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AN IMAGE PROCESSING SYSTEM FOR EYE STATISTICS FROM EYE DIAGRAMS

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ABSTRACT

The seventh CCITT (Consultive Committee of International Telephone and Telegraph), Plenary Assembly has defined ISDN (Integrated Services Digital Network) as a evolution from the existing telephone network that provides end to end digital connectivity. Wide range of services are anticipated. Both voice and non-voice services will be offered. The network users will have access to these services via the standard multipurpose customer interfaces. ISDN Network simulation plays a significant role in the services and the capabilities of the future networks. In this paper we concentrate upon the simulation and image processing aspects in the transmission of data over the subscriber lines.

I. INTRODUCTION

The transmission of data for the emerging ISDN calls for extensive simulations. The ISDN rates have been standardized at 128 (2B), 384 (6B), 1,536 (23B) kb/s with signaling on separate D channels. Various subrates of 2.4, 4.8, 9.6, 8, 16, and 32 kb/s also exist for the local loop plant. The line code selected by the Bell Operating Companies is also defined as the 2B1Q block code. In addition, the local characteristics of the loop environment can also vary significantly from one country to the next, and from one geographical area to the next.

In view of the enormous amount of computing required to optimize the system components like the equalizers, echo cancelers, matching circuits, etc., we have developed a dependable and inexpensive methodology which permits the system designer to automatically process each loop simulation as ISDN data is transmitted. The techniques are applicable to any simulation environment ranging from time-shared mainframe to a stand-alone Personal Computer. The time domain simulations lead to wave shapes and eye diagrams of the received data. The image processing algorithms presented in the body of the paper scan the eye diagrams for seven eye statistics; the average positive eye opening, the average negative eye opening, the top eye thickness, the top eye opening, the central eye thickness, the lower eye opening, and the lower eye thickness.

These statistics are normalized to the eye height and simumulation program can thus scan many thousands of loop configurations effectively in a single simulation run. The eye statistics are then displayed to indicate broad and significant effects of changing system components like the echo canceler, or the equalizer, etc.

In light of this emerging and intelligent network to provide a wide variety of services, it becomes necessary for the vendors of network components to ascertain that the components can perform under a widely varying subscriber loop environment. Experimental verification under laboratory conditions with every possible loop impairment is impractical if not impossible. For this reason, computer simulation studies provide a significant amount of confidence regarding component performance. This approach is highly desirable because installation of poorly designed components can seriously mar the network performance and such components can cause bottlenecks in the complete utilization of the network over a long period of time. The simulation and design approach for networks is practical and feasible as it has been documented in the VLSI industry. The network industry stands to benefit greatly by having access to standard design algorithms and fairly sophisticated databases.

Some of the classic methodologies for loop system studies exist (1,2). Some of the Subscriber Loop Survey databases (3,4) published both as computer files and as technical documents facilitate vendors and component designers. The network studies can be accurately and efficiently performed.

The major validation of vendor components is based upon studying the accuracy of data transmission over the subscriber network. Data accuracy (5) is evaluated by measuring the bit error rates, by measuring noise events, and by evaluating the eye openings. In this paper we confine the study to the eye diagrams and the role they play in evaluating the system performance.

II. SIMULATION METHODOLOGIES

Time domain simulation that lead to eye diagrams and eye statistics are essential in studying system performance. Two techniques exist. The first technique, depends upon calculating the system response over short finite durations of time. Initial conditions are defined and a predefined sequence of inputs generates the system response. When steady state response is desired the input sequence (of repetitive pattern) is made arbitrarily long and the output is obtained after the transient conditions have settled down.

In the second technique, the entire system is excited by the repetitive input sequence of an arbitrarily long duration. The boundary conditions at the start and finish of this input sequence are matched and the system is trapped in a cycle of repetitive performance. The input sequence and its duration being user defined, permits the simulationist to study the system performance under a wide variety of input conditions. The accuracy of this technique depends upon the number of Fourier components and the sampling interval of the input sequence. These user parameters are generally programmed and offer the simulationist ample flexibility. In the results presented in this paper we have used the later technique with the number of excitation pulses ranging from a minimum of 48 pulse with a sampling frequency of five points per pulse to 16,384 pulses with one sample per pulse, or 2048 pulses with 8 samples per pulse.

III. EYE DIAGRAMS AND EYE STATISTICS.

Time domain simulations of the data transmission through the subscriber loop yields the signal pulse shapes at selected points. This signal undergoes a certain amount of signal processing before the data can be recovered. At the subscriber end the two major aspects of signal processing include equalization and timing recovery. When the recovered data is superposed in the same time slot, eye diagram is generated. The loop plant, however, consists of a widely diverse collection of loops. If a given component has to perform with a very large percentage of these loops, then the significant information in the eye diagrams will have to be extracted from the eye diagram of a large number of loops. The eye statistics contain the summary of these significant results.

3.1 Eye Diagrams and Line Code

The line code influences the shape of the eye diagram. Two major line codes for basic rate ISDN transmission are the alternate mark inversion (AMI) and the two binary to one quaternary (2B1Q) codes. The standard adapted by the Bell Operating Companies in the US is the later 2B1Q code. For this reason the techniques discussed are limited to these two codes.

3.2 The Generation of Eye Statistics for the AMI Code.

The number of pulses and the number of points per pulse both influence the control parameters necessary for the generation of the eye statistics. These two variables are defined and held fixed for the simulation of each loop in any particular system configuration. For the purpose of illustration, we derive the eye statistics for a repetitive pulse duration with 48 pulses with 5 points per pulse. There are three signal levels at + 1, 0, and -1 in this code and two eye openings are generated.

Two hundred and forty equally spaced instants of time span the forty-eight pulse period over which the forty-eight AMI sequence of data pulses is transmitted. The pulses are thus approximated as a sequence of five straight lines (in the time domain). Out of the 240 instants of time for scanning forty eight ones, zeros or minus ones, 144 instants are selected for the scanning of the 48 data bits. The first set of 48 instants contains the instant at which the absolute maximum value of the incoming magnitude is located. The second set of 48 instants precedes the first 48 instants by 1/5 the pulse duration and the third set follows the first 48 instants by 1/5 the pulse duration.

Next, for each of the three sets of 48 instants at which the scanning can be done, the data is arranged in descending order of magnitude. Three clusters of data are generated: (a) at the upper level corresponding to the plus ones received in the data; (b) at the intermediate level corresponding to the zeros received and (c) at the lower (minus) level corresponding to the minus ones received. From these clusters seven eye statistics can be generated. In Figure 1 the three scanning instants t_1, t_2, and

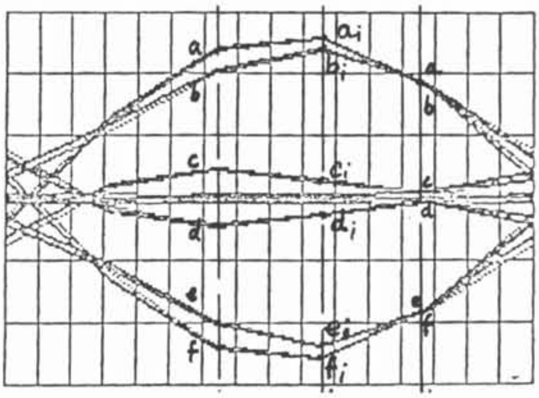

Figure 1 Eye Statistics from Eye Diagrams.

t_3,and the three data clusters representing the distances a_i b_i, c_i d_i, and e_i f_i (i = 1, 2, or 3) are indicated. Next, a_i b_i expressed as a proportion of the average eye height constitutes the top eye thickness. The distances b_ic_i, c_id_i, d_ie_i and e_if_i, also expressed as proportions of the average eye height constitute the top eye opening, the central thickness, the lower eye opening, and the lower eye thickness respectively. Finally, the positive average eye height and negative average eye height constitute the sixth and seventh pertinent eye statistics from the eye diagram at each of three scanning instants t_i (i = 1, 2, or 3).

However, the scanning instant t is selected to have the maximum average top and bottom eye opening leading to a unique scanning instant and a unique set of seven statistics stored away for each eye. Two such seven parameter eye statistical sets for each of the two eyes generated by data from CO to subscriber and from subscriber to CO are thus stored for each loop.

Scanning the eye at three rather one instant gives two relevant insights into the functioning of the system. First, the time differential of the opening indicates the horizontal eye opening. Second, the difference in the differential on the positive (i. e., from t_1 to t_2 as compared against t_1 to t_3) indicates the asymmetry of the eye. Generally, any tails in the single pulse response make the eye opening greater on the t_2 side compared to the t_3 side. These additional numerical quantities govern the timing recovery circuit on the subscriber side. The display of these quantities depends upon the system user.

3.3 Scatter Plots For the AMI Code

We display a representative eye diagram (Fig. 2) which lead to one of the scatter plots (Fig. 3) obtained by the image processing programs. The scatter plot is generated by displaying the eye opening of all the

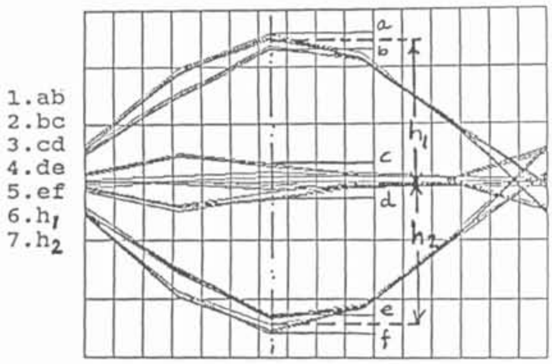

Figure 2 The Seven Eye Statistics of a Typical Eye.

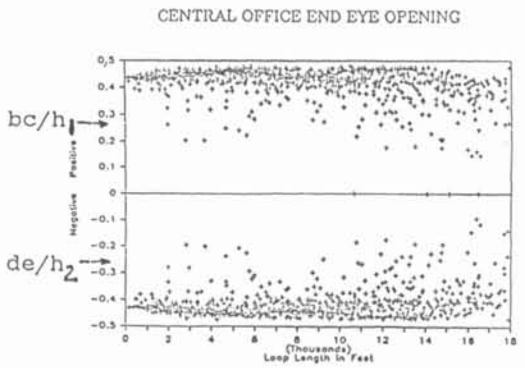

Figure 3 Scatter Plot of Two of Seven Eye Statistics.

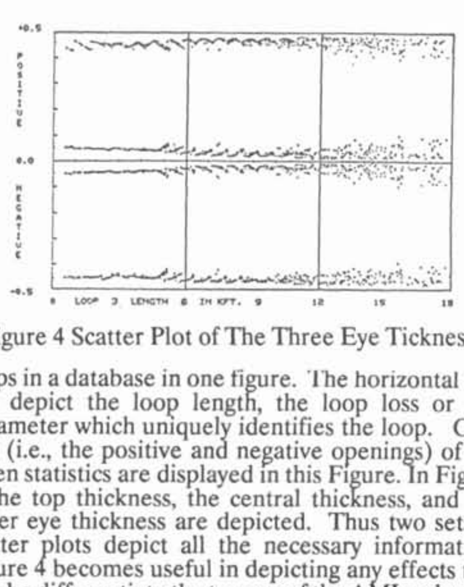

Figure 4 Scatter Plot of The Three Eye Ticknesses.

loops in a database in one figure. The horizontal axis can depict the loop length, the loop loss or any parameter which uniquely identifies the loop. Only two (i.e., the positive and negative openings) of the seven statistics are displayed in this Figure. In Figure 4, the top thickness, the central thickness, and the lower eye thickness are depicted. Thus two sets of scatter plots depict all the necessary information. Figure 4 becomes useful in depicting any effects that may be differentiate the top eye of the AMI code with respect to the the lower eye or the top thickness with respect to central or negative thickness of the eye.

The eye statistics of loops in the database are generated and stored under a predefined set of terminal conditions. The eye statistics can now be displayed as a collection of scatter plots, each dot denoting a particular eye statistic of a particular loop. The top and bottom eye opening statistics are assembled in one scatter plot (Figure 3). Along the X-axis the physical length of the loop or the equivalent length of #22 AWG cable (or equivalently the loop attenuation) may be plotted. The top central and bottom eye thickness may also be plotted on one scatter plot (Figure 4). With two independent directions of transmission a set of four scatter plots are obtained.

3.4 The Generation of Eye Statistics for the 2B1Q Code.

The number of pulses for the 2B1Q code is 200 and the number of points per pulse is 10. These two variables are predefined and held fixed for the simulation of each loop in any particular system configuration. However, the 2B1Q code has 4 signal levels at +3, +1, -1, and -3 and three eye openings are generated. The number of eye statistics increases and the depiction of the composite results for the entire loop population need reappropriation.

In Figure 5, an eye diagram for the 2B1Q code is depicted. At the maximum eye height at instant t, there are seven actual distances ab, bc, cd, de, ef, fg, and gh which completely characterize the thicknesses and openings. However, the average heights at the +3, +1, -1, and -3 levels add 4 additional statistics and there is no elegant way of displaying these 11 statistics even after proportioning the distances to the average values. For this reason, we have made an underlying simplification. All the eye diagrams are rescaled to a maximum eye height from +3 to -3 even if the system cannot perform to yield these extreme values. The seven distances (ab through gh) are then proportioned to generate a composite plot for all the loops.

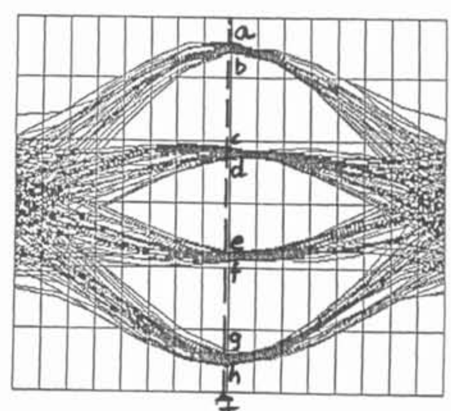

Figure 5 Typical Eye Diagram of the 2B1Q Code.

3.5 Eye Statistics to Composite Plots

Figure 6 depicts a composite 2B1Q plot for all the loops in a database for the central office to the subscriber data transmission. Here an ideal 2B1Q eye with zero eye thicknesses would be represented as four points. The eye thicknesses ab, cd, ef, and gh in Figure 5, would be four single points at +3, +1, - 1, and -3 levels. However, due to the imperfection of the system vertical lines of finite length appear at the levels. The eye openings bc, de, and fg in Figure 5 start to close. A completely closed eye would be a vertical line between +3 and -3.

In Figure 6, the horizontal axis depicts the loop length. Longer loops display eye closure since the composite plot becomes dense with longer vertical lines in the right side of the display. Two plots are necessary to depict the bidirectional mode of the ISDN data transmission. In Figure 7, we depict the composite plot at the subscriber side obtained from the eye diagrams at the subscriber. Duplex data transmission with adaptive echo cancellation suffers more at the subscriber side because of the increased number of bridged taps. This effect is clear by comparing Figure 7 with the plot in Figure 6 obtained at the central office side.

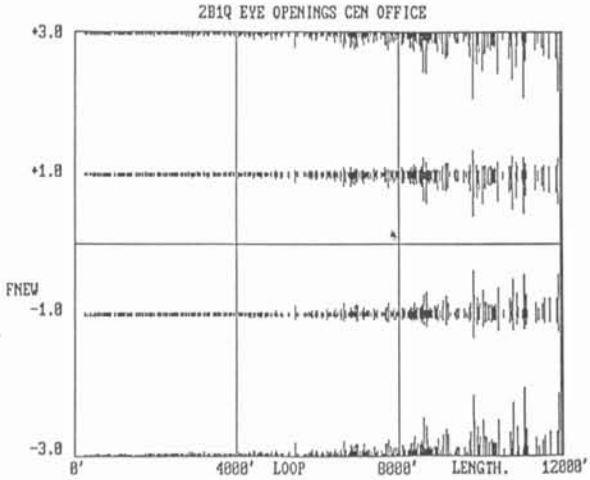

Figure 6 Composite Scatter Diagram of the 2B1Q Code Eye Diagrams of a Loop Population in any given loop database

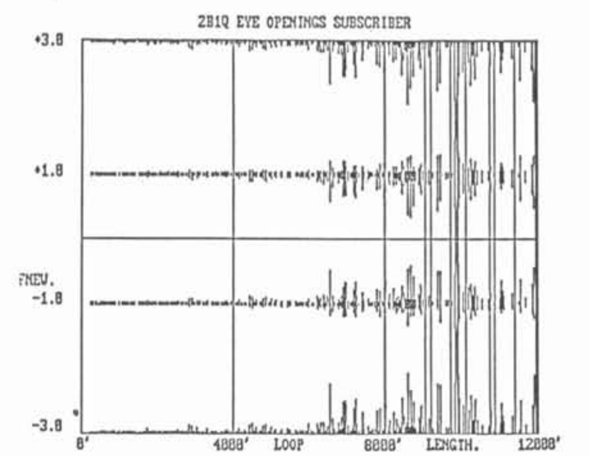

Figure 7 Composite Scatter Diagram of the 2B1Q Code Eye Diagrams of a Loop Population in any given loop database

IV. Discussion of the Algorithms and Their Use

An automatic scanning of the eye to evaluates system performance under the highly variable system and loop configuration facilitates the comparison of a large cross sections of results. The algorithms presented in this paper generate diagrams and plots which can be easily scanned by the system designer to get a qualitative picture of the acceptance or rejection of a certain system. With this initial inference, the system designer may persue promising system configurations. When more detailed evaluation is necessary, other scatter plots with signal to noise ratios or circular plots may be attempted with additional computing and programming efforts.

The time required to execute the algorithms presented in this paper represents about 15 to 20 percent of the total execution time. Considerable part of this time is consumed by the disk access and the overall simulation time for the loop can be reduced by allocating additional memory in the mainframe environment or by executing the program in a virtual disk in the PC environment.

The simulation studies that have been attempted incorporate this eye scanning postprocessors for generating the eye statistics or to derive the signal to noise ratio (20 times logarithm to base 10, of the ratio of eye opening to eye closure) for large cross sections of subscriber loops.

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