DATA TRANSMITTER COUPLING METHODS: DC VERSUS AC

A. A. VIGGIANO
Senior Design Engineer
Lockheed Missiles & Space Company
Sunnyvale, California

Summary Radiofrequency telemetry systems using digitized data and FM transmitters in missile development tests result in serious loss of data at the receiving stations when the receivers have narrow bandwidth. This problem is related to the capacitive coupling network between data input and the transmitter exciter. The relative merits of capacitive coupling versus DC coupling are discussed in this paper on the basis of Fourier analysis of a series of pulses. It may be observed that the digitized data in the systems studied always manifest a DC component due to uneven distribution of binary digits 1 and 0. This DC component is eliminated by a capacitor coupling, but is preserved with a DC coupling. This paper assesses the effects of the elimination of the DC component on the relative position of the spectrum to the carrier. The discussion draws on the results of a test situation of an actual telemetry system. In this test, two identical telemetry transmitters were used; the only variable was the type of coupling exciter employed. A DC coupling is recommended for the transmission of binary information on an FM telemetry transmitter as a result of this test and analysis. Conditions for the proper use of such a coupling are stated.

Introduction During the course of the design and flight tests of telemetry systems in the Missile System Division (MSD) of Lockheed Missiles & Space Company (LMSC), problems have arisen regarding link bandwidth occupancy and data reduction; more specifically, the receiver bandwidth as originally designed was too narrow to handle the data. This problem has focused the engineer Is attention upon the method of coupling digital data into a frequency modulated transmitter. Since coupling may be implemented only through a DC network or an AC network, a study was conducted to evaluate the merits of each scheme.

For background purposes, a summary of a few telemetry concepts is presented here. Multiplexing techniques are commonly used today in communication links. Originally developed to send telemetry data during flight tests of aircraft and missiles from an airborne station to a ground station, these techniques are primarily used in satellites, space probes, and manned spacecraft communications. The aim of multiplexing is to accommodate several data channels in a communication link, due to limitations in available radio frequencies, and can be accomplished by either frequency division or time division. In a frequency division multiplexing scheme, a number of subcarrier waves are individually frequency-modulated by data and added together to form a composite signal. In a time division multiplexer, data channels are sampled by a communicator in a cyclic sequence to generate a train of pulses.

Analog to digital conversion methods were developed parallel to the advancements in multiplexing techniques in order to provide better recording accuracy and computer compatibility. Pulse Code Modulation (PCM) is the most efficient of the coding systems; it utilizes a quantizing process by which peak-to-peak amplitude of a signal is indicated by a code of binary pulses. Other coding methods include Pulse Duration Modulation (PDM), Pulse Position Modulation (PPM), and Pulse Amplitude Modulation (PAM). (See Figure 1.)

In radio frequency telemetry, data modulate a radiofrequency-carrier in a transmitter receiver link. Once again, alternative modulation schemes can be used by varying either the amplitude of the transmitter sinewave or the angle, resulting in generation of Amplitude Modulation (AM) in the former and Frequency Modulation (FM or Phase Modulation (PM) in the latter. The combination of data processing and modulation make up a telemetry system. Therefore, we may utilize FM/FM, PDM/FM, PPM/AM, PCM/FM, and many other combinations in such a system.

The evaluation of these systems is presented in many authoritative books and publications (Refs. 1, 2). One of the most important criteria identified is the signal-to-noise (S/N) ratio. Since noise varies directly with the bandwidth required to transmit the information with a selected data format, it is important to keep this bandwidth as small as possible. This result is accomplished in a receiver by limiting the bandwidth by a filter.

Figure 2 illustrates a basic quantized data transmission system. For the purposes of the following discussion, the transmitter is assumed to be FM modulated. (This scheme is one of the most common types used in present communication systems.) The data are assumed to be in a PCM format. There are three common types of coding used in PCM telemetry: return-to-zero (RZ), non-return-to-zero (NRZ), and Manchester or split phase. Figure 3 illustrates these three PCM code patterns. It may be observed that the use of NRZ code results in the smallest bandwidth occupancy.

Data Transmission through the Coupling Network In order to study the effect of the coupling network characteristics on a sequence of digital data, it is beneficial to translate the time function into a frequency function. For purposes of simplification, assume that the digital data are represented by a series of periodic rectangular pulses, as in Figure 4. They may be expanded, in the following Fourier Trigonometric series:

$$f(t) = \frac{a_o}{T} + \frac{2}{T}\sum_{n=1}^{\infty}\left(a_n \cos \omega_n t + b \sin \omega_n t\right)$$

where

$$\omega_n = \frac{2\pi n}{T}$$

For an evaluation of the coefficients in a Fourier series, integrate the function over

a period $T = \frac{2\pi}{\omega_o}$ and multiply by $\cos \omega_n t$.

The results are expressed by (see Reference 3 for details):

$$a_n = \int_{-\frac{T}{2}}^{\frac{T}{2}} f(t) \cos \omega_n t \; dt$$

$$b_n = \int_{-\frac{T}{2}}^{\frac{T}{2}} f(t) \sin \omega_n t \; dt$$

Then,

$$f(t) = \frac{a_o}{T} + \frac{2}{T}\sum_{n=1}^{\infty} \sqrt{a_n^2 + b_n^2} \; \cos\left(\omega_n t + \theta_n\right)$$

where

$$\theta_n = \tan^{-1} \frac{b_n}{a_n}$$

The amplitude frequency plot is $\sqrt{a_n^2 + b_n^2}$ versus ω_n, and is called the spectrum of the function.

The Fourier series can be expressed also in a complex exponential form by introducing a complex coefficient, $c_n = a_n - jb_n$ whose absolute value is

$$|c_n| = \sqrt{a_n^2 + b_n^2}$$

Then,

$$f(t) = \frac{1}{T}\sum_{n=1}^{\infty} c_n e^{j\omega t}$$

Further development and the use of the values indicated in Figure 4 yields:

$$c_n = \tau A_m \frac{\sin x}{x}$$

where

$$x = \omega_n \frac{\tau}{2}$$

The frequency spectrum is then represented by Figure 5. It can be noted that there is an inverse relationship between pulse width or duration and the frequency spread of the pulses. Since the greater part of the energy associated with the pulses is confined to the lower frequencies, the bandwidth may be expressed:

$$\Delta f = \frac{k}{\tau}$$

where k is a constant whose selection is dependent on the choice of the criterion.

The DC component is the average value of the function multiplied by T. Therefore, this component will be equal to zero only if the function is such that the positive area above the horizontal axis is equal to the negative area below the axis and they therefore cancel out.

The next step is to consider these pulses as they run through the input to the transmitter exciter. In its most elementary form, this input network will be in the form of a series resistor or a series capacitor. Assume that the time response of the system to the pulses is such that it will not affect the information content of the data because parasitic capacitance and inductance will always be minimized in a well-designed transmitter. The DC component will be removed when passed through a capacitor, but will remain if passed through a resistive network. Figure 6 shows such an action. In either situation, the frequency spectrum and the associated bandwidth are not altered within the framework herein considered.

It is known from basic FM theory that the modulation signal alters the instantaneous frequency of a carrier wave by an amount directly proportional to the voltage amplitude of the carrier signal. The instantaneous frequency may increase or decrease, depending on the polarity of the signal voltage. Conventionally, a positive signal produces an increase in the carrier frequency. The ratio of the peak frequency deviation to the amplitude of the signal causing it is a preset characteristic of the transmitter and is called FM deviation sensitivity. By observing Figure 6, it is clear that the voltage levels of the binary pulses have been altered by the coupling capacitor in the case of the AC coupling scheme. No alterations are introduced by a DC coupling scheme.

It may be concluded that a well designed coupling network will not alter the frequency spectrum of the pulse train. However, if an AC coupling is used, the spectrum will shift in relation to the unmodulated carrier. In a typical situation, the binary digits may have a lower level of -2. 5 volts and an upper level of +2. 5 volts. Regardless of the digital format used, the average statistical distribution of Bit 1's to Bit O Is is such -is to cause a positive DC component in the Fourier analysis. If we have a DC coupling network, the frequency spectrum of the transmitter will be centered around the unmodulated carrier itself. If the receiver is bandwidth-limited around the carrier, no problem will arise in the reception of the data transmitted, apart from considerations of the Doppler shift. In the case of a capacitive coupling, however, the removal of the DC component causes a shift of the frequency spectrum in respect to the unmodulated carrier. This shift causes the elimination of some frequency components in a narrow-banded receiver.

Further problems may be encountered when the received data are processed through the FM discriminator. Any change in the constant component due to random variation of the digital data in an AC scheme will cause a change in the baseline of the digital data record. It is easy to see how serious this problem may be in the case of a PAM format. Regardless of the type of format utilized, the cumulative effects of receiver bandwidth limitation, baseline instability, noise, and possible carrier drift may be large enough to result in complete loss of information, when added to the AC coupling effect.

System Test To further evaluate the relative merits of DC versus AC coupling, a system test was conducted, taking advantage of the availability of two S-band telemetry transmitters of identical design varying only as to the type of coupling (AC vs DC).

The test setup diagram is shown in Figure 7. The calibration operation consisted in setting up the unmodulated carrier at the center line of the video oscilloscope display. In addition, the DEI receiver has a spectrum analyzer unit with a small oscilloscope display. The carrier was set at the center of the DEI spectrum analyzer. Unfortunately, no pictures of the spectrum have been taken.

By injecting successive plus and minus 2.5 volts, the oscilloscope was calibrated for a sensitivity of approximately 2 volts/centimeter. The PCM Simulator unit as diagrammed was set with a NRZ format of 72 kilobits/second, 8 bits per word. The number of Bit 1’s per word was increased from 1 to 7 progressively, using first the AC and then the DC coupled transmitter. The results are shown in Figures 8 and 9. The bits had the following characteristics: Bit 0 was represented by 0 ±0.25V; Bit 1 was represented by -5 ±0.25V. The DEI spectrum analyzer showed bandwidth displacements in relation to previous carrier position proportional to the baseline shifts on the video oscilloscope. That is, the position of the frequency spectrum was always on one side of the unmodulated carrier in the case of the DC coupling, as a result of the nonsymmetrical voltage levels of the binary digits.

Frequency spectrum and video binary digits were perfectly centered around the unmodulated carrier only in the case of equal binary 1’s and O’s in the AC coupling.

Conclusion A constant component is present in varying amplitudes in a sequence of digitized data. It has been shown that capacitive coupling of the data input to the transmitter exciter removes the DC component from the frequency spectrum of the data. This phenomenon causes the modulated signal spectrum to be shifted assymmetrically in respect to the unmodulated carrier. The same shift of the frequency spectrum is present at the receiver end and may cause the loss of valuable frequency components due to filter action. In order to avoid any of this data loss, the receiver bandwidth may be increased, at the expense of a decrease of the SIN ratio. A further effect will be noted as drifts of the recorded data baseline due to random changes of the Bit 1-to-0 ratio.

All of these problems may be avoided by the adoption of a DC coupling scheme. This scheme should be recommended whenever the design of the transmitter will allow its adoption. It should be emphasized, however, that extreme care must be taken to prevent ground loops or the flow of steady current at the transmitter modulation input. The voltage levels of the binary digits should be equal and of opposite sign in respect to the modulation input common terminal.

An additional advantage of the DC coupling of the FM transmitter exciter consists in simplifying and increasing the accuracy of the measurements of the deviation sensitivity and deviation linearity of the transmitter. These measurements may be implemented, in effect, by using a calibrated DC voltage and a frequency counter.

References

1. Nichols & Rauch. Radio Telemetry, Wiley, New York, 1956.
2. Leroy E. Foster. Telemetry Systems, Wiley, New York, 1965.
3. Mischa Schwartz. Information, Transmission, Modulation and Noise, McGraw-Hill, New York, 1959.

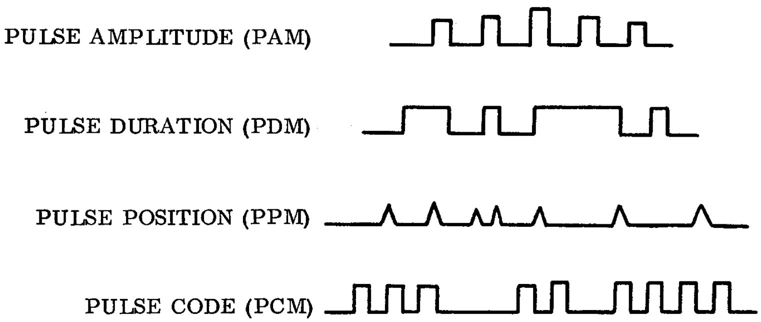


Fig. 1 - Coding Modulations

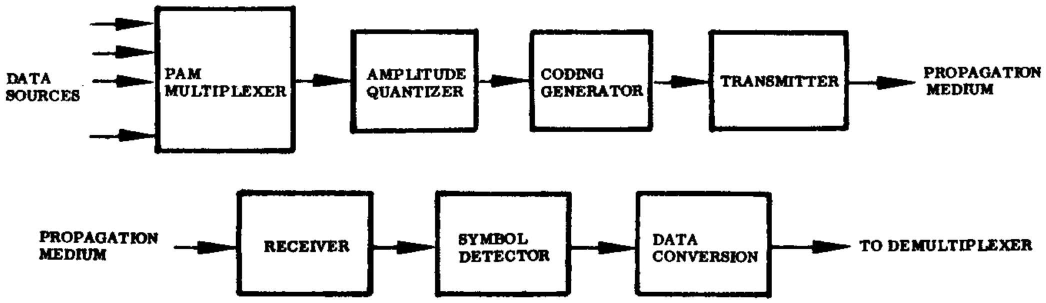


Fig. 2 - Basic Quantized Data Transmission System

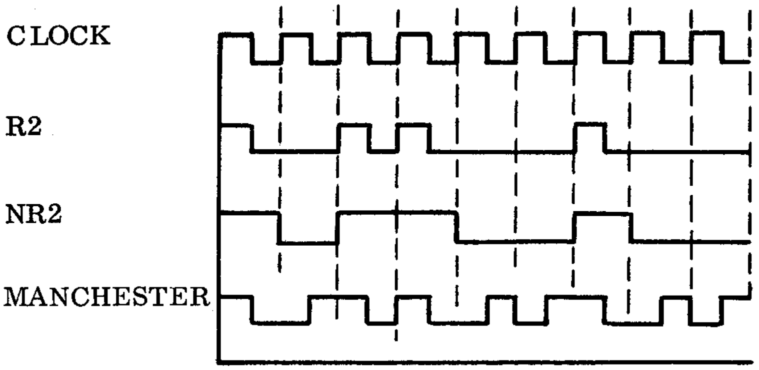


Fig. 3 - PCM Nomenclature and Format

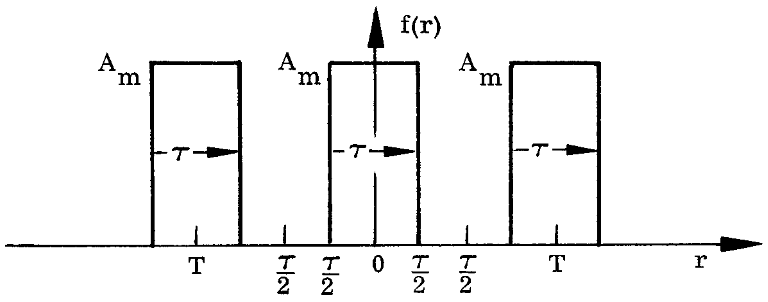


Fig. 4 - Fourier Analysis of Pulses

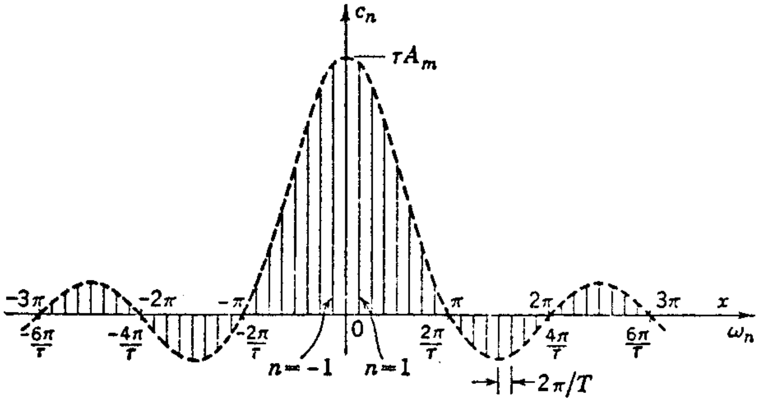


Fig. 5 - Frequency Spectrum of Rectangular Pulses ($\tau \ll T$)

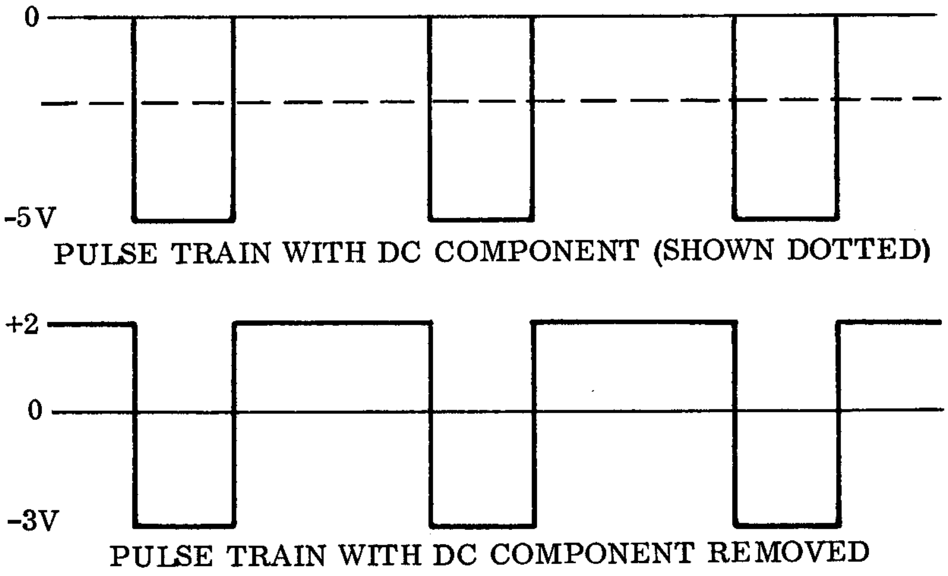


Fig. 6 - Removal of the DC Component By an AC Coupling

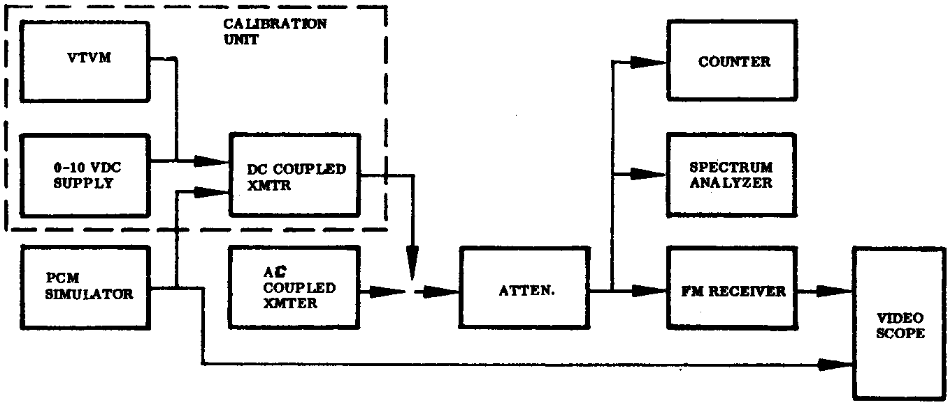
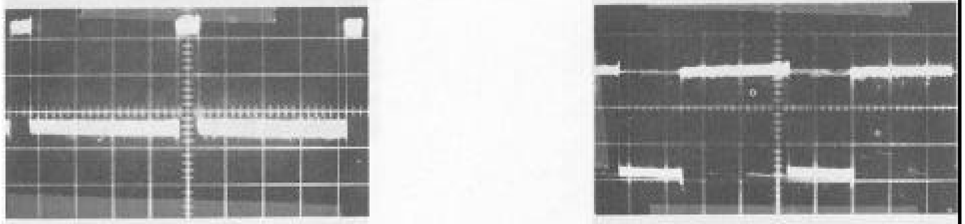


Fig. 7 - Test Set Diagram

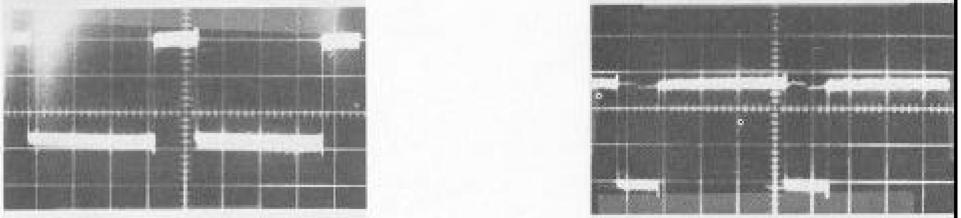
Unmodulated Carrier Calibration

4 bits per word



1 bit per word

5 bits per word



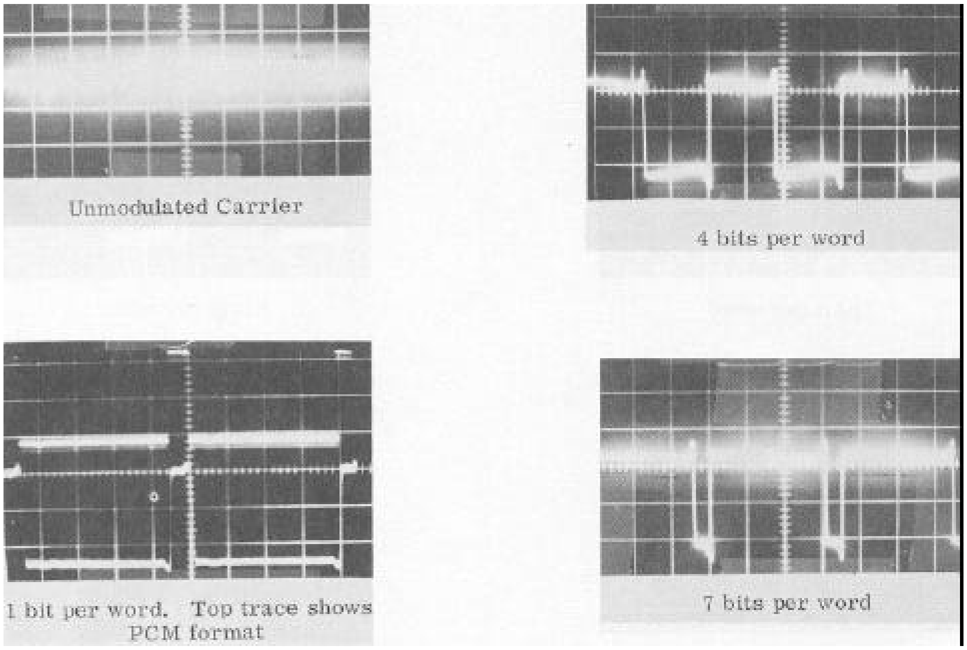
2 bits per word

6 bits per word

3 bits per word

7 bits per word

Fig. 8 - Video Oscilloscope April 2, 2003isplay of varying Numbers of Bit 1's per Word, AC Coupled



Unmodulated Carrier

4 bits per word

1 bit per word. Top trace shows PCM format

7 bits per word

Fig. 9 - Video Oscilloscope Display of Varying Numbers of Bit 1’s per Word, DC Coupled