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Fujisaki et al.

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[54] **SPEECH SIGNAL TRANSMISSION SYSTEMS UTILIZING A NON-LINEAR CIRCUIT IN THE BASE BAND CHANNEL**

[76] Inventors: **Hiroya Fujisaki,** 3-31-12, Ebisu, Shibuya-ku, Tokyo; **Shigeo Nagashima,** 1-18-21, Yamato-cho, Nagano-ku, Tokyo; **Masahiro Iwasaki,** 717-26, Baba-cho, Tsurumi-ku, Yokohama; **Nobuyuki Goto,** 1100-9, Shimoda-cho, Kohoku-ku, Yokohama, all of Japan

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[21] Appl. No.: **68,237**

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Sept. 2, 1969 Japan 44/69197

[52] **U.S. Cl.** ..... **179/1 SA**
[51] **Int. Cl.** **G10l 1/00**
[58] **Field of Search** ..... 179/15.55 R, 1 SA

[56] **References Cited**

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Primary Examiner—Kathleen H. Claffy
Assistant Examiner—Jon Bradford Leaheey
Attorney—Kemon, Palmer and Estabrook

[57] **ABSTRACT**

In a speech signal transmission system there are provided means including a non-linear circuit and a band-pass filter to produce from a speech signal a base band signal representing the spectral fine structures of the speech signal and to transmit the base band signal to the receiving side, a vocoder channel analyzer to convert the speech signal into a second signal representing the spectral envelope of the original speech signal, a second non-linear circuit on the receiving side to convert the base band signal into an exciting signal and a vocoder synthesizer which acts to synthesize the original speech signal from the exciting signal and the second signal.

2 Claims, 5 Drawing Figures

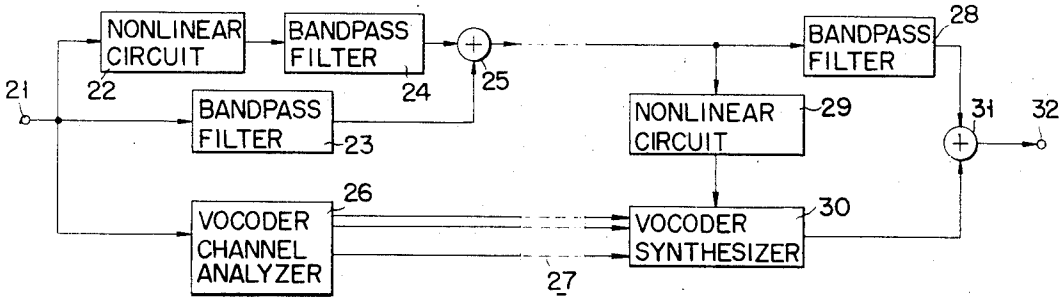


FIG. 1

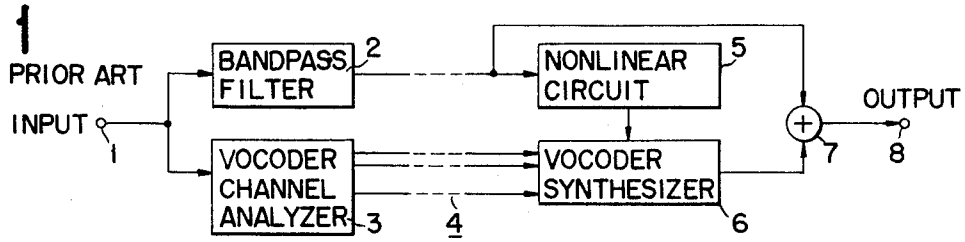


FIG. 2

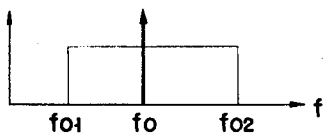


FIG. 3

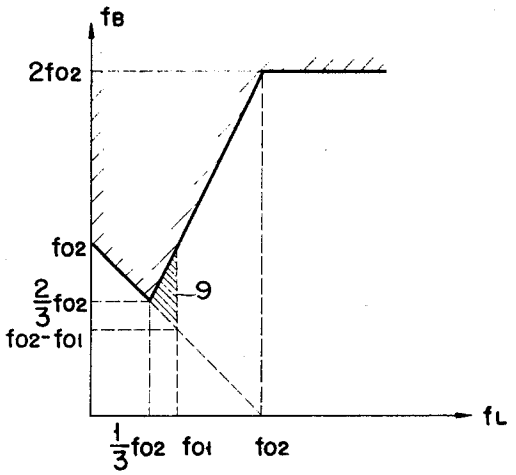


FIG. 4

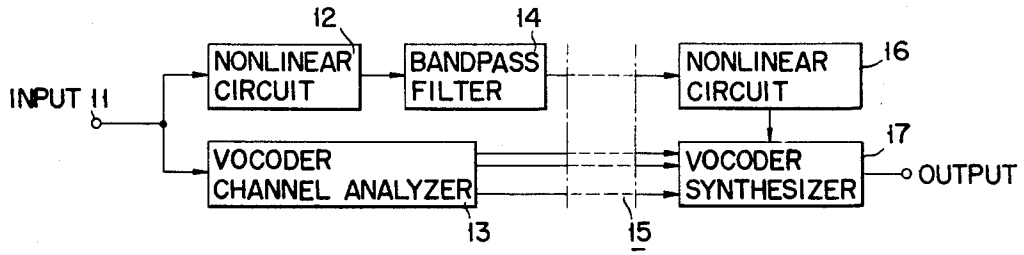
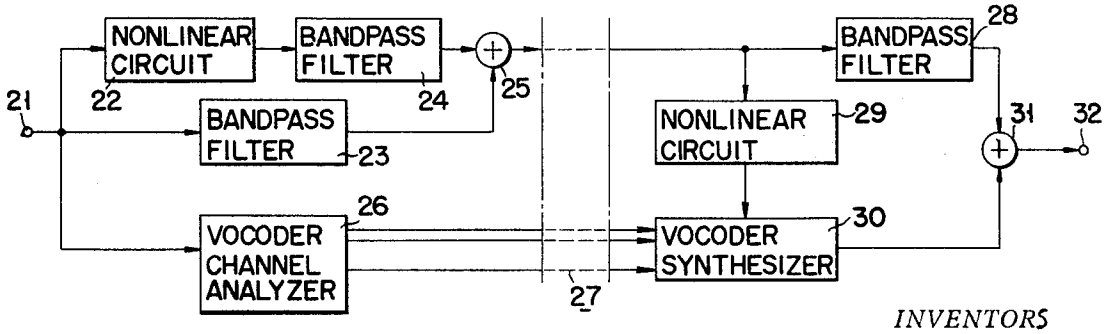


FIG. 5



INVENTORS
HIROYA FUJISAKI
SHIGEO NAGASHIMA
MASAHIRO IWASAKI
NOBUYUKI GOTO
BY
Kemon, Palmer & Estabrook

SPEECH SIGNAL TRANSMISSION SYSTEMS UTILIZING A NON-LINEAR CIRCUIT IN THE BASE BAND CHANNEL

BACKGROUND OF THE INVENTION

This invention relates to a speech signal transmission system and more particularly to a speech signal transmission system employing a novel speech band compression system.

Band compression of speech is important for communication systems utilizing expensive transmission circuits, such as communication systems utilizing satellites or submarine cables. A channel vocoder is a typical speech band compression system. According to this system, the frequency spectrum of the speech signal is analyzed into signals or informations representing the spectral envelope and fine structures thereof on the transmission side, the spectral envelope is detected by more than 10 bandpass filters, rectifiers and low pass filters while spectral fine structures are detected by determining whether the sound is a voiced sound or a unvoiced sound and by extracting the pitch frequency in the case of the voiced sound. The informations regarding spectral envelope and spectral fine structures are sent from the transmission side as a plurality of band compressed signals. On the receiving side a frequency spectrum approximating that of the original speech is reproduced from these signals. While this system provides a band compression ratio of more than ten to one it is difficult to detect the spectral fine structures of the speech on the transmission side thus lacking articulation and naturalness in the reproduced speech.

To eliminate these difficulties, a voice excited vocoder (VEV) has been developed wherein determination of the spectral fine structures is not performed on the transmission side. According to this system a portion of the speech band near the lower end of the speech spectrum (hereinafter termed as the base band) is transmitted directly to the receiving side thus eliminating the necessity of the detection of the voiced sound and unvoiced sound as well as the extraction of the pitch frequency.

FIG. 1 shows diagrammatically the construction of this system according to which components in the base frequency band f_1 to f_3 ($f_1<f_3<f_2$) of the speech signal ranging from f_1 to f_2, where $f_1<f_2$, and impressed upon an input terminal 1 are separated by a bandpass filter 2 of the frequency band f_1 to f_3 and the separated components are transmitted to the receiving side as the base band signal through one of the transmission lines 4. The remaining components of the input speech in the frequency band f_3 to f_2 are converted into a plurality of signals with their frequency bands compressed by a vocoder channel analyzer 3, and the converted signals are transmitted to the receiving side over other transmission lines.

On the receiving side, the received base band signal is sent to an output terminal 8 through an adder 7. The received base band signal is also supplied to a nonlinear circuit 5 to regenerate, by the action of the nonlinear circuit, components in the frequency band f_3 to f_2 which have been removed on the transmission side, thus providing an exciting signal in the frequency band f_1 to f_2 containing fine structures of the original speech spectrum. Signals from the vocoder channel analyzer 3 are supplied to a vocoder synthesizer 6 and combined therein with the exciting signal to reproduce components of frequency band f_3 and f_2 of the original speech. The reproduced components are sent to the output terminal 8 via adder 7 thus reproducing all components of f_1 to f_2 of the original speech at the output terminal 8.

As above described since in the VEV system a portion of the original speech spectrum is transmitted without being processed in any way, the qualities of the reproduced speech, such as articulation and naturalness, are excellent but this system requires wide transmission band thus decreasing the band compression ratio. The band width required to transmit the base band signal is determined in the following manner. More particularly, since the base band signal serves to transmit informations of the pitch frequency;

1. As long as the pitch frequency is included in the base band, the base band is not required to contain higher harmonic components of the pitch frequency. 2. Where the pitch frequency is not included in the base band it is necessary that at least two adjacent higher harmonic components of the pitch frequency should be included in the base band.

The pitch frequency of ordinary speech generally ranges from about 50 to 450 Hz so that the base band always satisfying either one of the two conditions mentioned just above is determined in the following manner. Denoting the pitch frequency of the speech by f_0, the lower limit of its variation by f_{01}, the upper limit by f_{02}, base band by f_L to f_U (where $f_L<f_U$) and its band width by f_B ($=f_U-f_L$) then

from condition 1 : $f_L \leqq f_0 \leqq f_U$

from condition 2 : $2f_0 \leqq f_U-f_L = f_B$

With reference to FIG. 3, the shaded area shows the range of f_B which satisfies at least one of thess conditions. The solid line in FIG. 3 shows the necessary minimum value of f_B for a given f_L, or the lower limit of the base band, when f_{02} is greater than $3f_{01}$ as in the case of conversational speech of an indefinite number of talkers covering a wide range of variations in the pitch frequency. In this case, when f_L is selected to be equal to $\frac{1}{3}f_{02}$ and f_U is selected to be equal to f_{02} the base band width will be minimum and thus the minimum value $\frac{2}{3}f_{02}$ is obtained. Where a particular talker is specified, the range of the pitch frequency would be narrowed to satisfy the condition of $f_{02}<3f_{01}$, so that a small shaded triangular range 9 shown in FIG. 3 will be added with the result that the minimum value of f_B is realized when f_L is selected to be qual to f_{01}, and f_U is selected to be equal to f_{02} and thus the minimum value f_{02} minus f_{01} is obtained. As above described since the pitch frequency of ordinary speech ranges from 50 to 450 Hz, frequencies from 150 to 450 Hz may be taken as the minimum base band having a band width of 300 Hz.

However, in the ordinary telephone transmission system the band width of speech signals is limited to 300 to 3,400 Hz, for example, so that it is impossible to select a frequency less than 300 Hz as the lower limit of the base band. In view of the requirement shown in FIG. 3 it is necessary to select a band width of 600 Hz, so that it is necessary to use a band width of 300 to 900 Hz for the base band signal. In this case, the base band is twice as wide as the minimum value.

SUMMARY OF THE INVENTION

It is an object of this invention to provide a novel voice excited vocoder which enables to use the minimum base band mentioned above even when the portion of the spectrum from 150 to 300 Hz of the original

speech has been removed, as if such portion were still contained in the spectrum.

Another object of this invention is to provide a novel speech signal transmission system according to which a conventional telephone transmission system of a limited band width can be used to efficiently transmit speech signal informations of wider band width.

In accordance with this invention there is provided a speech signal transmission system comprising means including a non-linear circuit and a bandpass filter to produce from a speech signal a base band signal representing the spectral fine structures of said speech signal and to transmit said base band signal to the receiving side; a vocoder channel analyzer to convert said speech signal into a second signal representing the spectral envelope of the original speech signal; a second non-linear circuit on said receiving side to convert said base band signal into an exciting signal and a vocoder synthesizer which acts to synthesize said original speech signal from said exciting signal and said second signal.

BRIEF DESCRIPTION OF THE DRAWING

FIG. 1 shows a schematic block diagram of a prior art speech signal transmission system employing a voice excited vocoder;

FIG. 2 is a diagram to show a range including the pitch frequency of the voice;

FIG. 3 is a diagram to show the range of the base band to explain the operation of the vocoder shown in FIG. 1;

FIG. 4 shows a block diagram of one example of the speech signal transmission system utilizing the novel speech band compression system; and

FIG. 5 shows a block diagram of a modified embodiment of this invention.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

According to this invention, a non-linear circuit is included also on the transmission side to regenerate the components of the frequency band which have been removed from the original speech signal and to utilize the regenerated components as portions of the base band signal.

For example, it is assumed that the spectrum of the speech signal impressed upon an input terminal **11** (FIG. 4), is limited to the ordinary telephone frequency band of 300 to 3,400 Hz. Although the frequency of usual speech signal ranges from about 50 Hz to several thousand Hz its energy is concentrated mostly in a band ranging from 300 to 3,400 Hz, the telephone transmission lines are generally designed to operate most efficiently in this range. For this reason frequencies of the speech signal lower than this range are removed by a filter before application upon input terminal **11**. On the other hand, in the vocoder system it is necessary to send informations regarding the pitch, voiced sound or unvoiced sound as well as spectral envelope of the speech signal. However since the pitch frequency lies in the range of 50 to 450 Hz, it is difficult to send all speech signal informations by the ordinary telephone lines. According to this invention a portion of the speech signal is supplied to a non-linear circuit **12** and the remaining portion to a vocoder channel analyzer **13**. Non-linear circuit **12** produces from the input speech signal, a signal containing frequency components within the band 150 to 450 Hz required to regenerate the spectral fine structures of the speech. This signal is band limited to 150 to 450 Hz by a bandpass filter **14**, and transmitted over one of the transmission lines or channels **15** as the base band signal.

On the other hand, vocoder channel analyzer **13** operates to convert a speech signal of 300 to 3,400 Hz into a plurality of signals representing the spectral envelope of the signal whose frequency band has been compressed in the same manner as in the conventional vocoder. The converted signal is transmitted by other transmission lines or channels **15**. Respective signals transmitted in this manner are reproduced as speech on the receiving side in the following manner. More particularly, the transmitted base band signal having frequencies of 150 to 450 Hz is applied to a non-linear circuit **16** to convert it into a signal, that is an exciting signal, representing the fine structures of the frequency spectrum of the speech signal of 300 to 3,400 Hz. The output from the non-linear circuit is combined in a vocoder synthesizer **17** with the band compressed signal supplied from the channel analyzer of the vocoder **13** and representing the envelope of the frequency spectrum of the input signal of 300 to 3,400 Hz to produce the speech signal of 300 to 3,400 Hz.

Degree of improvement of the band compression ratio obtainable with the novel system is compared with a prior system as follows: Where an analogue transmission system is used both systems require the following frequency bands. It is to be understood that a vocoder channel of 20 Hz width is assigned to each frequency band of 250 Hz width of the input speech and that speech of 300 to 3,400 Hz is considered.

PRIOR SYSTEM		
Base band	300 to 900 Hz	
Vocoder channel	900 to 3400 Hz	
Base band width	600 Hz	sum 800 Hz
Vocoder channel band width	200 Hz	
THIS INVENTION		
Created base band	150 to 450 Hz	
Vocoder channel	300 to 3400 Hz/13 channels	
Base band width	300 Hz	sum 560 Hz
Vocoder channel band width	260 Hz	

As can be clearly noted from this table of comparison the band required in the illustrated example is reduced to about two-thirds of the prior art. However, in the analogue transmission system with ordinary telephone lines as it is impossible to effectively transmit signals of less than 300 Hz, it is necessary to shift the frequencies of portions of the speech generated on the transmission line to higher frequencies.

Since the base band signal in the novel system is required to convey only the information concerning the spectral fine structure and not the spectral envelope, it can be transmitted over a transmission line with lower signal to noise ratio than that required for the transmission of ordinary telephone speech and thus further improvements of the band compression ratio can be achieved by converting signals to be transmitted into digital signals and by transmitting these digital signals.

Following table shows the comparison between the prior art system and the novel system.

PRIOR ART

Base band—1200 Hz sampling × 5 bit quantalization = 6000 bits/sec.

Vocoder channel—40 Hz sampling × 3 bit quantalization × 10 channels = 1200 bits/sec.
Total 7200 bits/sec.

THIS INVENTION

Base band—600 Hz sampling × 3 bit quantalization = 1800 bits/sec.
Vocoder channel—40 Hz sampling × 3 bit quantalization × 13 channels = 1560 bits/sec.
Total 3360 bits/sec.

In this manner, according to this invention it is possible to efficiently compress the band width occupied by the prior art base band vocoder to about two-thirds to one-half and yet with equal quality of transmitted speech.

In the modified embodiment shown in FIG. **5** non-linear circuit **22** and bandpass filter **24** operate in the same manner as the corresponding elements **12** and **14** of the previous embodiment to produce a signal of 150 to 300 Hz. Another portion of the input signal applied to input terminal **21** is passed through a second low pass filter **23** to produce a signal of 300 to 450 Hz. Outputs from two low pass filters **23** and **24** are combined by an adder **15** to provide a base band signal of 150 to 450 Hz which is transmitted over one of the transmission lines **27.** Vocoder channel analyzer **26** functions just in the manner as the element **13** of the previous embodiment but in this case produces a signal representing the spectral envelope of the input signal from 450 to 3,400 Hz.

On the receiving side, the received base band signal is converted by a non-linear circuit **29** into a signal, or an exciting signal representing the fine structures of the frequency spectrum of the speech signal of 300 to 3,400 Hz and a portion of the received signal corresponding to 300 to 450 Hz is extracted by a bandpass filter **28** and applied to an adder **31.** The vocoder synthesizer combines the exciting signal and the band compressed signal into the speech of 450 to 3,400 Hz. Thus the adder **31** provides the original input speech of 300 to 3,400 Hz at the output terminal **32.**

This embodiment enables the use of the conventional vocoder operating at a band width of 450 to 3,400 Hz by merely adding bandpass filters **23** and **28** to the first embodiment.

The results of the embodiment shown in FIG. **5** when using analogue and digital transmission systems are as follows.

ANALOGUE

Created base band	150 to 450 Hz	
Vocoder channel	450 to 3400/12 channels	
Base band width	300 Hz	sum 840 Hz
Vocoder channel width	540 Hz	

DIGITAL

Base band—600 Hz sampling × 5 bit quantalization = 3000 bits/sec.
Vocoder channel—40 Hz sampling × 3 bit quantalization × 12 channels = 1440 bits/sec.
Total 4440 bits/sec.

Thus according to this embodiment it is possible to reduce the band occupied by the prior art base band vocoder to about two-thirds and yet with similarly high quality of the transmitted speech.

What we claim is:

1. A speech signal transmission system for transmitting speech signals of a relatively narrow frequency band from a transmitting side to a receiving side over relatively narrow band transmission channels which comprises at the transmitting side:

an input terminal for receiving speech signals;
a first non-linear circuit connected to said input terminal for producing signals including pitch frequency components of the voiced signal in the speech signals which are not involved in the relatively narrow frequency band speech signals;
a band pass filter connected to said non-linear circuit for producing base band signals including said pitch frequency components produced by said non-linear circuit and representative of the spectral fine structure of the speech signals;
a vocoder channel analyzer connected to said input terminal for converting the speech signals into a plurality of band compressed signals representative of the spectral envelope of the speech signals;
and which comprises at the receiving side:
a second non-linear circuit for receiving said base band signals to produce exciting signals; and
a vocoder synthesizer for receiving said band compressed signals and said exciting signals to reproduce substantially the original speech signals.

2. A speech signal transmission system for transmitting speech signals of a relatively narrow frequency band from a transmitting side to a receiving side over relatively narrow band transmission channels which comprises at the transmitting side:

an input terminal for receiving the speech signals; a first non-linear circuit connected to said input terminal for producing signals including pitch frequency components of the voiced signal in the speech signals which are not involved in the relatively narrow frequency band speech signals;
a first band pass filter connected to said non-linear circuit and arranged to pass said pitch frequency components which are not involved in the speech signals for producing a portion of base band signals representative of the spectral fine structure of the speech signals;
a second band pass filter connected to said input terminal for producing the remaining portion of said base band signals, the pass band of which is adjacent to that of said first band pass filter;
adding means for adding the outputs of said first and second band pass filters;
a vocoder channel analyzer for converting a portion of the speech signals having a frequency band above the pass band of said second band pass filter into a plurality of band compressed signals representative of the spectral envelope of the speech signals;
and which comprises at the receiving side:
a second non-linear circuit for receiving said base band signals from the transmitting side to produce exciting signals;
a vocoder synthesizer for receiving said band compressed signals from the transmitting side and said exciting signals from said second non-linear circuit to produce said portion of said speech signals;
a third band pass filter having the same pass band as said second band pass filter at the transmitting side, for receiving said base band signals from the transmitting side; and
adding means for adding the outputs of said vocoder synthesizer and said third band pass filter to reproduce substantially the original speech signals.

* * * * *

UNITED STATES PATENT OFFICE

CERTIFICATE OF CORRECTION

Patent No. 3,743,787 Dated July 3, 1973

Inventor(s) Hiroya Fujisaki et al

It is certified that error appears in the above-identified patent and that said Letters Patent are hereby corrected as shown below:

[73] Assignee: Tokyo Shibaura Electric Company, Ltd., Kawasaki-Shi, Japan, and Hiroya Fujisaki Tokyo, Japan

Signed and sealed this 19th day of November 1974.

(SEAL)
Attest:

McCOY M. GIBSON JR.
Attesting Officer

C. MARSHALL DANN
Commissioner of Patents

USCOMM-DC 60376-P69
* U.S. GOVERNMENT PRINTING OFFICE : 1969 O—366-334.

UNITED STATES PATENT OFFICE

CERTIFICATE OF CORRECTION

Patent No. 3,743,787 Dated July 3, 1973

Inventor(s) Hiroya Fujisaki et al

It is certified that error appears in the above-identified patent and that said Letters Patent are hereby corrected as shown below:

[73] Assignee: Tokyo Shibaura Electric Co., Ltd. & Hiroya Fujisaki of 72 Horikawa-cho, Kawasaki-shi, Japan

Signed and sealed this 12th day of March 1974.

(SEAL)
Attest:

EDWARD M. FLETCHER, JR.
Attesting Officer

C. MARSHALL DANN
Commissioner of Patents

FORM PO-1050 (10-69)

USCOMM-DC 60376-P69
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