THE BELL SYSTEM TECHNICAL JOURNAL
Vol. 50, No. 5, May-June, 1971
Printed in U.S.A.

A Full-Duplex Echo Suppressor Using Center-Clipping

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(Manuscript received October 9, 1970)

For telephone circuits which include synchronous satellites, conventional echo suppressors of the voice-switching type are less than satisfactory because of speech mutilation and the presence of echo during double talking.[1] *We have found that a multiband center-clipping process may be used as an echo suppressor. This echo suppressor is unique in that no double-talking decision has to be made. The near-end signal, plus echo of the far-end signal, is divided into several contiguous bands with each filter output going to a center clipper. A control circuit sets each clipping level equal to or greater than the echo level in that band. A preliminary analogue implementation of this echo suppressor, in which control circuit gains were manually adjusted to match the experimental return loss, was informally demonstrated using a simulated satellite circuit. Although no attempt at quantitative evaluation has yet been carried out and further evaluation is necessary, no echo was reported during this demonstration, even during double talking, for return losses approaching 0 dB. Operation appeared to be full-duplex at all times with little distortion of the speech. For return losses greater than about 15 dB, the center-clipping system was almost indistinguishable from a 4-wire connection with no echo path. In practice, adaptive setting of control circuit gains as a function of return loss would be desirable if this technique is used as a replacement for conventional echo suppressors.*

I. INTRODUCTION

During investigations of a multiband center-clipping process for use in reverberation reduction[2] it occurred to us that this process, which can remove the effects of long-time reverberation or echoes in a room, could also be used to remove echoes in telephone lines resulting from imperfect hybrid junctions.[3] Independently, J. R. Pierce also suggested that this process could be applied to echo suppression and proposed a scheme for controlling the levels of the center clippers in a conventional split echo suppressor configuration.[4]

One end of a conventional split echo suppressor is shown in Fig. 1. It is located in the 4-wire section of line near the hybrid junction to the 2-wire loop of the near-end customer. A similar configuration is inserted at the other end of the 4-wire trunk. Because of imperfect balancing of the hybrid, part of the received signal from the far-end talker feeds through the hybrid to the transmit side of the 4-wire line. The return loss of the hybrid is typically 15 dB, that is, the echo level at the echo suppressor is 15 dB below the normal transmit signal level of the near-end talker measured at the same point. The conventional echo suppressor is a voice-operated switch. The logic and control circuit detects the presence of received signal and causes a loss of at least 50 dB to be inserted in the path of the echo signal on the transmit side. Since the loss would also attenuate the signal from the near-end talker, and temporarily make the connection one way, the logic and control circuit also detects the presence of double talking and puts the suppressor into a "break-in" mode which allows an interruption to take place.

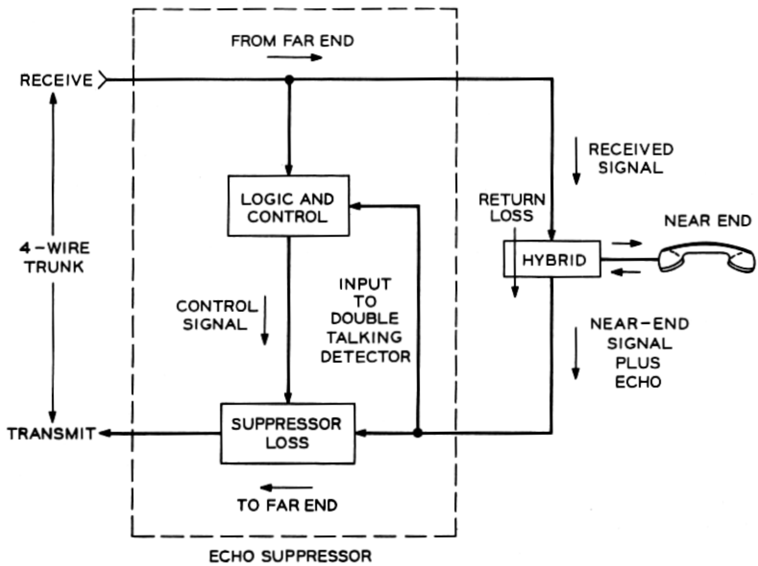

Fig. 1—One end of a conventional split echo suppressor.

Alternatively, we have found that the echo signal can be removed by replacing the voice switch with the multiband center-clipping process which is mentioned above, and which we have described previously.[2] This configuration is shown in Fig. 2. The outgoing signal from the hybrid is divided into a number of contiguous frequency bands by an input filter bank, each band is center clipped independently, and then the odd harmonic distortion products introduced by the center clippers are removed by an output filter bank generally identical to the input filter bank. For echo suppression, the center-clipping levels are controlled by the received signal. This signal is divided into contiguous bands by a control filter bank which is identical to the input filter bank. The attenuation in each band is adjusted to be equal to or less than the trans-hybrid loss in that band so that control signals identical to or larger than the filtered echo are obtained. The output of each band is peak detected and the detected output sets the clipping level in the corresponding center clipper so as to remove the echo signal in that particular band. In the absence of received signal, the clipping levels are zero. The clipping-level rise-times are comparable to the speech bandwidth and should have a hold time greater than the echo end-delay which may be up to 25 ms.

This center-clipping system has several advantages over existing echo suppressors of the voice-switching type. Since the frequency spectrum is divided into a number of bands, the near-end signal is unaffected in bands where there is no energy in the echo signal and the echo is completely removed in bands where there is no near-end signal component. However, the main advantage appears to come from the use of center clipping as opposed to voice switching. Break-in of the near-end talker can occur without a double-talking decision, even for a return loss approaching 0 dB, and no echo is heard during double talking. A comparison of the effect of center clipping and voice switching on signals will be discussed in the next section to show how these advantages come about.

II. CENTER CLIPPING AS AN ALTERNATIVE TO VOICE SWITCHING

The transfer function of the center clipper we will discuss is shown in Fig. 3. This center clipper completely eliminates signals below the clipping level, but leaves instantaneous signal values greater than the clipping level unaffected. In a sense, a center clipper is a voice switch operating on the instantaneous amplitude of the signal. However, it differs greatly from the process commonly referred to as voice switch-

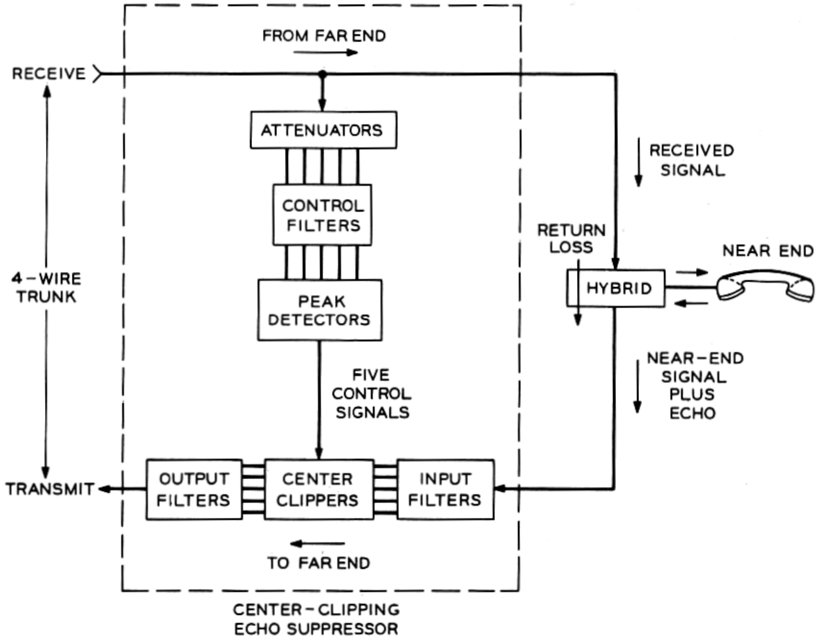

Fig. 2—One end of a split center-clipping echo suppressor.

ing. As we have mentioned in the preceding section, a large constant amount of attenuation (>50 dB) is generally switched into the transmit path in response to the control signal. In principle a more ideal kind of voice switching would be switching of only the amount of attenuation required, in addition to existing hybrid return loss, to

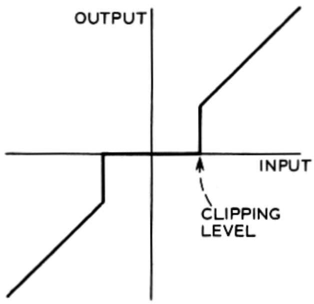

Fig. 3—Minimum distortion center-clipping transfer function.

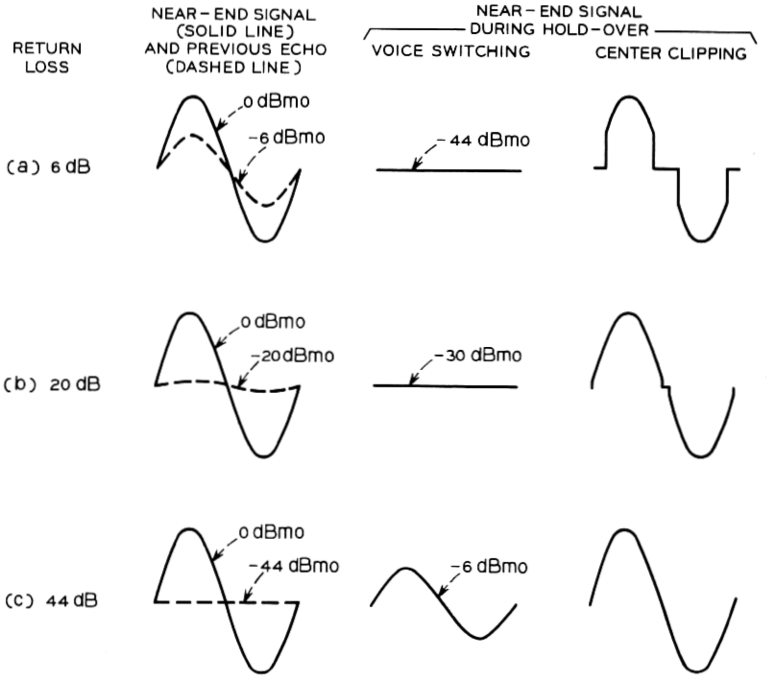

Fig. 4—Comparison of voice-switching and center-clipping necessary to produce 50 dB of echo suppression for return losses of: (a) 6 dB, (b) 20 dB, (c) 44 dB.

reduce the unwanted signal to a tolerable level. It is this kind of voice switch which we will compare with the center clipper of Fig. 3.

For satellite communications connections, a conservative estimate is that the echo signal level should be about 50 dB below the level of the near-end talker. Consider the situation depicted in Fig. 1, however, where the suppressor loss is replaced by either the minimum amount of attenuation or center clipping required, and where no double-talking detector is provided. The basic difference between these two hypothetical processing systems is shown in Fig. 4 for three values of return loss. The output of the echo suppressor for each case is shown in response to a sinusoidal signal, at 0 dBm0, from the near end into the echo suppressor. These graphs apply during the hold-over time after the voice switching or clipping level has been set by a previously received signal of the same transmission level as the near-end signal, and where the echo level has decreased to a negligible value.

In Fig. 4a, for a return loss of 6 dB, the echo signal is at −6 dB relative to the near-end signal, i.e., at −6 dBm0. Consequently, an attenuation of 44 dB has to be switched into the transmit path to achieve the desired 50 dB suppression. During the hold-over, this would drop the near-end signal by 44 dB. On the other hand, center clipping at one-half peak amplitude eliminates the echo and results in only 6 percent loss of fundamental signal energy.

In Fig. 4b, the signals for a return loss of 20 dB are shown. The echo signal is at −20 dBm0. Voice switching of 30 dB of attenuation reduces the near-end signal to −30 dBm0 while center clipping at 10 percent of peak, sufficient to remove the echo, produces very little distortion of the near-end signal.

Even when the unwanted signal is −44 dBm0 as in Fig. 4c, voice switching of 6 dB is necessary. This reduces the near-end signal to half amplitude while the corresponding center clipping at 1 percent of peak results in negligible effect on the near-end signal.

It is evident in Fig. 4 that, for reasonable return loss, center clipping is a much less severe form of processing than is voice switching, especially when narrow-band center clipping is used to avoid harmonic distortion products in the output. Because of the relatively slight mutilation of the near-end signal by the center clipping, the center clippers do not have to be removed during double talking. Thus no separate double talking detector has to be used. Echo suppression is also quite effective during double talking and will be discussed in more detail in Section V.

III. SIMULATION AND IMPLEMENTATION

Initially, we simulated the center-clipping echo suppressor on a CDC 3300—EAI 8800 hybrid computer. Double talking was simulated with return losses of 15 and 30 dB and the output of the center-clipping process was recorded for each condition. No echo was heard in either case. For 15 dB return loss, a small amount of degradation of the near-end speech was noticeable after processing. For 30 dB return loss, negligible degradation of the near-end speech resulted from the center clipping.

In order to study the center-clipping process under actual conditions of double talking, we needed a real-time processing system. The required center clippers and control circuits for the clipping levels were designed and built using analogue components. However, the clippers used were not the minimum distortion form shown in Fig. 3, but the somewhat less efficient form of Fig. 5.[5] The peak detectors had switchable decay times of 0 ms for alignment and 10 ms for use during echo suppression. Three General Radio (GR) Model 1925 filter banks composed of 1/3-octave 6th-order Butterworth filters were used to complete the center-clipping system.

We investigated the center-clipping system as an echo suppressor in a simulated toll circuit designed for evaluation of echo suppressors. Figure 6 is a simplified diagram of one end of the circuit. This circuit connects two 4-wire telephones, with active sidetone, via a 4-wire delay path. Hybrids are simulated by echo paths in which return loss can be set from 0 to 50 dB. Selection of various echo suppressors or a 4-wire line is provided between the two echo paths and the 4-wire network. For comparison, we had available the center-clipping echo suppressor (one end of a split system), a split 3A echo suppressor with speech compression, and a 4-wire connection. All systems were lowpass-filtered at 3200 Hz. The 3A units are echo suppressors employing voice switching, currently in use in the telephone plant. We also had available about 0.6 second of tape delay, which was introduced as shown in Fig. 6, for simulation of a satellite connection.

The control circuit attenuators in the center-clipping system (Fig. 2) were adjusted manually so that echoes of far-end sinusoidal signals were completely eliminated in each band for the selected return loss. This initial adjustment resulted in no echo being heard during single talking.

IV. RESULTS

Evaluation of the performance of an echo suppressor is a difficult task because most meaningful testing has to be done during normal

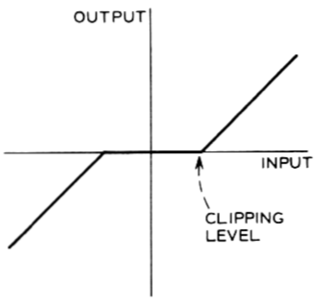

Fig. 5—Center-clipping transfer function implemented in analogue circuits.

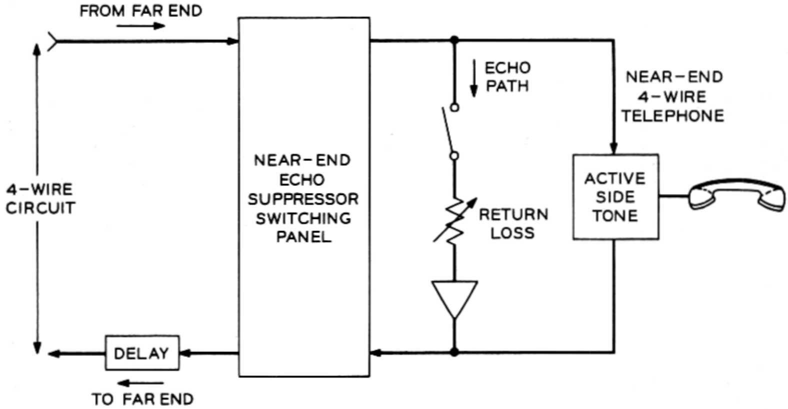

Fig. 6—One end of simulated toll circuit for testing echo suppressors.

conversations. No attempt at a quantitative evaluation of the center-clipping echo suppressor has as yet been carried out. However, in this section we present results of informal demonstrations using the simulated toll circuit.

The system initially used had six 2/3-octave bands. It performed very well in suppressing echoes in that no echo was heard by the far-end talker, even during double talking, for return losses down to 0 dB. However, even during single talking from the near end, some degradation was unexpectedly still present. This was due to a combination of phase distortion and coloration caused by passing the speech through two of the GR filter banks before recombining the bands. Each of the filter banks has a spectral ripple which is about ± 1 dB. However, the spectral ripple is several dB for two filter banks in series. In addition, phase distortion, which is not serious in one filter bank, is doubled for two filter banks and becomes objectionable. Because the phase delays correspond to those of the 1/3-octave filters combined to make 2/3-octave bands, the distortion is greater than was present in the original computer simulation.

In order to improve the speech quality in single talking, we substituted GR 1-octave filters, center frequencies 250, 500, 1000, and 2000 Hz, for the four lowest filters and used a 1/3-octave filter, center frequency 3150 Hz, at the top of the frequency band to make a 5-channel system. This system covered the same total bandwidth as the 6-channel system but had less phase distortion because of the wider filters used. Its performance is expected to be nearly identical to that of a 4-channel system since the same bandwidth could be covered by 4 filters, each only slightly wider than one octave.

The 5-channel system was as effective in suppressing echoes as the 6-channel system. As expected, the speech quality for single talking from the near end was improved but was still slightly degraded by coloration. As a result, we found that we could get better quality during single talking by removing the output filter bank. Because there is no clipping during single talking, output filters are unnecessary for this condition since no distortion products are generated. Surprisingly, however, distortion of the near-end speech during double talking was not very noticeable to the far-end talker who was simultaneously talking and listening. This was apparently due to masking.

We have demonstrated the systems to numerous people in different areas of Bell Laboratories. In these demonstrations, the speech quality of the center-clipping system was judged to be comparable to the simulated 4-wire satellite connection (or the 3A echo suppressors) for single talking conditions. When a comparison was made between the center-clipping system and the 3A echo suppressors during double talking, they differed in two respects. First, noticeable echo could be heard during double talking with the 3A echo suppressors since the 3A's offer little echo suppression in the break-in mode, while no echo was heard during double talking with the center-clipping echo suppressor. Second, the 3A's gave a chopped quality to the speech apparently independent of the return loss, as they switched between suppression and break-in, while this kind of switching sound was absent from the center-clipping system. (In the break-in mode of the 3A's during double talking, a variable amount of loss is introduced into the receive paths depending on the relative and absolute levels of the two end signals.) With the control circuits adjusted for return losses less than about 15 dB, the center-clipping system contributed some distortion to the speech during double talking which became more noticeable as the return loss was decreased to 0 dB. However, for return losses greater than 15 dB, the center-clipping system was almost indistinguishable from a 4-wire connection with no echo path.

V. DISCUSSION

The center-clipping process is a unique echo suppressor in that no decision between single talking and double talking has to be made. It is obvious how it operates under single-talking conditions. In single talking from the far end, the clipping levels are set with a rise time faster than any speech component so as just to remove the echo in each band. When the received signal ceases, the clipping levels fall to zero with a holding time greater than the end delay. For single talking from the near end, the clipping levels are zero and the speech is, in principle, unaffected.

It is not so apparent how echo is eliminated during double talking. In this case, the echo signal is added to the near-end signal and this composite signal is fed to the input filter bank. The clipping levels still follow the echo signal, and eliminate echo in bands where the two signals do not overlap and during gaps between words and sentences in the near-end speech. When energy from both signals appears in any band, clipping cannot remove the echo signal. However, it appears that, in this case, the echo is partially masked in that band. For these reasons, it is probably advantageous to have the bandwidths of the channels as small as possible compatible with other system requirements of speech quality and cost. These considerations indicate that the minimum number of channels possible may be determined by the effectiveness in echo suppression rather than by the avoidance of harmonic distortion. That is, a 3-channel system may not perform as well in echo suppression even though there is no harmonic distortion at the output. (A 3-channel system with bandwidths of individual filters just under two octaves includes no harmonic distortion products in the output since only odd-harmonic distortion products are produced by the center clippers). So far a 3-channel system has not been investigated.

In the demonstrations described, control signal levels were adjusted manually to match the trans-hybrid loss. In practice, this setting should either be permanently adjusted for worst case or adaptively controlled. If a center-clipping system is used as a back-up for an echo canceller,[6] worst-case setting will still yield almost perfect results. However, in the normal network, where 6 dB return loss is the worst case, adaptive setting, even if quite crude, would be desirable.

As mentioned in the preceding sections, several kinds of speech degradation occur in the center-clipping echo suppressor. Inherent in the process is the degradation observed in the computer simulation where coloration and phase distortion of the filters and nonlinear distortion of the center clippers were minimized. In this case, degradation resulted mainly from loss of part of the signal caused by the center-clipping process. However, considerable loss of information can be tolerated without significant decrease in subjective quality because of the redundant nature of speech. In the analogue experiments, other distortions were present in addition to this inherent one. Because of this, optimum operation was realized with the output filter bank removed even though nonlinear distortion was present during double talking.

So far, all the discussion of evaluation of center clipping echo suppression has been for the case of a 0.6-second transmission delay. For shorter delays, the subjective effect of the degradations present during double talking is greatly reduced and speech of comparable quality is obtained for smaller return losses.

VI. CONCLUDING REMARKS

We have described demonstrations of an experimental center-clipping system for electrical echo suppression. This echo-suppressor principle is unique in that no double-talking decision has to be made, Echoes appear to be completely removed, even during double talking, for return losses as small as 0 dB. Speech communication is full-duplex at all times and, for return losses greater than about 15 dB, is almost indistinguishable from a 4-wire connection. The center-clipping echo suppressor would appear to be an excellent back-up for an echo canceller if the echo cancellation plus return loss reduces the echo level to −20 dBm0 or less.

We have also made tests of this echo suppressor using a "real" end section including an N3-carrier, 4-1/2 miles of simulated loaded cable, and a real telephone and hybrid. The results were similar to those already discussed when the attenuation in each band was manually adjusted to match the return loss characteristics of the carrier system. (Return loss varied from about 6 to 18 dB.)

In another experimental application, we have used the center-clipping system as a replacement for voice switching in the suppression of acoustical echo generated in an idealized 4-wire speakerphone.

VII. ACKNOWLEDGMENTS

We are indebted to C. A. Ross for the circuit design and initial construction of the analogue center-clipping system, to J. E. Unrue, Jr., and G. K. Helder for several stimulating discussions, to B. E. Crawford for assistance with the simulated toll circuitry, to G. H. Yates for help with some of the wiring and alignment, to B. J. Karafin for his cooperation in our use of the CDC 3300 computer, and to J. S. Courtney-Pratt for valuable discussions and continued encouragement.

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