ANDØYA
ROCKET RANGE

Payload Services

Telemetry Tutorial

Document revision: C
Date issued: 11 August 2009

Table of contents

Table of figures

Document History

Date	**Version**	**Notes**
29 Sept. 2006	Revision A	
11 July 2007	Revision B	-Layout changed
11 Aug. 2009	Revision C	-Minor modifications

1. Introduction

A brief overview of telemetry applications and PCM encoding terminology is explained for people unfamiliar with PCM encoding. The tutorial has been developed by L-3 Communications (L3Com) and can also be found at their web site: www.l3com.com

2. Telemetry explained

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.

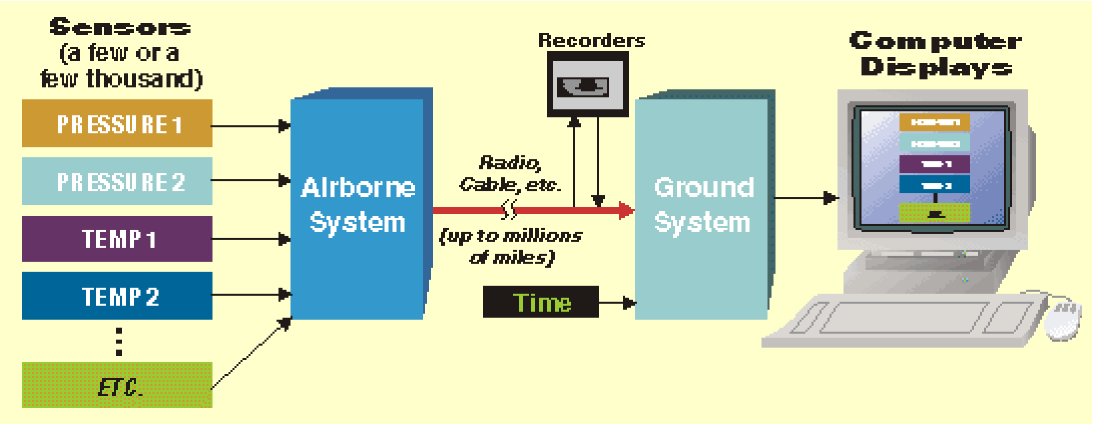


Figure 1: Telemetry system overview.

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.

2.1. Telemetry systems overview

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.

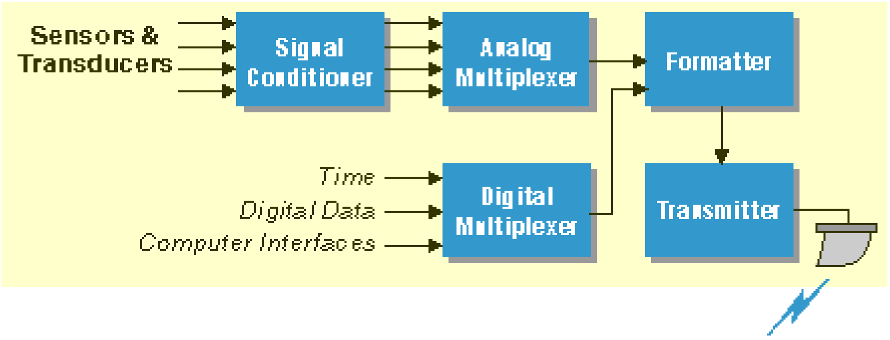


Figure 2: Sensor data acquisition system.

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.

Figure 3: Measurand in TDM format.

2.2. Commutation

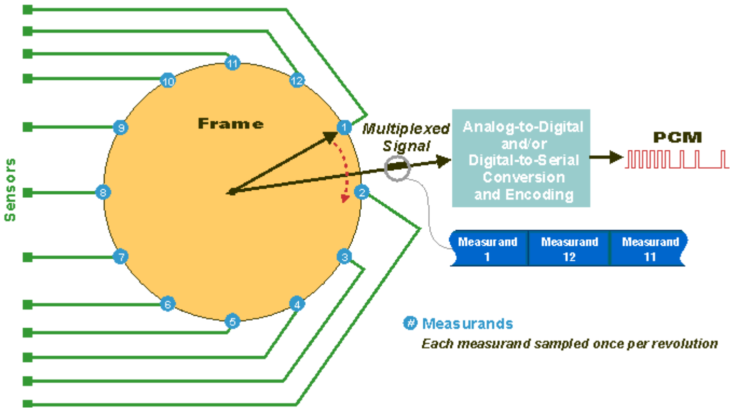


Figure 4: Principle of commutation.

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).

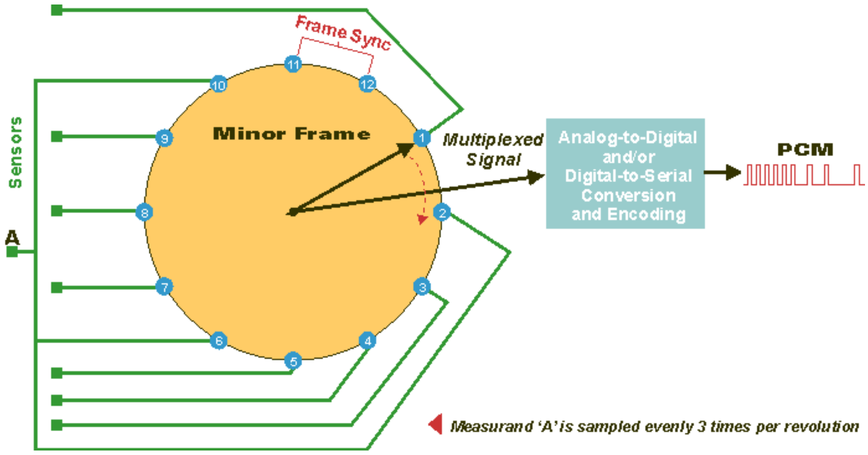


Figure 5: Principle of supercommutation.

The opposite scheme occurs in sub commutation 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.

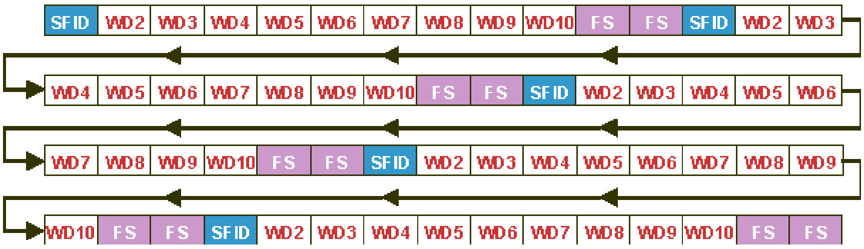


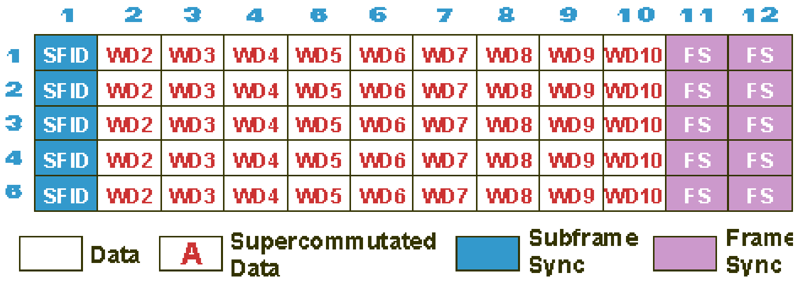
Figure 6: PCM data stream.

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.

2.3. 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).



	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

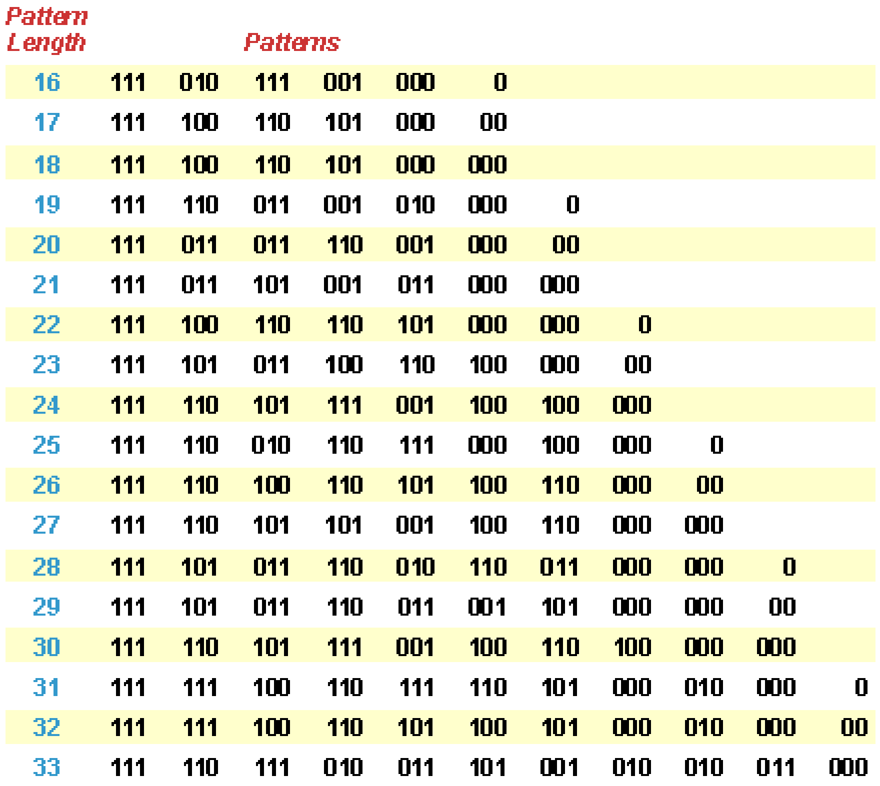
Figure 7: Data words.

2.4. 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.

2.5. 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.



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

Figure 8: Optimum Frame Synchronization patterns.

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.

2.6. Supercommutation

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

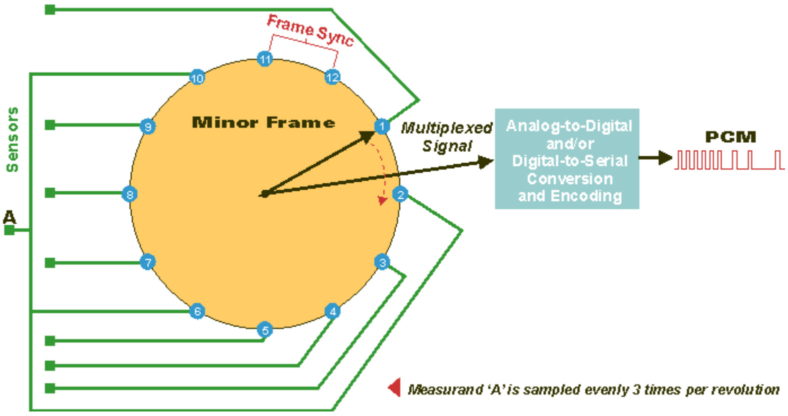
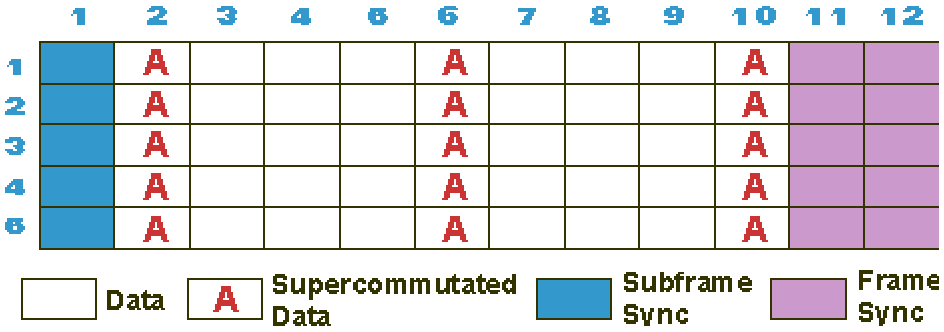


Figure 9: Supercommutation.

Usually, the number of words between the supercommutated measurands are equal to accommodate the regular sampling schemes required for Fast Fourier Transform (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.



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

☐ Data
A Supercommutated Data
🟦 Subframe Sync
🟪 Frame Sync

Figure 10: Supercommutated subframes.

2.7. *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.

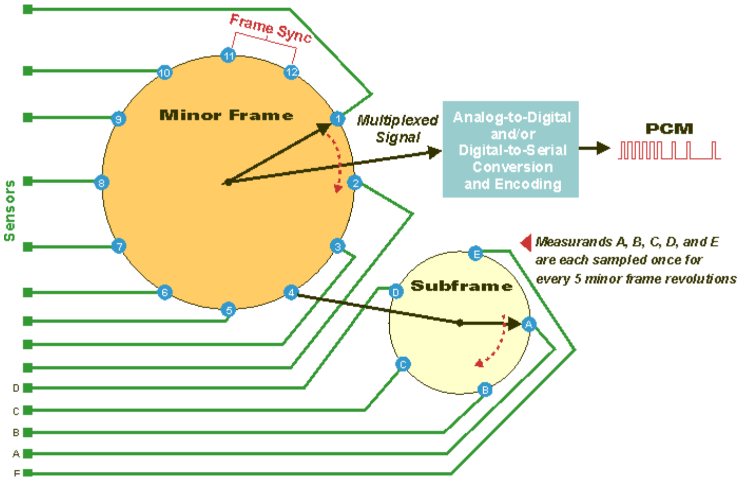
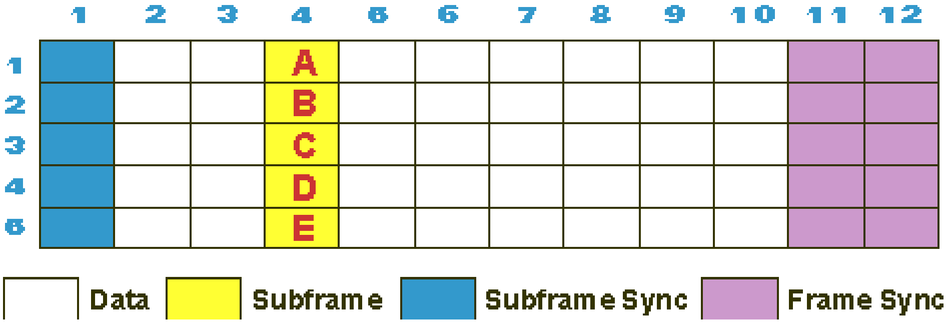


Figure 11: Principle of subcommutation.

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.



	1	2	3	4	5	6	7	8	9	10	11	12
1	🟦			A							🟪	🟪
2	🟦			B							🟪	🟪
3	🟦			C							🟪	🟪
4	🟦			D							🟪	🟪
5	🟦			E							🟪	🟪

☐ Data 🟨 Subframe 🟦 Subframe Sync 🟪 Frame Sync

Figure 12: Subcommutated subframes/words.

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.

3. References

- L3 communications, Telemetry tutorial
  http://www.l-3com.com/tw/tutorial (cited: 11 November 2006)
  http://www.l-3com.com/tw/tutorial/telemetry_tutorial.pdf