A TECHNICAL COMPARISON OF FREQUENCY AND PHASE MODULATION RELATIVE TO PCM DATA TRANSMISSION SYSTEMS.

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ABSTRACT

Direct experience in the design and developement of airborne telemetry systems utilizing both principles of modulation. System level analysis of receiver phase coherency, bit sync error codes, data band width, transmission efficiency and overall system complexity. High reliability, miniaturized packaging and HI-G survivability will be stressed as well as illustrated.

SUMMARY

The proper selection and utilization of a particular modulation principle is extremely important in determining cost, complexity, ease of maintenance, data accuracy and overall system performance. This presentation will evaluate and compare two of the most widely used modulation principles, through assessment of a customers' individual needs.

The evaluation of two complex systems must be broken out into major areas of interest. These areas include:

FREQUENCY MODULATION		PHASE MODULATION
* Bandwidth		* Bandwidth
* Analog Data		* Analog Data
* Digital Data	-vs-	* Digital Data
* Carrier Frequency		* Carrier Frequency
* Receiver Complexity		* Receiver Complexity
* Data Accuracy		* Data Accuracy

A unified analysis of both principles include:

1. In depth analysis cf both systems.
2. Maximum utilization of the proper system.
3. Hybrid systems design.
4. Realization of improvement of existing designs.

The importance of a simplified analysis of frequency and phase modulation principles will be evident as it will provide insight and direction for the next generation of PCM data transmission systems. Since an acceptable analysis must be readily interpreted in terms of conventional approaches, this analysis will cover coherent and non-coherent carrier detection of frequency or phase modulated signals.

Both of these modulation techniques can easily be divided and explained, this will begin to establish the base for this comparison. Frequency modulation is considered to be a non-coherent form of modulation in that it does not require a reference carrier at the receiver and can be detected by other means. Phase modulation is considered to be a coherent form of modulation in that it requires a reference carrier at the receiver having the exact frequency and phase of the transmitter carrier.

The mathematical analysis of frequency or phase modulation is not necessary. For the purpose of this paper it will suffice to simply give the solutions and utilize them accordingly. For frequency modulation, the equation for the instantaneous voltage is;

$$e = A \cos (W_c T + M_f \sin W_i t)$$

$$M_f = \text{FM modulation index} = \frac{\delta}{fi}$$

where = maximum frequency shift caused by the intelligence signal. (deviation)

f_i = frequency of the intelligence (modulation) signal.

The following equation provides the equivalent formula for phase modulation.

$$e = A \cos (W_c t + M_p \sin W;t)$$

where e = instantaneous voltage

A = peak value of original carrier wave

W_c = Carrier angular velocity ($2\pi F_c$)

M_p = Maximum phase shift caused by the intellegence signal (Radians)

W_i = modulating (intelligence) signal angular velocity ($2\pi F_i$)

The maximum phase shift caused by the intelligence signal M_p, is defined as the modulation index for phase modulation. A comparison of both equations points out the difference between PM and FM. The equation for PM shows that the phase of the carrier varies with the modulation signal amplitude (since M_p is determined by this) , and in FM the carrier phase is determined by the ratio of intelligence signal amplitude (which determines δ) to the intelligence frequency (f_i). (1) Thus, PM is not sensitive to the modulating signal frequency but FM is. The difference between them is subtle in fact, if the intelligence signal is integrated and then allowed to phase-modulate the carrier, an FM signal is created. This is exactly the method used in an indirect FM system.

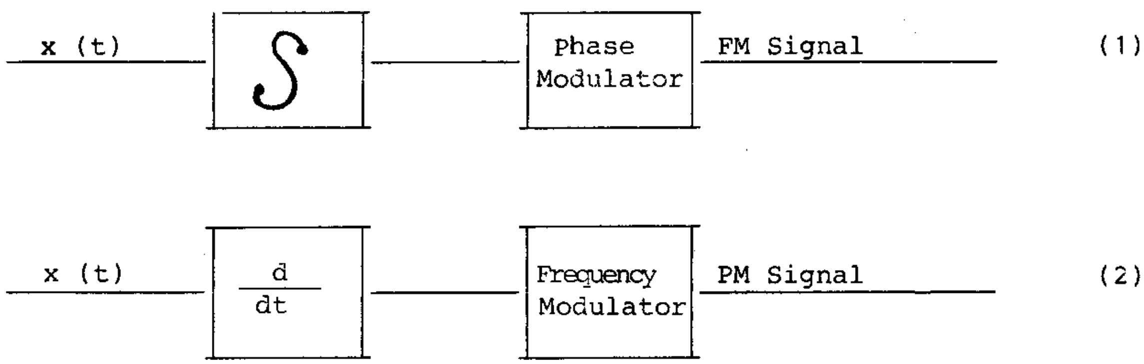


Figure (1) A PM modulator may be used to generate an FM signal if the modulation signal is integrated first.

Figure (2) An FM modulator may be used to generate a PM signal if the modulating signal is differentiated first. Because of this subtle but distinct difference it is important to define their use in PCM transmission systems. PCM is a time multiple or sampled data system. In any sampled data system, the sampling rate of a given channel dictates the frequency response which may be obtained in a given measurement. Analog reproductions of the original signals are produced by filtering of the sampler of a single channel. In general, when more than 20 or so channels of data are to be handled in a data transmission system, time multiplex systems provide more information bandwidth for a given transmitter carrier frequency. PCM makes maximum use of digital techniques. In PCM the series of pulses or levels are fed to an encoder which generates a series of N successive pulses for each sample. The presence or absence of each of the N pulses is binary coded to describe the level of the sample to the nearest discrete level between zero and full scale which can be described by N binary digits. Since only the existence or absence of pulses is required only two signal levels are required to be transmtted. On level represents a “one” bit; a second level represents a “0” bit. In PCM, the modulator, transmitter, receiver and detection equipment need only handle two levels; therefore linearity of these components is not necessary. Once in code form, parity check bits and other forms of redundant or error correcting codes may be used to make a PCM system less susceptible to noise in the RF link. (2)

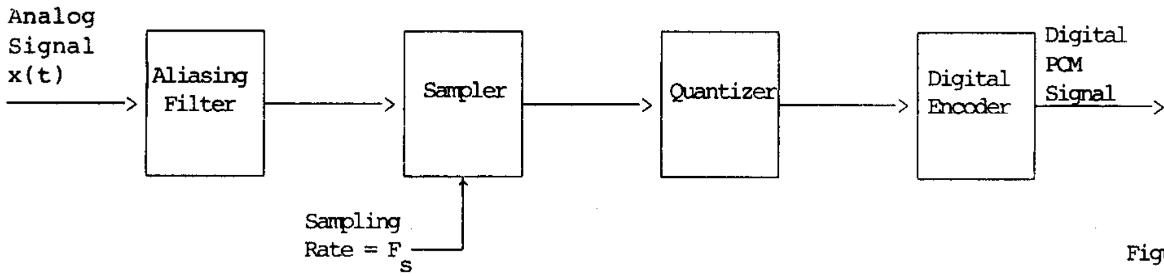


Figure (3)

Figure (3) illustrates the steps involved in generating a digital PCM signal. Assume an analog signal x(t), band-limited from near dc to w hertz, which is to be converted to PCM form. The signal is first filtered by an aliasing analog filter whose function is to remove any superfluos frequency components above W that might appear at the input and be shifted into the data band by the aliasing effect. The signal is then sampled at a rate $F_s > 2W$. A process unique to all digital-modulation methods is now performed. Each sampled data pulse is converted into (or replaced by) one of a finite number of possible values. This process is called quantization. Following the quantization process, each of the standard levels generated is encoded into the proper form for transmission of subsequent signal processing. Each of the composite encoded samples appearing at the output of the encoder is called a PCM word. Thus, the infinite number of possible amplitude levels of the sampled signal is converted to a finite number of possible PCM words. So far, all the binary PCM signal forms considered have employed natural binary encoding. While some systems transmit the natural binary words directly, other systems convert the natural binary word to special formats prior to actual transmission or high frequency modulation. In the design and implementation of their systems PSL has chosen both biphase-L and NRZ-L as the most comparable baseband encoding forms. One of the telemetry systems built and designed by PSL for the NASA sounding rocket program will be the first example of an FM system. This sounding rocket TM unit was utilized for the optical ozone program which had a stringent space requirement. The TM unit was to fly aboard a 2 1/8 inch vehicle known as the super loki dart. The design was to conform to NASA requirements those being size, number of available data channels and the carrier frequency for receiving data. The TM unit operated in the “L” band region 1680MHz via an RCA pencil cavity oscillator. The antenna was a flexible turnstyle type providing an omnidirectional radiation pattern. This unit utilized a 6 volt nickel cadmium battery pack which powered the DC to DC convertor module. This module converted the raw 6 volts into a ± 15 volts to power the encoder and a +110 volts to power the cavity oscillator CMOS surface mount and dual in-line integrated circuits were used throughout to minimize both power and size requirements. The encoder utilizes a ramp or countdown type A/D converter, a ten bit digital to analog convertor (DAC) is also used. The encoder is adjusted for 255 counts to equal 2.50 volts. With this adjustment 510 count (MAX) analog input is 10 volts. Digital resolution is 15 millivolts. Bi-phase level modulation is used. Nine words per frame-eight data words and one sync word. The frame sync word is 10111000. The main crystal controlled oscillator is 2.048 MHz. The clock rate for A/D is 512 KHz. The bit rate is 8 KHz. This gives a word rate of 1000 per second or frame rate of 111 per second. The TM unit is then subjected to an environmental temperature test of -40°C to +70°C and checked for full operation. This test also includes a shock test of 100G for 2 milliseconds. In construction of the TM units, a flexible wrap around printed circuit board is used along with conventional PC board construction. Figure (4) is a general block diagram of the system and figure (5) is a schematic diagram of the electronics.

The second example of a PSL built system is a true phase modulated telemetry unit.

System Capabilities. The ATS is designed to monitor missile functions both on the ground and in flight. Since the ATS is battery powered, it can transmit information even when missile power is not operational. During flight, the ATS transmits vertical, horizontal, and logitudinal (pitch, roll, and yaw) attitude information to the MTRS Data Acquisition System (DAS). The ATS will also monitor missile guidance functions, pressure transducer data from the booster and sustainer, acceleration information, and timing events such as warhead arm and fire commands. Figure (6)

Prior to flight, the ATS will transmit data that verifies proper missile operation. This function verification can identify faults before the missile is launched, saving valuable equipment and manpower.

PCM Encoder. Data frame format is controlled by the PCM encoder. Frame format consists of the following:

- Number of words per frame (32)
- Frame rate (390.6 per second)
- Number of bits per word (8)
- Bit rate (100 Kbps)

Identification of each data frame requires a frame synchronization (sync) code. This code is generated by the PCM encoder and consists of two of the 32 words in each frame of data. These two words have the same bit pattern in every frame of data, and allow identification and decommutation of the transmitted serial data. Figure (7)

PCM serial data consists of data works and frame sync codes contained in the data frame output as a serial signal. This serial signal is combined with a timing clock to generate a serial, bi-phase coded PCM signal. The resulting signal is suitable for modulating the telemetry transmitter.

Encoder functions are controlled by the basic 200 KHz clock oscillator, bit counter, and word counters. The clock provides the Bi-phase frequency, which is divided by two to produce a 100 KHz data bit rate. The 100KHz clock advances a synchronized 0 to 8 decimal counter for various bit time outputs. These outputs are used to control ATS signal interface encoder operation and other signals.

The word counter is also a synchronized counter. It is an 8 bit type with 2 and 4 bit counters. The outputs of this counter address the E-PROM.

The E-PROM is a C-MOS device with 2k x 8 memory. Multiplexer control, frame sync word insertion, and command of the parallel/serial function of the shift register are performed by the E-PROM.

Synchronization code is produced by parallel input and serial output shift registers. There are two of these registers. Code is “shifted” into the sync code registers in a parallel mode at word time 31. Code is then “shifted out” of the register in serial form for the next two word times (16 bit times), producing a 16 bit (Barker code) data synchronization code.

The A/D converter has an internal control clock that controls the data ready output to the sample and hold amplifier. Data is presented to the A/ D converter from the sample and hold amplifier at bit time 7 of the preceding word count. The conversion from an analog to digital signal is completed by bit time 7 of the present word conversion time. At bit time 0 of the next conversion time, the data is transferred from the A/D to the data register in a parallel form (all 8 bits at one time) and then transferred from the register in a serial form. The A/D converter changes a -5 V to +5 V analog input into an 8 bit binary digital word. The resulting digital resolution is 10 V/255 bits or 40 mV/bit.

Data Format. Data is output from the ATS at 100 Kilobits per second (kbps), bi-phase L. The data is converted to an 8 bit binary code, which is transmitted most significant bit first. Standard Barker code is used with two words of frame synchronization (sync). One frame of data consists of 30 data words and two sync words.

Programming Scheme. The sampling rate of individual data channels A_1 through A_{30} is controlled by ATS programming. The functioning sequential binary counter (word counter), consisting of two 74C163 counters, counts from 0 to 255 in binary. These counts sequentially “address” a particular location in the memory (E-PROM) at a specified time. Data stored in that location will be presented to the eight output lines of the E-PROM memory. These output lines contain control information for various ATS unit functions, as shown below:

- Bit 1 provides control pulse to strobe data from the A/D to the data register
- Bit 2 provides control pulse to strobe the sync word into the sync-code registers

- Bit 3 selects the frame sync code
- Bit 4 selects multiplexer 1 or 2
- Bits 5,6,7, and 8 allow data to be presented to the A/D by addressing selected multiplexer inputs.

ATS Power System. The ATS operates from either battery or MRM missile launcher power. The primary ATS power system consists of control circuitry, a magnetic relay, voltage converters/regulators, and the internal battery. External inputs to the ATS power system include the +27 V launcherpower, +27 V missile power common ground, and relay reset. The ATS unit is automatically turned on when launcher power is activated, allowing MTRS data acquisition system (DAS) operators to monitor the transmitted ATS signal. When missile fire is initiated, the ATS relay is switched to battery power. The ATS remains in battery power mode for the duration of a flight.

Transmitter and Premodulation Filter. The S-band telemetry transmitter is crystal controlled, and uses solid state circuitry. The transmitter is preset at the factory to a frequency of 2236.5 MHz, and supplies a minimum of two watts output power. The 6.0 cubic inch transmitter is enclosed in a milled aluminum housing to withstand the missile flight environment.

Power is supplied to the transmitter by a +28 Vdc power buss within the ATS signal interface encoder. Current drain is 650 milliamps nominal.

Transmitter modulation is true PM (phase modulation), and requires a positive input signal. ATS encoder output is a bi-phase level modulation code that is easily handled by the S-band transmitter.

High frequency components of the data train pass through a pre-modulation filter, which controls the modulation level of the transmitter. The single pole modulation filter consists of a resistor-capacitor network. Values are selected for .82 times the bit rate. Transmitter carrier deviation will remain within +/- 120 KHZ. The filter circuit components are located in the ATS signal interface encoder.

RF (radio frequency) output from the transmitter consists of a 2236.5 MHz signal that is deviated +/- 120 KHz. Frequency stability is +/- .003% of the assigned carrier frequency. The output signal is cabled directly to the power divider. The signal at this point is divided into two equal outputs and routed to the two antennas.

Through this analysis and comparison I have concluded as a general rule, coherent systems tend to provide better performance in the presence of noise if all other factors are the same. However, noncoherent systems generally are less complex in design and operation, so both types of systems have their merits.

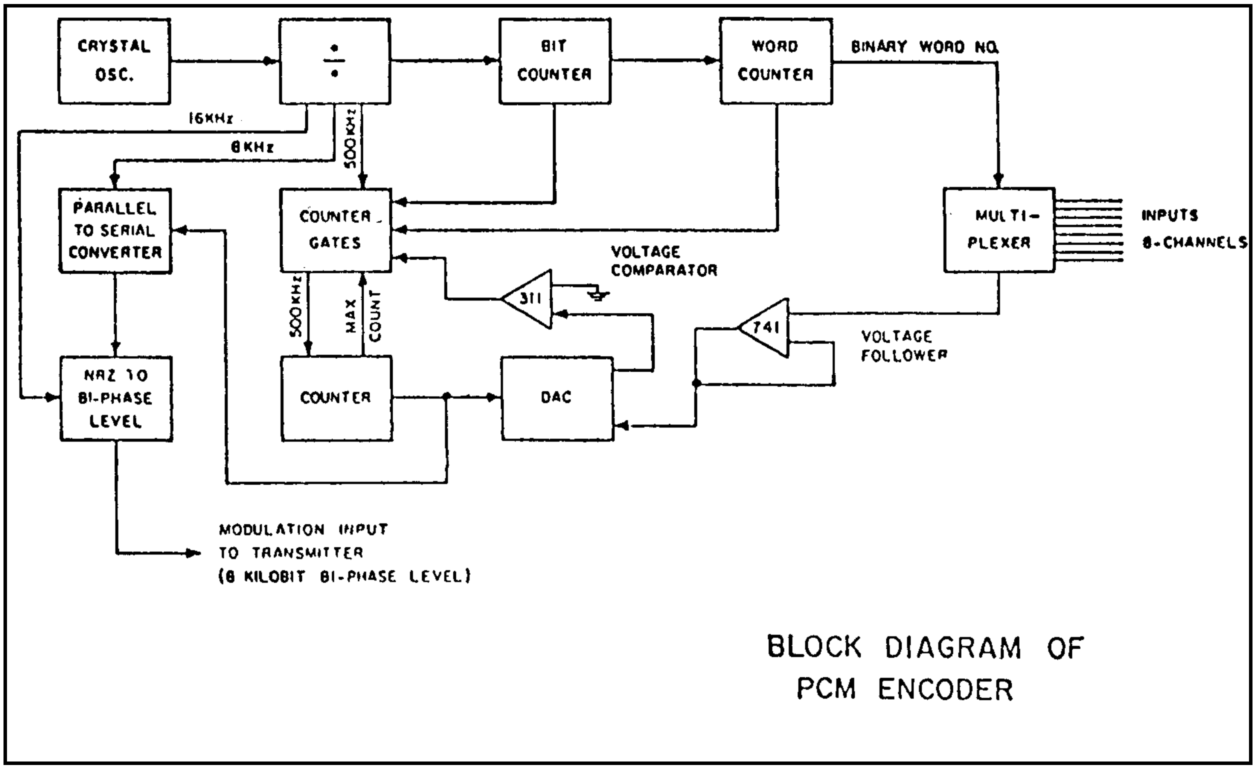
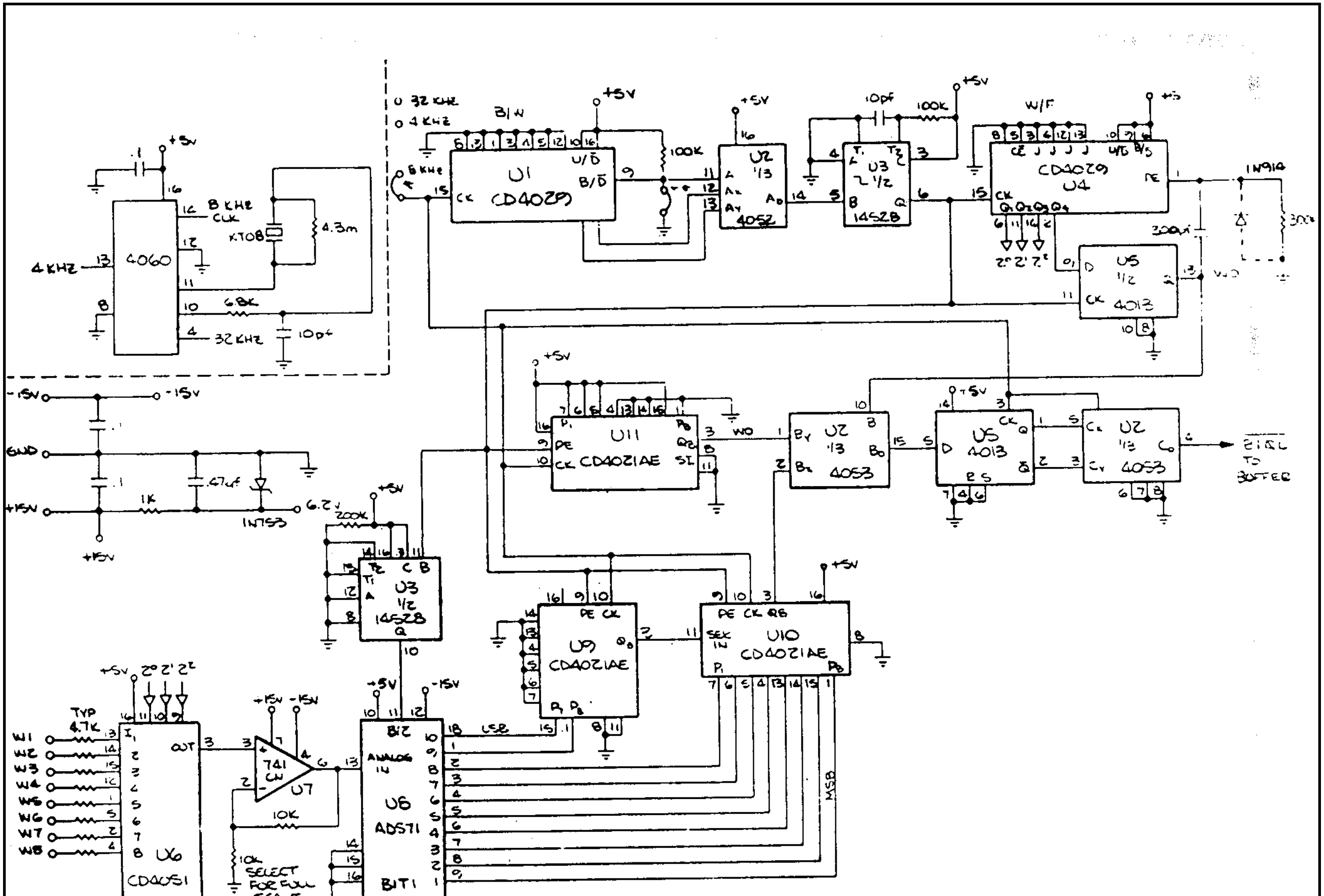

CRYSTAL OSC.
BIT COUNTER
WORD COUNTER
BINARY WORD NO.
16KHz
8KHz
500KHz
PARALLEL TO SERIAL CONVERTER
COUNTER GATES
MULTI-PLEXER
INPUTS 8-CHANNELS
VOLTAGE COMPARATOR
311
741
VOLTAGE FOLLOWER
500KHz
MAX COUNT
NRZ TO BI-PHASE LEVEL
COUNTER
DAC
MODULATION INPUT TO TRANSMITTER (8 KILOBIT BI-PHASE LEVEL)
BLOCK DIAGRAM OF PCM ENCODER

FIGURE (4)



DART ENCODER
9 words/frame 8 or 10 bits/word
schematic

FIGURE (5)

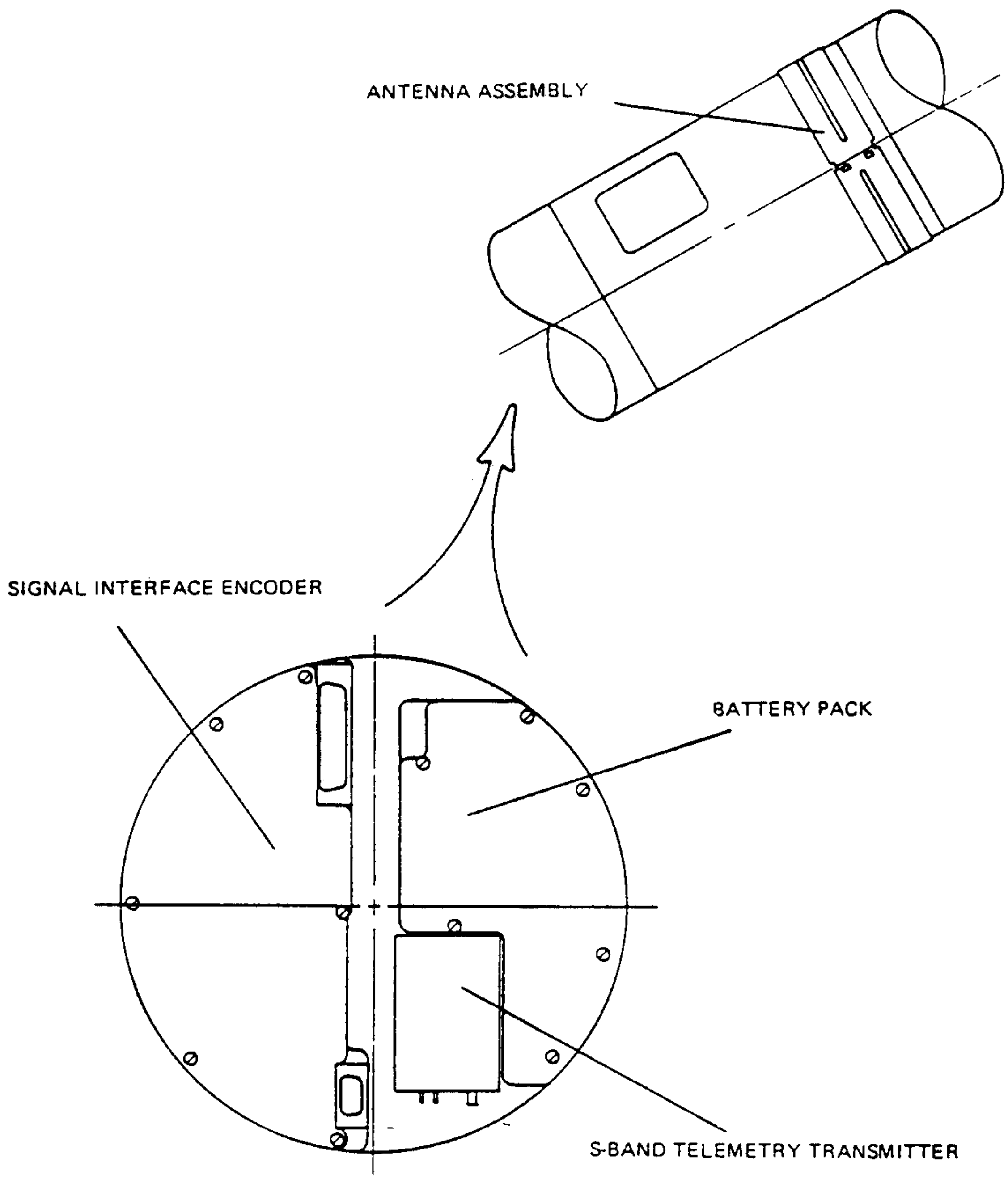


FIGURE (6) AIRBORNE TELEMETRY SYSTEM ASSEMBLIES

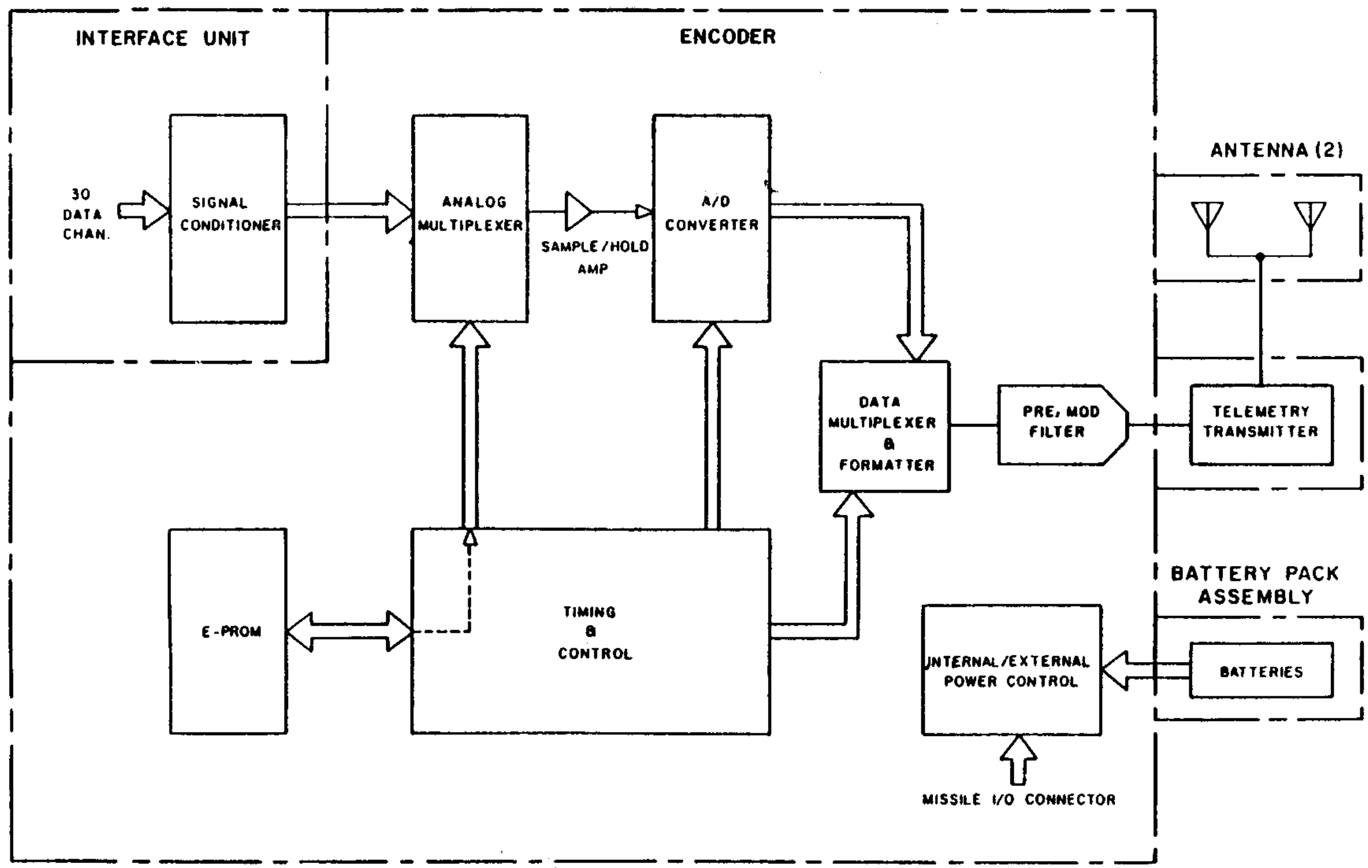


FIGURE (7) PCM SYSTEM BLOCK DIAGRAM

Books:

1. Stanley, William D., Electronic Communications Systems, Reston Publishing Company, Inc. Reston, Virginia, 1982.

2. Miller, Gary M., Modern Electronic Communication, second edition, Prentice Hall, Inc. Englewood Cliffs, NJ 1983

3. Stiltz, Harry L., Aerospace Telemetry, Prentice Hall Inc. Englewood Cliffs, NJ 1961.