

A 4 MBPS DIGITIZER WITH 100 KHZ SIGNAL BANDWIDTH

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ABSTRACT

This paper presents a non-standard digitization scheme which samples the data asymmetrically in order to maximize data bandwidth. Two frame synchronization words are utilized in a separated manner to permit their replacement with the average value of adjacent data words during the decommutation process.

INTRODUCTION

Telemetry engineers are frequently confronted with the requirement for processing wide bandwidth signals such as doppler and television video. These requirements often exceed the capabilities of off-the-shelf components such as pulse amplitude modulation (PAM) and pulse code modulation (PCM) encoders. When this happens the designer is faced with some tough decisions: Does he provide his customer with less bandwidth than he wants because of the limitations of current hardware which is built to the standards of the Inter-Range Instrumentation Group (IRIG)? (This may be the best solution if time and money constraints are critical and if the reduced bandwidth will satisfy the basic needs of the customer.) Does he request proposals from industry to develop a faster (wider bandwidth) device? (This path will take substantial quantities of time and money and may hold considerable risk.) Does he review the limitations on bandwidth imposed by using IRIG standard techniques and devices and attempt to implement a non-standard design? (This solution will take additional schedule and dollars but may be the most cost effective if the requirement for the wide bandwidth is critical. Note that non-standard processing equipment may also be required for data reduction as an additional penalty.) The latter approach was used on the program being discussed here. The system requirement was for 100 kHz minimum signal bandwidth and 8 bit resolution. The design goal was to sample the 100 kHz signal at five times per Hertz which resulted in a 4 Mbps system bit rate. The noise performance and amplitude resolution were to be compatible with the characteristics of magnetic tape recording. The system was also specified to use a PCM-FM modulation format.

SAMPLED DATA THEORY

Sampled data theory requires that the input signal be symmetrically sampled in order that the output be a faithful reproduction. Figure 1 shows examples of symmetrical and asymmetrical sampling. In this figure, straight line approximations through the sample points are used to illustrate the sampled output. In a practical system the sampled output is filtered to eliminate the sample frequency components and restore the output to the original wave shape. The asymmetrical example results in a severely distorted output. However, symmetrical sampling also has limitations and becomes expensive in terms of bandwidth as the number of input signals is reduced towards one. For a system with a single input signal, assuming one frame synchronization (sync) word per frame, the overhead cost is 50% and if two frame sync words are used the cost reaches 66.7%, as shown in Figure 2. Hence symmetrical sampling can lead to very inefficient designs in terms of bandwidth. Assuming 100 kHz data bandwidth, the sampled system bandwidth would have to be 300 kHz where only 1/3 of it is available for signal processing. An alternative is to sample asymmetrically and pay the price by either accepting the accompanying higher noise or by somehow reducing it.

ASYMMETRICAL SAMPLING AND FRAME SYNCHRONIZATION REPLACEMENT

An asymmetrical format was selected for the application referenced above. It consists of 254 data words and 2 frame sync words as shown in Figure 3. Thus the frame sync overhead consumes only 0.78% of the 100 kHz system bandwidth. This leaves 99.22 kHz available for use by the input signal. Although this is less than the 100kHz specified signal bandwidth, if we can allow the accuracy to degrade slightly and require only 4 samples per cycle of input signal, then the bandwidth extends to 125 kHz which is more than adequate. In this instance the input signal is a frequency variable sinusoid. Hence the accuracy degradation in allowing 4 samples per cycle is only very slight since there is little energy beyond the 100 kHz maximum limit.

A brassboard digitization and decommutation system was built and evaluated. The increased noise was found to be excessive in low signal-to-noise ratio conditions. The noise results both from asymmetrical sampling, as shown in the example earlier, and from injecting the frame synchronization words into the data stream. Noise reduction was attempted by removing the frame sync words and inserting an approximation of the missing data in their places. Four methods of replacing the frame sync words with data approximations were evaluated. These four methods are described in the paragraphs following:

- 1) Contiguous Hold (CH): Position the missing samples together as words 255 and 256 and set both to the value of the final data word 254.
- 2) Separated Hold (SH): Position the missing samples as words 253 and 256 with two data samples between them. Set the value of each to the value of words 252 and 255 respectively.
- 3) Contiguous Interpolation (CI): Position the missing samples together as words 254 and 255. Set each to the interpolated value of words 253 and 256.
- 4) Separated Interpolation (SI): Position the missing samples as words 253 and 256 with two data words between them and set each to the average of the adjacent data samples (words 252 & 254 and words 255 and 1 of the next frame respectively).

COMPUTER SIMULATION

Power spectral density plots for each of the four methods were generated using computer simulation techniques. These plots were compared to evaluate the relative performance of each method. The noise floors contributed by the various schemes are not flat; hence, some standard frequency offset from the input signal frequency had to be chosen for a uniform comparison of results. This offset was chosen to be 50 KHz above the input signal in each case. Figure 4 compares the four methods of frame synchronization replacement with the plots for the original data (sinusoid without frame synchronization inserted) and for a data stream with the imbedded frame synchronization (labelled Frame Sync). This last plot was empirically derived and is not the result of a computer model. The ordinate scale represents the power difference between the peak signal level and the noise floor at the indicated 50 KHz offset.

The original data represents the optimum signal-to-noise (S/N) condition while the data with imbedded frame synchronization represents the worst S/N condition for signal frequencies up to about 65 KHz. Beyond the 65 KHz frequency, the CH method has a slightly worse S/N ratio. The SI method added the least amount of noise to the noise floor, and the CH method was the worst. CH added 10 dB more noise than SI across the signal range tested (12.5 KHz to 100 KHz). The other methods, CI and SH, fall in the mid-range for noise addition between the best (SI) and the worst (CH). The added noise for each method increased with increasing signal frequency. This is a result of the sample rate being fixed so that the angular period between samples increases with increasing frequency. For example, each sample has a period a $2 \mu\text{s}$ which represents an angular period of 14.4° for one cycle of 20 kHz. However at 100 kHz, the same $2 \mu\text{s}$ period of equates to 72° of angular period. Hence regardless of sample replacement method selected, the sample approximation becomes more coarse as the signal frequency is increased.

SEPARATED INTERPOLATION DATA

Figure 5 shows two oscilloscope patterns of sinewaves which had been processed by the asymmetrical sampling technique described and had been decommutated by a specially designed system. Each photograph indicates the relative distortion due to the SI frame sync replacement method. Figure 5a) is of a 20 kHz signal and shows only slight distortion where the SI replacement occurred at the peak of the center waveform. Figure 5b) shows a much more significant amount of distortion at 100 kHz where the angular period is up to 72° for each frame sync word replacement.

Figure 6 shows two more photographs from the same system. These output photographs are taken with the input signal being swept from 2 kHz to 200 kHz in sweep times of 1.0 msec and 0.1 msec respectively. The effects of 20 kHz low pass and 140 kHz high pass filters can easily be seen as can distortion due to the frame sync replacement.

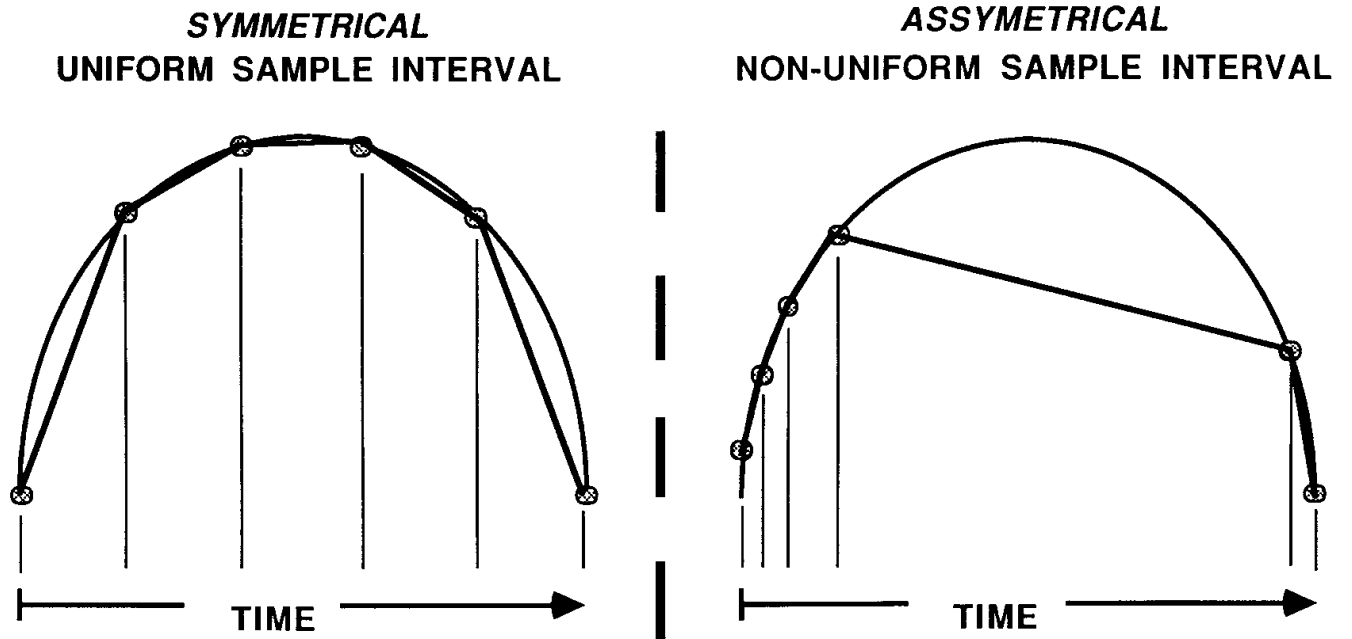
BLOCK DIAGRAM

The digitizer block diagram is shown in Figure 7. The analog input signal is conditioned in amplitude and bandwidth by the filter stages prior to the sample and hold. The analog-to-digital converter provides an 8 bit binary output in parallel format to the parallel-in-serial-out (PISO) conversion circuit. Two additional PISO devices are used to generate the frame synchronization words, FS1 and FS2. The inputs to these circuits are connected to either +5 vdc or ground as necessary to generate the proper bit sequences. Addressing for the PISO devices is generated by the divide by 4, 8 and 16 outputs from the counter. The timing block generates the necessary signals to control switching the data, FS1 and FS2 in the mux output. The mux then provides the format shown in Figure 3.

CONCLUSION

Asymmetrical sampling may offer a useful alternative for processing wide band signals when standard PAM/PCM encoders are not fast enough. It can pay large dividends in terms of bandwidth by reducing that required for frame synchronization overhead. The penalty exacted for this added performance is an increase in system noise. If the increase is too large to live with then some form of frame synchronization replacement may be required. Four methods of replacement were evaluated, and of the four, Separated Interpolation was the best. Separated Interpolation replaces each frame synchronization word with the average value of the data samples before and after it. Use of such a system will require reversing the process to recover the data so generated; hence, specially designed decommutation equipment may also be required. The specific technique described is useful where a serial output bit stream is necessary as may be dictated by compatibility or data encryption requirements.

SYMMETRICAL VS ASYMMETRICAL SAMPLING



**ASYMMETRICAL SAMPLING BIASES THE DATA AND
DISTORTS THE RECONSTRUCTED SIGNAL**

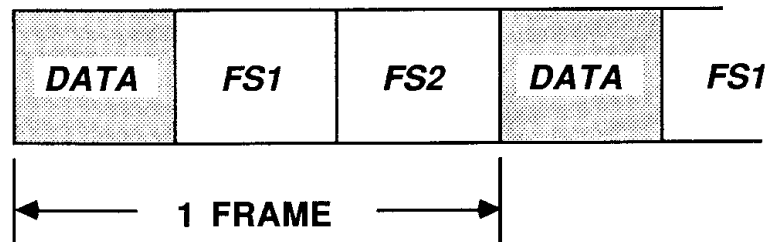
FIGURE 1

SYMMETRICAL SAMPLE FORMAT

REQUIRED:

**A SAMPLED DATA SYSTEM FOR 1 ANALOG SIGNAL IN A SYSTEM
REQUIRING 2 FRAME SYNC WORDS**

FORMAT:

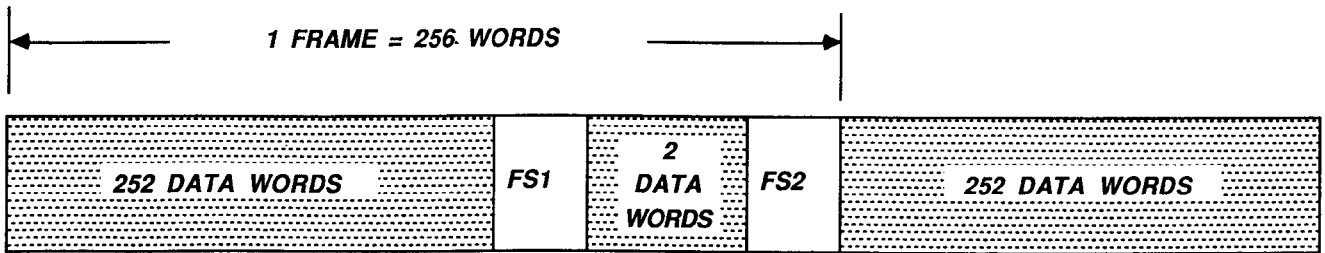


NOTES:

- a) THE SYSTEM IS SPENDING 2/3 OF IT STIME PROCESSING FS WORDS.
- b) 1/3 OF THE ENCODER BANDWIDTH IS AVAILABLE FOR DATA WHEN THE SYSTEM IS SAMPLED SYMMETRICALLY.

FIGURE 2

SELECTED ASYMMETRICAL SAMPLE FORMAT



NOTES:

- a) THIS SYSTEM SPENDS 1/128 OF TIME PROCESSING FS WORDS.
- b) 127/128 OF SYSTEM BANDWIDTH IS AVAILABLE FOR DATA IN THIS ASYMMETRICALLY SAMPLED SYSTEM.

FIGURE 3

COMPARISON OF FRAME SYNCHRONIZATION REPLACEMENT METHODS

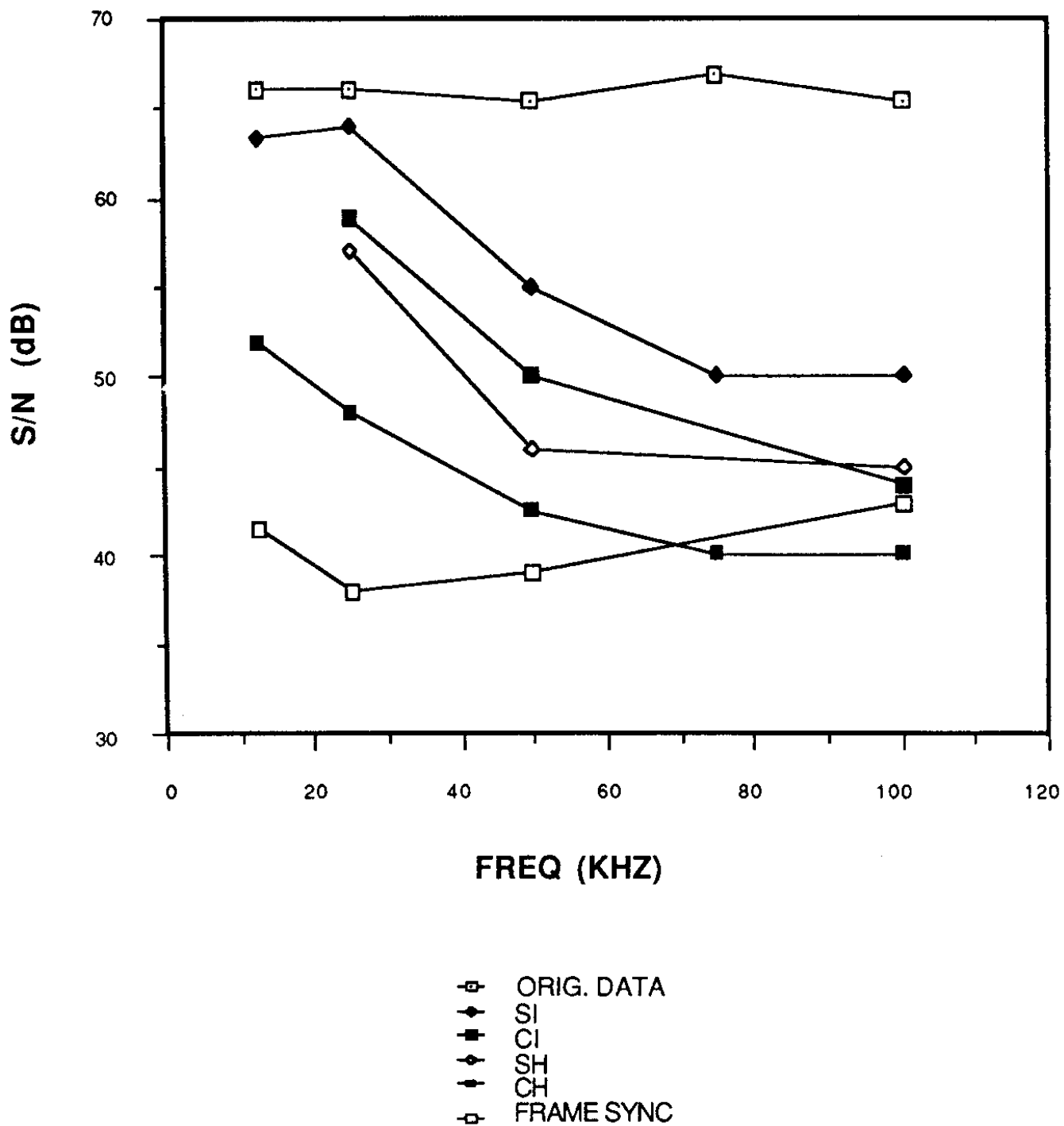
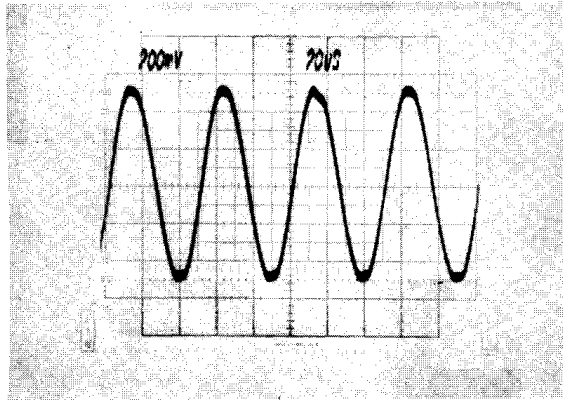
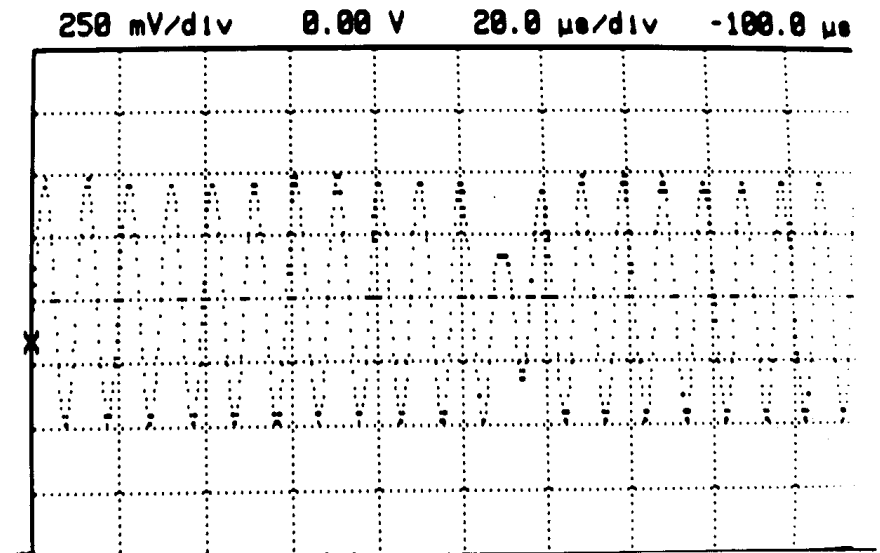


FIGURE 4

SCALE: 200 mv 20 μ s



a) FREQUENCY = 20 KHz

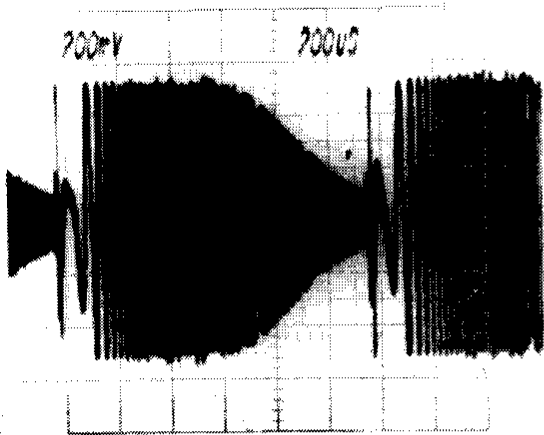


b) FREQUENCY = 100 KHz

DECOMMUTATED OUTPUT PHOTOGRAPHS SHOWING SIGNAL DISTORTION RESULTING FROM USE OF THE SEPARATED INTERPOLATION METHOD OF FRAME SYNCHRONIZATION WORD REPLACEMENT.

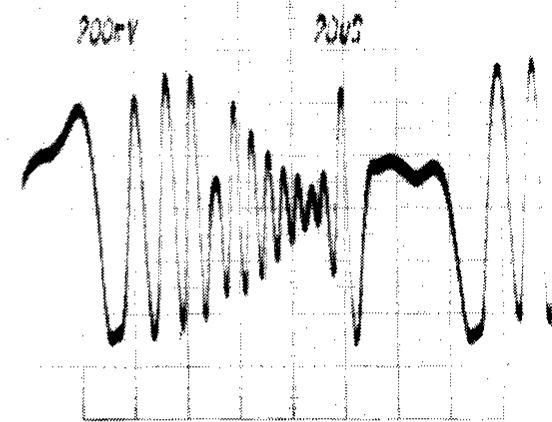
FIGURE 5

SCALE: 200 mv 200 μ s



a) SWEEP TIME = 1.0 MSEC

SCALE: 200 mv 20 μ s



b) SWEEP TIME = 0.1 MSEC

DECOMMUTATED OUTPUT PHOTOGRAPHS SHOWING SYSTEM RESPONSE TO A SINEWAVE SWEEPED FROM 2 KHZ TO 200 KHZ IN THE INDICATED TIMES. THE SAMPLE REPLACEMENT DISTORTION DUE TO THE SEPARATED INTERPOLATION METHOD OF FRAME SYNCHRONIZATION REPLACEMENT CAN BE SEEN IN EACH PHOTOGRAPH.

FIGURE 6

DIGITIZER BLOCK DIAGRAM

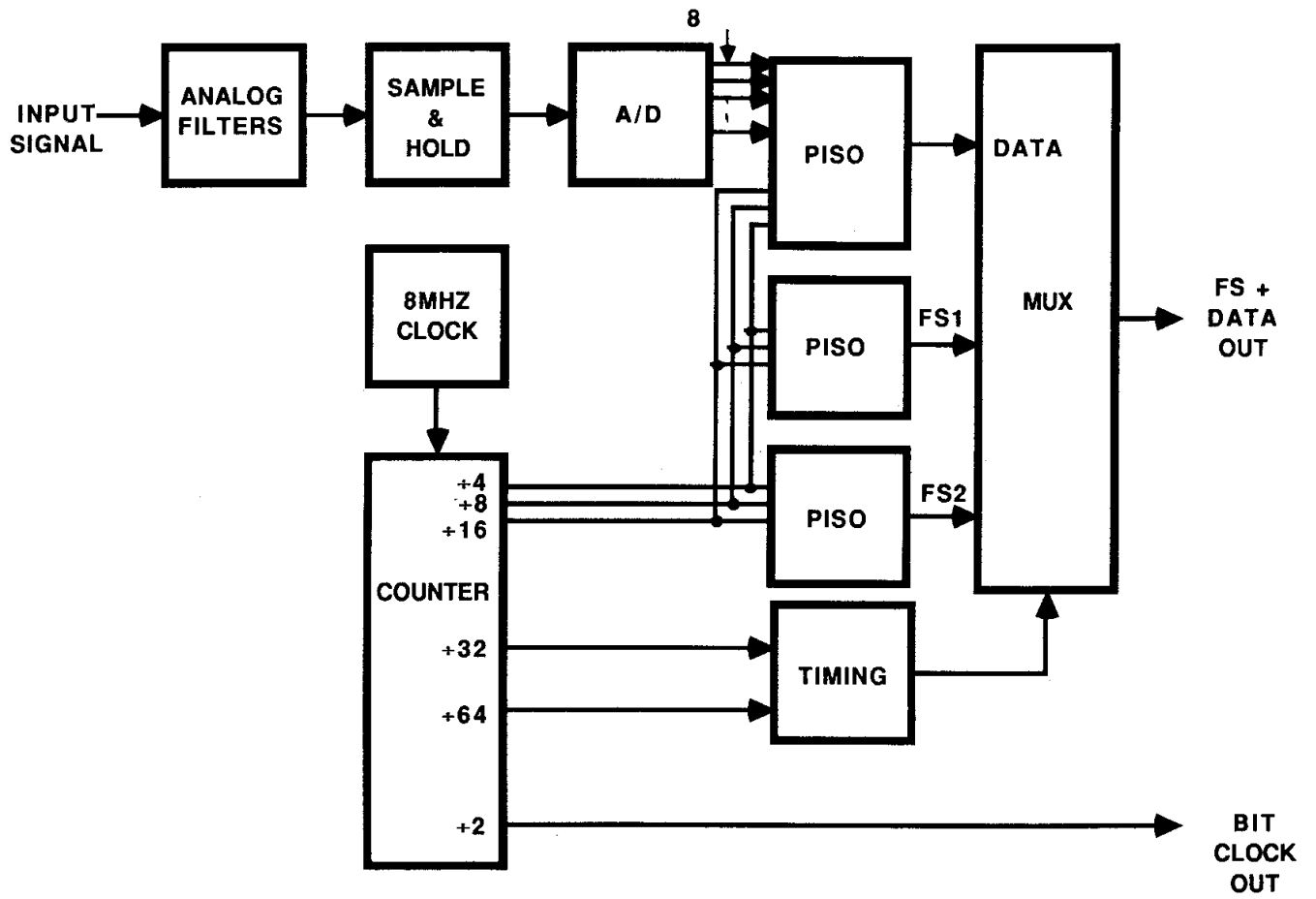


FIGURE 7