No. 1 July 20, 1990

Capsim Application Note

Joint Echo Cancellation/Equalization and Timing Recovery for High Speed Full Duplex Baseband Transmission Systems

Introduction

In this application note, we will describe the simulation of the ISDN U-interface for high speed data transmission over the subscriber loop. The subscriber loop may contain bridged taps and twisted pair transmission lines of various gauges. In full-duplex transmission, the echo across the hybrid must be cancelled. The received signal is distorted by the subsciber loop and must be equalized. Moreover, timing information must be extracted from the received signal for proper operation of the echo canceller and equalizer[1,2]. However, the echo must be substantially reduced for proper timing recovery operation. The interplay between echo cancellation/equalization and timing recovery can be studied through hierarchical block diagram simulation of the various subsystems that form the simulation. Many issues, such as the effects of bridge tap lengths, total distance of the subscriber loop, symbol rate versus fractionally spaced echo cancellation/equalization and line codes can be examined using Capsim as the simulation tool.

The U-Interface

The Capsim universe for the simulation of the U-interface is shown in Fig. 1.

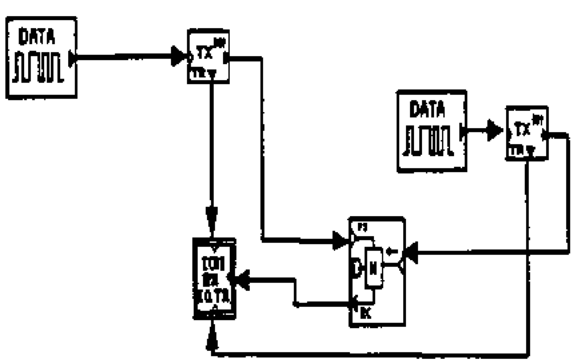

Figure 1. U-Interface

The remote transmitter sends data which is received by the local receiver. The local transmitter also sends data which appears as an echo added to the received signal from the remote transmitter. The receiver must cancel the echo from the local transmitter, equalize the distorted remote signal, recover the correct timing information, sample the signal and detect the symbol that was transmitted.

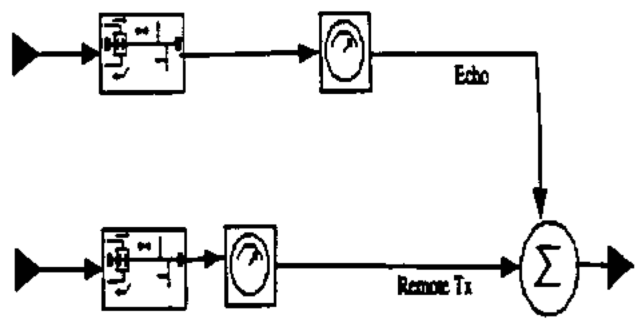

Figure 2. Subscriber Loop Galaxy

The subscriber loop is a galaxy which uses stars to model the tranmission line network and echo path. The galaxy is shown in Fig. 2. The transmission line star models the subscriber loop with wires of various gauges and with bridged taps by computing the impulse response given the topology of the transmission line network. This is done during the initialization phase of a Capsim simulation. The impulse response is then convolved with the input samples during the run phase using the overlap save method.

The subscriber loop impulse response and frequency response for the loop shown in Fig. 3 appear in Fig. 4 and 5. The echo path impulse response appears in Fig. 6. The loop is terminated in a 100 Ohm load. The hybrid balance circuit is based on [1,2].

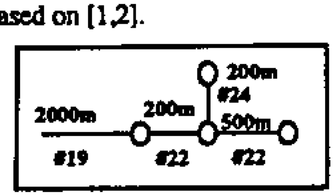

Figure 3. Subscriber loop topology

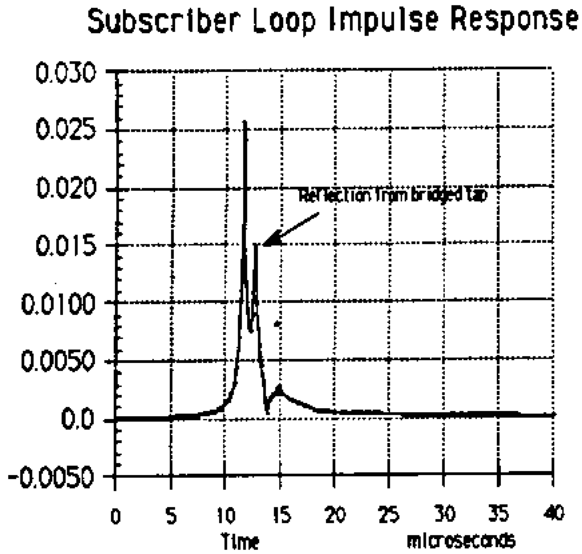

Figure 4.

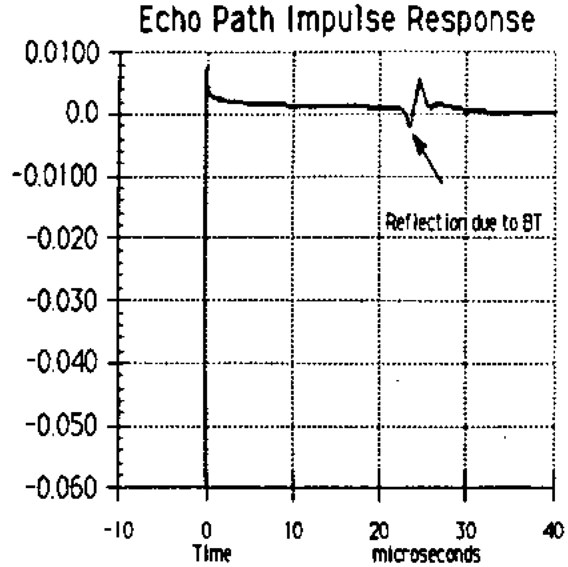

Figure 6.

The impulse response shows the reflection due to the bridge tap. Also note a pure delay corresponding to the distance between the source and the load. The frequency response shows the increasing loss at high frequencies due to skin effect. The echo path impulse response shows a strong negative going impulse at zero delay. The echo due to the bridge tap also appears in the impulse reponse. Note the long delay and compare with the distances in Fig. 3.

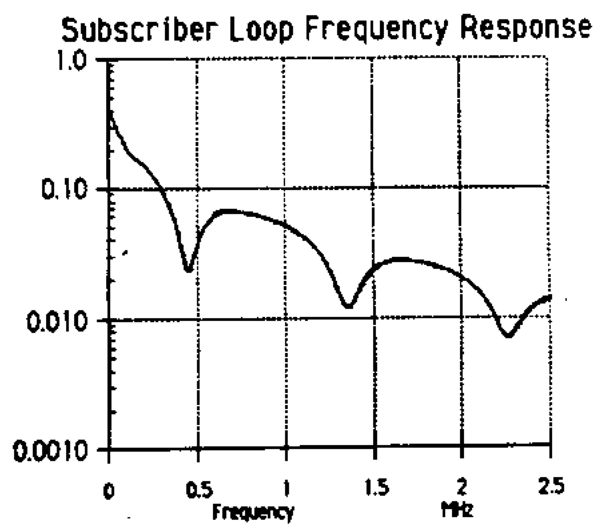

Figure 6.

The transmitter galaxy is shown in Fig. 7. The transmitter encodes the binary data into the 2B1Q line code. The sampling rate is also increased by 8. Let the bit rate be 160 kbits/sec. Then, for every two bits one 4-level symbol is produced. Thus, the symbol rate is 80 ksymbols/sec. The sampling rate is thus 640,000 Hz (8*80 kHz). The echo path and subscriber loop impulse responses are generated at this rate. The coded symbols at the high rate are then filtered using a Nyquit pulse shaping with 100% rolloff factor. This filter also bandlimits the signal.

At the receiver, the signal is filtered with a matched filter (the transmitted and receive filter combined form the Nyquist pulse shaping.) Note that the transmitter galaxy also outputs the symbols at the symbol rate. These symbols are used by the receiver to train the echo canceller and the equalizer.

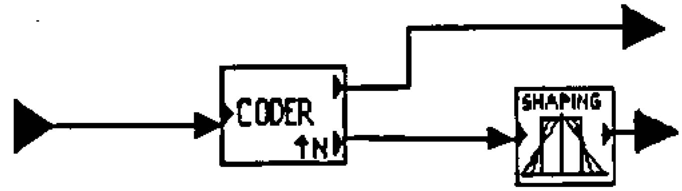

Figure 7. Transmitter galaxy

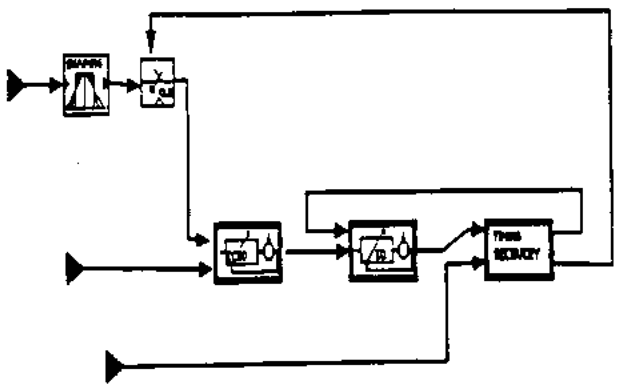

Figure 8. Receiver galaxy

The galaxy for the receiver is shown in Fig. 8. The eye diagram for an ideal channel at the output of the pulse shaping filter is shown in Fig. 9. The eye diagram with for the subscriber loop topology of Fig. 3 is shown in Fig. 10.

The receiver samples the filtered signal at time instances determined by the timing recovery galaxy. The sampling is done at the recovered symbol rate of 80 kHz. The samples are then passed to the echo cancellation galaxy along with the local transmitter symbols. The echo canceller cancels the echo and passes the samples of the remote transmitter, along with any residual error, to the equalizer. The equalizer has access to the remote symbols during the training phase. In an actual system, these symbols will be available to the receiver as stored symbols in ROM or by other means. The galaxy for the echo canceller is shown in Fig. 11.

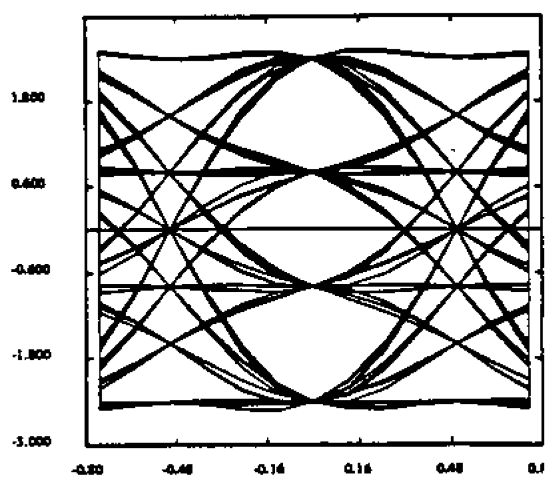

Figure 9. Eye Diagram at Receiver with ideal channel

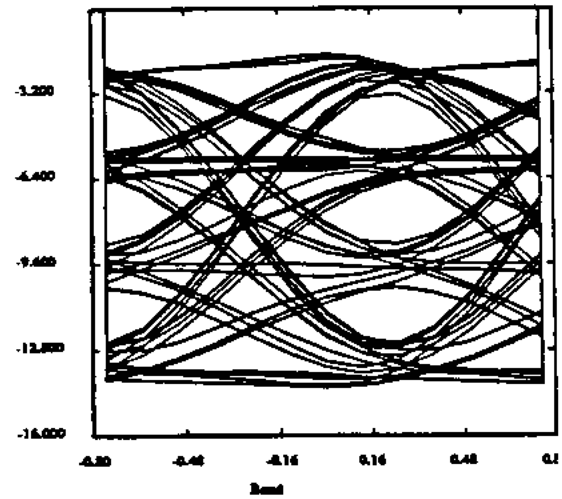

Figure 10. Eye diagram for subscriber loop with bridged tap

Echo Cancellation/Equalization

The main star in both the echo canceller and equalizer galaxies is the *predftf* star. This is a very flexible and powerful star for adaptive filtering using the multichannel arbitrary order fast transversal algorithm derived in [3]. The star was written by Faber. The star uses auto fan-out and fan-in techniques in Capsim which were introduced in [4] so that it can be setup as a fractionally spaced, or symbol rate pole-zero/all zero echo canceller. The equalizer, can be setup as a symbol rate , fractionally spaced equalizer with and without decision feedback. All these different adaptive filtering configurations are achieved with a single star. A related star is *predlms* which is exactly the same but uses the LMS adaptive filtering algorithm. In fact, the user can replace the *predftf* star with the *predlms* star in order to compare performance.

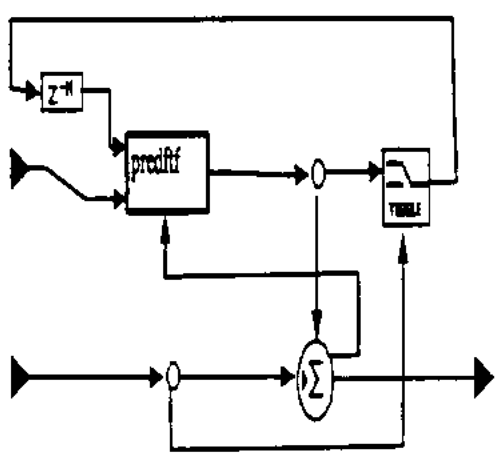

Figure 12. Echo Canceller Galaxy

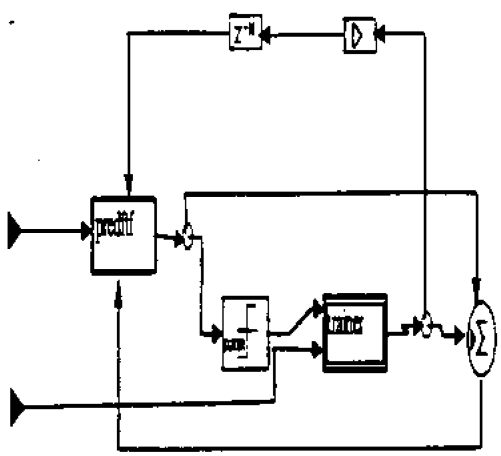

Figure 12. Equalizer galaxy

The equalizer galaxy is shown in Fig. 12. The equalizer is setup as a symbol rate equalizer with decision feedback. Note the slicer at the *predftf* star output. This is fed back to the equalizer input channel and forms the decisions. The order of this channel can be specified through the *predftf* star parameters. The trainer galaxy, shown in Fig. 13, has a toggle switch which selects between the training symbols during synchronization, and the decisions after convergence and tracking. The *ecount* star is used to count the number of symbol errors. The delay is necessary to line up the detected symbols at the receiver and the transmitter symbols.

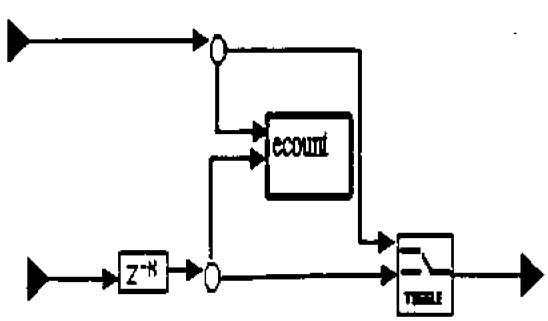

Figure 13. Trainer galaxy

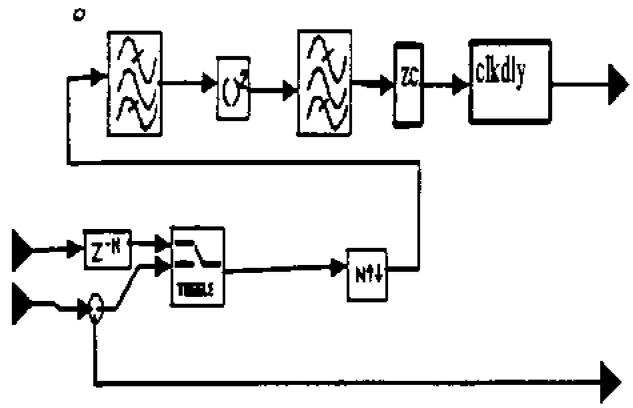

Figure 14. Timing Recovey galaxy

Timing Recovery

The timing recovery galaxy is shown in Fig. 14. The toggle switch selects between the training symbols for data aided timing recovery, or the decisions during regular operation. The sampling rate is increased using the resample star (it also does interpolation). Timing recovery is performed using a prefilter, a square law device, a tuned bandpass filter , and a zero crossing detector. The *clkdly* star is similar to the *delay* star except that it initially outputs ones so that the input signal is sampled. Otherwise, initially no sampling will take place and the system will obviously fail. Fig. 15 shows the recovered clock overlayed with the received signal. Clearly, sampling takes place at the correct phase. There is some jitter in the

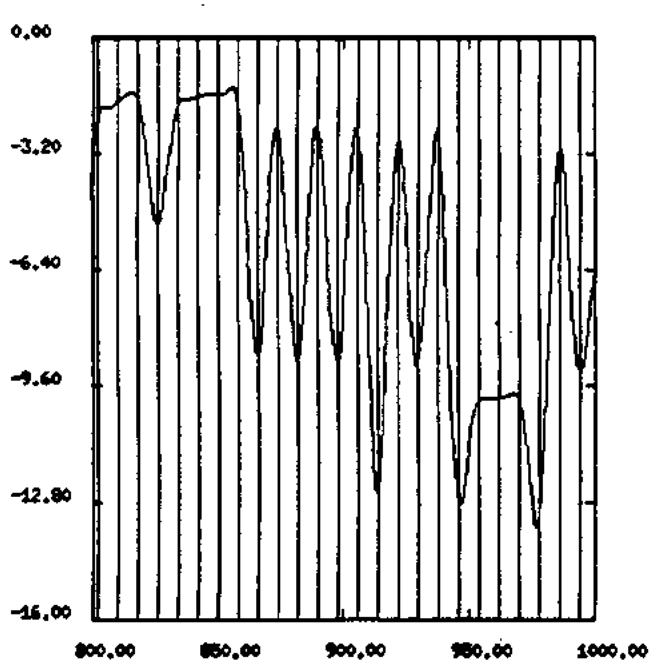

Figure 16. Timing recovey simulation result

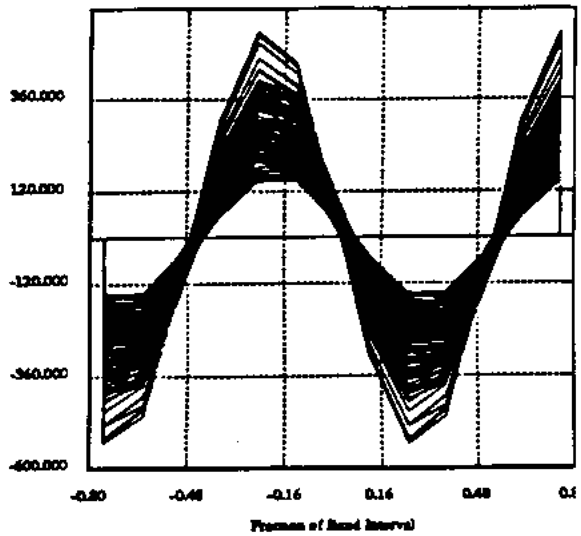

Figure 17. Timing wave eye diagram

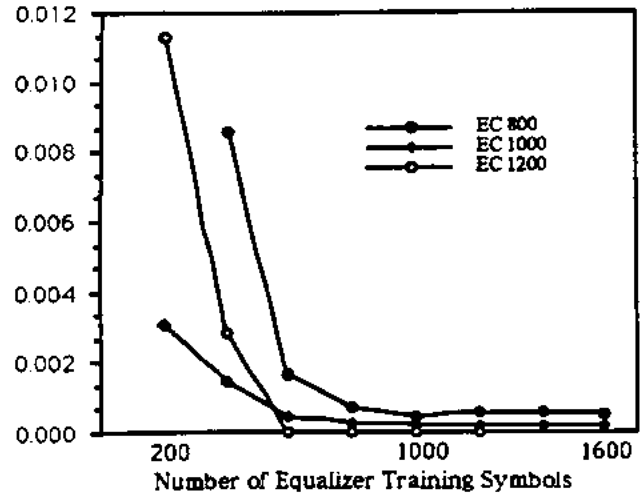

Figure 18. Effect of increasing equalizer training symbols on BER for various echo canceller training lengths.

recovered clock. The jitter is illustrated by plotting the eye diagram of the timing wave, before the zero crossing detector star, zc, in Fig. 14. The result is shown in Fig. 17.

Many simulation studies can be performed. For example, in Figures 18 and 19, the results of changing the length of the training sequence for the equalizer and echo canceller are shown. These results give great insight into the convergence behaviour and the effect of residual echo on system performance[5].

We can also investigate the effect of various line codes on the performance of adaptive filters [7].

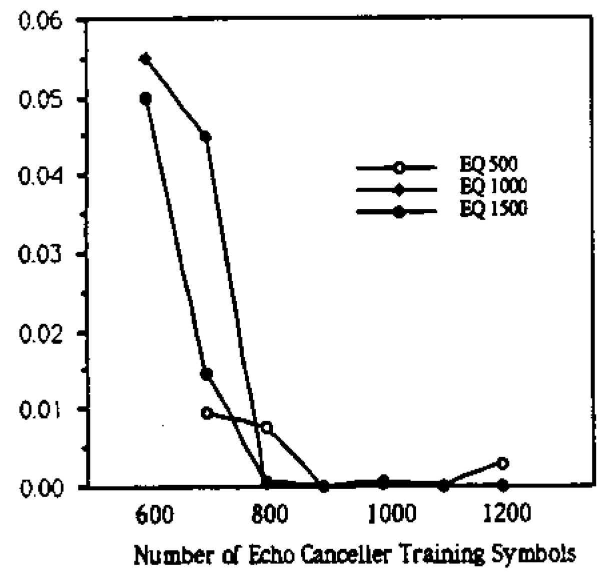

Figure 19. Effect of increasing echo canceller training symbols on BER for various equalizer training lengths.

References

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All topologies and eye diagrams in this report were produced by Capsim in PostScript.