AUTOCORRELATION APPLIED TO THE MAGNETIC RECORDING CHANNEL

KRIS S. BALCH
Manager, Advanced Digital
Eastman Kodak
Advanced Development-Magnetic Systems
San Diego, California

INTRODUCTION

Today I will describe the application of the Autocorrelation function to the Magnetic Recording Channel. I will explain what is an autocorrelated function, how does it behave and where may it be applied in the Magnetic Recording channel.

There will be a brief description of Kodak San Diego's Autocorrelator and how we apply this technology. If I have done my job well at the end of this presentation you will have enough knowledge about autocorrelation to access your own application. Before I start, let me give a brief overview on the application of an Autocorrelator. The Autocorrelator can be used to collect information on signals in a magnetic recording system and display this information graphically as a statistical plot. Autocorrelation, in the time domain, is the counter part to a spectrum analyzer in the frequency domain (Fourier Pair).

The information about the signal of interest must be stored for post analysis. This information called a database must then be processed by a computer. The computer passes the database through the autocorrelation algorithm and produces a second database. This second database represents a plot of the autocorrelated function. The next step is to plot the database on a video screen. This plot can be examined for periodicities, randomness, and relational influences on a captured signal. In our application, this signal is an error flag or a dropout flag. We want a statistical picture of the magnitude of errors and their relative frequency. The information gained from Autocorrelation can aid in solutions for:

- Error Correction Codes
- Media Evaluation/Qualifications
- Media Process Defect Identification
- Mechanical Eccentricities
- Modulation Code Performances
- System's Figure of Merit

To use a cliche, “one picture is worth a thousand words,” is exactly the point of the Autocorrelator’s graphical display. It yields information useful to those disciplines which often find difficulty in describing an event in understandable terms.

AUTOCORRELATED FUNCTION

Let us begin with the Autocorrelated function. Mathematically, the correlation function is defined as:

$$S(\tau) = \lim_{T \to \infty} 1/2T \int_{-T}^{T} K(t)M(t+\ )dt \qquad (1)$$

Where K(t) and M(t) are two waveforms which are time dependent.

The correlation between waveforms is a measure of the similarity or relatedness of each to the other by a certain interval. When K(t) and M(t) are the same waveform this is called an autocorrelated function. Figure 1 shows an uncorrelated signal described as uncoherent at T. Figure 2 shows a maximum correlation when τ=T.

The Autocorrelation function and its power spectral density is a fourier transform pair. Waveforms, which are deterministic (statistically predictable), can be more completely described through spectral techniques. However, random waveforms that are, by definition, undeterministic must be described in probabalistic terms. Autocorrelation is a method for describing the Random behavior. Both random and periodic behavior can be evaluated in deterministic terms as limits once autocorrelated.

In our application, the signal to be autocorrelated, is the error flag or dropout flag. Depending on the type of flag, the reliability of the flag and the point in the system where the error is detected will influence the amount of interspection on the error mechanisms. In practical terms we have a finite length of media and we must restrict the database to a manageable capacity. Keeping these global influences in perspective at the time of analysis will increase the knowledge derived from the Autocorrelated plot.

AUTOCORRELATED BEHAVIOR

Next, let us move on to a more exact description of an Autocorrelated function. Again, mathematically, an autocorrelated function is defined as:

$$S(\tau = \lim_{T \to \infty} 1/2F \int_{-T}^{T} K(t)\ K(t+\ )\ dt$$

Limiting our sample to a finite window, we have an ensemble average:

$$S(\tau) - \sum K(t)\;K(t+\tau)$$

When a function is periodic, we can write:

$$k(t) - \sum K e^{j2\pi nt/T}$$

and Autocorrelated:

$$S(t) - \frac{1}{2T}\int_{-T}^{T}\left[\sum_{m=-\infty}^{\infty} K_m e^{j2\pi mt/T}\right]\left[\sum_{n=-\infty}^{\infty} K_n e^{j2\pi nt/T}\right]dt$$

Integrated and summed,

$$S(t) = \sum_{n=-\infty}^{\infty} K_n K_{-n} e^{j2\pi nt/T} = |K_0|^2 + 2\sum_{n=1}^{\infty} |K_n|^2 \cos 2\pi n t/T$$

Figure 3 shows the graph. When a function is Random, we can write:

$$S(t) = \int_{-\infty}^{\infty} K_m(t)\,K_n(t)\,dt = \frac{1}{(S-n)T}\sum_{n=0}^{S-n-1} K_n K_{n+t}$$

where (S)is the number of equidistant samples within the Autocorrelation window T seconds separated by:

(K) is the nth sample of the function

NT is right boundage of the autocorrelation window

Figure 4 shows the graph.

Taking a complex ensemble average of an error signal may produce a graph shown in Figure 5. This graph’s units are bits on the X-axis and of occurence on the y axis. The X-axis is called our viewing window. Uncorrelated random errors can be found at the zero bin on the y axis peak munus the start of the negative sloped area. Various durations of random errors clustered in groups or bursts produce the linear sloped area.

Random events have a slope of zero and are called the Noise floor. Periodicity’s may have a gaussian distribution. Peaks outside the neg sloped burst area that have a magnitude in excess of 100 occurrences correlate as a periodic event. It should be noted that the X-axis is listed as Bins. The implication here is that the Bins can be scaled to represent 1 Bit or 10,000 Bits. Effectively, this increases the amount of media which is under examination. This plot may take over 100 recursive calculations before the total sample has been evaluated. Each pass represents the correlation ofr several hundred errors. This is the reason that the graph appears incompletely filled.

MAGNETIC RECORDING CHANNEL APPLICATION

Now that we know what the Autocorrelation function represents and how it behaves, let us see how to apply the technology. To run the autocorrelator we need the signal to be examined and a bit clock that is in sync with the data rate of the sampled signal. The first requirement in applying this tool, is to decide what do we want to view. As an example, if dropouts are to be measured at what link along the signal chain do we monitor the signal.

One approach could detect a phase reversal in a Bandedge signal. Another could detect an amplitude loss of 6 or 12 dB. Both acceptable, but subject to extraneous influences. A cognitive process must be taken concerning the point of application in the system. Also, as interpreting the extraneous influences on the results is critical for clarity.

Threshold loss detectors, sync loss detectors, Bit Error rate detectors, modulation code failures, or error correction code failures all could be used as input to the Autocorrelator. The resolution that is desired for analyzing the Magnetic Recording Channel governs the detector's selection. Resolution can also be extended if scaling is used with the error flag. This allows through the viewing window to examine related errors which span more than 10 feet of tape.

ANATOMY OF KSD AUTOCORRELATOR

Let us turn our attention to the hardware implementation. Shown in Figure 6 is a block diagram of our hardware. To perform an autocorrelated function, a database representing the signal is required. To capture this signal and relate it to a timed event a large memory buffer is required. To note each event (error flag) to a time interval counter is also required.

Once the database is captured. we process it through the algorithm. In our case, to produce meaningful results we can simultaneously collect data and process it. This rate is limited only by computer capability to execute the algorithm and the capacity of the memory buffer. Currently, our limitation is 16 mB/s. However, we have an improved architecture which will provide realtime analysis. Our hardware controllers fit either CAMAC Card configuration or the IBM AT. The CAMAC configuration is suitable for application ot powerful minicomputers such as a VAX. The IBM AT configuration is suitable for use as a portable laboratory tool.

The algorithm provides pre-scaling for large window spans, variable window resolution and can transform the autocorrelated function into power spectral density plot. Hard copies of plots and storage of the database is possible. Our application, although not complete, has been in error analysis and media evaluation.

We use these plots to estimate Burst magnitudes and Randomness of errors. These plots represent ten's of millions of bits and have provided a high degree of correlation with traditional methods (Burst/Gap analysis).

We have done some preliminary tests on media evaluation. Tests have shown some promise in segregating media samples into manufactured types by the shape of the autocorrelation plot. Further testing may show that there is a profile which is acceptable for a give system. Those media samples falling out of this sample may require rejecting. Figures 7 & 8 and Figures 9 & 10 show the profile difference between two media samples and two different media types.

CONCLUSION

We now know that the Autocorrelation function is a measure of the similarity between a signal with itself shifted in time. We learned what the characteristic features imply in the graphical plots.

Hopefulyy, the suggested areas for application of this technology will develop new and greater useage.

Autocorrelation is indeed a new tool for Magnetic Recording technologists. We would welcome further industry input on the application of the Autocorrelator. Application is the key for further understanding.

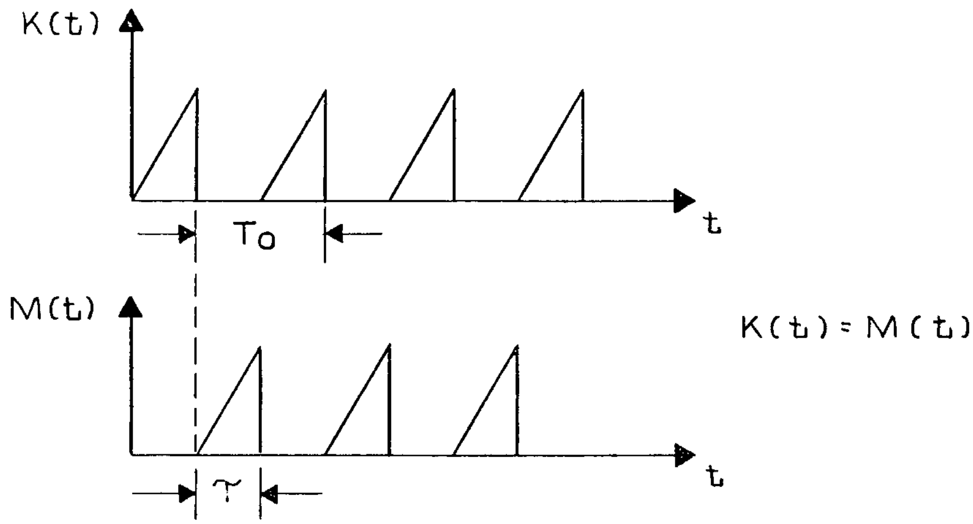

FIGURE 1 DISPLACEMENT AT WHICH THE CORRELATION IS ZERO

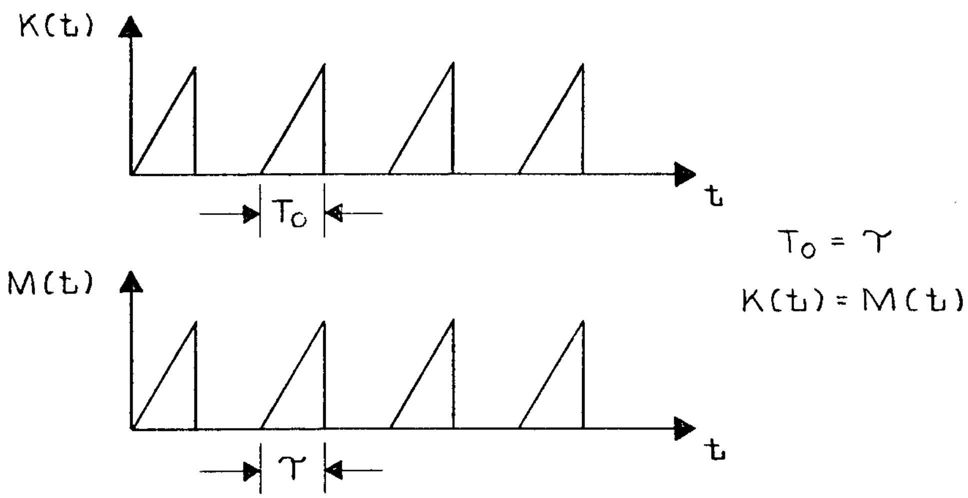

FIGURE 2 DISPLACEMENT AT WHICH THE CORRELATION IS A MAXIMUM

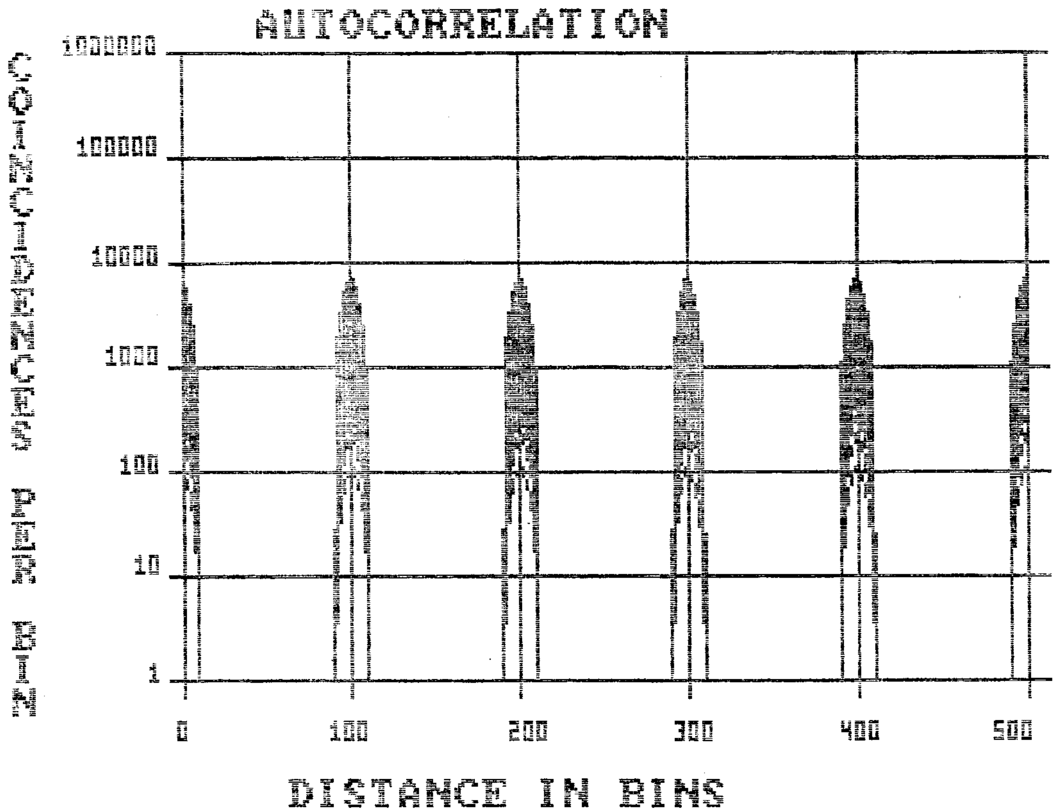

FIGURE 3

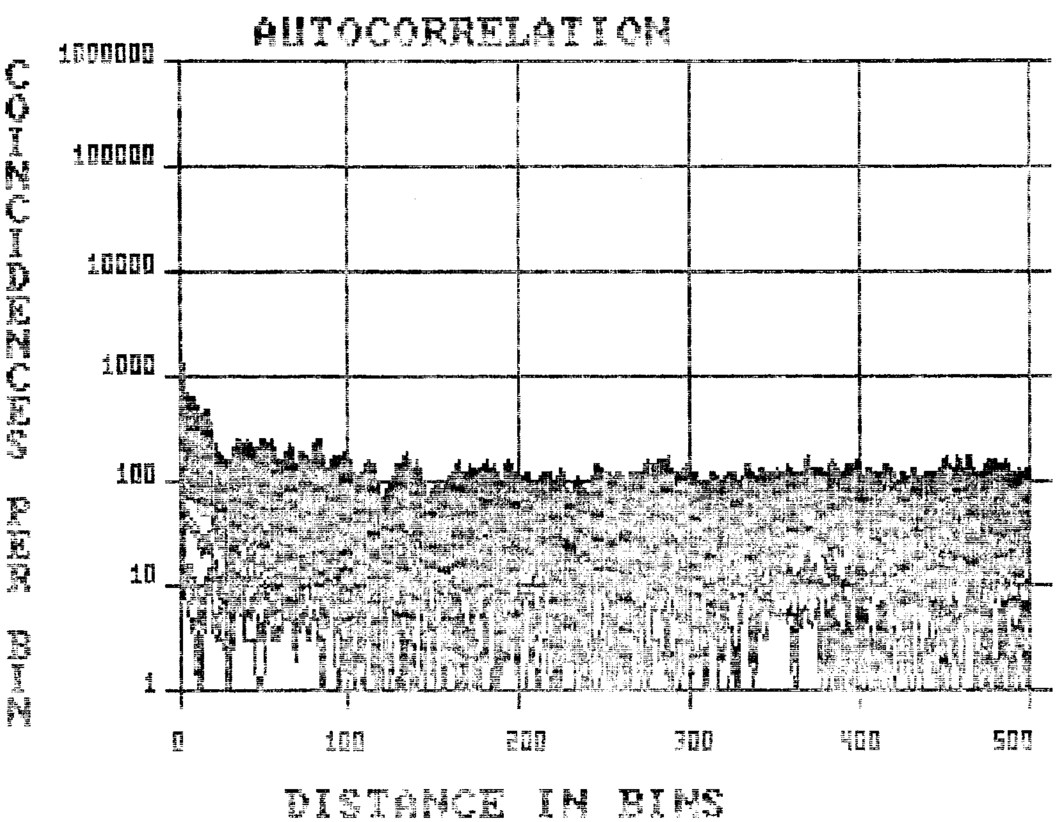

FIGURE 4

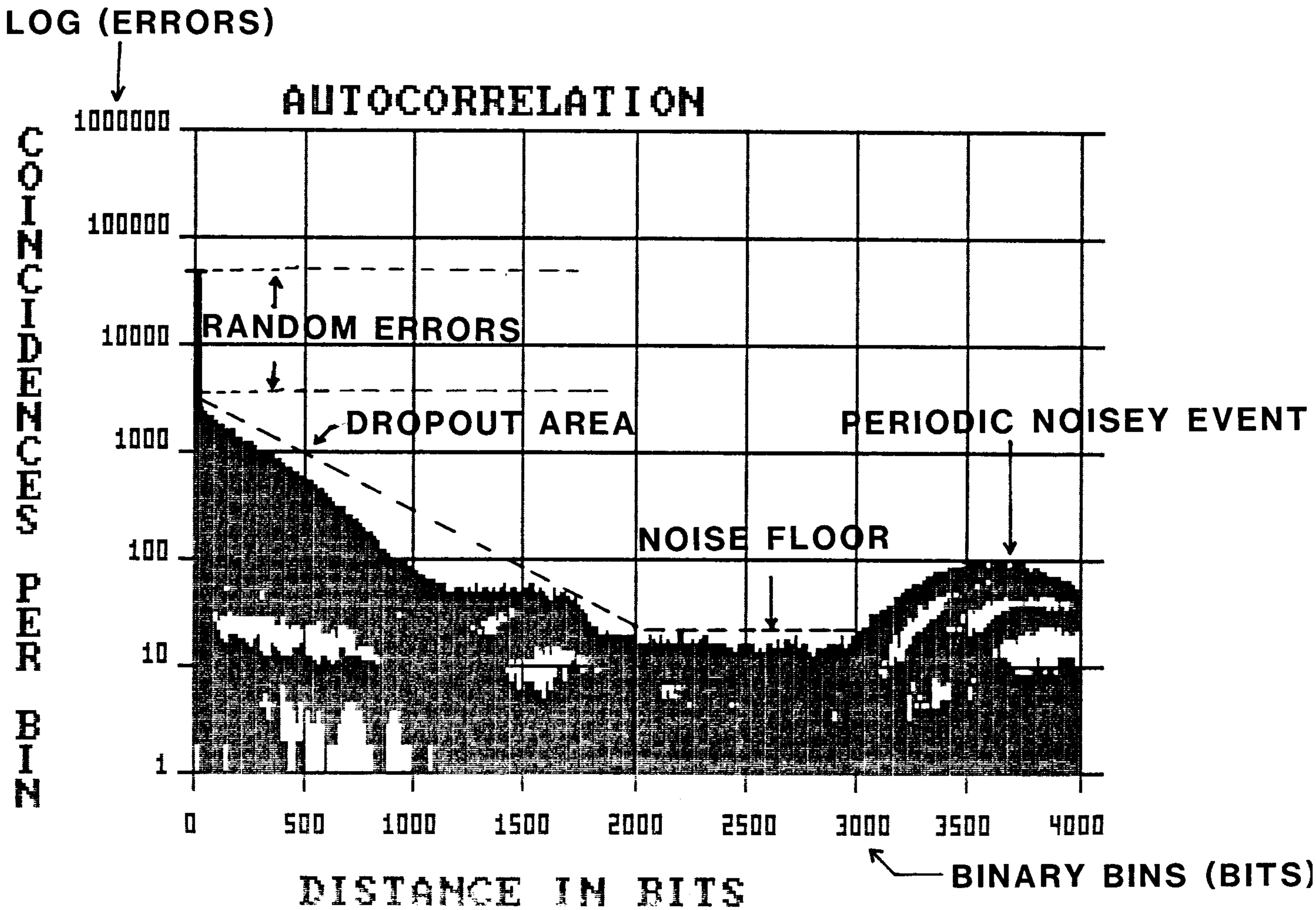
LOG (ERRORS)
AUTOCORRELATION
COINCIDENCES PER BIN
1000000
100000
10000
1000
100
10
1
RANDOM ERRORS
DROPOUT AREA
NOISE FLOOR
PERIODIC NOISEY EVENT
0
500
1000
1500
2000
2500
3000
3500
4000
DISTANCE IN BITS
BINARY BINS (BITS)

Figure 5

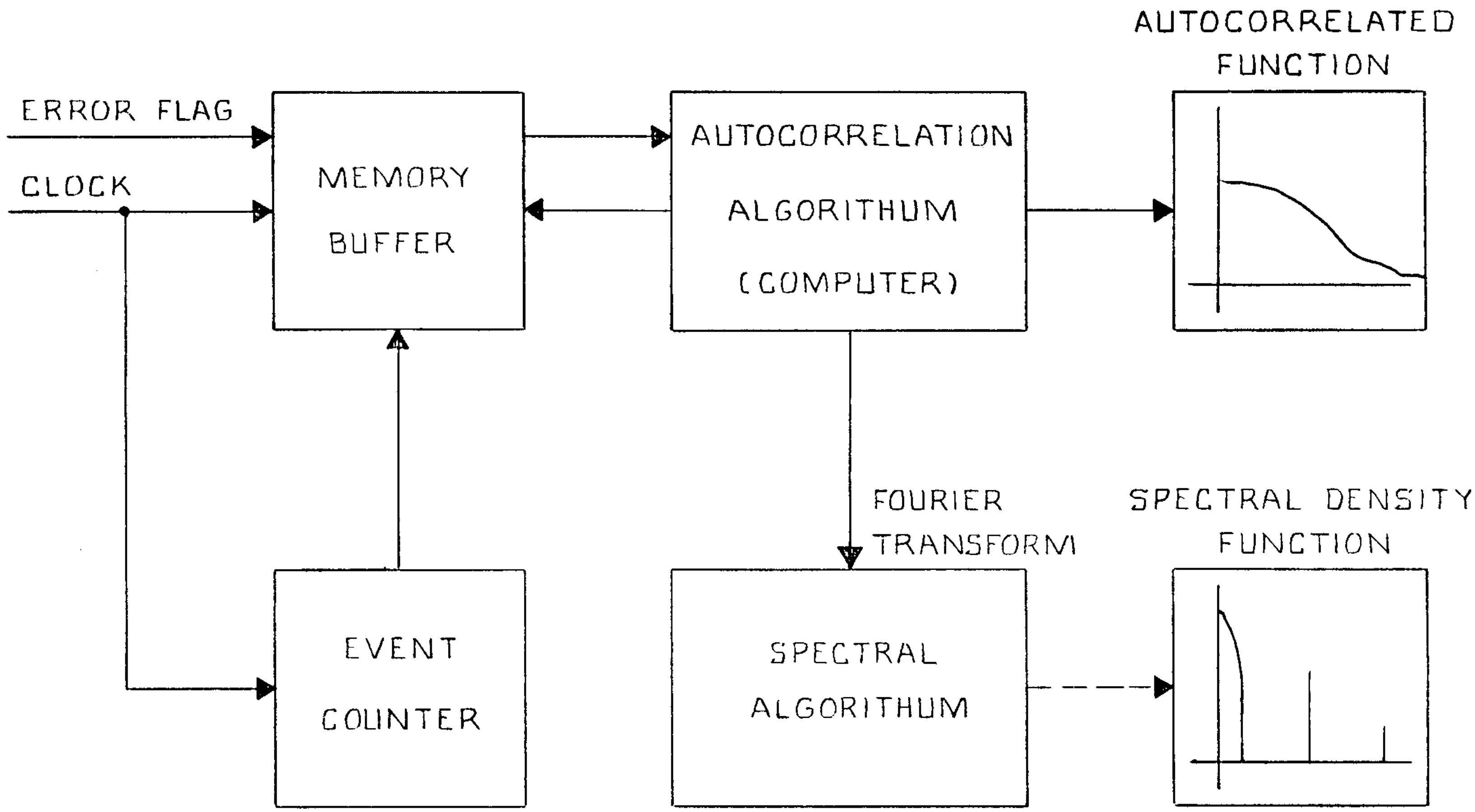
ERROR FLAG
CLOCK
MEMORY
BUFFER
AUTOCORRELATION
ALGORITHUM
(COMPUTER)
AUTOCORRELATED
FUNCTION
EVENT
COUNTER
FOURIER
TRANSFORM
SPECTRAL
ALGORITHUM
SPECTRAL DENSITY
FUNCTION

FIGURE 6

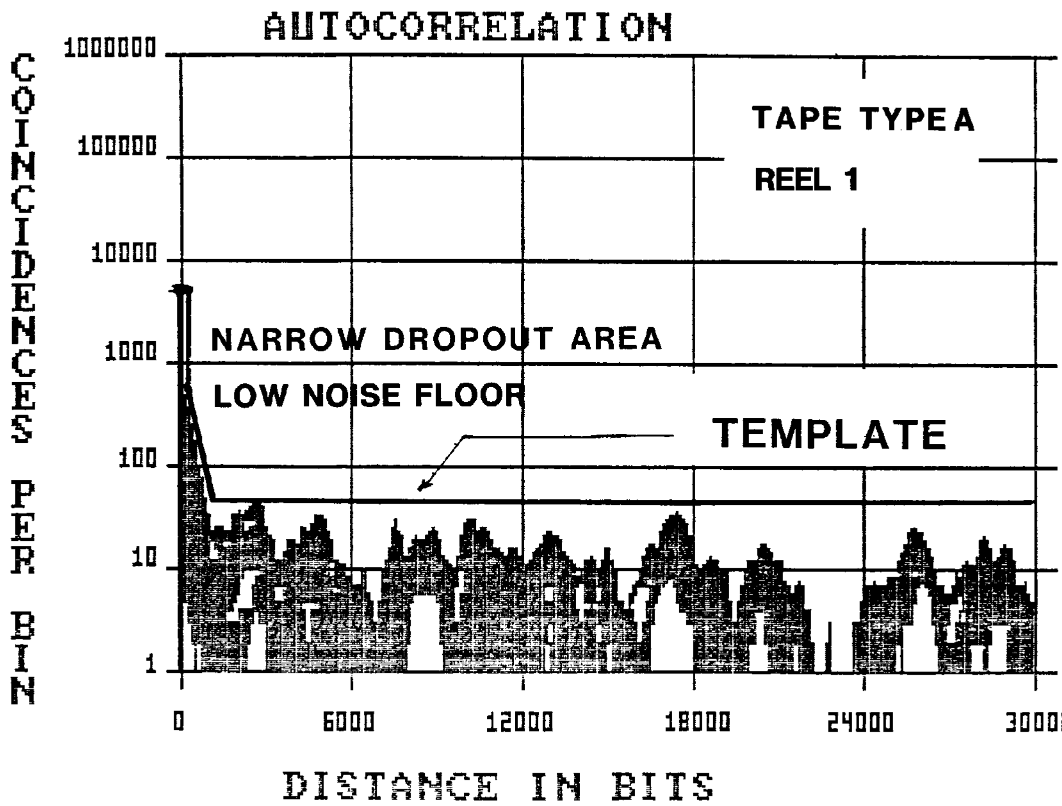

Figure 7

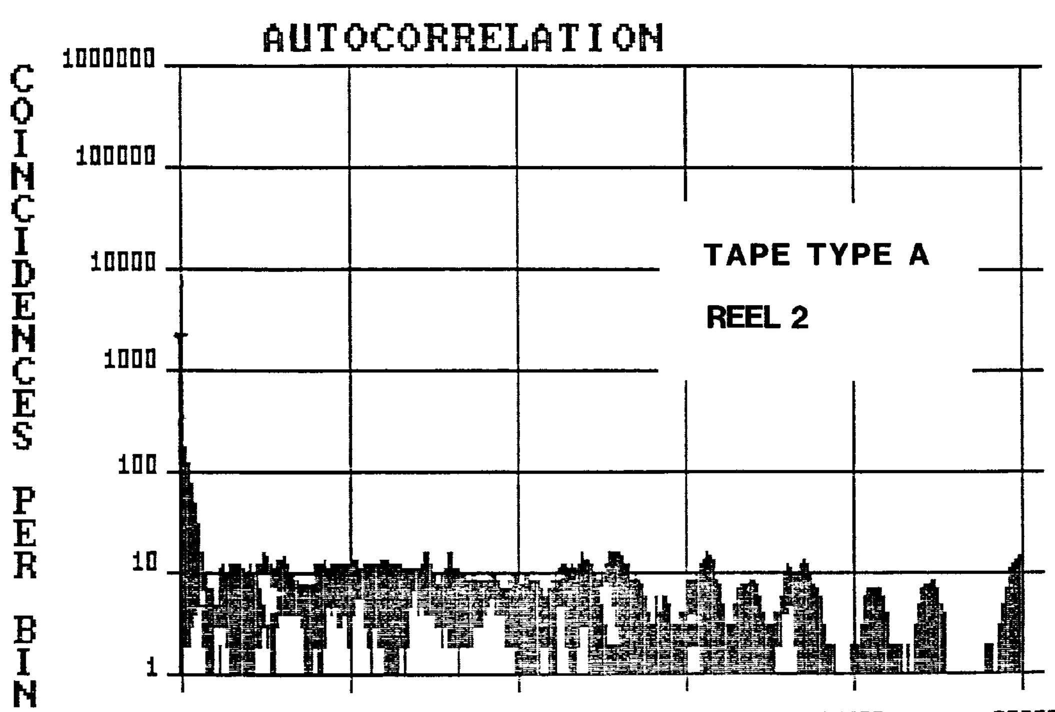

Figure 8

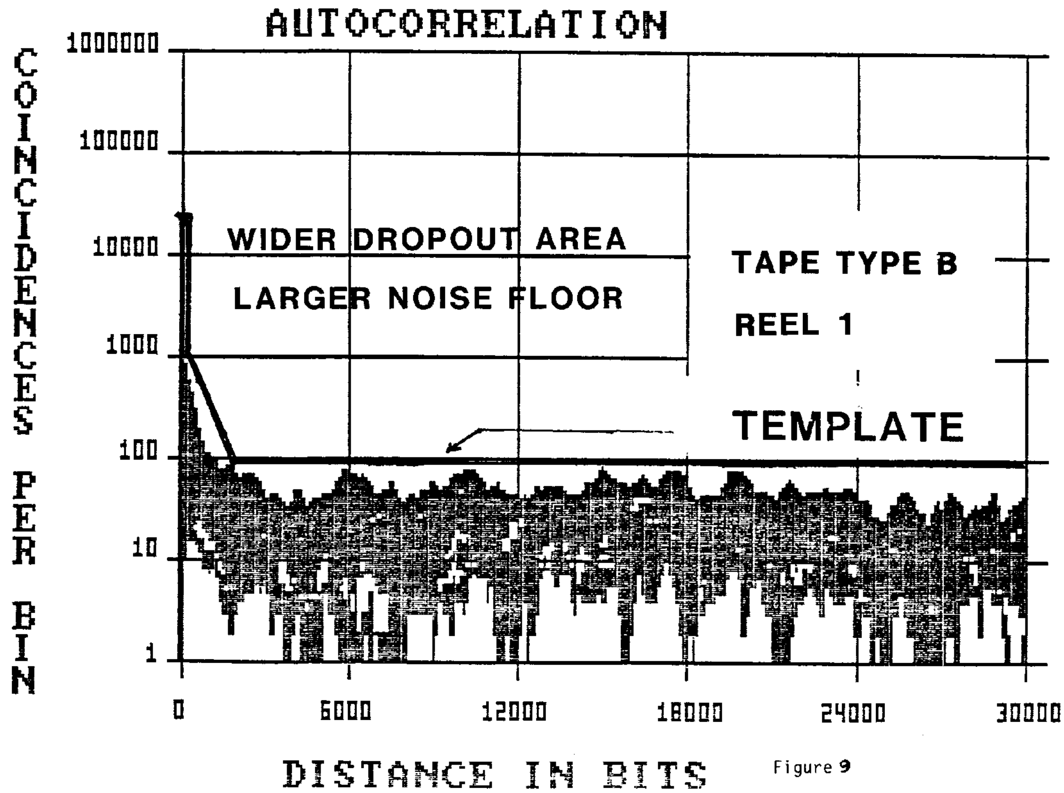

Figure 9

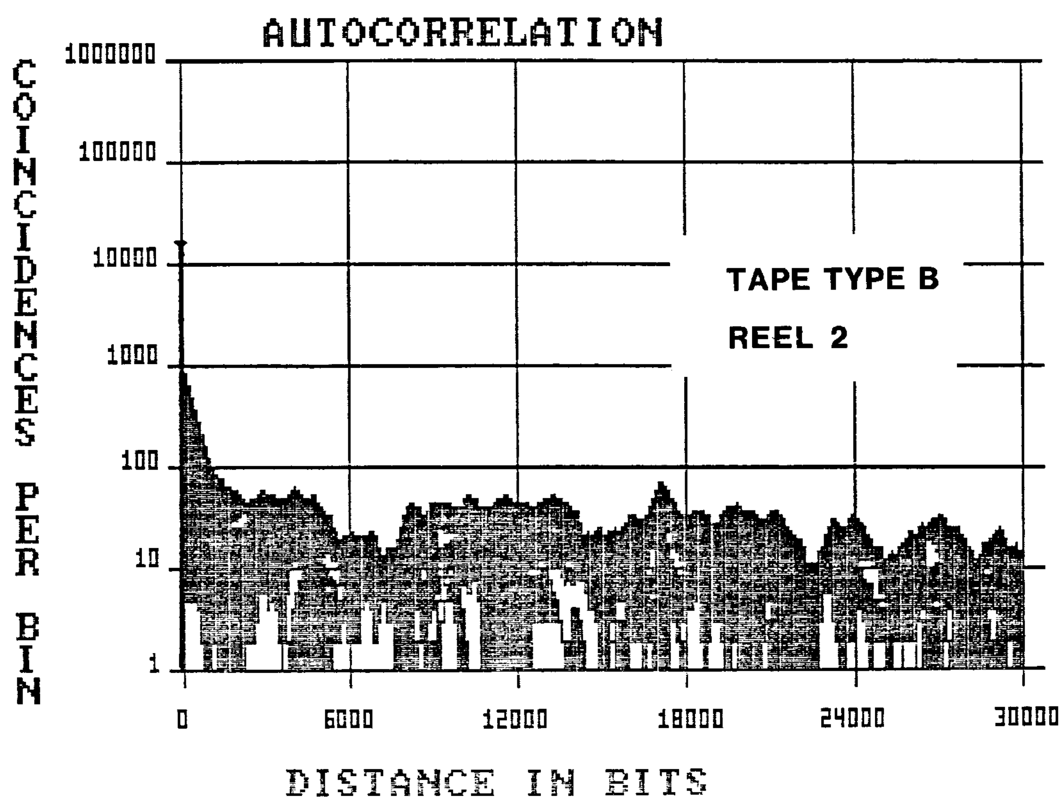

Figure 10