

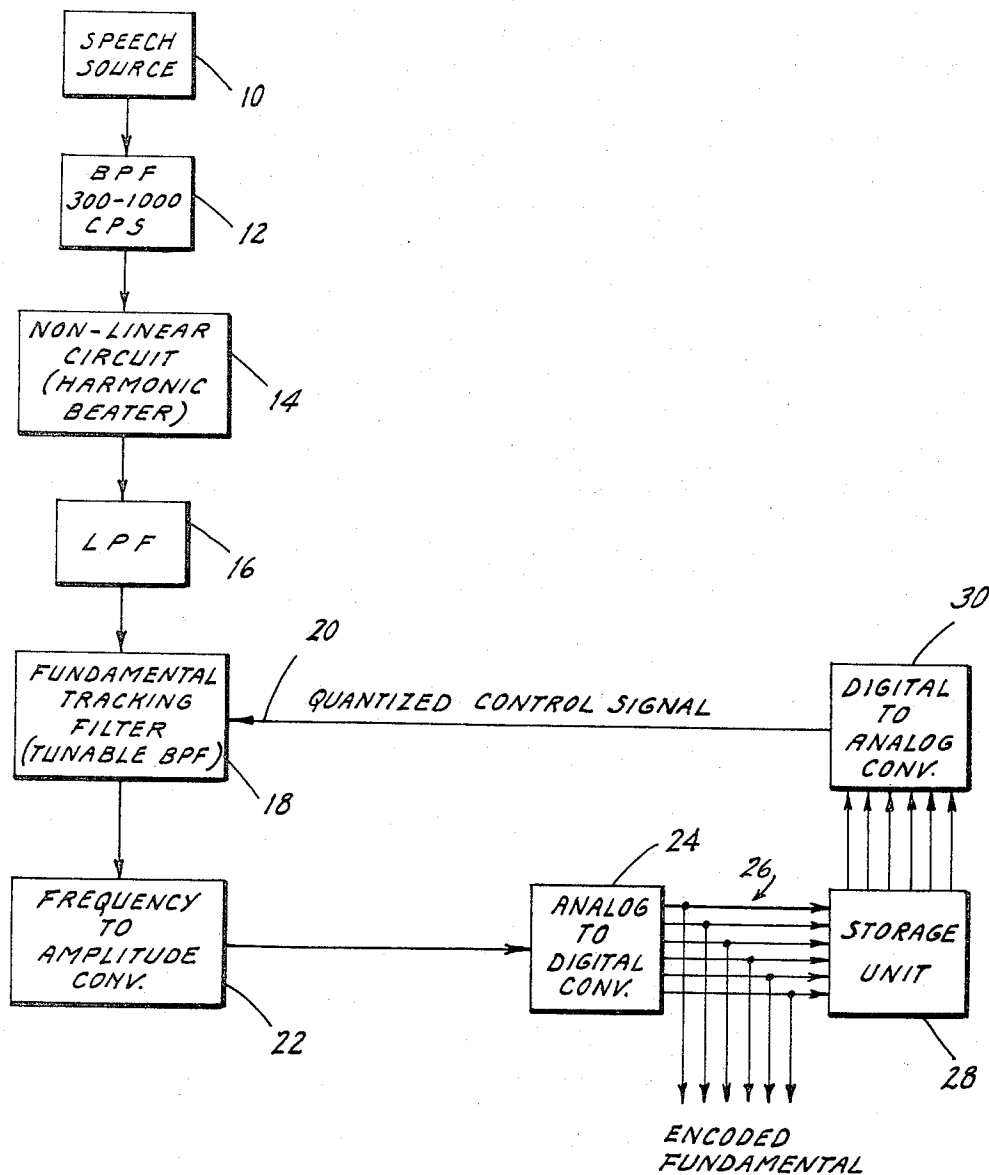
April 2, 1968

L. E. CASSEL

3,376,387

FUNDAMENTAL FREQUENCY EXTRACTOR FOR VOICE SIGNALS

Filed May 15, 1964



INVENTOR.

LAWRENCE E. CASSEL

BY

D. Pressman

ATTORNEY

1

3,376,387

FUNDAMENTAL FREQUENCY EXTRACTOR FOR VOICE SIGNALS

Lawrence E. Cassel, Norristown, Pa., assignor to Philco-Ford Corporation, a corporation of Delaware
Filed May 15, 1964, Ser. No. 367,736
16 Claims. (Cl. 179-1)

ABSTRACT OF THE DISCLOSURE

Fundamental frequency extractor for voice signals using tunable tracking filter to isolate fundamental, converter to supply digital signal indicative of frequency of isolated fundamental, unit for storing each digital signal until new one appears, and converter, responsive to stored digital signal, for supplying quantized analog signal to control input of tracking filter.

This invention relates to vocoders and in particular to fundamental frequency extractors as used in vocoders.

In the transmission of speech signals, vocoding is often desirable for reasons of economy of bandwidth, limitations in channel high frequency capacity, secrecy, etc. Most vocoders usually have a circuit for continuously extracting the fundamental frequency component of the input voice signal. The accuracy of extraction of this fundamental component determines, to a large extent, the quality of the speech which may be reconstituted at the receiver. Thus it is highly important that the fundamental frequency extractor should function with accuracy and reliability.

Extraction of the fundamental from a voiced signal is not an easy operation due to the fact that the fundamental usually undergoes rapid frequency and amplitude changes as each syllable is uttered. Furthermore the fundamental may be severely suppressed or entirely absent, as is the case when the speech signal has been generated in a carbon microphone or has been carried over a standard telephone link which passes only signals in the 300 to 3300 Hz. range.

Another problem encountered in fundamental extractors is that of recovery after silent or unvoiced intervals. Fundamental extractors usually include a tracking filter whose bandpass is continuously adjusted to the frequency of the fundamental during voiced intervals. When a silent interval occurs, the adjustment of the tracking filter will drift to a remote value, preventing prompt accurate re-tracking upon the resumption of voiced speech.

OBJECTS

Accordingly, several objects of the present invention are:

- (1) to provide a new and improved fundamental frequency extracting circuit,
- (2) to provide a fundamental extractor which recovers rapidly upon the termination of silent intervals,
- (3) to provide a fundamental frequency extractor of increased accuracy and reliability, and
- (4) to provide a fundamental frequency extractor which is operable from signals having a suppressed or non-existent fundamental component.

Other objects and advantages of the present invention will become apparent from a consideration of the ensuing description.

SUMMARY

According to one preferred form of the present invention, a speech-derived signal is supplied to a fundamental frequency tracking filter, whereafter it is converted to digital form and sent to utilization means. The digital

2

signal is also sent to a storage unit, and thence to a digital to analog converter from which is derived a feedback control signal for the tracking filter.

In another preferred form of the invention, wherein the fundamental component is absent from the speech signal, the speech signal is applied to a nonlinear circuit and a low pass filter before being applied to the tracking filter.

DRAWING

The system of the invention is shown in the single figure of drawing.

DESCRIPTION OF STRUCTURE

Speech source 10 represents any source for supplying human speech. Source 10 may be a highly quality source, such as moving-coil microphone, in which case the frequencies of the speech signal supplied may extend down to 70 Hz. or less and thus include the fundamental component. On the other hand, if source 10 represents a variable-resistance carbon microphone, such as is used in telephony, the frequencies of the speech signals supplied are usually severely attenuated below 300 Hz. and consequently the fundamental component may be absent.

BPF (Band Pass Filter) 12 receives the speech signal from source 10 and transmits substantially only frequencies within a preselected range. The pass band of BPF 12 is empirically selected to enhance the fundamental frequency component of the output signal from circuit 14. In one exemplary construction of the fundamental extractor, BPF 12 had a pass band of 300 to 1,000 Hz. with a 24 db/octave attenuation beyond these limits.

Non-linear circuit 14 is designed to provide a nonlinear response to the bandpass-limited signal from BPF 12 so as to beat together the harmonics thereof. Circuit 14 may be a transistor amplifier whose emitter-base diode is biased on the knee of the emitter current v. base-emitter voltage curve. Alternatively a nonlinear diode circuit may be used.

LPF (Low Pass Filter) 16 is designed to pass substantially only those components of the signal from circuit 14 whose frequencies lie below a predetermined value, e.g. 300 cycles.

BPF 12, circuit 14, and LPF 16 can be eliminated if the fundamental component is present in source 10. If not, elements 12, 14, and 16 are required to regenerate the fundamental in a manner which will be described.

Fundamental tracking filter 18 is a variable band pass filter, designed to pass substantially only those components of the signal from LPF 16 whose frequencies lie within a selected range, as determined by the control signal on an input 20 thereof.

Frequency to amplitude converter 22 is arranged to provide an analog (nonquantized direct or slowly varying alternating) voltage proportional to the frequency of the signal at the output of filter 18. Such converters, well known to those skilled in the art, may comprise, for example, the driving circuitry of a frequency meter, or more specifically, a limiter-differentiator-clipper for providing uniform spike pulses of proportional frequency which are arranged to drive a monostable multivibrator in order to produce constant-width pulses of proportional frequency. The constant width pulses are low-pass filtered to obtain a direct voltage proportional to the average value of the pulses and hence the frequency of the signal at the output of filter 18.

Analog to digital converter 24 converts the analog signal at the output of converter 22 to a digital signal indicative of the amplitude of the analog signal and hence the frequency of the signal at the output of tracking filter 20. Many types of analog to digital converters are known and although one specific type will be discussed and illustrated, it will be understood that the invention is not

limited thereto. Converter 24 may be of the sampling variety wherein periodic samples of the analog input signal are converted to corresponding groups of digital output pulses, or it may be a nonsampling converter wherein the digital output signal changes only when the input signal changes. Also the groups of digital output pulses may be either of the parallel or serial variety. In the serial type of encoder (sometimes termed a pulse code modulator or PCM) a group of sequential coded digital pulses are provided on a single output lead. In the parallel type of encoder, which is illustrated in the drawing, the digital output pulses appear simultaneously on leads 26, the presence of a pulse on each lead representing a particular power of two. Output connections are made from leads 26 so that the digitally encoded fundamental may be supplied to appropriate utilization means, e.g., a shift register for conversion to serial output, and then a multiplexer and transmitter.

Storage unit 28 is designed to receive the digital signals from converter 24 and transmit the same to its output leads, and also store the last-received digital signal at its output leads upon termination thereof. Storage unit 28 is shown as a parallel-input—parallel-output device and as such may simply comprise a plurality of flip-flops. However if the digital output of converter 24 is of the serial variety, storage unit 28 may include a serial-parallel converter to provide a parallel output, or it may be of the recirculating type and provide a serial output. Various other arrangements will be visualized by those skilled in the art which will fulfill the aforescribed function for storage unit 28. Unit 28 may be omitted entirely if its function can be fulfilled by converter 24.

Digital to analog converter 30 is arranged to convert the digital signals present at the outputs of unit 28 to an analog form. As is well known, if a parallel input is supplied, converter 30 may simply take the form of a resistive summer whose resistors have values proportional to successive powers of two. If storage unit 28 is arranged to supply a serial signal, converter 30 may include a serial-to-parallel converter.

The analog output from converter 30 constitutes a quantized feedback control signal which is supplied to input 20 of filter 18 to control the bandpass thereof.

DESCRIPTION OF OPERATION

The speech signal from source 10 is bandpass filtered in BPF 12 in order to optimize the fundamental to second harmonic ratio at the output of circuit 14. It has been empirically determined that the fundamental output of circuit 14 is maximized when BPF 12 had a 300 to 1000 Hz. range.

The bandpass filtered speech signal is supplied to circuit 14 where the harmonics thereof are heterodyned to generate the sum and difference frequencies in familiar fashion. The difference frequency between adjacent harmonics is the fundamental frequency. The input to circuit 14 will usually include several adjacent harmonics; therefore a strong fundamental component will be present at the output thereof, even if no fundamental was present in the input.

LPF 16 suppresses most of the sum components generated in circuit 14 to further enhance the fundamental.

The amplitude of the control input to tracking filter 18 is proportional to the frequency of the output signal of filter 18. The center frequency and the frequency of upper and lower limits of the variable band pass range of filter 18 will, in turn, be proportional to the amplitude of the control signal at input 20. In addition, the width of the band pass is proportional to the frequency of the output signal of filter 18.

The tracking filter effectively isolates the fundamental by severely attenuating all other higher frequency harmonics and lower frequency noises. The feedback control signal adjusts the pass frequency of the tracking filter to

the fundamental. The principle of operation of the fundamental tracking filter is further discussed in Patent 2,859,405 to Feldman et al., granted Nov. 4, 1958.

The fundamental signal at the output of filter 18 is converted to analog form in converter 22 and then to digital form in converter 24. The digitally encoded fundamental may then be appropriately multiplexed with other encoded components of the speech signal to supply the complete vocoded signal in familiar fashion.

The digital signals on leads 26 are also sent, via storage unit 28, to converter 30 where they are retransformed to an analog signal (quantized) to provide the feedback control signal for input 20 of filter 18. During those intervals when source 10 supplies no signal (e.g., when voice transmission pauses or when a voicing indicator disables the input to BPF 10 during unvoiced speech), storage unit 18 will retain the value of last encoded fundamental, thus holding the pass frequency of filter 18 at its last value. This is advantageous since it has been found that after a pause or unvoiced interval, the new fundamental of speech is likely to be the same as the last value thereof. Storage unit 28, being a digital device, will advantageously retain the exact value of the last encoded fundamental indefinitely without drift.

The fundamental extractor of the invention was found to operate satisfactorily and provide excellent recovery of the fundamental signal, even when it was missing entirely from source 10.

It will be appreciated that many modifications of the specific system described and illustrated may be made without departing from the true scope of the invention, which is indicated by the appended claims only.

I claim:

1. In combination:

- (a) a tunable bandpass filter having a control input,
- (b) first means, connected to the output of said filter, for providing an analog voltage proportional to the frequency of an alternating input signal received from said tunable bandpass filter, for deriving samples of said analog voltage, for providing a digital output signal for each of said samples, and for storing the last-provided signal in absence of said alternating input signal, and
- (c) second means for continuously converting said digital signal to a quantized analog signal, the output of said second means being connected to said control input.

2. The combination of claim 1 further including means for supplying a speech-derived input signal to said filter.

3. The combination of claim 2 wherein nonlinear means are interposed between said means for supplying said input signal and said filter.

4. The combination of claim 3 wherein a low pass filter is interposed between said nonlinear means and said tunable filter.

5. A system for extracting the fundamental frequency component from a speech signal, comprising:

- (a) a tunable bandpass filter arranged to receive said signal,
- (b) first means for providing an analog signal proportional to the frequency of the signal at the output of said filter, for converting said analog signal to a digital signal, and for storing said digital signal at its output upon termination of said output signal, and
- (c) means responsive to said digital signal for supplying a control signal to said tunable bandpass filter.

6. A system for extracting the fundamental frequency component from a speech signal, comprising:

- (a) a tunable bandpass filter arranged to receive said signal,
- (b) first means for providing a digital signal indicative of the frequency of the output signal from said tunable bandpass filter, and for storing said digital signal at its output upon termination of said output signal, and

5

(c) means, comprising a digital to analog signal converter, responsive to said digital signal, for supplying a control signal to said tunable bandpass filter.

7. A system for extracting the fundamental frequency component from a speech signal, comprising:

(a) a fundamental frequency tracking filter having a tunable bandpass arranged to receive said speech signal, the center frequency of the bandpass of said tracking filter being proportional to the magnitude of a control signal supplied thereto,

(b) means for providing an analog signal proportional to the frequency of the output signal of said tracking filter and for providing a periodic digital signal continuously indicative of the magnitude of said analog signal.

(c) storage means for continuously transmitting said digital signal to an output thereof and storing said digital signal thereat in absence of said speech signal, and

(d) a digital to analog converter arranged to receive the output of said storage means and provide a control signal for tuning the bandpass of said tracking filter.

8. The system of claim 7 wherein said periodic digital signal is supplied in parallel form simultaneously on a plurality of output leads.

9. The system of claim 7 wherein said speech signal is supplied to said tracking filter via a nonlinear circuit and a low pass filter.

10. In combination:

(a) a source for supplying an electrical signal,

(b) a tunable bandpass filter having a signal input connected to said source, a control input, and a signal output, the center frequency of the bandpass of said filter being proportional to the magnitude of the signal supplied to said control input,

(c) means having an input connected to the output of said filter and an output and arranged to provide an analog signal proportional to the frequency of the signal supplied to its input,

(d) an analog to digital converter having an input connected to the output of said last-named means and an output,

(e) storage means having an input connected to the output of said converter and an output, and

(f) a digital to analog converter having an input connected to the output of said storage means and an output connected to said control input of said filter.

6

11. The combination of claim 10 wherein the outputs of said converter, and said storage means and the input of said storage means each comprise a plurality of terminals arranged to supply a parallel digital signal.

12. The combination of claim 11 further including a nonlinear circuit interposed between said source and said filter.

13. The combination of claim 12 further including a low pass filter interposed between said nonlinear circuit and said tunable bandpass filter.

14. A system for extracting the fundamental frequency component from a speech signal in which said component has been severely attenuated or eliminated, comprising:

(a) means for beating together the harmonic components of said signal,

(b) means for low pass filtering the output of said last means to recover the difference beat signal between adjacent harmonics,

(c) a tracking filter having a tunable bandpass arranged to receive the output of said last-named means,

(d) means for providing a digital signal indicative of the frequency of the output of said tracking filter,

(e) means, having an output, for transmitting said digital signal to its output and retaining the last value of said digital signal thereat in absence of said speech signal, and

(f) means responsive to the output of said last-named means for providing a feedback control for said tracking filter.

15. The system of claim 14 wherein said means for providing a digital signal includes a signal frequency to signal amplitude converter and a digital to analog converter.

16. The system of claim 15 wherein said speech signal is bandpass filtered before being applied to said first means.

References Cited

UNITED STATES PATENTS

2,699,464	1/1955	Di Toro et al.	179—1
3,176,073	3/1965	Samuelson et al.	179—1

WILLIAM C. COOPER, *Primary Examiner*.

KATHLEEN H. CLAFFY, *Examiner*.

R. MURRAY, R. P. TAYLOR, *Assistant Examiners*.