United States Patent

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[54] TELEPHONIC TRANSMISSION USING COMPLEMENTARY COMB FILTERS
4 Claims, 6 Drawing Figs.

[52] U.S. Cl. .... 179/170.2, 179/1 HF
[51] Int. Cl. H04m 9/08
[50] Field of Search .... 179/1 HF, 170.2, 170.4, 170.6, 170.8, 15.55

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ABSTRACT: This disclosure describes a system for assuring circuit stability in a telephonic link having substantial acoustic coupling at stations therein, as well as eliminating remote end echo in such circuits. The system uses complementary comb filter banks in which the passband center frequencies are selected to reduce the incidences of harmonic relations among the passband at any one of the filter banks. The system is adapted also to the reduction of electrical circuit echo.

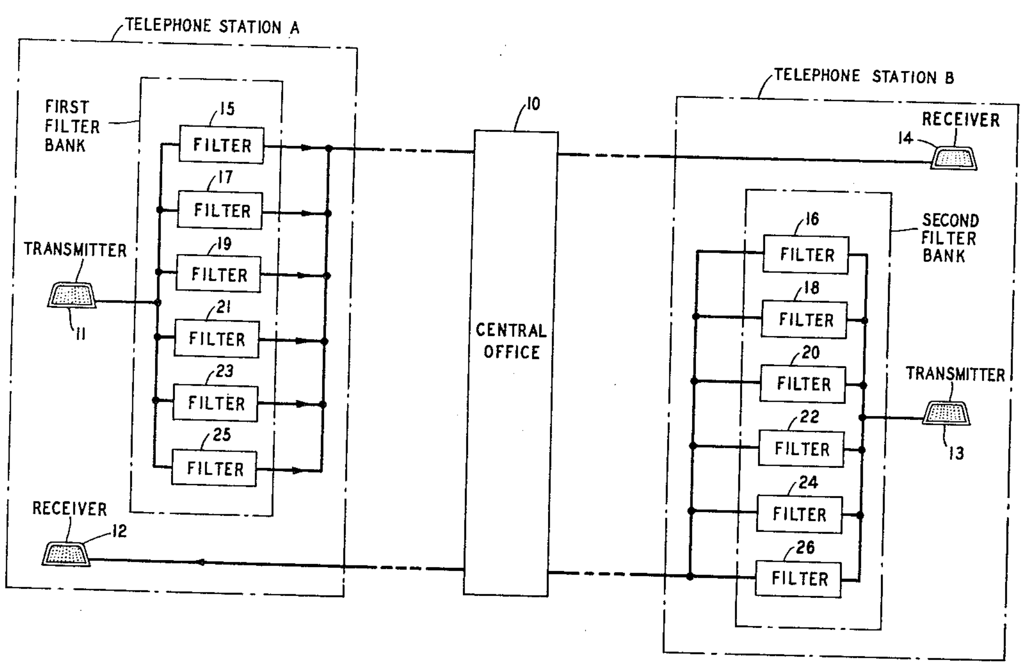
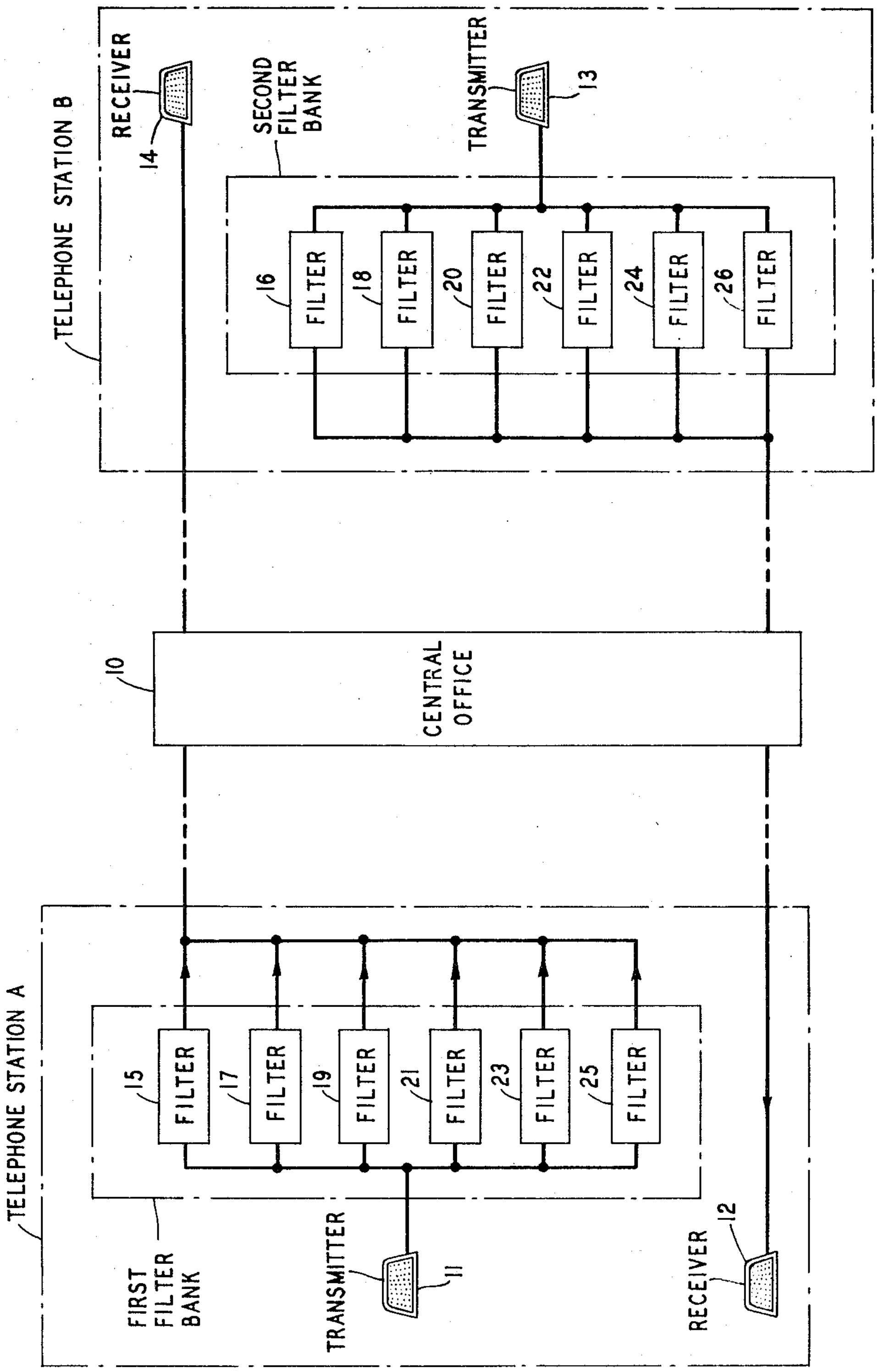


FIG. 1



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BY [signature]
ATTORNEY

FIG. 2

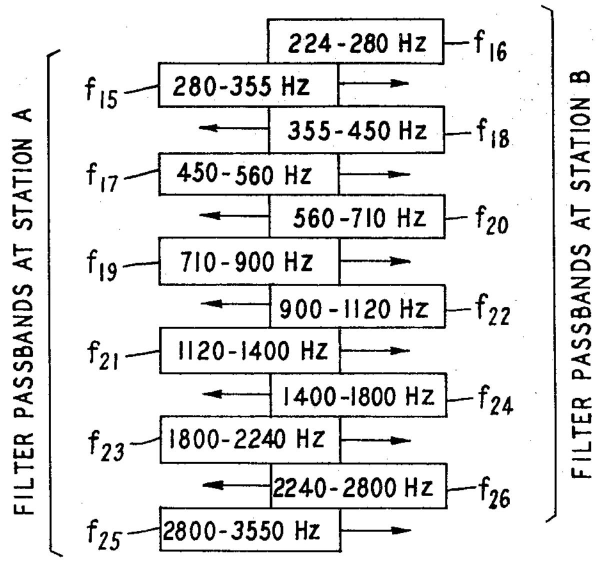
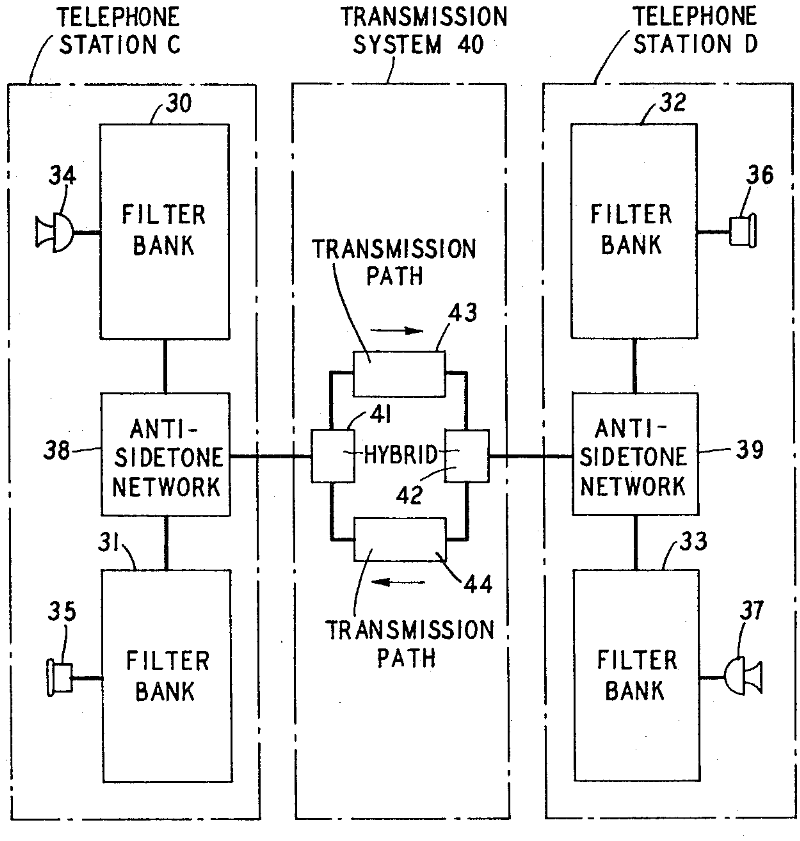

224-280 Hz
f_{16}
f_{15}
280-355 Hz
355-450 Hz
f_{18}
f_{17}
450-560 Hz
560-710 Hz
f_{20}
f_{19}
710-900 Hz
900-1120 Hz
f_{22}
f_{21}
1120-1400 Hz
1400-1800 Hz
f_{24}
f_{23}
1800-2240 Hz
2240-2800 Hz
f_{26}
f_{25}
2800-3550 Hz
FILTER PASSBANDS AT STATION A
FILTER PASSBANDS AT STATION B

FIG. 3


TELEPHONE STATION C
TRANSMISSION SYSTEM 40
TELEPHONE STATION D
30
32
34
36
FILTER BANK
FILTER BANK
TRANSMISSION PATH
43
41
HYBRID
42
38
ANTI-SIDETONE NETWORK
ANTI-SIDETONE NETWORK
39
31
33
44
35
37
FILTER BANK
FILTER BANK
TRANSMISSION PATH

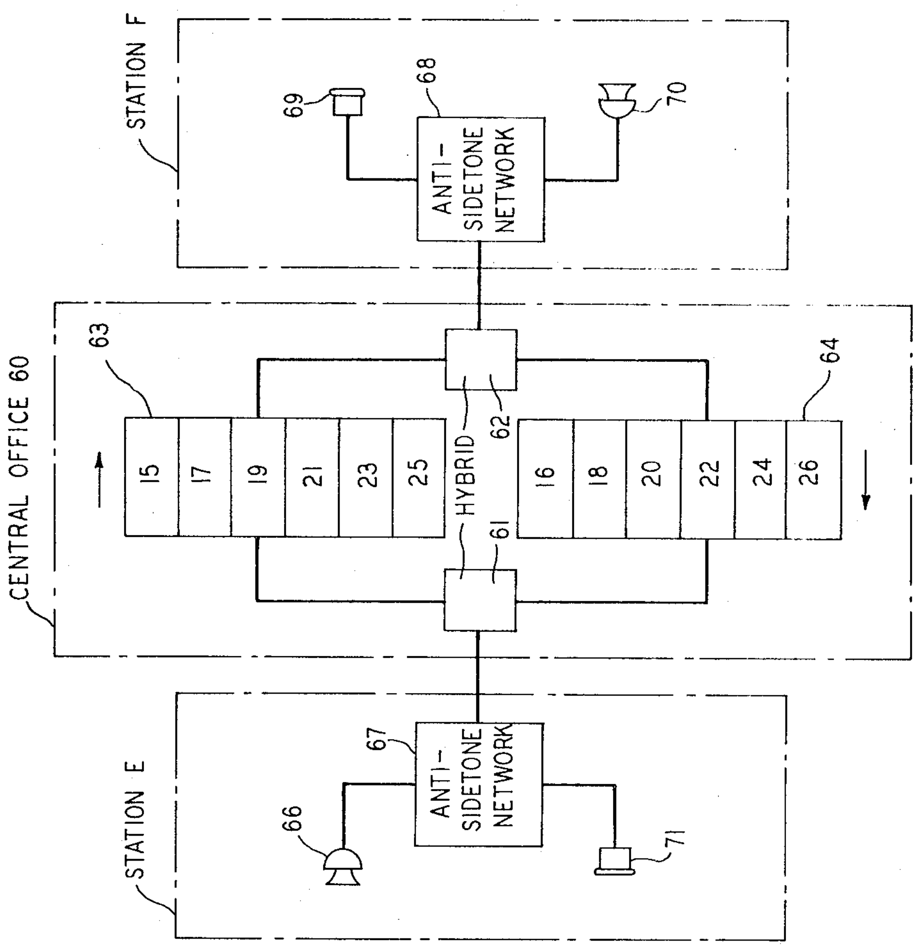

STATION F
69
68
ANTI-
SIDETONE
NETWORK
70
CENTRAL OFFICE 60
63
64
15
17
19
21
23
25
HYBRID
62
61
16
18
20
22
24
26
STATION E
66
67
ANTI-
SIDETONE
NETWORK
71

FIG. 4

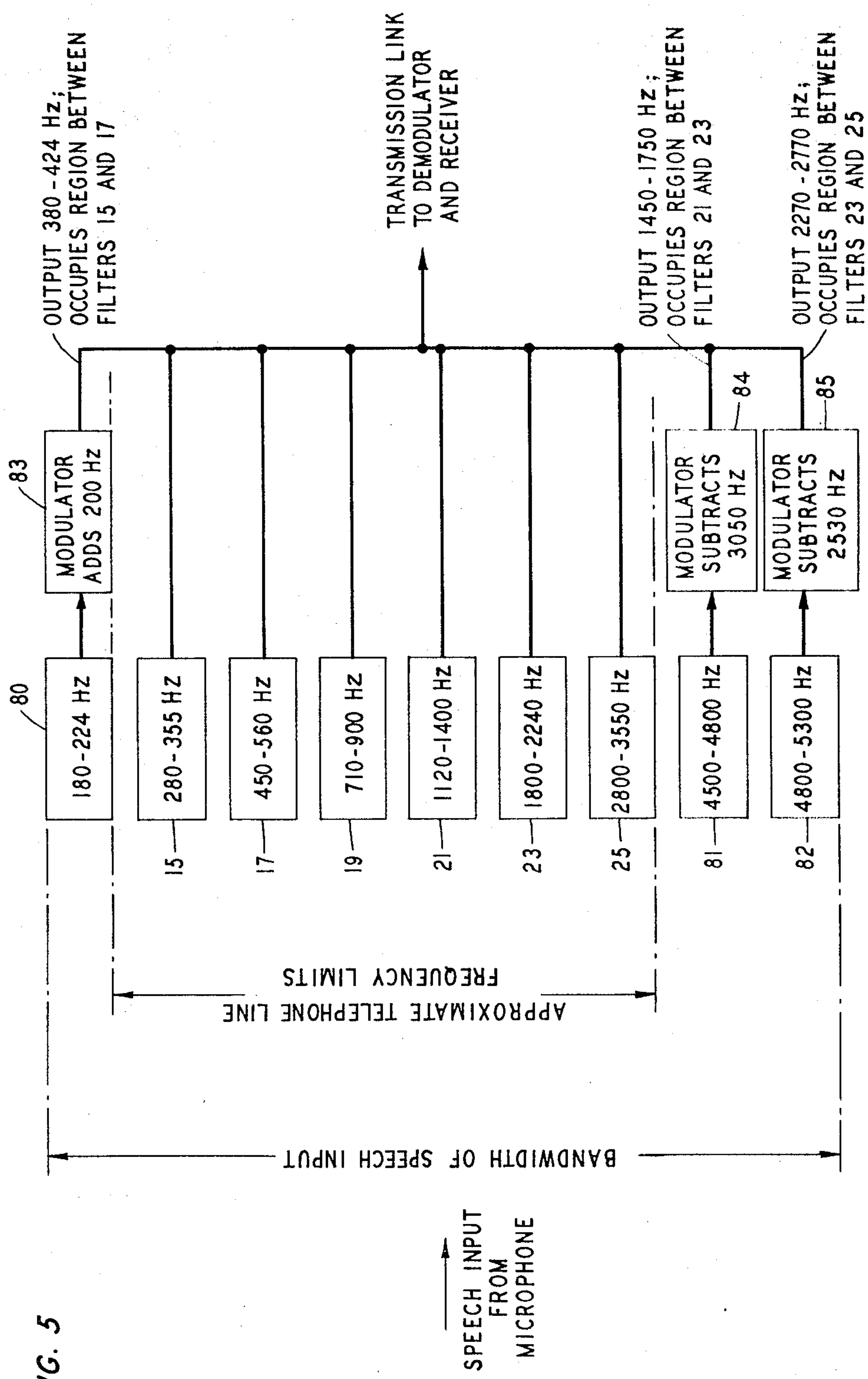
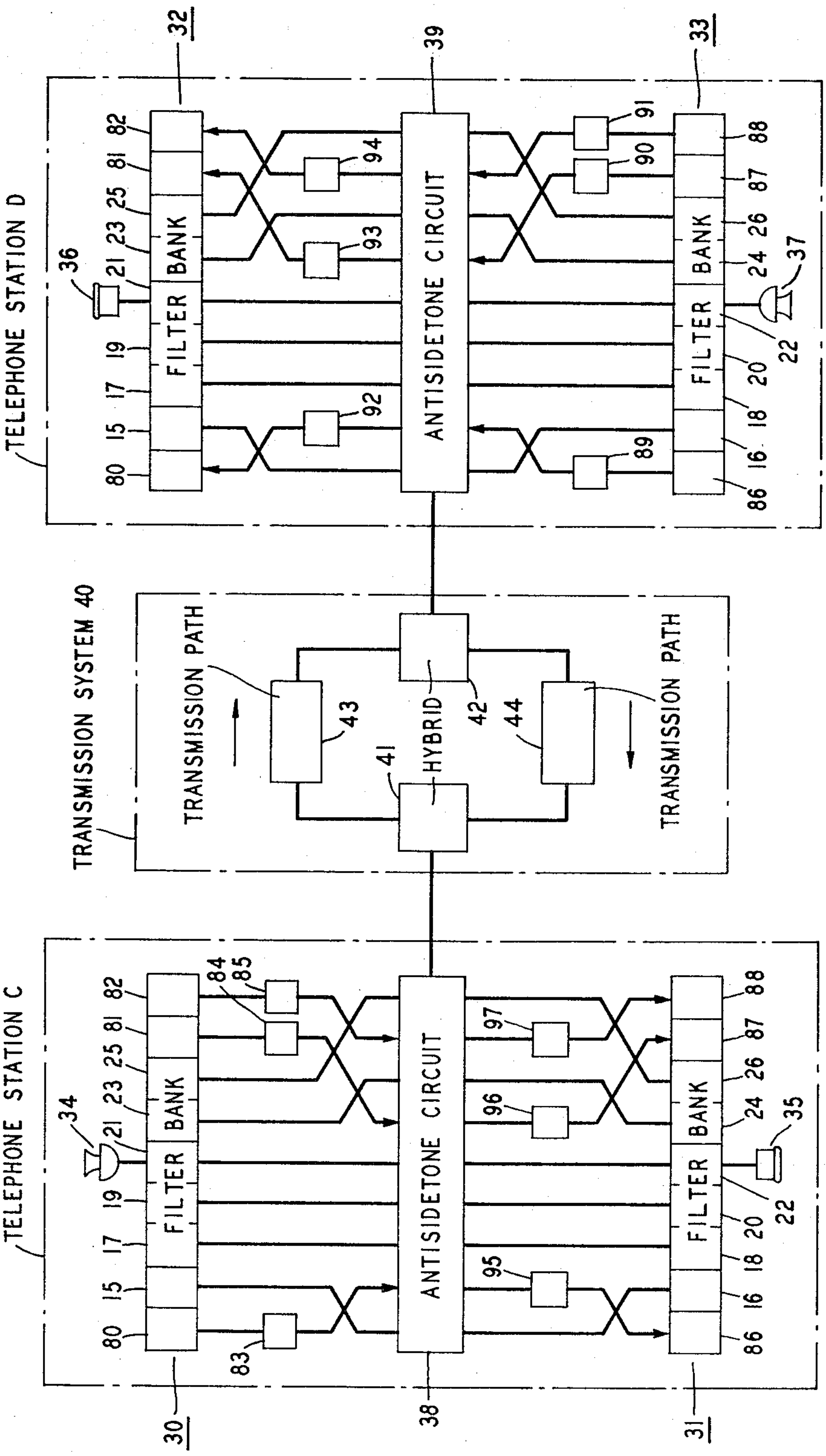

OUTPUT 380-424 Hz; OCCUPIES REGION BETWEEN FILTERS 15 AND 17
TRANSMISSION LINK TO DEMODULATOR AND RECEIVER
OUTPUT 1450-1750 Hz; OCCUPIES REGION BETWEEN FILTERS 21 AND 23
OUTPUT 2270-2770 Hz; OCCUPIES REGION BETWEEN FILTERS 23 AND 25
83
MODULATOR ADDS 200 Hz
84
85
MODULATOR SUBTRACTS 3050 Hz
MODULATOR SUBTRACTS 2530 Hz
80
180-224 Hz
280-355 Hz
450-560 Hz
710-900 Hz
1120-1400 Hz
1800-2240 Hz
2800-3550 Hz
4500-4800 Hz
4800-5300 Hz
15
17
19
21
23
25
81
82
APPROXIMATE TELEPHONE LINE FREQUENCY LIMITS
BANDWIDTH OF SPEECH INPUT
SPEECH INPUT FROM MICROPHONE

FIG. 5

FIG. 6


TELEPHONE STATION D
ANTISIDETONE CIRCUIT
FILTER BANK
FILTER BANK
TRANSMISSION SYSTEM 40
TRANSMISSION PATH
HYBRID
HYBRID
TRANSMISSION PATH
TELEPHONE STATION C
ANTISIDETONE CIRCUIT
FILTER BANK
FILTER BANK

TELEPHONIC TRANSMISSION USING COMPLEMENTARY COMB FILTERS

FIELD OF THE INVENTION

This invention relates to telephonic communications, and broadly concerns the suppression or elimination of an unwanted recurrence of a desired speech signal in such systems.

BACKGROUND OF THE INVENTION

A number of instances exist in telephony where speech quality and intelligibility are seriously reduced by the recurrence somewhere in the system of a desired speech signal.

In a loop comprising two "hands-free" stations, for example, there can be a substantial direct acoustic coupling between the local receiver and the transmitter at each station. If at any time the net loop gain is greater than unity, the loop becomes unstable and may oscillate. The undesired speech signal recurrence can be viewed as a talker's voice returning to his own transmitter via the two direct acoustic paths, one at the remote station and the other at the talker's station.

In such loops, even when overall gain is low, there still is the problem of remote end echo, which stems from a speaker's voice returning to his ear, at a reduced but discernible level, after traveling around such a loop. For remote end echo to occur requires only one hands-free station in the loop; and both the direct and indirect acoustic paths at such station contribute to the echo.

The usual countermeasure has been to employ various voice-switching schemes which in effect make the loop transmission direction one way at a time. Although improving stability and remote end echo problems, this expedient creates the problem that only one party can talk and be heard at a given time. If both parties attempt to talk at once, this "double talk" will lead to lockout. If, further, the loop has relatively long delays for any reason, the conversation can break down altogether when lockout occurs.

In addition, voice switching at best will on the average degrade the quality of received speech by clipping initial message requests. Not always can the listener supply the missing parts from the context, and thus requests by users of such loops for the speaker to repeat himself are frequent. With such circuits there is also a significant risk of a listener misunderstanding what was said altogether.

Besides the signal recurrences already mentioned, there also is electrical echo, particularly on long telephone circuits. This echo is a talker's signal returning to his ear, say, from a remote hybrid. With large enough levels and round-trip delays, this echo too has the psychoacoustic effect on a speaker of drastically interrupting his free-cadenced generation of speech.

Accordingly, the following are important objects of the invention:

to assure loop stability in a two-way hands-free voice communications channel without degrading the quality or message content of received speech;

to eliminate the requirement of voice switching on such channels;

to eliminate wherever present, the problem of remote end echo;

to reduce the problem of electrical echo;

to permit simultaneous, two-way conversation on circuits now requiring voice switching due either to the need for circuit stability or the need to reduce the effect of echo;

to preserve the naturalness of received speech on such channels without using voice switching and without requiring added bandwidth; and

importantly, to assure the capability of hands-free audio communications on a video telephone link without the need for a handset.

In connection with echo suppression, it has previously been proposed to use complementary comb filters at, for example, the two ground stations in a synchronous satellite telephone system, to allocate the available bandwidth of a single-voice channel between a send path and a receive path. Each path includes a filter bank consisting of several filters. In terms of attenuation vs. frequency characteristic, certain of the filters of the send path bank are complementary to certain of the filters of the receive path bank. When a "double talk" occurs, this feature is turned to account by providing in effect acceptable two-way transmission with adequate loss inserted in the echo path.

SUMMARY OF THE INVENTION

In broadest terms, the present invention utilizes two banks of comb filters in a voice telephone system. Each bank has several comb teeth, or filters. The filter passbands of the first bank are stopbands in the second bank, and vice versa; thus, no passband in one filter bank overlaps any significant portion of a passband in the other filter bank. The passbands of the two filter banks are in this sense complementary.

The passbands at each bank are in addition frequency spaced pursuant to a system that reduces the incidence of harmonic relations among the passbands at that bank. In general, this is achieved to advantage by a logarithmic spacing of passband center frequencies of the successive complementary comb teeth of the two banks. In a particular embodiment, adjacent passband center frequencies are logarithmically spaced by a selected odd simple fraction of an octave for example, one-third octave. In either of the filter banks then, the blocking of both a fundamental and its second harmonic thereby is avoided, which preserves highly useful recognitional features of a speaker's voice.

A suitable incorporation of the two filter banks as, for example, in the circuitry of two communicating hands-free telephone stations of the system, creates a stable loop. Specifically, at either of the stations, the signal received includes frequencies only within the passband set of the sending station. As the two passband sets are mutually exclusive, no closed feedback path exists in the loop to cause instability.

Further, if acoustic coupling of a received signal to the transmitting microphone does occur at one of the stations, that signal is for the same reason precluded from returning as a remote end echo to the originator's ear. To the listener's ear however, the received signal despite the filtering is substantially undegraded, owing to the unique harmonic relations of the passbands at each bank.

Using conventional modulation techniques, an improvement in speech quality is achieved by multiplexing additional voice frequency passbands, which fall outside the normal telephone channel band limits, into the stopband regions of each comb filter. The added speech quality is in some instances an advantageous trade-off for a certain amount of remote end electrical echo which might then be passed by the system.

By concentrating the complementary comb filters of the present invention at a central point such as a central office the problem of suitably matching sets of combs is simplified.

The invention and its further objects, features and advantages will be readily discerned in detail from a reading of the descriptions which follow of its illustrative embodiments.

THE DRAWING

FIG. 1 is a block diagram embracing the basic invention;

FIG. 2 is a schematic diagram of frequency allocation between two filter banks;

FIGS. 3 and 4 are block diagrams of two systems using the invention;

FIG. 5 is a block diagram depicting an added speech processing features; and

FIG. 6 is a block diagram showing a further inventive system using the feature of FIG. 5.

ILLUSTRATIVE EMBODIMENTS

The basic invention is broadly depicted in FIG. 1 in which two telephone stations, A and B, are connected through a central office 10. For simplicity's sake, only relevant station and transmission elements are shown. Stations A and B are hands-free telephones for which there exists a strong acoustic coupling between transmitter 11 and receiver 12 of station A, and between transmitter 13 and receiver 14 of station B.

Pursuant to the invention, transmitter 11 is connected to a first filter bank consisting of several voice frequency band-pass filters 15, 17, 19, 21, 23, 25. Similarly, transmitter 13 is connected to a second filter bank consisting of several voice-frequency band-pass filters 16, 18, 20, 22, 24, 26.

The passbands of the first filter bank are, in the second filter bank, unused or blocked portions of the channel spectrum. Similarly, the passbands of the second filter bank are the unused or blocked portions of the first filter bank. In this sense, the two filter banks are complementary.

Pursuant to an important general aspect of the invention, the passband frequencies in the several filters of each bank are so selected that at least some harmonic of a blocked fundamental is passed if it lies within the band limits. This is achieved by spacing the center frequencies in accordance with odd logarithmic relations between the center frequencies. Thus, considering both the first and the second filter bank, the center frequencies of adjacent passbands are separated by a selected odd simple fraction of an octave such as one-third, one-fifth, one-seventh, etc. In the present embodiment, the spacing is one-third octave.

FIG. 2 depicts schematically the meshing of complementary comb filter teeth wherein the passband width, within each bank, and the center-frequency spacing with respect to all passbands, is one-third octave. For ⅓-octave bands, if a fundamental is passed by the bank comprising filters 15, 17, 19, 21, 23, 25, so also is at least its fourth and tenth harmonics if they are within the limits of the bank. If a fundamental doesn't pass, its fourth and 10the harmonics must pass the bank comprising filters 16, 18, 20, 22, 24, 26. The fundamental must, of course, be not less in frequency than the lowest passband limit.

Also with respect to ⅓-octave bands, as to fundamentals below the lowest passband limit, if its second harmonic passes, so may its third, fifth, sixth, seventh, eighth, ninth, 11th and so on. If the second harmonic does not pass, at least the fourth and 10th harmonics will pass. The selection of ⅓-octave bands appears particularly advantageous. A bandwidth of 1 octave is too wide to enable a sufficient number of teeth to be built into the complementary combs to obtain good transmission in both directions, due to the limited bandwidth available in a telephone voice channel. On the other hand, ringing of the filters becomes significant for one-fifth octave and smaller teeth.

Linear bands can, of course, be constructed to pass harmonics, but not within the limited telephone channel bandwidth. The excessive bandwidth required at lower frequencies in such case would prevent building a complementary filter with good transmission quality. The choice of ⅓-octave bands guarantees the passage of some harmonics of any given signal, while retaining good complementary characteristics.

In the particular embodiment of FIG. 2, if an input signal to the filter at station B has fundamental acoustic energy density centered at 400 Hz. (roughly the center frequency of filter 18 but a no-transmit region for said first bank) then although the fundamental is blocked, the second harmonic, 800 Hz., of that signal is transmitted through filter 19. In addition, the third, fifth, and eighth harmonics, 1,200, 2,000, and 3,200 Hz., likewise are transmitted through filters 21, 23, and 25. Further, if the input signal centers at about 505 Hz., the center frequency of filter 17, it will pass, as will its fourth and sixth harmonics, 2,020 and 3,030 Hz., via filters, 23 and 25.

The harmonic richness of human voice assures the broad workability of the above scheme. It has been found to preserve the recognitional quality of the transmitted voice as well as intelligibility. The invention substantially precludes the occurrence of a closed loop in the paths connecting stations A and B. In the example of FIG. 1, acoustic coupling unavoidably exists between transmitter 11 and receiver 12 as well as between transmitter 13 and receiver 14. But by virtue of the complementary comb filter banks, no significant amount of the signal energy passing through one filter bank—even when acoustically coupled directly or through room reverberation into the remote receiver—will pass through the other filter bank associated with said remote receiver.

The invention finds further use as a suppressor of electrical echo. In this embodiment, a complete set of filters is provided at each of the two stations.

In FIG. 3 telephone stations C and D are shown connected through transmission system 40. The filter banks 30 and 32 at stations C, D each contain, for example, the filters 15, 17, 19, 21, 23, 25 referred to earlier in connection with FIGS. 1 and 2. The filter banks 31 and 33 similarly each contain the filters 16, 18, 20, 22, 24, 26. Conventional antisidetone networks 38, 39 are provided respectively at stations C and D. Transmission system 40 includes typically four-wire terminal sets 41, 42 and transmission channels 43, 44. The transmission path between station C and station D thus includes transmitter 34, filter bank 30, network 38, hybrid 41, channel 43, hybrid 42, network 39, filter bank 32, and receiver 36. Similarly, the transmission path between station D and station C includes transmitter 37, filter bank 33, network 39, hybrid 42, channel 44, hybrid 41, network 38, filter bank 31, and receiver 35.

For same reasons stated above with respect to the FIG. 1 embodiment, isolation is afforded between the two transmission paths, in consequence of which circuit quality and stability are not affected by acoustic coupling, if any exists, of receiver and transmitter at the respective stations C and D.

Additionally, however, neither station when transmitting will experience a remote end echo of its own transmission. For example, if an echo develops at hybrid 42 of a transmission from station C, such echo—being frequency-limited to the subbands passed by filter bank 30—will not be passed by the filter bank 31. The same situation obtains as to transmission from station D.

In a variation of the inventive embodiment of FIG. 1, the first and second filter banks instead of existing at the separate station sets, are centrally located at a common switching point. FIG. 4 shows such a system. The station sets E and F are connected through a central office 60, which includes hybrid networks 61, 62 and filter banks 63, 64. Bank 63 comprises filter 15, 17, 19, 21, 23, 25 as described in FIG. 2; and similarly, bank 64 comprises filters 16, 18, 20, 22, 24, 26.

The transmission path to station F includes the transmitter 66 at station E, antisidetone network 67, hybrid 61, filter bank 63, hybrid 62, and at station F, antisidetone network 68, and receiver 69. The transmission path to station E includes the transmitter 70 at station F, network 68, hybrid 62, filter bank 64, hybrid 61, and at station E, network 67, and receiver 71.

Circuit stability in the FIG. 4 embodiment is realized for the same reasons stated with respect to the FIG. 1 embodiment. In addition, pursuant to the invention, voice quality is maintained by the use of particular passbands in each filter bank, such as has been described with respect to FIG. 2. Moreover, by placing the comb filter centrally with respect to the communicating station sets, the proper allocation and matching of passbands is readily realized.

A further aspect of the invention relates most particularly to speech quality. As is known from long-time power density spectrum analysis, continuous speech exhibits maximum power density in the region centering on about 500 Hz. Relatively high-power levels for both men and women are also present in the 125–200 Hz. region, however. Further, voice energy is generated also in the frequency range 4,000–8,000 Hz., particularly by women. Although relatively much lower in power, the latter region nevertheless contains signal components valuable in the present scheme for speech recognition, intelligibility, and quality.

Telephone bandwidth, however, is limited in voice telephone systems to the range of about 225–3,500 Hz., which normally precludes transmission of the information in the regions adjoining.

Accordingly, in the following inventive embodiment, speech power in the frequency regions adjoining this normal voice-frequency band are, in each transmission direction, frequency-multiplexed into unused spectral regions between the comb teeth. FIG. 5 depicts such speech processing. Speech input, for example, from a microphone and having a bandwidth of, say, 180 to 5,100 Hz., is to be transmitted over a telephone channel. The channel band extends from 280 Hz. to 3,550 Hz. approximately. The channel is equipped, for one of the above-mentioned inventive purposes, with a complementary comb filter. The in-band filters **15, 17, 19, 21, 23, 25** are those shown in FIG. 2. An additional filter **80** with a passband of 180–224 Hz. is here provided to receive speech in this region; and two additional filters **81, 82** with contiguous passbands of 4,500–4,800 Hz. and of 4,800–5300 Hz. respectively are provided in the region beyond the upper channel edge for speech in that region.

The bandwidth of the filter **80** is the one-third octave that obtains with respect to the filters **15, 17, 19, 21, 23, 25**. The combined bandwidths of filters **81, 82** however are slightly less than one-third octave.

Speech is processed in filters **15, 17, 19, 21, 23, 25** as already described; and in this instance also by passband filters **80, 81, 82**. The respective outputs of filters **80, 81, 82** are frequency-shifted by the respective modulators **83, 84, 85** into selected unused regions. These regions are in the present embodiment, respectively, between 355 and 450 Hz.; between 1,400 and 1,800 Hz.; and between 2,240 and 2,800 Hz. These particular unoccupied spaces are preferred because they minimize the number of modulators required. It is, of course, possible to use additional space for further multiplexing of speech or data.

All signals are then conventionally transmitted to a remote point where the frequency-shifted signals are demodulated and, along with the unshifted signals, are connected to a receiver, not shown.

The processing principle illustrated in FIG. 5 is advantageously incorporated in a two-way telephone link in the general fashion shown in FIG. 6. Except as mentioned below, the components of FIG. 6 are identical to those described with respect to FIG. 3; and like numerals are accordingly used.

In FIG. 6, the lines at station C leading from filter **30** to antisidetone network **38** represent the output bands from the filters **80, 15, 17, 19, 21, 23, 25, 81, 82** which are contained therein. Similarly, the lines at station D leading from filter **33** to antisidetone network **39** represent the output bands from the filters **86, 16, 18, 20, 22, 24, 26, 87, 88** contained therein.

Filters **86, 87, 88** of bank **33** have band-pass regions selected in the manner already described with respect to filters **80, 81, 82** in the principle's illustration in FIG. 5. The outputs of filters **80, 81, 82** are respectively frequency-shifted as described by modulators **83, 84, 85**, the outputs of which in FIG. 6 are symbolically placed between the appropriate filter outputs to connote the frequency multiplexing that has occurred. Similarly, the outputs of filters **86, 87, 88** are respectively frequency-shifted by modulators **89, 90, 91**.

After transmission through system **40** from station C and passage through network **39**, the modulated portion of the signal is demodulated back to the regions embraced by the filters **80, 81, 82** by the respective demodulators **92, 93, 94**. The signal components then pass to filter bank **32** which is substantially the same as filter bank **30**. Similarly, after transmission through system **40** from station C and passage through circuit **38**, the modulated portion is demodulated by demodulators **95, 96, 97** back to the regions embraced by the filters **86, 87, 88**. The signal components then pass to filter bank **31** which is substantially the same as filter bank **33**.

The system just depicted is effective in achieving circuit stability without voice switching, while recovering a high degree of voice quality. Additionally, given reasonably good hybrids, the system is also effective in reducing some of the electrical echo that might be present, depending on how much of the unused spectrum at each filter bank is utilized to transmit out-of-band voice energy.

The addition of center-clipping stage, not shown, following the filter of each passband reduces filter ringing, if present. Clipping distortion then is removed by following each clipping stage by a second filter (none shown) substantially embracing the same frequency band as the first. The center clippers, when used, supply the additional benefit of reducing room reverberations in the manner described in the U.S. Pat. application of D. A. Berkley and O. M. M. Mitchell, Ser. No. 854,457 filed concurrently with the present application, and which is hereby incorporated by reference into the instant application. The further use and implementation in the present application of the center-clipping teachings of that invention will be readily apprehended by a reading of that disclosure.

The spirit of the invention is embraced in the scope of the claims to follow.

What is claimed is:

1. In a voice telephone system, apparatus for processing speech signals between first and second stations comprising:
   first and second filter banks disposed in the transmission paths between the respective said stations, each bank comprising a plurality of passband filters, the passbands of the respective banks being complementary, and the passband center frequencies between adjacent complementary comb teeth of the combined filter banks being spaced by a selected odd simple fraction of an octave.

2 The system of claim **1**, wherein said odd fraction is substantially one-third.

3. The system of claim **2** wherein said first and second filter banks are located respectively at said stations.

4. The system of claim **2**, wherein said filter banks are located at a switching center common to said stations.

* * * * *