Echo Suppressor Design in Telephone Communications

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An elementary echo suppressor is described which consists of a single voice-operated switch located at each end of a four-wire toll connection. It is shown that this circuit is unsuitable for telephone conversations if there is an appreciable delay between the speakers. Modifications and additions to the elementary echo suppressor are made in an effort to improve its performance. Action in the presence of break-in speech is discussed in some detail. The operation of four present-day echo suppressors is described.

I. INTRODUCTION

In a companion paper by J. W. Emling and D. Mitchell,[1] it was shown that the problems due to telephone echoes increase as the propagation time between speakers increases. As a result of the recent interest in satellite transmission, efforts have been made by several groups within and outside of Bell Telephone Laboratories to build echo suppressors particularly suited to the long delays encountered in such communications. In the first part of this paper, an elementary echo suppressor is described so that the reader may become familiar with some of the terminology used in this field and problems associated with the use of echo suppressors. Then, additions and modifications made to the simple echo suppressor to improve its performance are discussed. Finally, some of the more recent suppressor designs are illustrated. The echo suppressors to be described in the later sections of this paper are the same echo suppressors used in the subjective tests reported in a companion paper by Riesz and Klemmer.[2]

II. AN ELEMENTARY ECHO SUPPRESSOR

2.1 *Functional Description*

Assume a telephone circuit of the type shown on Fig. 1 is set up between two speakers A and B. The round-trip delay is appreciable, and is

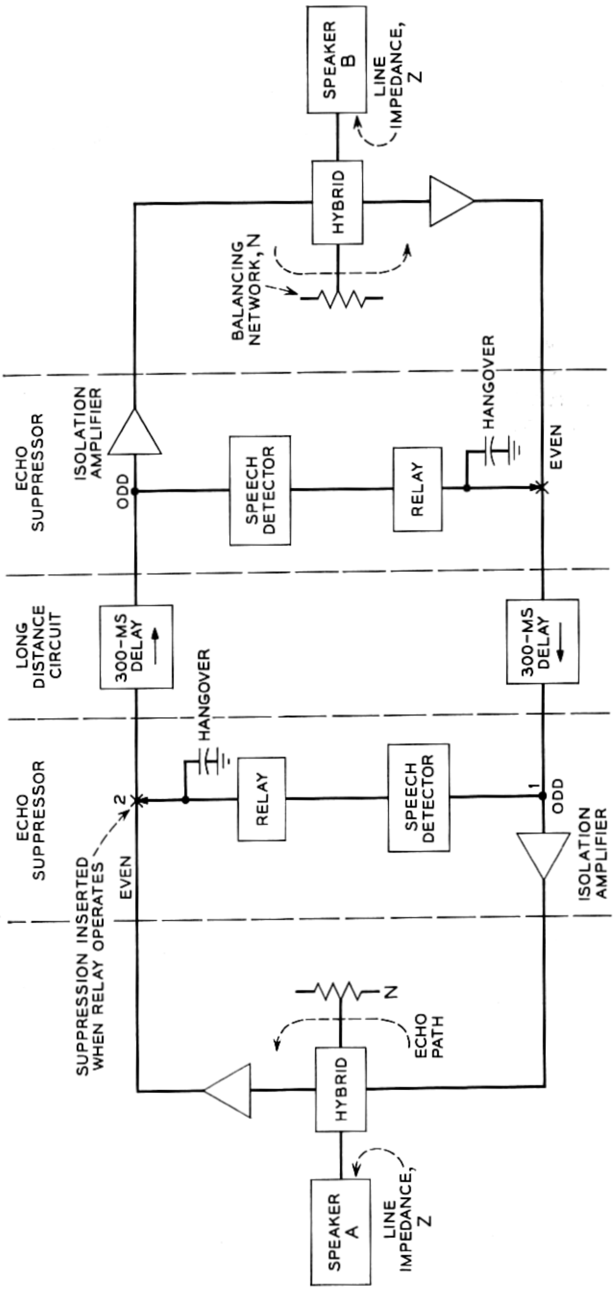

Fig. 1 — A simple echo suppressor.

shown for illustrative purposes as lumped and equal to 600 msec. Since the match of network N to the impedance Z of the 2-wire line at the hybrid is never perfect, echo is generated at the hybrids. If no devices were used to control the echoes on this circuit, it would be at best confusing and frustrating for the speakers if they attempted to converse. To block the echoes, a simple voice-operated relay or echo suppressor, as illustrated, can be installed at each end of the 4-wire portion of the circuit. Now, if speech from B appears at point 1 (generally called the "odd" side of the echo suppressor), the relay operates to open the line completely from A to B at point 2, the "even" side of the echo suppressor. These relays are effective in eliminating virtually all echoes, but they introduce other difficulties.

Assume that speaker B is talking and speaker A is silent. The transmission path from A to B will be blocked at point 2. If A now begins to talk at the same time B is talking (a condition called "double talking"), it is apparent that A cannot interrupt B's speech no matter how loud he talks. However, A has no way of knowing that his interrupting speech has failed to get through to B, and he may think that B is being impolite in not responding to his speech. This type of degradation would occur even if there were no delay between the speakers, and by itself could be a serious drawback of this echo suppressor design.

The delay coupled with the suppressor action causes an additional effect which is more pronounced and is very irritating. Assume B talking, A silent. At time t_0, B pauses momentarily, then at time $t_0 + 0.3$ sec, A hears this pause, and immediately interjects a short comment, such as "Uh huh," or "Yes, of course." Because there is no speech at point 1 (Fig. 1), A's comment gets through to B. Assume now that B had resumed talking at time $t_0 + 0.2$ sec. At $t_0 + 0.6$ sec, A's comment arrives at the echo suppressor near B and suppresses B's continuing speech for the length of A's comment. Then, at $t_0 + 0.9$ sec, A detects a short interruption of B's speech.

Two disturbing events have thus occurred. First, B heard A's comment at an inappropriate time, after he had resumed speaking, and second, A heard a break in B's speech. Although the second event is intuitively the more disturbing one, the first could well cause B to stop talking so he could hear the interrupting speech. Normal conversation would then come to a halt and be replaced by a frustrating attempt by each speaker to establish what the other person was trying to say. This and similar sequences could occur many times in a conversation and result not only in annoying the speakers but also in causing them to waste time repeating their remarks and commenting on the bad circuit.

The intermittent interruptions which the echo suppressors introduce are commonly referred to as "chopping." Chopping is most serious when the conversation alternates rapidly between speakers, and is nonexistent if only one person is talking. It becomes more objectionable as the delay between the speakers increases.

Methods to reduce this objectionable chopping have been devised and will be discussed later, after some characteristics of the simple echo suppressor are further described.

2.2 *Characteristics of a Simple Suppressor*

2.2.1 *Amount of Suppression*

It has been found that in circuits with long round-trip delays (say 200 msec and longer) and with echoes at their present-day levels, considerable attenuation must be supplied by the echo suppressors to reduce echoes so they are not annoying. Typically, about 50 db or more attenuation is provided. The present trend is to use some type of solid-state switching to introduce the loss, but a relay which short-circuits the line is very effective. In most recently designed echo suppressors, the attenuation introduced is so great that for all practical purposes the transmission path is completely blocked. Some suppressors, however, insert only a moderate amount of loss if the speech signal at point 1 of Fig. 1 is very weak, and insert larger amounts of loss for strong speech signals. They employ a "variolosser" which inserts a loss whose magnitude is a smooth function of the controlling signal. This would appear to be a good method of applying suppression since only the amount required is present at any time, and hence double talking should be easier. However, the variolosser provides satisfactory echo suppression only when it begins to insert loss on very weak speech signals. For signals of more typical magnitudes, at least 50 db suppression is required, and hence the variolosser is not much different from a relay. Further discussion of the operation of an echo suppressor will be with reference to relay operation, although an echo suppressor employing variolossers will be described later.

2.2.2 *Sensitivity*

The local sensitivity of the echo suppressor can be defined as the level of a 1000-cps tone, applied at the odd input, just sufficient to cause the speech detector to operate the relay. The signal level is specified as a power level in dbm working into a 600-ohm load. The local sensitivity includes within it an adjustment for the transmission level point at which the suppressor is operated. Since it is much simpler to discuss its operation at the zero transmission level point (0TL),* all references to sensitivity hereafter will apply to the zero-level sensitivity, i.e., the sensitivity at 0TL.

If the speech detector shown in Fig. 1 has a flat frequency response, it will generally provide marginally acceptable suppression of long delayed echoes if its 1000-cps sensitivity is about -32 dbm. Greater (lower-level) 1000-cps sensitivities are required if the frequency response of the detector is weighted in such a way that it is less sensitive to frequencies below and above 1000 cps.

It would seem advisable to build a suppressor which has a very high sensitivity to assure complete suppression of echoes of all speech sounds. But if the sensitivity is too great, the suppressors will operate on noise as well as speech, which certainly is not desirable. Recent data on noise on telephone circuits indicate that less than 1 per cent of the longer toll calls have a noise level at 0TL greater than about 51 dbrnc.† This equates to -37 dbm if the noise is flat over the voice spectrum. Thus the sensitivity of an echo suppressor with flat bandwidth should not be greater than -37 dbm if operation on noise less than 1 per cent of the time is desired.

The sensitivity for adequate suppression and for minimal noise operation depends on the shaping of the dectector sensitivity characteristics. Previous studies have shown that a flat bandwidth between 500 to 3000 cps with reduced sensitivity is preferable for adequate suppression to a bandwidth with higher sensitivity at some of the frequencies in the band, if both suppressors are set for equal noise operation. The flat bandwidth helps to improve the sensitivity for initial consonants from many talkers.‡

2.2.3 *Pickup Time*

By definition, the pickup time is the time required for the suppressor to operate after the receipt at the odd input of a 1000-cps signal with a power level 3 db greater than the sensitivity. The pickup time should be short, since a long pickup time would cause the speaker to hear brief spurts of echo. These would sound like short "blips" and could be

* The zero transmission level point is a point to which all level points in a toll system can be referred. It is analogous to citing altitude by referring to height above sea level. The zero-level point is at the transmitting toll switchboard of the system under consideration.

† 51 dbrn as measured on a 3A noise meter with C message weighting.

‡ See Ref. 3, page 1458.

annoying even if they were not recognized as echo. A pickup time of about 5 msec is satisfactory, but this may produce operation on impulse noise, which again is not desirable. However, the bad effects of impulse noise operation can be minimized by proper control of the hangover, as discussed in Section 2.2.4.

2.2.4 *Hangover*

When the speech signal appearing at the odd input ceases, the suppression relay should remain operated briefly, for two reasons:

1. The speech signal may not terminate abruptly, but rather may contain low-level energy, such as that provided by a fricative. This speech may be below the sensitivity of the suppressor, but it should still be suppressed.

2. The echo may appear at the even side after speech appears at the odd side, due to the delay in the telephone circuit between the echo suppressor and the near telephone set (commonly called end delay).

To suppress these weak speech endings or delayed echoes, the echo suppressor is supplied with a slow release, or hangover time, which holds suppression after the speech level at the odd input has fallen below the sensitivity. The required hangover is dependent on at least three factors:

1. the end delay,
2. the echo suppressor sensitivity, and
3. the total circuit delay.

Generally, more hangover is required for long end and circuit delays and for lower sensitivities. No one hangover can be said to be acceptable in all cases. In the Bell System, where circuit delays of 30–40 msec and end delays of 20 msec are typical, the Western Electric 1A echo suppressors, having a detector with a shaped frequency response and a 1000-cps sensitivity of -31 dbm, have a suppression hangover of 50 msec.

If impulse noise operates the echo suppressor as described above in Section 2.2.3, the suppression hangover could chop appreciable portions of the speech if full hangover were applied for impulses. Most impulse noise is of very brief duration, and therefore the adverse effects of impulse noise operation can be minimized by providing a deferred or variable hangover which reaches full value only for speech sounds longer than about 50 msec.

2.3 *Full vs Split-Terminal Echo Suppressors*

In the suppressor just described the echo suppressor is split, with half located on either side of the major delay. The configuration shown in Fig. 2 can also be used. In this case the echo suppressors for both speakers are located at one terminal. The echo suppressor indicated as 1 operates in an identical manner to the one described previously, but a very long hangover is required for echo suppressor 2 because the delay between speakers causes the echo of party A to appear at the suppression point long after the speech appears at the detection point. The combination of echo suppressors 1 and 2 is known as a full echo suppressor. A full echo suppressor is frequently used for circuits in which the round-trip delay is not very great (e.g., 50 msec or less). The hangovers required for full echo suppressors on circuits with long delay considerably increase the difficulty in conversing.*

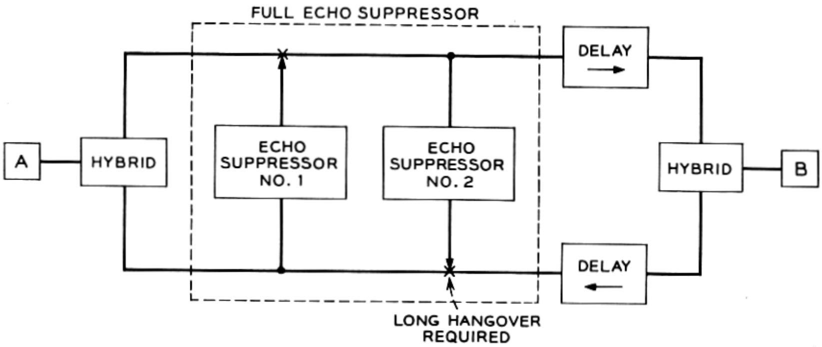

Fig. 2 — A full echo suppressor installed at one terminal.

The echo suppressors shown in Fig. 1 overcome this difficulty, and are called split-terminal echo suppressors because the functions of the full echo suppressor have been delegated to two units, located at the terminals of the intertoll trunk. Since the full echo suppressor requires only one installation, it has obvious economic advantages over the split-terminal echo suppressor, but because of its unsuitability for use in long-delay circuits, almost all recent design efforts have been devoted to developing an improved split-terminal echo suppressor.

III. DIFFERENTIAL ACTION

The conversational difficulties introduced by the echo suppressors of Fig. 1 arise from the failure to take into consideration the rapid inter-

* Years ago a full suppressor was sometimes installed midway between the speakers, and the long hangover previously required for one echo suppressor was divided between the echo suppressors. Such use today is in most cases impractical, since many circuits are multiplexed from end to end and revert to voice frequency only at the terminals.

changes of speech and the occurrence of simultaneous or double talking. The simple design which provides for silencing the even side at all times that speech appears at the odd side is not sufficient to provide a good communication path. A modification must be found which allows the echo suppressor to operate in a different mode if "break-in" speech is present at the even side at the same time that speech appears at the odd side, i.e., when double talking is taking place.

Ideally, during periods of double talking, the suppression should be removed so that free to and fro conversation can take place. Of course, when the suppression is removed, the echo is also transmitted with its degrading effects. The problems associated with double talking are discussed below.

3.1 *Detecting Break-in Speech*

Recognition of break-in speech in the presence of distant party speech is a most difficult problem in echo suppressor design, and no completely successful solution of this problem has been achieved. The nature of the problem is illustrated in Fig. 3, which is a simplified schematic of one end of a long distance telephone connection. Speech received from B appears at point 1, and speech from A appears at point 2 along with the echo of B's speech.

A simple speech detector installed at point 1 will easily recognize B's speech, and only B's speech, since the isolation amplifier prevents A's speech from reaching this point. But there is no point at which A's speech appears by itself, except of course at A's transmitter which is,

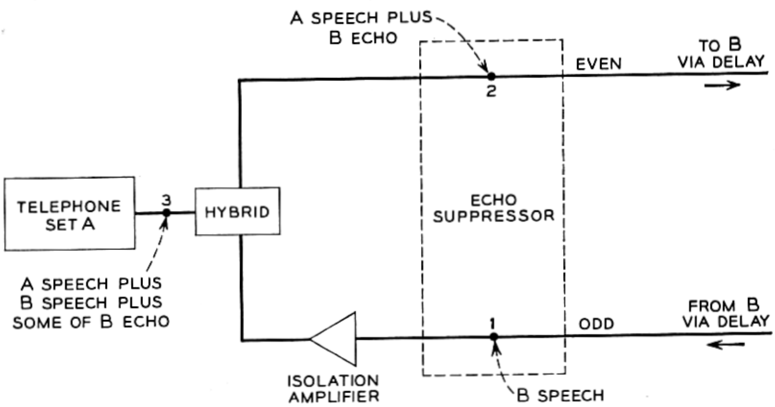

Fig. 3 — Speech signals at various points in a two-wire to four-wire connection.

unfortunately, inaccessible. A's speech is present at point 3, but B's speech is also present here, traveling not only toward A's telephone set but also reflected from the telephone set toward the hybrid. Furthermore, point 3 is generally inaccessible. It may be located miles away from the echo suppressor and is frequently not permanently associated with the same trunk on which the suppressor is installed. It is apparent that point 2 is the only point which can conveniently be examined for A's speech.

A simple speech detector, such as that used for suppression, installed at point 2 to detect break-in speech and remove the suppression, will operate on echo as well as local speech and is thus inappropriate as a local speech detector. However, many properties of the echo are known, because the echo is a distorted reflection of the signal at point 1. All existing break-in speech detectors compare a signal derived from point 2 with a signal derived from point 1. This "reference signal" derived from 1 is a measure of what the echo is expected to look like. If the signal at 2 possesses only those characteristics which the echo would contain, that is, if the signal derived from 2 is contained within the reference signal, then echo only is assumed at point 2. If, however, the signal at 2 is sufficiently different from the reference, speaker A is assumed to be talking and the break-in detector is activated. A good break-in detector should be as sensitive as possible to the break-in speech, but it should not operate when echo alone is present. A break-in detector triggered by echo alone is said to exhibit "false break-in."

Many different break-in detectors have had as their basis for design the method outlined above. Two of these devices are described in more detail.

3.2 *The 1A Break-in Detector*

Fig. 4 is a block diagram of the suppression and break-in scheme of the Western Electric 1A Echo Suppressor. (This suppressor is more fully described in Section IV.) The speech signals from points 1 and 2 are amplified, rectified, and applied directly to the differential device as illustrated. The return loss at the hybrid has an average value of 15 db with a standard deviation of 3 db.[1] Thus, the echo at 2 is certain to be at least 6 db below the signal at 1 if both points are at 0TL. The differential comparator is therefore adjusted so that if echo of this level or less is present at 2, the differential will yield a positive output. When this happens, relay 1 blocks the even path at point 4 with a hangover of 50 msec and also blocks the negative output of the differential at point 3.

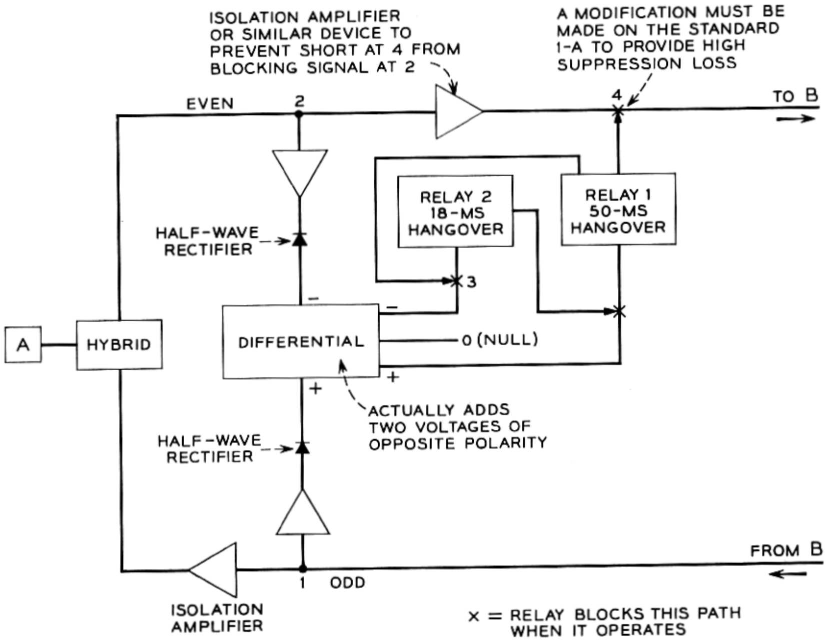

Fig. 4 — Block diagram of a 1A echo suppressor used in split-terminal fashion.

If speaker A begins to talk, the signal at 2 will occasionally override the differential and cause it to have an output on the negative side. If this occurs for 50 consecutive msec, relay 1 drops out and removes the block which it put in at points 3 and 4. Relay 2 now operates with an 18-msec hangover, assuring break-in for at least this hangover period. Break-in will continue until the differential becomes positive for at least 18 msec, in which case suppression will be restored. If no one is speaking, the differential has a null output and neither relay will be operated.

The "reference signal" referred to in Section 3.1 is in part the rectified signal derived from 1, but it also is contained in the hangover of the relays. For example, if B talks and then stops (A is silent), the echo may be delayed in reaching point 2. The echo could operate the differential for a brief period (up to about 20 msec) after speech ceases at 1, but the 50 msec hangover of relay 1 will prevent false break-in.

3.3 *Break-In Detection by Means of Smoothed Rectified Speech*

The majority of suppressors designed in the past few years employ a break-in scheme which uses a differential to compare two speech signals which have been full-wave rectified and smoothed, as opposed to the 1A differential action which employs negligible smoothing. Fig. 5 shows a typical full-wave rectified speech signal which could appear at the odd side of the echo suppressor. The echo at the even side of the suppressor is certain to be at least 6 db (one-half amplitude) below the speech on the even side. It can also be delayed up to a maximum of about 20 msec. This "worst case" of echo is shown, full-wave rectified, as the dashed line of Fig. 5. Because of the delay, there are many times in which the echo signal exceeds the odd speech signal. But if the original signal is smoothed with an RC network so the voltage decays to one-half value in 20 msec, the echo will never exceed this smoothed signal. The smoothed signal is the reference signal and is indicated in Fig. 5. In practice, the echo signal is also smoothed, but with a smaller time constant (any value less than the time constant of the other). If the signal from the even side should ever exceed the reference, the local speaker must have been talking, and the break-in detector is activated. The break-in detector is completely independent of the suppressor relay operation, as opposed to the 1A action.

A block diagram of the instrumentation is shown in Fig. 6. A negative signal of sufficient strength from the differential (a simple voltage adder) will trigger the threshold and cause break-in to be indicated. Once break-in speech has been detected, the suppression is removed and the echo suppressor is in the break-in mode. The manner in which the suppressor operates in the break-in mode varies with different suppressors, and illustrations of various break-in modes of operation will be given later in this paper.

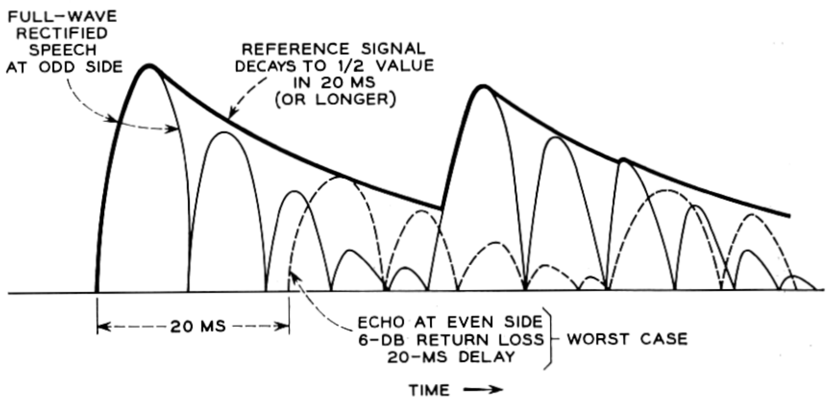

Fig. 5 — Typical waveforms appearing in rectified speech break-in detector.

3.4 *Sensitivity and Pickup of the Break-In Detector*

The parameters of the break-in detector will be discussed with reference to Fig. 6, with both the odd and even sides assumed at 0TL. These parameters are not, however, restricted to this circuit but apply to any break-in detector.

The break-in sensitivity is the 1000-cps signal power in dbm applied at the even input which will just cause the break-in detector to operate. This tone is applied with *no signal at the odd side*. A typical value is −32 dbm re 0TL. This sensitivity determines the ability to remove suppression during the suppression hangover after speech has disappeared from the odd side. It is also important in recognizing local speech just prior to the arrival of distant speech at the odd side. The break-in hangover (discussed later) will then prevent the local speaker from being immediately cut off.

The time required to operate the break-in detector or pickup time should be fairly fast, say 5 msec, but this is not so critical as suppressor pickup time. As shown before, long pickup times on the suppressor cause some echo to be returned. Long pickup times on the break-in detector cause initial fragments of speech sounds to be omitted or clipped if break-in is occurring when the suppressor is operated. Informal listening tests have shown that such front-end clipping is not very objectionable even when pickup times are as long as 20 or even 30 msec.

3.5 *Differential Sensitivity*

The differential sensitivity is a measure of the signal level at the even side required to operate the break-in detector in the presence of a signal at the odd side. A 1000-cps tone is applied to the odd terminal 3 db louder than the suppressor sensitivity. Then a 1000-cps tone is applied at the even side and is increased in level until break-in is detected. The difference in levels between the break-in signal and the odd signal is the differential sensitivity.

For example, assume the 0TL suppressor sensitivity is −32 dbm. A −29-dbm tone is applied at point 1 in Fig. 6. Break-in occurs when a −28-dbm tone is applied at the even terminal, point 2. The differential sensitivity is (−28) − (−29) db or +1 db.

The negative threshold detector requires a fixed voltage difference to operate. Its threshold is set to establish the break-in sensitivity by adjusting the amplifier on the even input, and the differential sensitivity is established by adjusting the indicated amplifier in the odd input. Because the threshold detector operates on a voltage which is the differ-

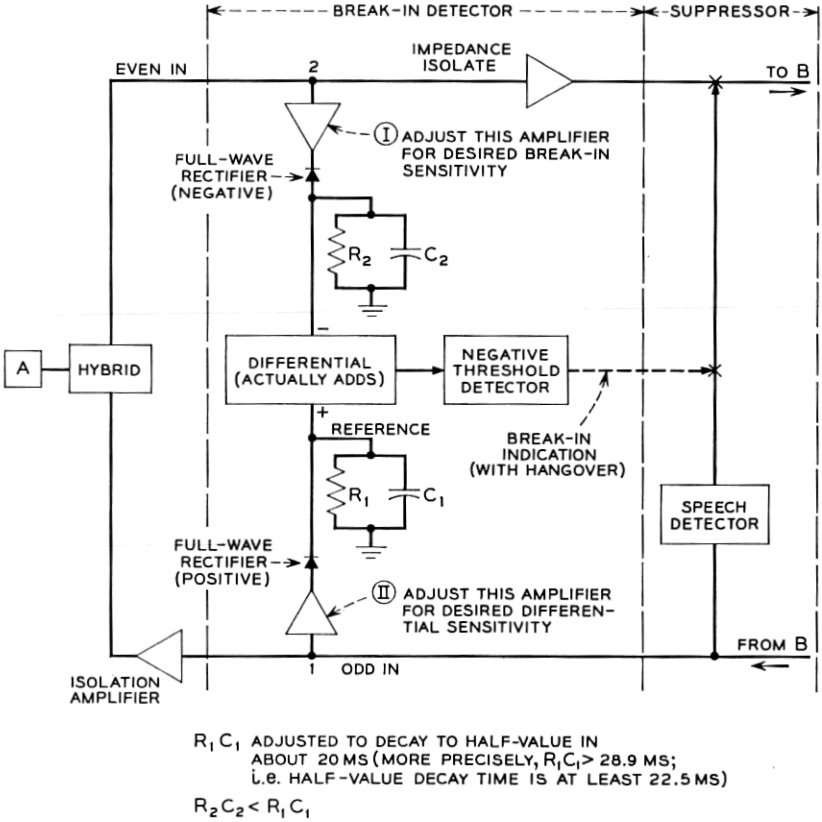

Fig. 6 — Rectified speech break-in detector.

ence between the voltages at the even and odd inputs, if the differential sensitivity is 1 db for a -29-dbm signal at the odd input, the differential sensitivity will decrease for louder odd signals (but will still remain positive). For example, if the odd input is a tone of -15 dbm, the same voltage *difference* at the negative threshold detector will be required to overcome this signal, but the voltage *ratio* will be lower. This is why the definition of differential sensitivity must specify the magnitude of the test signal applied at the odd input.

3.6 *Break-In Hangover*

The break-in detector operates to remove suppression when the even speech is sufficiently louder than the odd speech. Because of this, it is apparent that loud speech at the odd input may prevent the break-in detector from operating. In this case the echo suppressor reverts to the simple echo suppressor of Fig. 1, resulting in considerable speech mutilation. However, even when the odd speech volume is much greater than the even speech volume, because of the irregular nature of speech there are times when the even speech peaks will be sufficient to initiate break-in detector action and remove suppression. Shortly thereafter, the odd speech will once again be great enough to reinsert suppression. This alternate suppression and nonsuppression produces objectionable speech chopping.

To overcome this difficulty, a hangover is usually introduced on the break-in device. Once the local talker has broken in, he does not have to depend entirely on the differential, since the hangover will maintain break-in. Also, if he is talking and speech arrives from the distant talker, his speech will not be cut off by the suppressor for at least the break-in hangover period. (However, in the circuit of Fig. 6 if the distant speaker is talking and the local speaker breaks in, he does not have to wait for the suppression hangover to release before suppression is removed. The opposite is true in the 1A echo suppressor.)

If the break-in hangover is very long, practically no chopping will occur, but the break-in detector will remain activated when the local speaker has finished talking. During many of these times, distant speech will be present, and if transmission is allowed on the even side at these times, echo will be returned. This also can be very annoying on long-delay circuits.

The difficulties of achieving good break-in ability may now be summarized:

1. To avoid false break-in, the differential circuit must be made relatively insensitive to signals at the even side because the expected echo levels can be fairly high. This will cause chopping of local speech.

2. To avoid chopping, hangover is introduced on the break-in circuit. But this allows more echo to get through after the local speaker has stopped talking.

The break-in hangover is usually adjusted to effect a compromise between excessive chopping and echo. A typical value for recent designs is 150–200 msec. This is much longer than the 18-msec break-in hangover of the 1A suppressor. If a very good break-in detector could be built, the hangover would not need to be as long, and a better compromise between chopping and echo could be made. Also, if return losses could be improved (made greater), the existing break-in detectors could have even lower differential sensitivities, which would reduce the need for long hangovers. The accomplishment of either of these objectives would be of considerable value in improving present-day echo suppressors.

3.7 *Asymmetry in Echo Suppressor Environment*

Little attention has yet been given in this paper to the speech levels at the suppressors. If each speaker is a "normal" talker and has relatively little loss between his subset and the suppressor, his speech will appear at 0TL at a long-term average level of roughly −15 dbm. There can be wide variations from this level. The speaker may be an especially loud or weak talker, or he may be prone (as many people are) to holding the transmitter under his chin, or there may be additional loss between him and the suppressor.

Fig. 7 is an illustration of a long-delay circuit in which two loud talkers with equal speech volumes are connected. The losses L_A and L_B account for all the speech level variations due to the factors described above. If L_A equals L_B, then each speaker has the same ability to break into the other's speech. Consider though, the case in which L_B equals zero and L_A equals 10 db. Speaker B will have more difficulty than A in conversing for two reasons:

1. The echo returning to A is 20 db less than that returning to B (assuming equal return losses at both hybrids). Therefore, B will hear louder echoes during break-in than will A.

2. A has 10 db more difficulty in breaking in than B; consequently B will hear more chopping.

If the losses L_A and L_B differ by 10 db because of the actual circuit configuration, as may happen, the circuit is said to have 10 db asym-

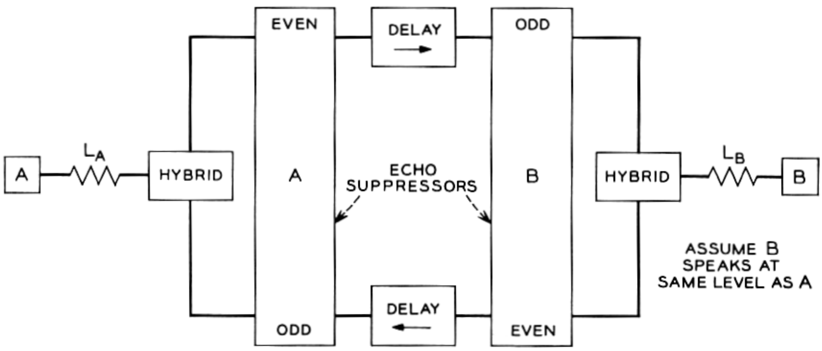

Fig. 7 — Asymmetry in an echo suppressor connection; the difference in losses L_A and L_B is a measure of the asymmetry.

metry. An asymmetry of only 10 db is sufficient to often cause one speaker to have considerable difficulty, whereas the other speaker may hardly notice anything wrong with the circuit. Differences in talker levels at the two ends, which may frequently occur, are also causes of asymmetry, much as if the physical losses differ.

IV. TYPES OF ECHO SUPPRESSORS

Four echo suppressors are described below to illustrate the various approaches taken to the problem of designing echo suppressors which permit double talking. All of the echo suppressors are similar in that they employ a suppression device and a differential circuit. However, each has some peculiarity which distinguishes it from the others.

4.1 *1A Echo Suppressor*

This echo suppressor has been standard in the Bell System since the late 1930's. About twenty thousand are presently in use on long distance continental and ocean cable circuits.

A simplified schematic of the 1A echo suppressor (used as a full echo suppressor) is shown on Fig. 8.* In the quiescent state with speech in neither the odd nor even path, the DA tube current flowing through the EM and OM relays is such that OM is operated and EM is not. If the tube current decreases, OM releases; if it increases, EM operates.

Consider speech in the odd path. Part of this speech enters the odd amplifier via the hybrid,† is amplified and half-wave rectified, and is then applied to the cathode of the DA tube. This makes the cathode more positive with respect to the grid, which decreases the tube current and releases relay OM. Release of OM removes ground from one winding of the OH relay and applies ground to the second OH winding, causing it to operate. Operation of OH places a ground return path in parallel with the EM relay, which prevents its operation and also removes ground from the hybrid balancing network N in the even path. Network N now balances the input impedance of the even amplifier and this provides a high (35 to 40 db) transhybrid loss across the hybrid in the transmission path which suppresses the echo. Suppression hangover is supplied by the RC network in one winding of the OH relay.

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* The block diagram shown in Fig. 4 is for the split-terminal suppressor and is not a representation of the full suppressor of Fig. 8.

† The echo suppressor hybrids are branching devices for transferring energy from the speech path to the suppressor circuitry and should not be confused with the terminating hybrids that convert the 2-wire line to a 4-wire line.

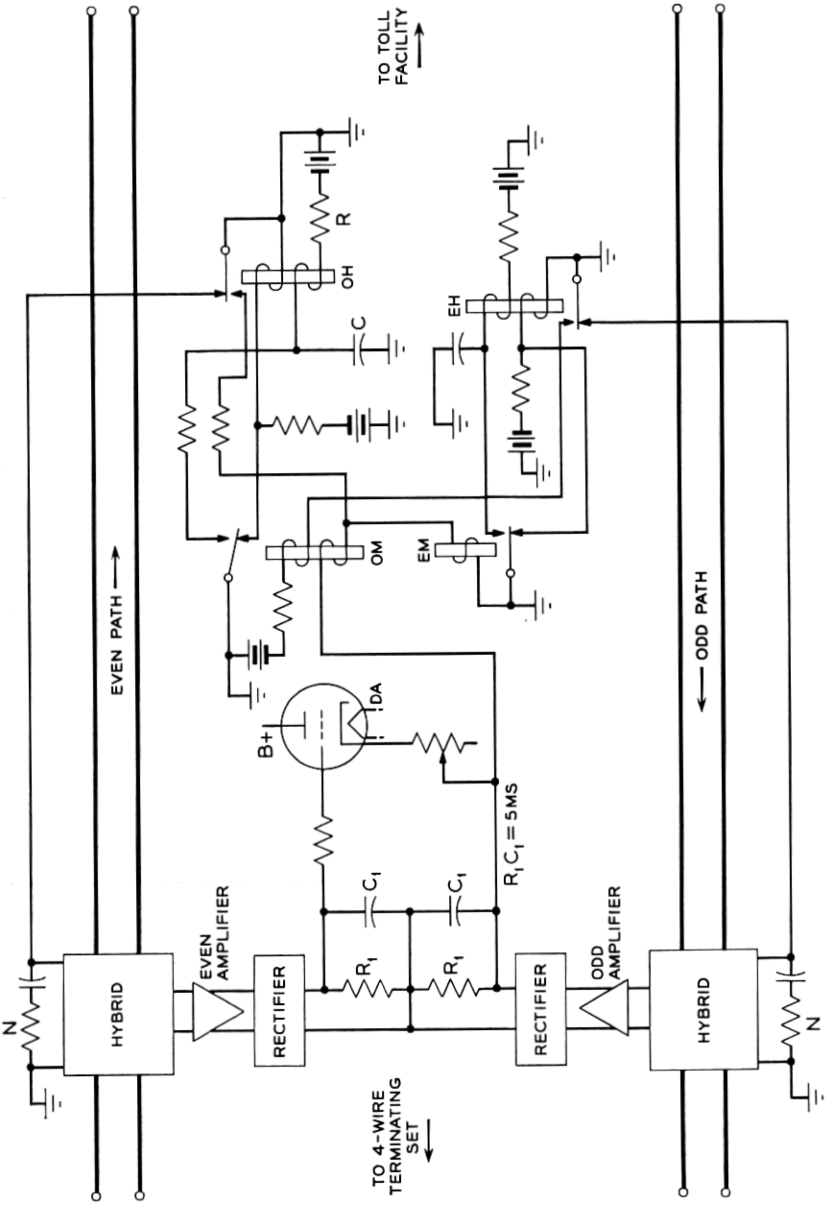

Fig. 8 — Simplified schematic of 1A echo suppressor.

If speech is present in the even path, the operation is similar except that the DA tube current is increased and the EM relay operates, causing the EH relay to operate and place loss in the odd path.

When speech is present in both paths during double talking, the echo suppressor operates as follows. Assume initially that speech in the odd path occurred first. This speech operates the OM and OH relays, suppressing the even path with a hangover of 50 msec. If the even speech level is less than the odd speech level, the suppression remains in. If the even speech level rises above the odd speech level for 50 msec, the OH relay releases and the EM and EH relays operate. This removes suppression in the even path but places suppression in the odd path with a hangover of 70 msec. For about equal-volume talkers, the suppression will alternate between the two paths as the syllabic or peak power points of the speech in both paths alternate. Almost all echo will be suppressed, but the speech during double talking will be chopped or mutilated.

Operation in the manner described above occurs with a full suppressor. Split echo suppressor operation is obtained by permanently grounding the balancing network in the odd path, with the hangover on the EH relay set to its minimum value of about 18 msec. Two echo suppressors with this modification are used on one circuit — one at each end. The operation during double talking is similar to that of a full echo suppressor.

The 35–40 db suppression supplied by the hybrid balance is sufficient for most circuits today, but the longer-delay cable circuits or future satellite circuits require more suppression than this. A modification (shown on Fig. 9) was made to the echo suppressor to increase the suppression for tests on long delay circuits. The OH relay, instead of balancing the hybrid, applies a short circuit across the even path to

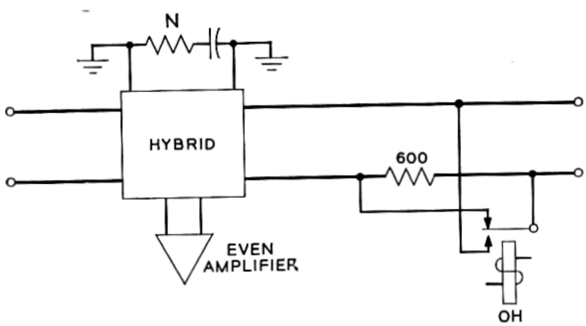

Fig. 9 — 1A echo suppressor modified for greater suppression.

suppress the echo. Two split suppressors modified in this fashion were subjectively tested on long-delay circuits at Bell Telephone Laboratories. The results of the subjective tests are given in a companion paper.[2]

4.2 *BH Echo Suppressor*

This echo suppressor, one of several experimental echo suppressors designed at Bell Telephone Laboratories, differs primarily from the 1A echo suppressor in that its suppression and break-in functions are independent of each other, while in the 1A these functions are combined into one differential circuit. A simplified schematic of the BH split echo suppressor is shown on Fig. 10.

If speech is present in the odd path, relay S operates and places a short across the even transmission path (provided relay B is operated) which suppresses the returning echo. Operation of suppression relay S is controlled by speech in the odd path only and is independent of speech in the even path. (This differs from the 1A where relay OM is controlled by speech in both paths as determined by the DA tube current.) Relay S provides a suppression hangover of about 50 msec.

Speech in the even path is amplified, rectified, and applied to the grid

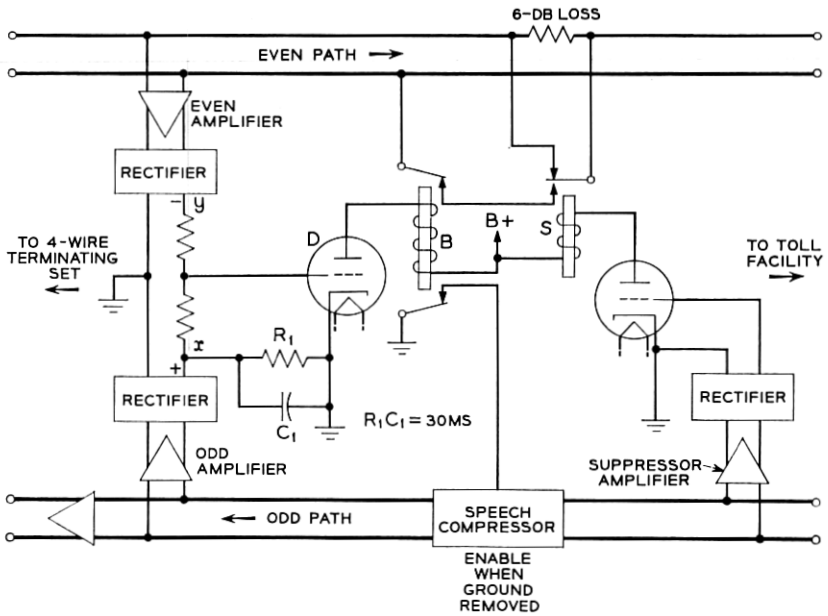

Fig. 10 — BH echo suppressor.

of tube D. The negative signal applied to the grid reduces the tube current which releases normally operated relay B. Release of B prevents or removes any suppression caused by operation of relay S and also removes ground to enable a speech compressor in the odd transmission path. (This is discussed later.) Once relay B has released, it remains released for a hangover time of 200 msec.

When speech is present in both paths, during double talking, the operation is as follows. Assume that speech in the odd path occurred first. This speech operates the S relay suppressing the even path with a hangover of 50 msec. If the even speech level is less than the odd speech level, relay B stays operated, and the suppression remains in. Since the even speech may be the echo of the odd speech, this speech must not operate relay B to remove suppression. Echo is prevented from operating relay B by proper choice of gains in the odd and even amplifiers and the R_1C_1 time constant. (This was discussed in Sections 3.1 and 3.3 above.) When true break-in speech of sufficient level is present in the even path, it will release relay B and remove the suppression for 200 msec. If relay S is operated when relay B releases, 6 db loss is inserted in the even path. Also, anytime relay B is operated, a speech compressor is enabled in the odd path. When the echo suppressor is used at 0TL, the speech compressor is adjusted to supply 0 db loss for a -50-dbm signal in the odd path and to smoothly increase this loss to 12 db for a 0-dbm signal. The 6-db loss in the even path and the speech compressor in the odd path are used to reduce the echo occurring during the double talking interval, when relay B is operated and suppression is removed.

If prolonged double talking is simultaneously present at the echo suppressors at both ends of the connection, all echoes would be attenuated by two compressors and two 6-db pads. This is not generally the case, however. Many echoes return at a time when the local talker is silent, and they are often reflections of speech generated when there was no distant speech. It is more accurate to say that all echoes are attenuated by at least one compressor and at least one 6-db pad.

4.3 *GN Echo Suppressor*

This split echo suppressor, also designed at Bell Telephone Laboratories, is unique in that it uses variolossers for suppression and thus applies a variable amount of suppression depending on the odd speech level. A simplified schematic is shown in Fig. 11.*

Speech present in the odd path is amplified, rectified, and applied to

* A more complete description of this echo suppressor is given in Ref. 4.

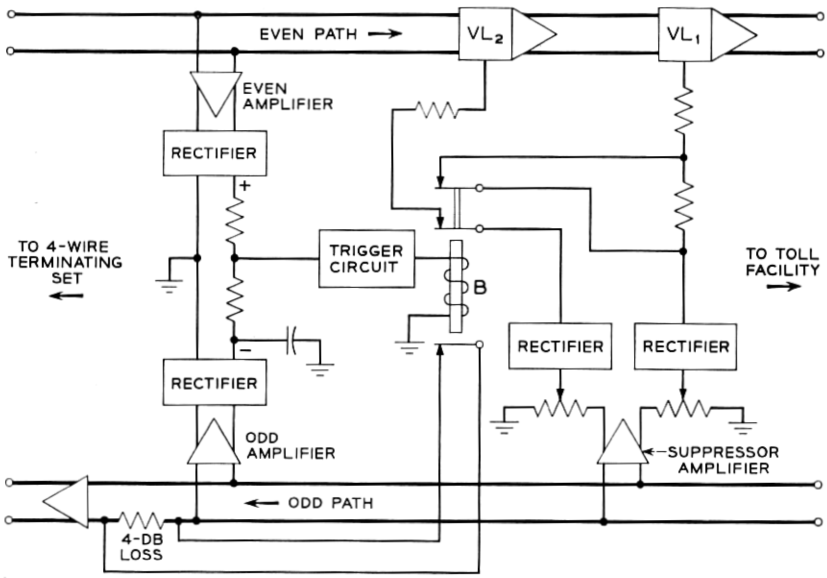

Fig. 11 — GN echo suppressor.

the variolossers VL_1 and VL_2. The combined suppression loss of VL_1 and VL_2 is shown on Fig. 12. It is seen that for very low-level speech the suppression slope is moderate, but for higher-level speech the suppression has a steep slope and rapidly reaches 80 db suppression. By proper choice of odd and even amplifier gains and the time constant on the odd input to the trigger circuit, echo is prevented from removing this suppression.

During periods of double talking, the operation is as follows. If odd speech is present first, suppression is applied. When break-in speech of sufficient amplitude then occurs, it is recognized as such at the input to the trigger circuit, which operates relay B. Operation of relay B removes the suppression of VL_2 to allow even speech to pass through the echo suppressor. It also reduces the suppression of VL_1 and places a 4-db loss in the odd path to reduce the echo. The suppression of VL_1 during double talking is shown on Fig. 12. Relay B provides a break-in hangover of about 400 msec.

4.4 *AM Echo Suppressor*

This echo suppressor, an experimental model by a United States manufacturer, differs primarily from other echo suppressors in its action

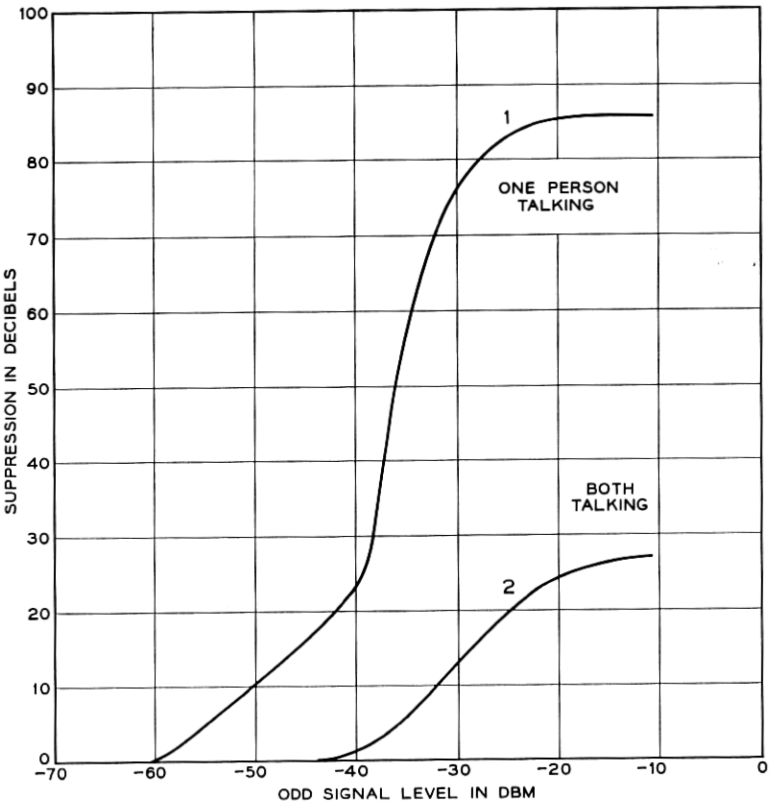

Fig. 12 — GN variolosser characteristics.

during double talking. A simplified block diagram of the AM echo suppressor is shown on Fig. 13.

If speech is present in the odd path, threshold detector TD_2 operates, producing a signal passing through gate 1 and enabling the transistor suppressor, which has about 60 db loss. Suppression hangover (about 100 msec) is supplied by hangover control HC_2.

Speech in the even path is amplified, rectified and applied to the differential amplifier. If the output of the differential amplifier operates threshold detector TD_1 as described in Section 3.3, gate 1 is inhibited, preventing suppression. The inhibit signal has a hangover time of about 200 msec.

When speech is present in both paths during double talking, the operation is as follows. Assume that speech in the odd path occurred first. This speech operates TD_2, suppressing the even path with a hangover

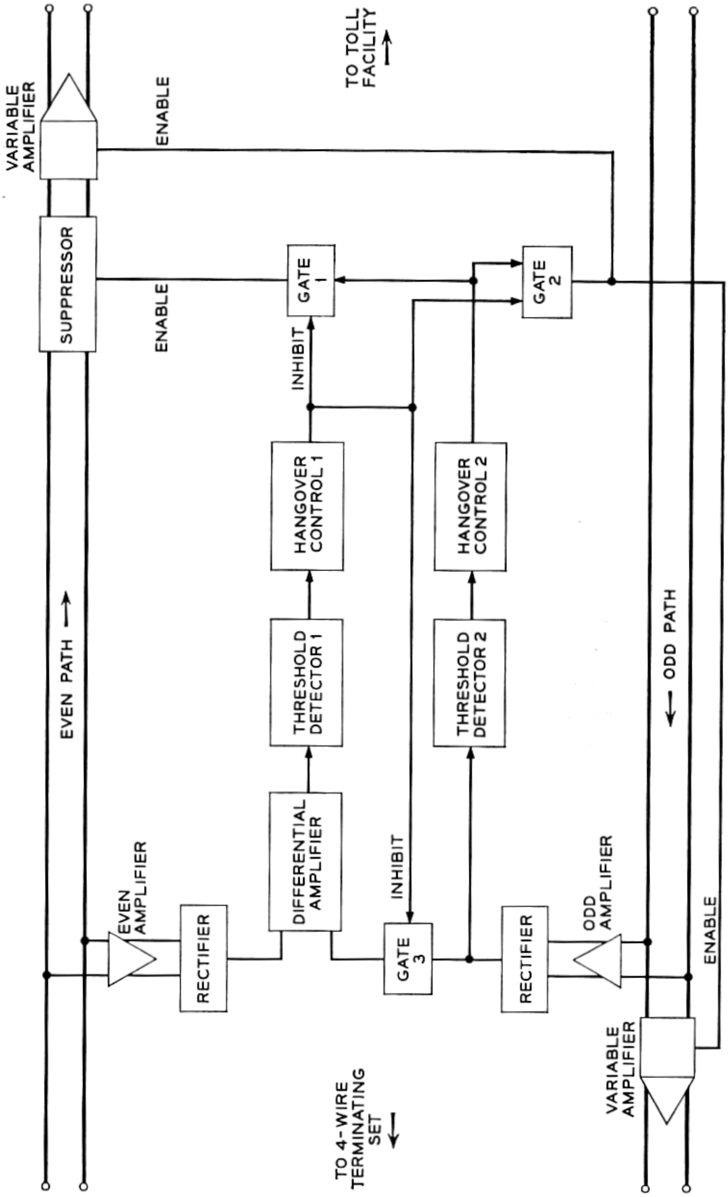

Fig. 13 — AM echo suppressor.

of 100 msec. Echo is prevented from operating TD_1 through use of proper time constants in the differential amplifier. When true double talking speech of sufficient volume is present in the even path, the differential amplifier will cause TD_1 to operate, removing suppression for at least 200 msec. TD_2 is still operated by speech in the odd path, and when TD_1 and TD_2 are operated, a 6-db loss is introduced in the amplifiers in the even and odd paths to reduce the echo. The operation of TD_1 also effectively inhibits a gate in the odd speech input to the differential amplifier. This inhibit signal prevents the release of TD_1 as long as the even speech is greater than the even sensitivity, irrespective of the speech present in the odd path. Thus, as long as the even speech level does not fall below the even sensitivity for over 200 msec (the hangover time of HC_1), gate 1 will always inhibit suppression no matter what the level of the odd speech. This action reduces the mutilation of even speech but also increases the unsuppressed echo, as discussed below.

Suppose the *odd* speech maintains an average level 10 db higher than the *even* sensitivity and the echo of the odd speech is reduced by an 8-db return loss such that the odd echo is 2 db higher than the even sensitivity. This echo will not by itself remove suppression because of the comparison action of the differential amplifier. However, if a short burst of break-in speech is present in the even path, TD_1 will operate to remove suppression and inhibit gate 3. Now the echo of the odd speech is sufficient to maintain TD_1 on, and gate 1 will be inhibited until the echo of the odd speech falls below the even side sensitivity for more than 200 msec. This action has been observed to produce considerable echo for some combinations of talkers and return loss.

V. CONCLUSIONS

In this paper we have discussed some of the design features of a particular type of echo suppressor. The philosophy behind the design of this type of echo suppressor is that a telephone channel should allow as much two-way conversation as possible consistent with proper echo control. Thus every effort is made to provide ease of break-in during double talking. Unfortunately, this generally results in a compromise between having too much echo or too much speech chopping during double talking. The echo and chopping are very disturbing to some people, and the disturbing effects may, in some cases, outweigh the beneficial aspects of attempting to provide a two-way circuit during simultaneous talking.

Ease of break-in is not the only principle which can be followed in designing echo suppressors. Other approaches have been suggested. For example, one echo suppressor has been proposed which is designed to train the conversants not to double talk by increasing the received volume of the distant speaker whenever the local speaker tries to interrupt, thereby "shouting down" the interrupter. Another proposal is aimed at preventing the chopping effect during double talking by allowing only one-way conversation at any time, the allowed direction being determined by examining which conversant spoke first.

All of these proposals include voice switching, and all produce transmission degradations. It is impossible to predict the subjective reaction to the degradation introduced by these various proposed echo suppressors merely by examining the design features of the suppressors. This reaction can be determined only through subjective tests, one type of which is described in a companion paper.

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