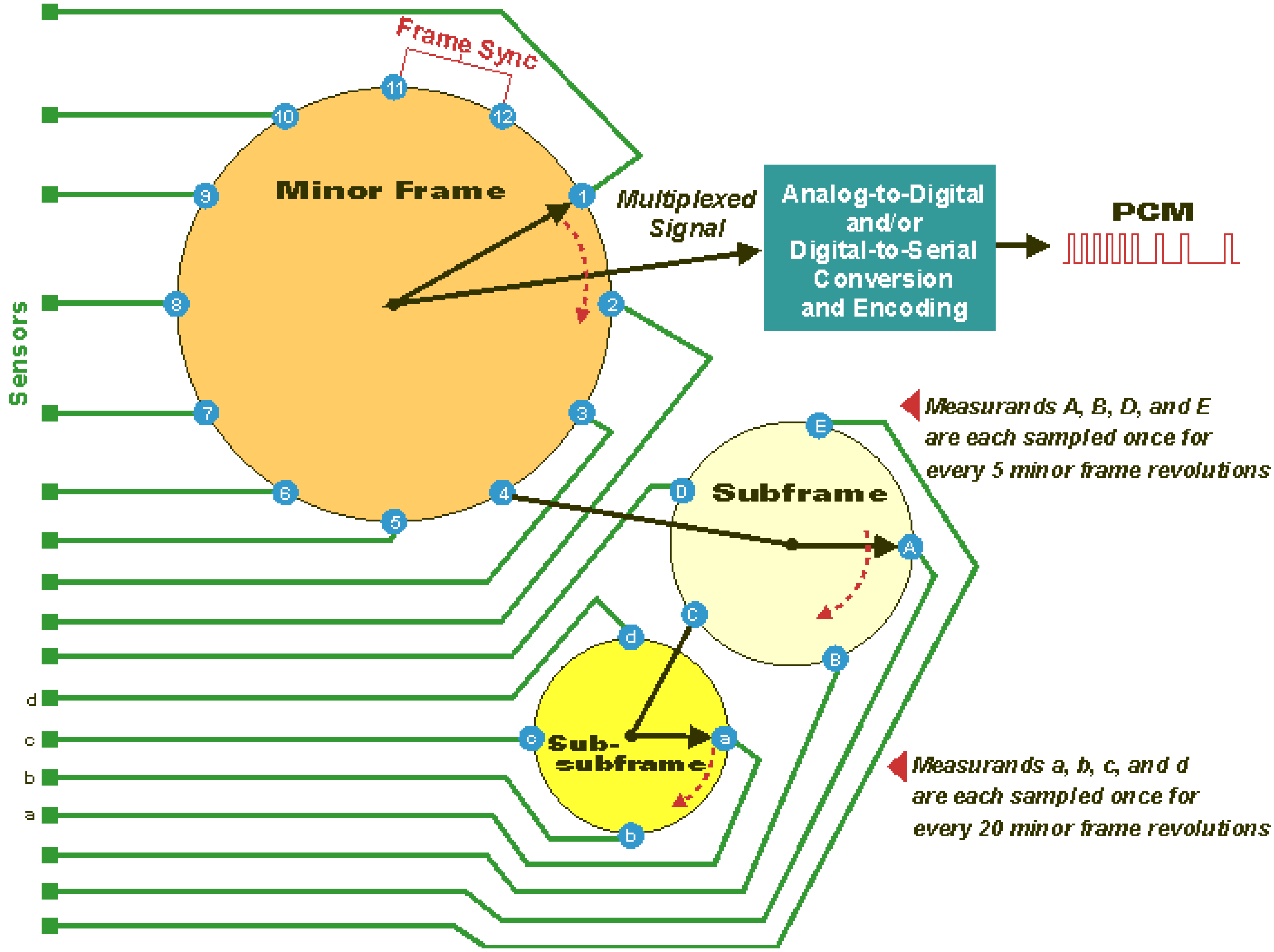
A sub-subframe consists of a group of measurands that occurs at a slower data rate than measurands in a subframe. Using supercommutation and subcommutation, you can easily achieve a 1,000 to one difference in sampling rates. Sub-subframes can easily add another depth of 10, for a 10,000 to 1 sampling ratio. To maintain the major frame data rate, each time the major frame word reserved for the sub-subframe is encountered, the next major frame word's worth of the sub-subframe data bits are entered into the PCM data stream.

The sub-subframe counter provides the only sync required for the sub-subframe. It counts the number of words in the sub-subframe. A sub-subframe counter must be defined as a major frame measurand and be inserted into the major frame for each sub-subframe defined.



The following figure is a mechanical wheel analogy illustrating the relationship between major, super, and minor frame and subframe multiplexing.

Sub-subcommutation



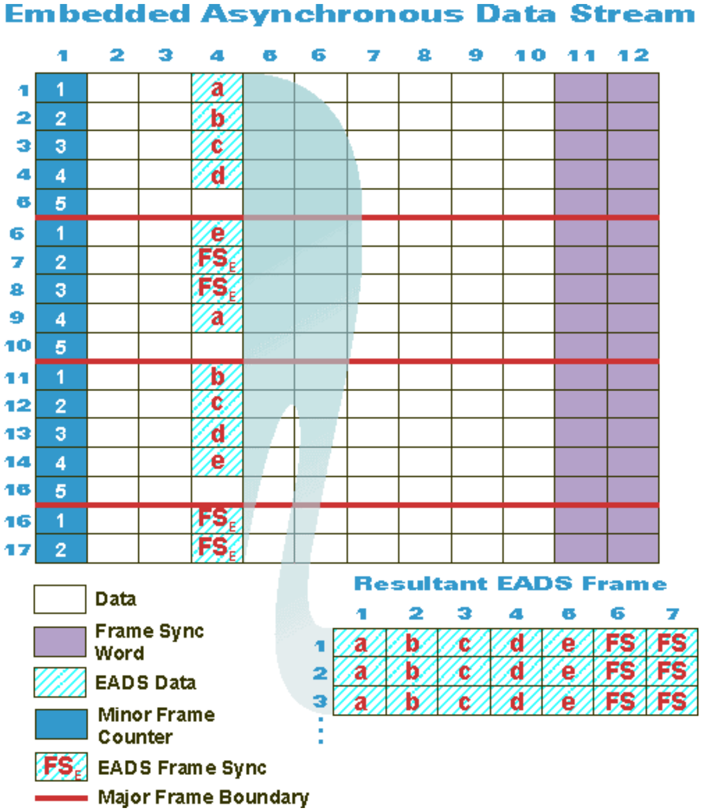
Embedded Asynchronous Data Streams

One or more completely independent, slower, asynchronous data sources, including those from an avionics subsystem, a serial output, a computer, or a video sensor, can be merged with the main telemetry stream to form an embedded asynchronous data stream (EADS). These embedded streams include overhead and synchronization words and are inserted into reserved words in the main frame. The embedded asynchronous data stream is a completely independent major frame and includes frame and subframe sync words. Each EADS word can be a discrete binary, octal, decimal, or hexadecimal format. CRC words can also be sent in the minor frame word along with flags for stale data (new data not present when required by the encoder) and overflow data (more data available than allowed for in the main frame). Since the EADS' embedded frame data rate is asynchronous to the minor frame, there is a chance that either more data is available than can fit in the EADS, with resultant data loss, or that there is insufficient data available to fill the frame.

The term asynchronous is used with respect to the appearance of the EADS' sync words. The EADS frame sync moves in time among the EADS words. This is the case in a frame with multiple EADS word locations where frame lengths are not even multiples of each other. The main frame may also be designed such that the main encoder is either in word synchrony with the EADS stream or that filler words are added when real data is not yet present (the ground system will need to remove this extraneous data).

At the ground station, a hardware decommutator extracts and directs the EADS words to an independent hardware decom for decommutation. Multiple independent EADSs can be supported by one main stream. Each of the streams is sent to its own decommutator. In theory, each EADS could have its own EADS, but in reality, this low sample rate is not seen. If the EADS is a much slower stream than the main stream, decommutation can be accomplished by a "software decom" in a front-end real-time processor or workstation. The IRIG-106 Standard indicates a maximum of two independent EADSs per major stream.

The example below requires transmission of 11 major frames to receive two EADS frames (assuming that the word lengths of both frames are identical). This is not a constraint for the EADS word in the main frame; it is just a series of bits in the embedded stream.



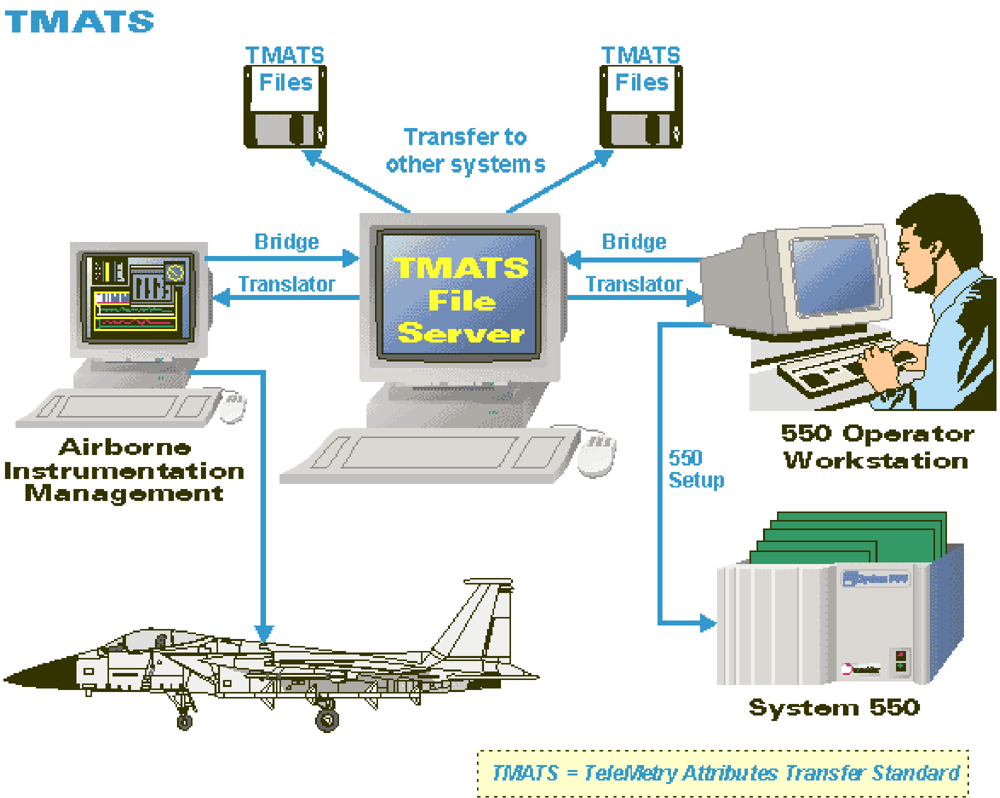
Ground System

Setup and Control

All the robust features of a ground system are for naught if you cannot easily set up and control it. This is where the term "user-friendly" takes on importance. Setting up a telemetry ground station includes:

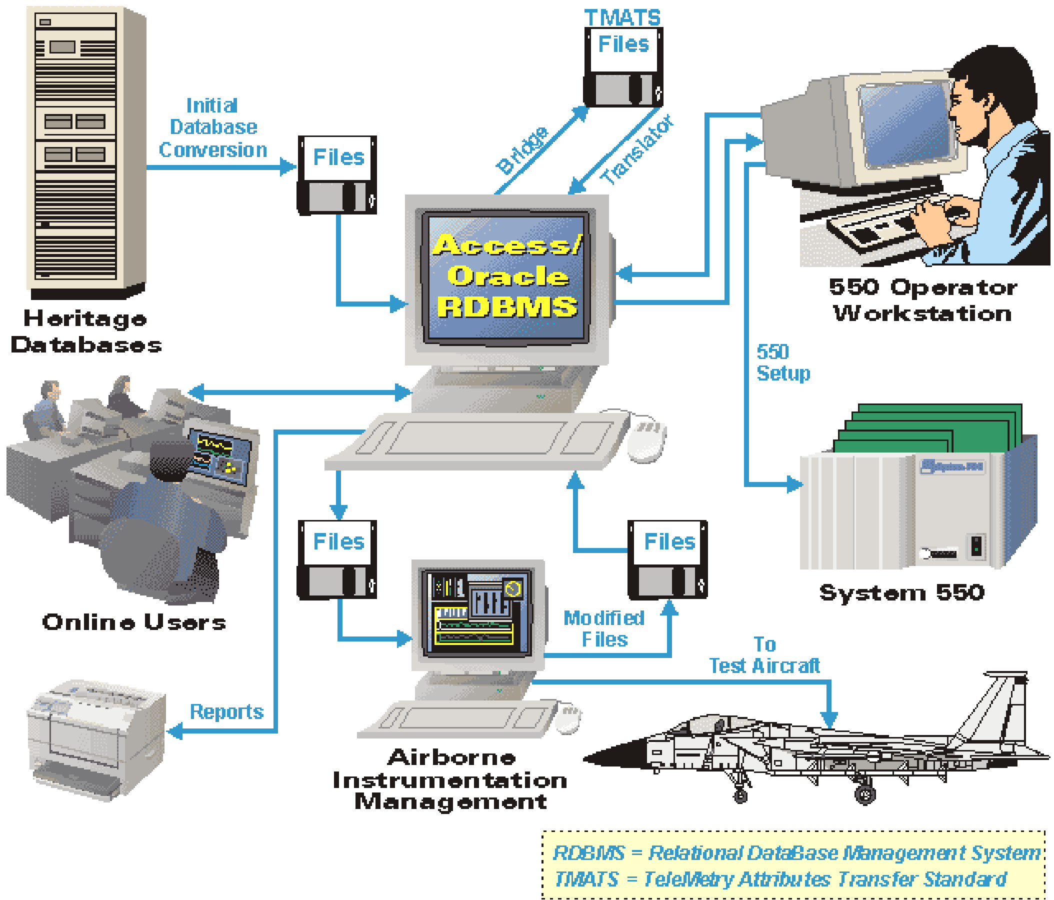
- Creating the definition for the data acquisition system, including sensor characteristics and signal conditioners.
- Defining the telemetry frame(s) to accommodate sampling rate requirements as well as limitations of the acquisition hardware. The stream is defined down to the word and bit level if results will be displayed or data analyzed in real time. (Wizards are available to automatically create the frame definition based on constraints and requirements.)
- Defining data for appropriate words in the stream to drive the PCM simulator for system checkout and training.
- 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.
- Allocating measurands and derived parameters destined for strip chart recorders and other output devices.

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. Chapter 9 of the IRIG-106 Standard defines an intermediate structure to specify a telemetry stream along with information about the data acquisition system and real-time processing . Use of the TeleMetry Attributes Transfer Standard (TMATS) is an increasingly popular method to transfer files between non-compatible ground systems. Since each system uses a different internal format, translators are required to convert data to and from the TMATS intermediate format.



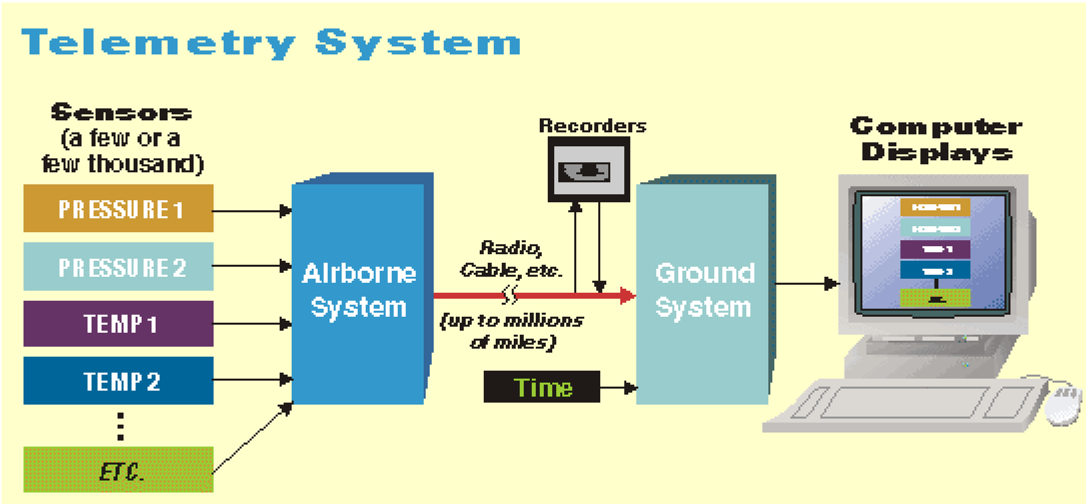
Other, more elaborate alternatives utilize a relational database management system (RDBMS) such as Microsoft Access or Oracle to maintain setup files for airborne, flight line, and ground systems. Information regarding the calibrations, data streams, etc. requires entry only once. Not only can these systems produce the complete set of setup files — from airborne sensors to ground station displays — but they can maintain historical files to recreate any specific test scenario. Generally, these are one-of-a-kind projects tailored to specially configured airborne and ground systems and they adhere to the methodology of the ground center. Recent vendor alliances and acquisitions offer purchasers a single source like L-3 Communications for an integrated system to set up and manage all telemetry system components

RDBMS for All Setup Files

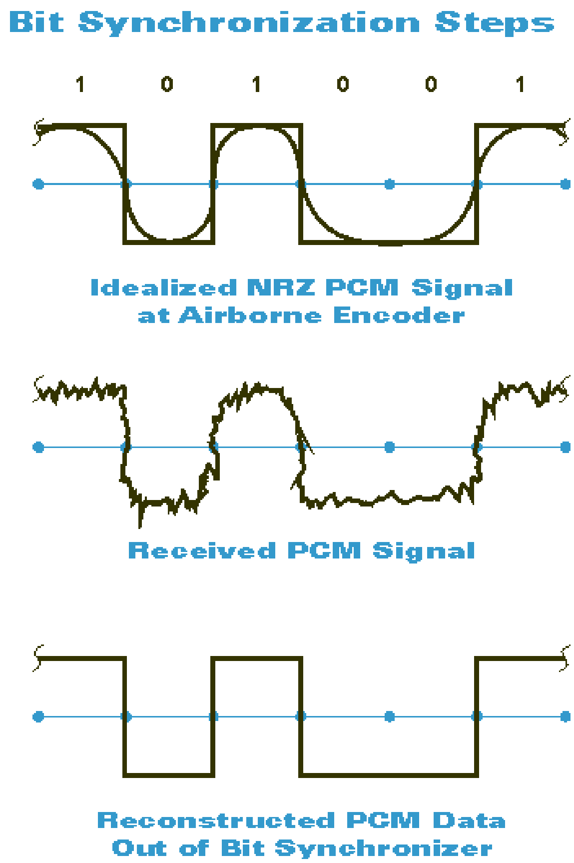


PCM Stream Reconstruction

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.



Because transmission distorts data for both transmission mediums (wire versus "antenna"), the received PCM data signal must first be reconstructed. Prior to transmission, the square wave PCM stream is filtered to round the wave train, thus reducing the bandwidth required to carry it and ensuring power is concentrated in the spectrum carrying the data. 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. The bit sync then classifies the value of each bit in the stream.



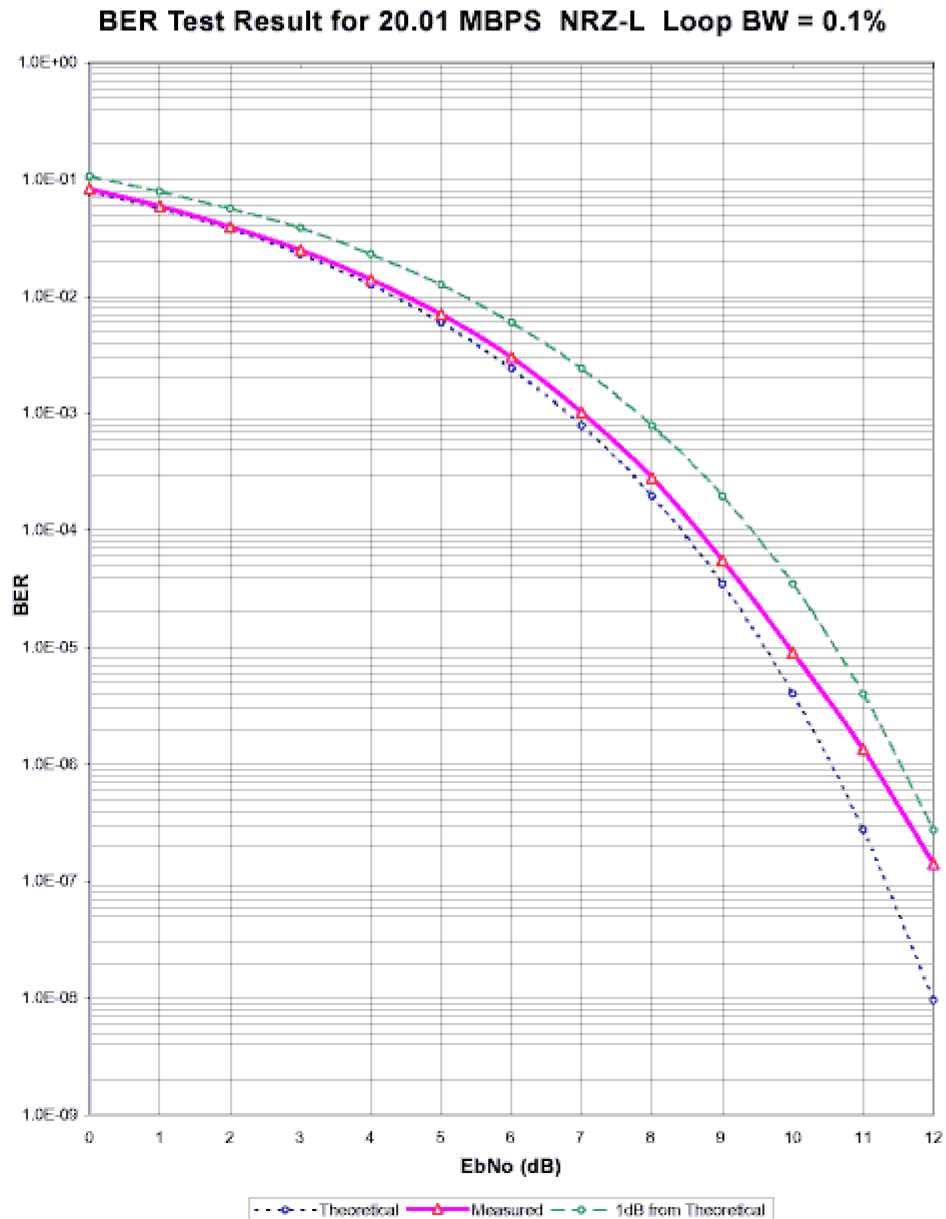
Bit syncs are available in a number of form factors. Heritage units typically occupied an entire 5.25-inch by 19-inch wide rack-mount chassis with controls for setup and LEDs for status. More recent technology, as used in L-3's EMR 832 or MBS 720 (shown below), supports up to four independent streams, continuously tunable to 30 Mbps — all in the same rack space as a heritage single channel unit. Similar technology is used in board-based bit syncs, which come in a variety of form factors such as VME and PC.

The bit synchronizer includes multiple inputs and allows the ground station to select the one of interest (e.g., telemetry receiver output, PCM simulator, or instrumentation tape recorder). The signal is amplified and an internal oscillator phase-locks to incoming data. Each bit is reconstructed by a conventional "hard" decision (0 or

1) circuit that produces bit decision accuracy within the unit's theoretical "signal-to-noise ratio versus bit errors" curve. If not originally in an NRZ-L format, the signal is converted and output to the next step in data reduction — the decommutator. Data is also output in any format for storage on an instrumentation tape recorder. At playback, the signal is reintroduced into the bit sync and output to the decom. Often, the tape is sped up by factors of 2, 4, and even 8 to decrease processing time.

The most frequently cited measurement of bit sync quality is "bit error rate probability as a function of input signal-to-noise ratio with respect to the theoretical." Typically, a goal of 1 dB of theoretical over the entire range of operation is specified (see the figure below). Bits syncs such as the EMR 832 achieve at least this result.

Other measures of performance include susceptibility to signal flutter when played back from analog tape recorders, the ability to support the time codes, and short acquisition time.

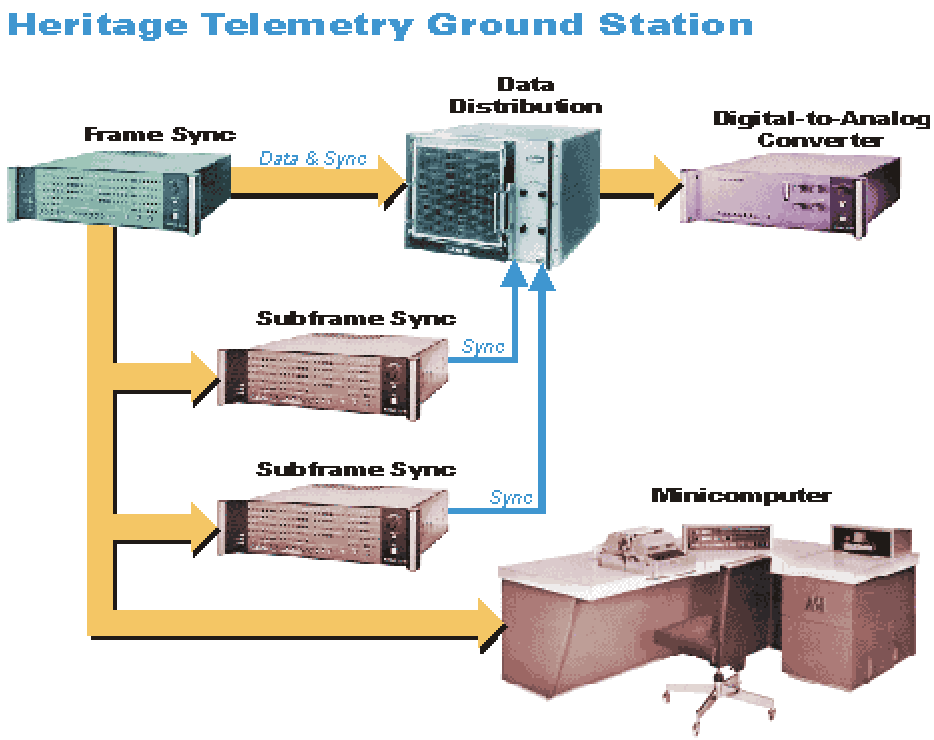


The next processing step is frame synchronization ...

Frame Synchronization

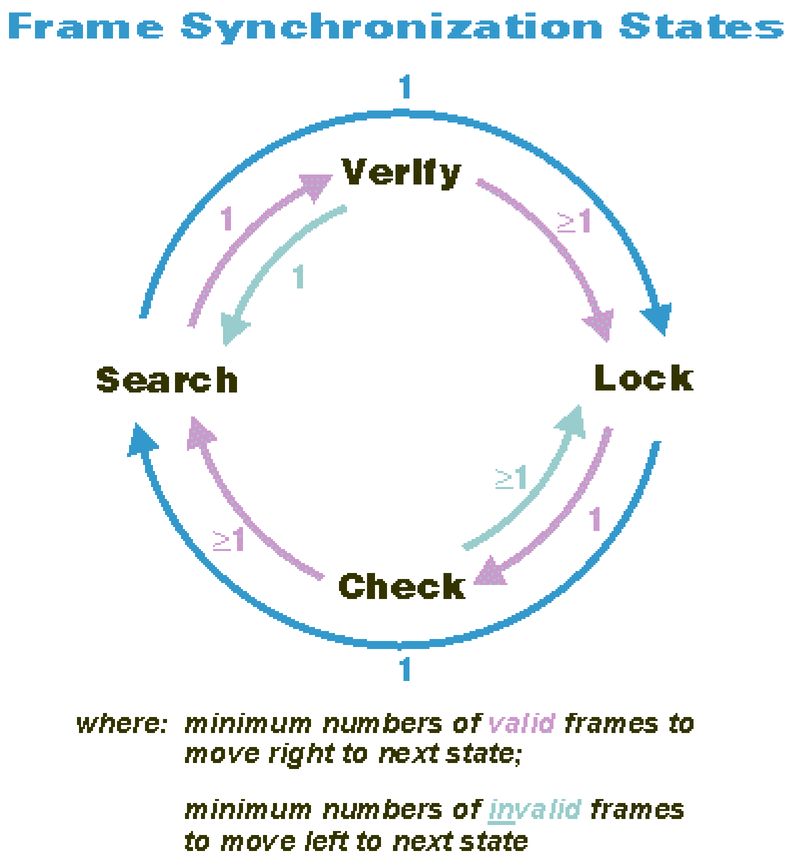
The reconstructed PCM telemetry stream remains a serial wave train of 1's and 0's. Before converting this serial stream into words containing characters, numbers, nibbles, and individual bits, the reference point or synchronization word must first be isolated. This is the task of frame synchronization.

Heritage ground telemetry systems required a frame synchronizer, a dedicated 5.25-inch by 19-inch rack-mount chassis, to isolate minor frames. The frame sync first located the frame synchronization pattern and then passed the frame of fixed length words to a word selector, subframe selector(s), or computer for decommutation into individual words. The word selector passed a few chosen words to an annunciator or strip chart recorder for real-time quick-look.



Today, the functions of frame synchronization, subframe synchronization, and decommutation of all words occupy a single decom board (even a fraction of a board).

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 diagram and definitions below:



- **Search** — The synchronizer looks for a possible sync pattern.

- **Verify** — 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. If the pattern recurs in the sync window for a prescribed preset number of frames, the synchronizer advances to lock.

- **Lock** — 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. Once frame synchronization is established, commutated and supercommutated measurands can be identified since the position of the data values is known relative to the frame sync pattern.

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

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

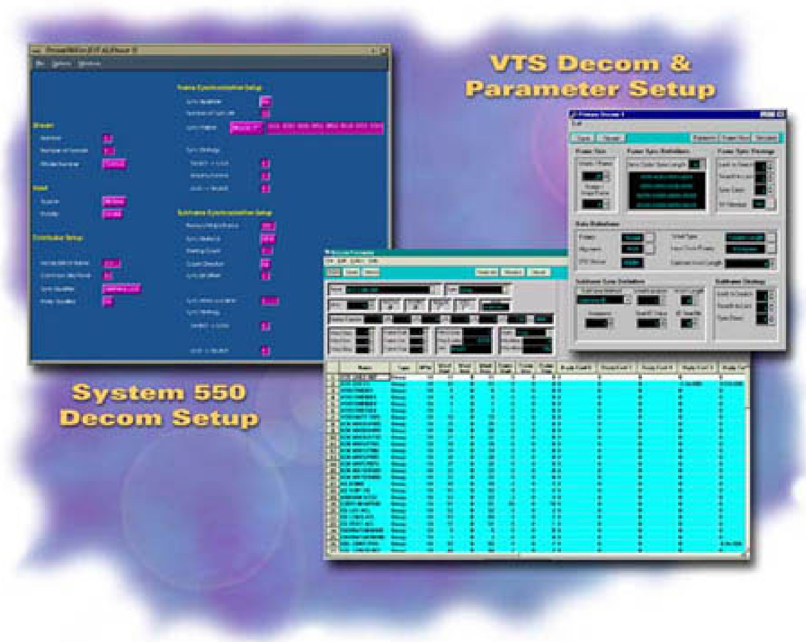
- **Lock to Search** —Number of consecutive invalid frame synchronization patterns that must be detected in the data stream before the decom goes into search mode. For example, if the constraint is set to 3, the decom will go into search if it detects three consecutive invalid frame synchronization patterns in the data stream. When it detects the first invalid frame synchronization pattern, it advances from lock to verify mode. It remains in verify mode when it detects the second invalid frame synchronization pattern. If the third frame synchronization pattern is invalid, it advances to search; otherwise, it will return to lock.

If the constraint is set to 1, the decom will bypass the verify mode and go right into lock upon the identification of one frame sync pattern.

- **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. For example, if you enter 3, the decom will not advance from search to lock until it detects three consecutive valid frame synchronization patterns in the data stream. When it detects the first valid frame synchronization pattern, it advances from search to check mode. It remains in check mode when it detects the second valid frame synchronization pattern. If the third frame synchronization pattern is valid, it advances from check to lock. Otherwise, it will return to search. A 100% match of the actual to programmed pattern may not always be attainable. Thus, decoms have several programmable options to allow advancement to the next state.

- **Sync Pattern Bit Errors** — Calculates the number of correct bits in the synchronization pattern for a valid pattern. For example, if the synchronization pattern is 32 bits long and the Sync Pattern Bit Errors is set to 4, then the decom will look for 28 good bits in a pattern.

- **Bit Aperture** — Allows or disallows bit slips in the frame synchronization pattern. Four example, 1 allows the frame synchronization pattern to be "early" or "late" by one bit time and still be valid for a lock state. Similar techniques can be used to detect subframe sync words. While sync words test the overall integrity of one location, a Cyclic Redundancy Check (CRC) word may be included in the frame to check the integrity of an entire frame (although this is not included in the IRIG-106 specification). The next figure shows an example of the decom status pages of L-3 Telemetry-West's Visual Test System and System 550.



Decommutation

After frame synchronization, individual measurands are identified according to the frame location. Hardware architectures differ in how they equate and maintain the data/definition relationship. For example, a unique tag may be appended to each raw measurand or data word in what may be called a data flow architecture. This tag remains with the data word unless it is changed; i.e., EU converted, processed, or its bits manipulated. 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.

The decommutator also identifies and extracts embedded asynchronous data stream (EADS) words. Words for each EADS are re-serialized and sent to separate hardware decommutators along with clocks, or if data rates permit, to a general-purpose embedded processor or workstation as contiguous bytes for software decommutation algorithms. All words in the same EADS stream have an identical tag or name. Thus, a major frame may have multiple EADS streams, each destined for an independent decommutator. The IRIG-106 specification calls out a maximum of two EADS streams, although some applications require even more. Analogous to sub-subframes, an EADS stream may itself have EADS stream(s).

Other features often found in hardware decommutators include the ability to support words of different lengths, multiple CRC and parity checking types, and selectable data alignment (MSB/LSB) on a per word basis.

Applications such as monitoring multiple stage rockets or testing multiple systems on one aircraft require changing the set of measurands being monitored. That means the contents of the entire frame will change significantly, if not completely. You could use a single large frame covering all measurands. However, the spectrum required to transmit this larger number of words is too large. Instead, formats are changed as each stage is jettisoned or test points fluctuate. The change occurs on the value of a specific measurand. A multi-format decom will switch to a new format either on the next word or next frame without loss of data. To achieve such a rapid response, the decommutator contains all the possible frame definitions in memory. The IRIG-106 Standard specifies a maximum of 16 formats. Only a few formats are typically used in aircraft flight test and rocket launches. Still, over a hundred formats may be used by a few satellites to accommodate relatively low data rates and multiple modes of operation. Fortunately, data rates are slow and could be accommodated by software 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 (e.g., audible and visual feedback if the words entered for a minor frame contain more bits than what is defined for the frame). To aid in data entry, tools automatically create dummy measurand names, or for a super-commutated frame, create multiple instances of measurands automatically based on frequency, etc.

Flight test programs often deploy multiple airborne and ground systems. Each system has unique data structures to define commutation and decommutation frame layout plus the governing attributes of the data acquisition devices or the ground displays. Each system may use independent databases. And each requires that redundant data be entered in a unique format.

Personnel at large ground stations generally develop their own capability to convert one database format to another. The alternative is manual reentry and testing of each database. Limiting a test program to a single hardware suite is not always possible, which can be quite cumbersome as programs may last many years, precluding use of newer technology. Similar hurdles exist if unique test resources are only available at distant test facilities, each with different equipment (e.g., major differences in operating climates, threat simulators, munition test areas, etc).

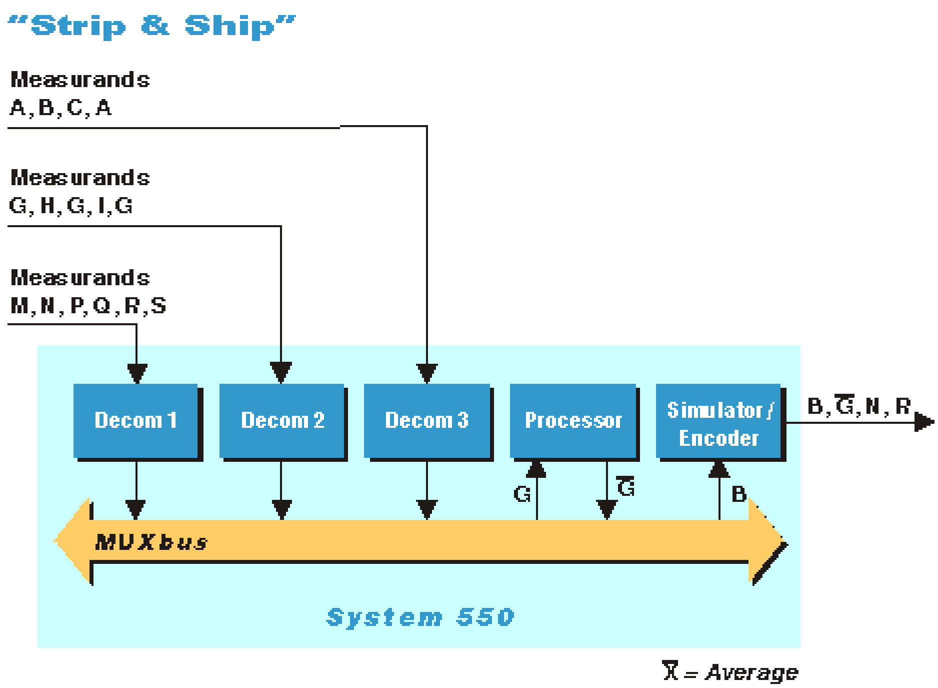
To eliminate the tedious task of database re-entry, ground station manufacturers have developed their own set of translators to support their equipment. A few have built this capability around a general-purpose relational database (RDBMS) such as Oracle or Microsoft Access. Recently, IRIG-106 included the definition of the TeleMetry Attributes Transfer Standard (TMATS), an intermediate common format that each ground and airborne system can use for data transfer. Today, a superset of the TMATS specification is required to encompass all the attributes of the airborne and ground systems.

Simulation and 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.

Simulators vary in performance; some produce a simple static frame at fixed rates, while others create the most complex frames and data rates to match the decommutator's capabilities. Describing the frame format for setup may not be required since the telemetry system can produce it from the decommutator's setup definition. The simulator produces major and minor frames, including super-commutated, sub-, and sub-sub frames; and multiple embedded asynchronous data streams. The PCM output signal is available in any of the standard IRIG codes and levels. Simulators and encoders also provide MSB or LSB word orientation, programmable synchronization words, and support for format switching. 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. An example of the former is to control the operation of a satellite, while the latter is for an airborne-based ground station to forward key measurands to the ground station during flight tests (see figure below). The airborne ground station not only selects all instances of individual parameters, but may compress them (e.g., averages values or combines multiple measurands, as in processed parameters).



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 (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.

To L-3 Telemetry-West, real-time processing means producing all the results from an algorithm before the next set of measurands arrive. The alternative is non-determinism and loss of data until processing resources are available. While buffering data for a very short period may be acceptable, loss of data is not. Adding more or faster resources may not produce desired results. In cases like this, you need a high-performance deterministic system that supports linear processing growth, where doubling the number of processors doubles processing resources.

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. It is up to the real-time processor to assemble the new measurand and inject the result into the stream for further processing.
- **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.

Off-the-shelf ground systems, like those from L-3, typically include an extensive algorithm library appropriate for a variety of telemetry applications (see the table below for a general military flight test algorithm library).

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
m average
m steady state
steady state
sum over n
trig value
word rotate

Logical
gray code convert
logical functions
trigger on parameter

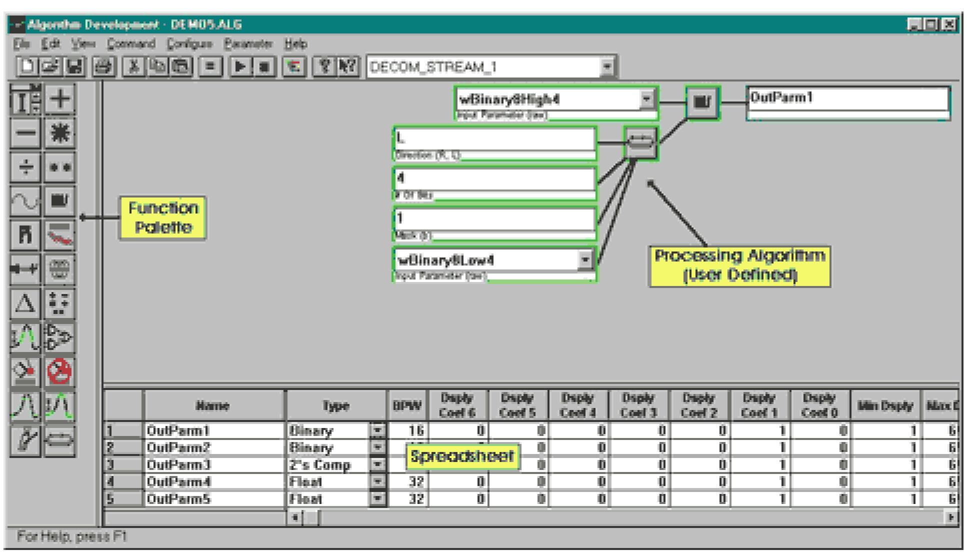
DSP
FIR

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

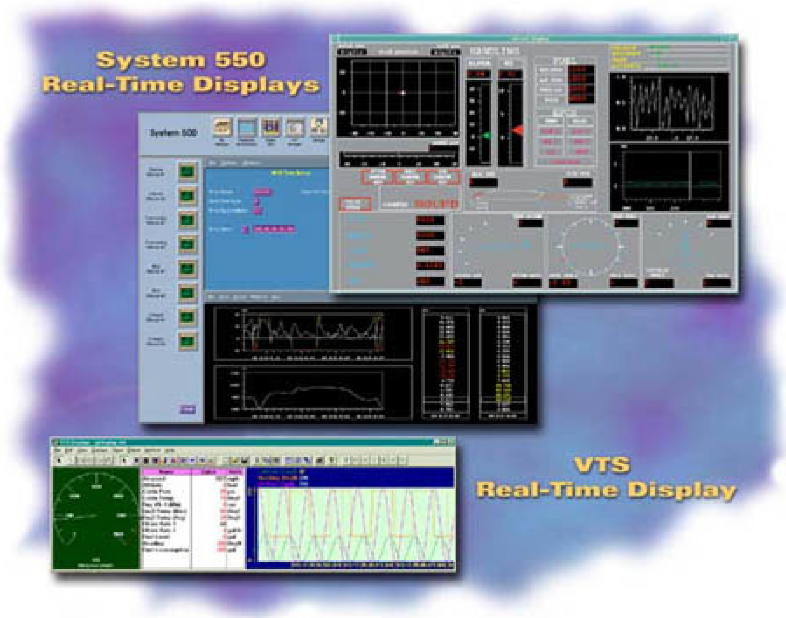
A GUI eases the creation of the ground system setup database for real-time processing. L-3 products incorporate GUIs that range from simple fill-in-the-blank displays to elegant drag-and-drop techniques, where you can build a logic tree from a palette of functions, easily enter data, and select parameters with a point and click.



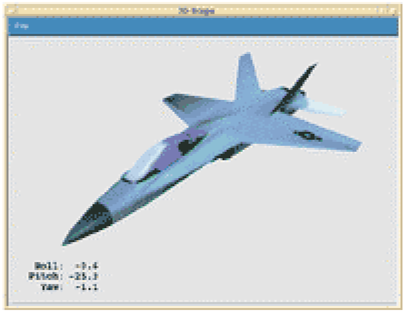
With L-3 systems, you can create your own application-unique real-time algorithms in traditional computer languages such as C, C++, and Java.

Real-Time Displays

Video displays are *the* conduit for real-time alphanumeric and graphic measurands and processed data. Local area networks and the Intranet expand the domain of displays beyond the operator's console so that each user can view data of interest in a meaningful manner independent of others. Telemetry streams can produce too much data for a single person to comprehend as alphanumeric information. Displays ease the task of interpreting raw measurands faster than the eye can fathom, depict when measurands are within safe and meaningful limits, show relationships between measurands, and spot trends. To assist these efforts, telemetry ground systems developers like L-3 developed a wide variety of customizable display objects, including strip charts, bar charts, vertical meters, round gages, cross plots, and annunciators, as well as tabular displays, orientation displays, and bit maps.



Each display type can easily be tailored with respect to size, foreground and background colors, fonts, grids, time and data format, etc. To speed comprehension, data can be presented in engineering units, as opposed to raw transducer output. The attributes of the object can change as the color of a curve or numeric value changes when a measurand approaches or is out of limits. In addition to processing algorithms, which detect changes, large time scales make it easier to visualize trends. Dynamic 3-D models of objects under test can be used to show orientation, as opposed to interpreting a table of numeric orientation values. And multiple objects can be grouped into a single window to form instrument panels.



Windows can be created for a test plan that is used over and over either with the same measurands and processed parameters or with new ones as required. Each version can be renamed and saved. Measurands and parameters can be changed in real time. Similarly, attributes such as limits can also be changed. Standard drawing and graphics tools are useful in creating process diagrams and embellishing control panels. The detail and complexity of displays is left entirely to your creativity.

Snapshots of events can be sent to color printers or saved to disk for inclusion in reports. Features such as local disk and ring buffers associated with video displays, and independent of system archiving, give operators the ability to recreate data leading to an event of interest.

Archiving

Telemetry data captured during operation of the ground station must often be archived for post acquisition analysis and to satisfy legal requirements that the vehicle under test was properly certified.

Typically, data is stored immediately in the ground system, as close to the received signal as possible (expensive instrumentation recorders store the PCM signal immediately after bit synchronization). Data is also archived to disk after decommutation and/or processing and is then backed up to inexpensive cartridge tape (e.g., DAT, 8mm, DLT). Selected measurands and processed parameters or the entire PCM frame can also be archived.

Current single disk technology permits storing an entire continuous 40 Mbps PCM stream for only 3 hours, and less if measurand and time tags are required. Archiving time may be extended by storing only time segments or reducing the number of measurands, i.e, data compression (see real-time processing). Conversely, if archival of EU-converted and processed data is required, storage requirements increase and archiving bandwidth may not be adequate. Bandwidth and volume size may be increased by recording to multiple disks in parallel (RAID subsystems). Single UltraSCSI disks achieve 10 MB/sec continuously over their entire 72 GB capacity, while an UltraSCSI RAID can archive rates approaching 40 MB/sec and 80 MB/sec for Fibre Channel. Archiving directly to commodity tape drives is limited to a few MB/sec and up to 15 MB/sec for expensive proprietary architectures. The system design using real-time tape must incorporate large buffers to accommodate the time required for the drive to reach operating speed.

Archiving the time of acquisition with data consume a large segment of both storage space and bandwidth. One extreme tags each measurement with either a minor time (least significant portion), only placing the entire time record periodically (once per telemetry frame). A more economic solution for synchronously acquired data is to insert time periodically; for example, at the end of each frame or block. The time associated with the acquisition of a particular measurement can be interpolated from its position in the telemetry frame. Storing aperiodic data requires time-tagging. Data playback from disk offers a challenge since measurements must be continuously metered to recreate continuous or real-time displays on workstations or strip charts.

Archival Media and Device Summary		
Media/Device Type	Uncompressed Capacity (GB)	Continuous Rate (MB/s)
Random Access		
Floppy	0.001	0.125
Optical	0.65	1
Disk drive	72	10
RAID	576	37
Sequential		
1/4" cartridge	0.15	0.09
1/2" reel	0.18	0.75
Beta	7	1
IBM	0.8	3
DAT (DSS-4)	20	3
VHS	10	4
DLT	40	5
Instrumentation	0.46	12
DTF	42	12

DCRsi	47	30
IDI	95	32

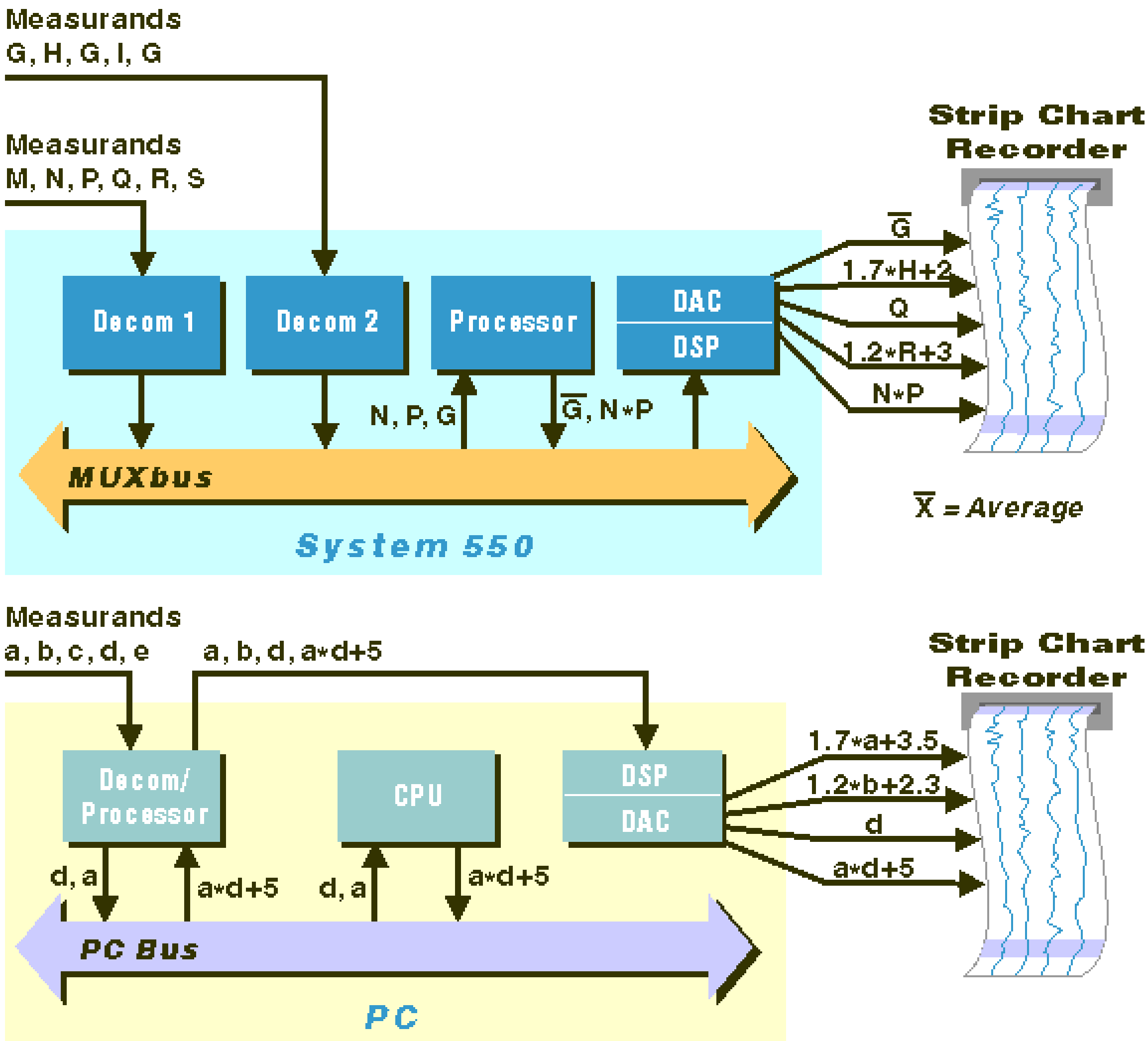
Data Distribution

Telemetry ground stations distribute a variety of real-time and post-flight products to a diverse group of customers. Typical ground station output for visualization is an 8-channel continuous pen strip chart recorder. The advent of powerful color graphic workstations and PCs has not replaced recorders for a number of reasons.

For many workstations, chart recorders continue to be important, despite the fact that technology has advanced from ink pens or heat styli to thermal arrays with laser printer resolution. The most common recorder interface continues to be analog, even though both the recorder and ground station are digital. Ground systems must therefore first convert a measurand's digital representation to analog; then the recorder digitizes the signal for presentation as an analog wave. Hardware architectures designed for telemetry incorporate schemes to ensure continuous deterministic data output. Such architectures permit selective output of any processed or derived parameter, even archived ones.

As far as PCs go, lack of determinism by the PC's operating system prevents sending real-time prime, let alone processed parameters to digital-to-analog converters (DACs) over the ISA or PCI bus. Therefore, in PC-based telemetry ground systems like L-3's Visual Test System (VTS), selected raw digital data measurands are taken directly from a decom (over the top as opposed to the system bus) to a DAC or analog port for output to the strip chart's analog input. The DAC module may incorporate a DSP chip to perform polynomial conversions to scale and produce output in engineering units. (Processed parameters require a more exotic, auxiliary processor solution.)

Processed Data to Strip Chart Recorder Architecture



Local and wide area networks (LANs and WANs) permit distribution of real-time data to multiple client workstations, where separately data can be viewed, analyzed, and archived. The same applications software running on the ground system PC will function on the clients, producing an identical look-and-feel. The workstation's non-determinism issue, seen with video strip charts, is not encountered as the display is discrete pixel based as opposed to the pure time base of recorders. That is, paper moves whether data arrives or not, while the display's trace only moves when new data arrives.

The concept of continuous playback is lost in disk archive playback. Consider that when a request for data is made to a disk file, the entire block is returned simultaneously. Clearly, a metering mechanism utilizing embedded time is required to produce synchronous data at the original or another continuous sampling rate.

An alternative for recording archived data is to recreate the PCM stream in a simulator/encoder that clocks out data regularly and then decommutates and converts it to analog — a roundabout mechanism to be sure, but quite accurate.

Another real-time output is parallel digital words (discretes). This output will drive annunciator panel lamps, showing the status of important measurands, control switches, etc. Many of the annunciator panel functions can be replaced by workstation displays where the entire screen or smaller window is a completely reconfigurable annunciator.

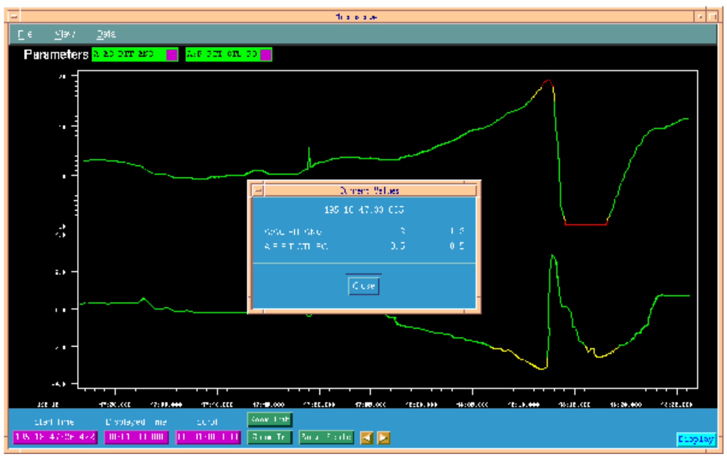
Large ground systems often have a requirement to distribute real-time data to heritage mainframes and proprietary memory mapping networks. When interfacing to mainframes and nodes, care must be taken to ensure that they are not overwhelmed by high-rate telemetry data. Large buffers allow a non-deterministic system to cope like a rubber band. But unless the heritage system has adequate performance, the buffer will overrun. One way to alleviate this problem is through data compression, i.e., reducing the amount of data transferred by taking only every nth sample, an average, or changes in values, or by using a current value table. In the last example, you can periodically interrogate a memory table for current measurand and/or processed parameter values. Both systems must support anomalies such as stale data (value(s) previously collected) since only a portion of the samples may be acquired and the application on the external system must be aware of data loss.

Post-Test Analysis

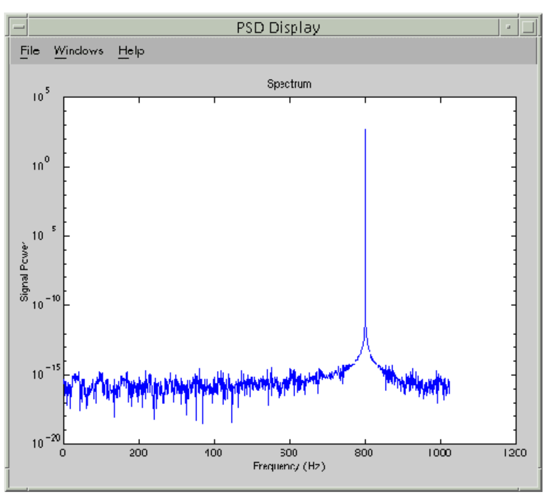
After viewing and interpreting real-time results, what happens to the archived data?

If the original streams were stored on an instrumentation tape recorder, data can be played back as originally recorded through a bit synchronizer and decommutator. Data can once again be viewed, processed, archived to disk, distributed, or sent to strip chart recorders for reports. You can continually repeat this process if you are interested in analysis by inspection. The tape can be replayed multiple times in real time if the ground system components (bit sync, decom, processor, and disk) all support these higher rates.

Another visual analysis technique extracts all instances of measurands for the entire test (hours, even days totaling millions of points) for display in a single window. While this places many instances on a single vertical line, out of tolerance data, whether trends or spikes, is highly visible. You can repeatedly focus in on significant data using a zoom technique until multiple pixels show a single instance. This technique greatly reduces the time required to seek aberrations and review areas of interest (from hours to milliseconds).



In addition to visual analysis, a host of third-party general-purpose analysis and visualization programs can be utilized to evaluate archived data, extract results, and produce reports. Each has its benefits and followers and is available for both UNIX and PC platforms. Some are essentially high-level analysis languages (MATLAB and PV-Wave), while others are GUI-based (Excel, DADiSP). All include a rich set of signal analysis and statistical tools from Fast-Fourier Transforms (FFTs) to t-tests. They may have links to process piped data for near real-time processing as shown in the example below, where MATLAB is used to feed a power spectral density (PSD) graphic from FFT algorithms. Often, scripts are used to create a batch process of reports from an entire test.



Additional Sources

Books in Print:

Strock, O.J. *Introduction to Telemetry*. Instrument Society of America (1987)

Strock, O.J. and Rueger, E.M. *Telemetry Systems Architecture*. Instrument Society of America (1995)

CD ROM:

Telemetry, a Short Course for the T&E Professional, Defense Test and Evaluation Professional Institute (1997)

World Wide Web:

Range Commanders Council Home Page http://tecnet0.jcte.jcs.mil:9001/htdocs/utl/plan/webdemo/Indexrw.htm

Range Commanders Council's List of Available Standards and Documents
http://tecnet0.jcte.jcs.mil:9000/RCC/doculist.htm

Glossary

Anti-alias Filter with respect to digital bit synchronizers is that analog function responsible for eleiminating noise signals greater than ½ the analog-to-digital sampling rate. Anti-alias filters can also affect the data detection performance of a bit sync, particularly at symbol rates approaching the cut-off frequency.

BER (Bit Error Rate) Performance is a fractional statistical measurement in bit errors per bit relative to Eb/No. Graphically presented with BER on the Y-axis with a log scale and Eb/No on the X-axis in dB. Random errors from gausian white noise can create a maximum BER of 0.5.

BERT (Bit Error Rate Tester) is any device, which can simultaneously transmit and receive a digital signal and derive a BER measurement by comparing the received with the transmitted signal. More sophisticated BERTs can add gausian noise and can include many other features helpful in testing bit syncs.

Biphase-L, -M, -S-Biphase –Level, -Mark, -Space are a set of PCM codes where there is at least one transition, but no more than two transitions in a bit period. In biphase-L a '1' is represented by a falling edge in the middle of the bit period and a '0' is represented by a rising edge. Unlike NRZ signals, biphase signals have no significant spectrum near DC and so are desirable when using media where DC response is not possible.

Bit Synchronizer is a device that establishes a series of clock pulses which are synchronous to an incoming signal. It then identifies each bit in the signal. The desired condition of a bit sync (i.e. lock) when the output data and clock signals match those of the transmitted signal. The bit rate of the output will average to the same as the transmitted signal and the phase will remain within 180 degrees.

Bit Acquisition is a statistical measurement of the number of bit periods between the beginning of a transmission and the last bit slip (if any) at the bit sync output.

Bit Slip is the occurrence of a 360 degree or more phase change at the output relative to the input.

Clock phase is a measurement of the phase relationship between a bit sync's data and clock outputs. Usually measured in degrees from a data transition to the rising edge of the clock where 360 degrees is 1 bit period.

Commutator is a device used to accomplish time-division multiplexing (TDM) by repetitive sequential switching.

Convolutional Encoding/Decoding is a technique using feedback shift registers to generate redundancy in a data stream for forward error correction. The original data is encoded into symbols at a multiplied rate where the higher the multiple, the better the error correction capability.

CRC is the acronym for **c**yclic **r**edundancy **c**heck. A procedure used in checking for errors in data transmission. CRC error checking uses a complex polynomial to generate a number based on the data transmitted. The sending device performs the calculation before transmission and sends its result to the receiving device. The receiving device repeats the same calculation after transmission. If both devices obtain the same result, it is assumed that the transmission was error-free. The procedure is known as a redundancy check because each transmission includes not only data but extra (redundant) error-checking values.

Data Detection is the function in a digital receiver where data symbols are identified.

Decommutator is a unit that reverses of the commutation process; separation of information in a commutated data stream into as many independent information channels as were originally commutated. A device that separates (or demultiplexes) commutated signals into its constituent measurands and data.

Derandomizer is a function that decodes randomized signals. See Randomizer.

Derived Parameter is a parameter that is not part an original telemetry stream's measurands, but is derived by processing the values of multiple measurands.

Differential-Data is extracted from the level of difference between two signals. Also called RS-422. Compare to Single-Ended.

Display is the visual output device of a computer, which is commonly a flat panel or CRT-based video display.

Display Object is the basic real-time dynamic unit within a window. For example: strip charts, bar charts, vertical meters, round gauges, cross plots, annunciators, tabular, orientation, and bit maps.

DM-M,-S-Delayed (or Miller) Modulation, -Mark, -Space are a set of PCM codes where there is at least one transition in each 1 ½ bit period and no more than one transition in each 1 bit period.

Eb/No-Energy per bit to noise density ratio is a measure of signal-to-noise ratio of a digital communications channel. Usually measured in dB. (0 dB means the signal and noise power levels are equal and a 3 dB increment doubles the signal relative to the noise.)

Encoder is an electronic version of a commutator.

Engineering Units (EU) are units of data measurement (e.g., degrees, Celsius, pounds, grams).

Filter-sample is a type of Matched-Filter implementation that takes into account the effects of past and/or future symbol levels in a band-limited channel.

Flash RAM is a form of non-volatile read/write memory.

Flywheel is the ability to generate a clock even without any input signal transitions. See Retention.

Forward Error Correction (FEC) is any technique used to transmit redundancy in a digital signal for the purpose of correcting random bit errors at the receiver without the need for a reverse data link.

FPGA-Field Programmable Gate Array is an integrated circuit where the functions of, and interconnections between, gates are programmable.

Frame in time-division multiplexing is one complete commutator resolution, including a single synchronizing signal or code.

Frame Synchronization Code is a unique 3- to 33-bit code, coded pulse, or interval that marks the end of a commutation frame period.

Frame Synchronizer is hardware that recognizes the unique signal that indicates the beginning of a frame of data. A typical frame synchronizer "searches" for the code, "checks" the recurrence of the code in the same position for several frame periods, and then "locks" on the code.

Input impedance is the load placed on the device driving an input. Ideally the impedance should be "matched" (the same as) the cable over which it is driven to prevent signal reflections that can degrade BER performance.

Integrate-Dump is a type of Matched-Filter implementation where signal energy is accumulated during a bit period. This technique matches "square wave" signals and is best used in non-band-limited channels.

IRIG for Inter-Range Instrumentation Group standard for telemetry on U.S. Government test ranges.

Jitter-Phase variation is usually measured statistically as a RMS deviation from a center value in degrees or radians. Usually caused in the input signal by noise but can be caused by encoders, modulators and channel distortion. Jitter is reduced by a bit sync depending on its loop bandwidth.

Loop Bandwidth is a characteristic of a phase locked loop (PLL) that limits the spectral response of a PLL. Noise at the input is generally translated to phase jitter at the output. By limiting the loop bandwidth, high frequency noise can be rejected by the bit sync, reducing the phase jitter. By increasing loop bandwidth, a bit sync is better able to acquire and track a time-varying PCM input bit rate. Loop bandwidth for PCM signals is usually expressed as a fraction of bit rate or transition rate.

Major Frame in telemetry formats, the time period during which all data (excluding sub-sub frame measurands) of a multiplex is sampled at least once. Includes one or more minor frames. Major Frame length is determined as (N) (Z) words. Where: N = no words per minor (prime) frame and Z = The number of words in the longest sub-multiple frame.

Matched Filter is the part of an ideal data detector implementation in which the receiver is looking for precisely the symbol waveform that was expected. Ideally taking into account the transmitted waveform and any predictable channel distortion. Also called correlation or auto-correlation.

Measurands are the physical or electrical quantity, property or condition which is measured. The term "measurand" is preferred over prime parameter to be measured.

Minor Frame is the period between frame synchronization words that includes one complete cycle of a commutator having the highest rate.

Modulation is the process of impressing information on a carrier for transmission. Various types include Amplitude Modulation (AM), Phase Modulation (PM), and Frequency Modulation (FM).

Multiplexer is multiple input digital device that can select one of a number of inputs and pass the logic level of that input to the output. Multiplexer size is normally defined by the number of bits of a single parallel input plus the ratio of the inputs to the output.

NRZ-L, -M,- S-Non-return-to-zero-Level, -Mark, -Space are a set of PCM codes where there is either zero or one transitions in a bit period. In NRZ-L a high level represents a ‘1’ and a low level represents a ‘0’. In NRZ-M a ‘1’ is represented by a transition and a ‘0’ by no transition in the bit period. NRZ-S is the inverse of NRZ-M. Mark and Space codes are used when a polarity neutral signal is desired, for example when transmitting encrypted data.

PCM (Pulse Code Modulation) is a class of digital baseband signals transformed to pulse waveforms. The timing and direction of level transitions in the waveform contain the digital information.

Phase Detector is the part of a PLL that measures the difference between the time of input transitions with the expected time.

Phase Locked Loop is a negative phase feedback technique for extracting a synchronous clock from an input signal. Implementations range from purely analog to various combinations of analog with digital and software. Second order loops are generally used in PCM bit syncs because of their strong retention and stability characteristics.

Processed Parameter is the resultant of the algorithmic manipulation of a single measurand (e.g., EU)

Pseudo-noise (PN) is usually meant to be a sequence of 1’s and 0’s generated by a feedback shift register and used to represent something resembling a random pattern. PN patterns are used in bit error testing in data communication channels because they simulate random data, and, are easy to generate at the transmitter and at the receiver for bit comparison. PN codes are generally identified by the length of the shift register. The larger the code the longer the sequence of non-repeating bits (2^n-1).

PRN-Pseudo-random noise or number. See PN.

Randomization is a technique in which a feedback shift register adds a PN sequence to the original data. This is used to add transitions to long sequences of 1's or 0's in the original data. The receiver subtracts out the PN sequence using a derandomizer, thereby recovering the original data. Randomized codes are generally identified by the length of the shift register. The IRIG-106 standard of 15 bit randomized NRZ-L code is usually employed.

Real-Time is the notion of completing a computing task before the next task arrives as in algorithm processing

Retention-(Bit rate retention) is a characteristic of a bit sync in which after acquiring an NRZ signal, the bit sync will correctly time bits during long sequences of no transitions without any bit slips. Usually measured by a statistical count of the number of bits of no transitions before a bit slip occurs within a otherwise random sequence transmitted every n bits.

Single-ended-A signal requiring only one wire for transmission. Referenced to ground.

Soft bit decision-An output of a matched filter that measures the relative (to other near-by bits) signal strength of a particular bit. Used as inputs to a convolutional and PCM decoder functions.

Subcommutation is commutation of a number of channels with the output applied to an individual channel of the primary commutator; subcommutation is synchronous if its rate is a submultiple of that of the primary commutator. Unique identification must be provided for the subcommutation frame pulse.

Sub-Frame A multiplex generated at a slower rate than a frame, and input to the frame through one of the channels.

Sub-Sub-Frame A multiplex generated at a slower rate than a frame, and input to the frame through one of the channels.

Supercommutation(1) Commutation at a higher rate than once per commutator cycle. Accomplished by connecting a single data input source to equally spaced contracts of the commutator (cross-patching). Corresponding cross-patching is required at the decommutator. (2) The technique of "strapping" commutator inputs to the same measurement point, such that it is sampled two or more times per minor frame.

Symbol-The shortest unit of transmission in a digital channel consisting of one of n possible waveforms. There may be more than one symbol per bit as in a convolutional code, or more than one bit per symbol as in QPSK.

Sync threshold is the minimum Eb/No at which a bit sync will acquire the input signal.

Tape output normally the PCM output of a bit sync that tracks the PCM input but optionally with a different code. The function generating a tape output is sometimes called a "code converter." Normally intended to be used to record a better quality signal on an instrumentation tape.

Telemetry is the science of measuring quantities, transmitting the results to a distant station, and interpreting, indicating, and/or recording the quantities measured.

Tracking is a characteristic of a bit sync where the output bit rate varies with (follows) the input bit rate. Track range is a measurement of tracking and defines the range in percent of bit rate from a nominal value in which tracking will be maintained without bit slips.

Transition Density is the statistical rate at which the signal varies from high to low and low to high during a specified number of bits. In NRZ-L, alternating 1's and 0's have a transition density of 100%, random data has a transition density of 50% and constant 1's or 0's have a transition density of 0%.

Viterbi Decoder-An efficient algorithm for decoding convolutionally encoded FEC signals. Developed by Andrew Viterbi.

View (see window)

Window is a portion of (or the entire) display {hot link} that contains its own document or display objects in an applications or graphical interface. The display can contain multiple windows either by stacking (only the top one is entirely visible) or tiling (all are visible) or a combination of both.