

April 8, 1969

C. H. COKER
SPEECH ANALYSIS SYSTEM

3,437,757

Filed June 15, 1966

Sheet 1 of 3

FIG. 1

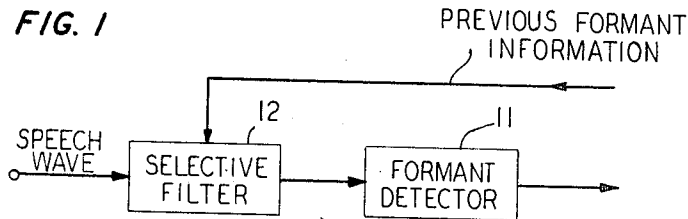


FIG. 2A

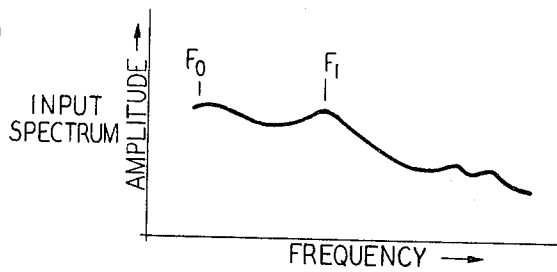


FIG. 2B

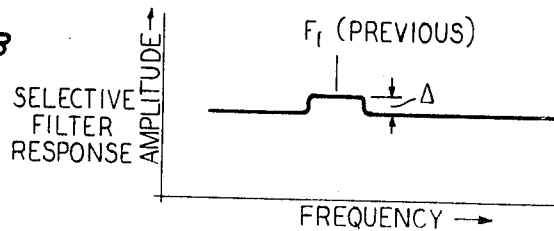
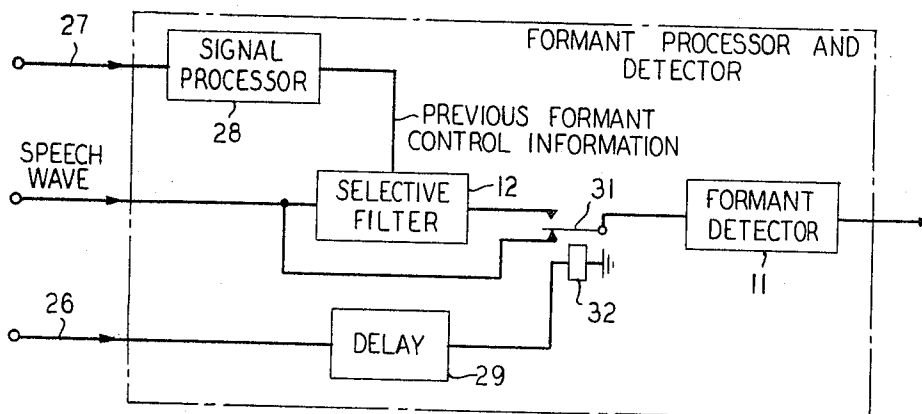


FIG. 4



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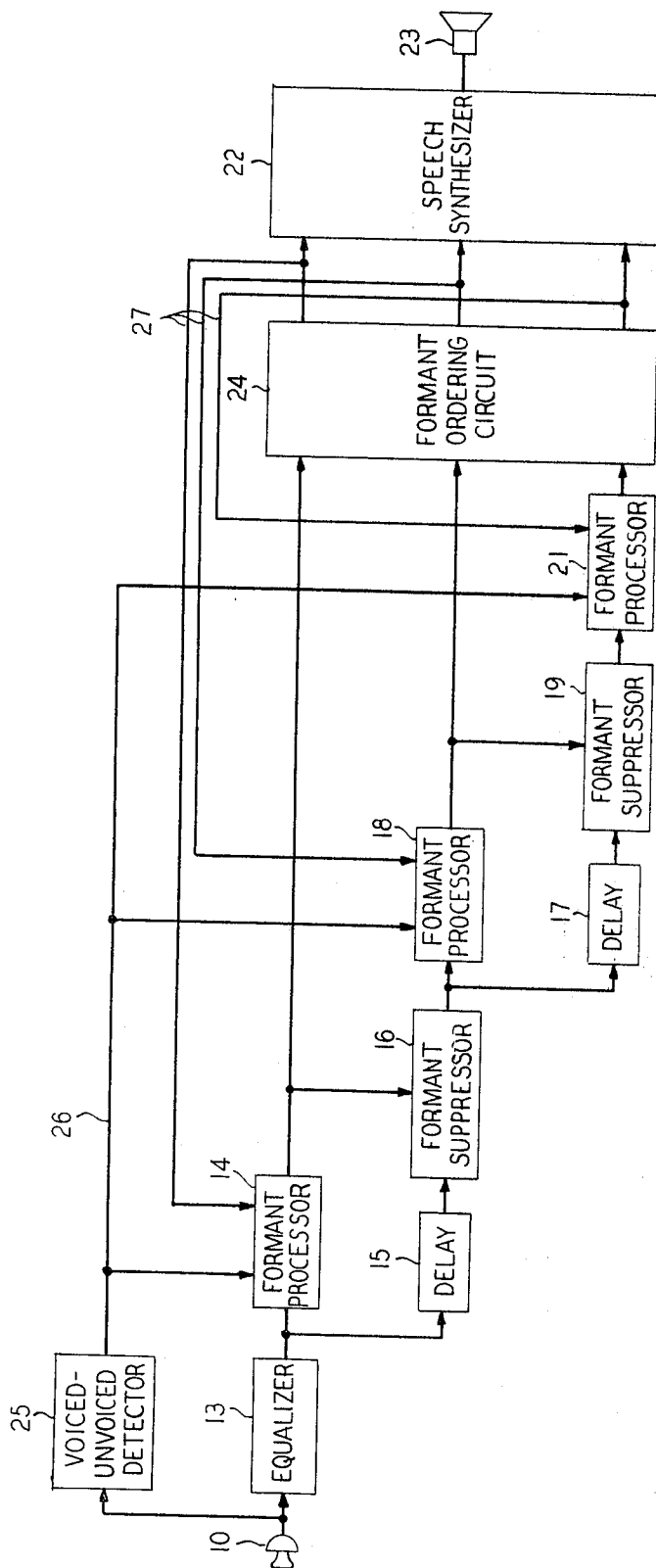
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SPEECH ANALYSIS SYSTEM

Filed June 15, 1966

Sheet 2 of 3

FIG. 3



April 8, 1969

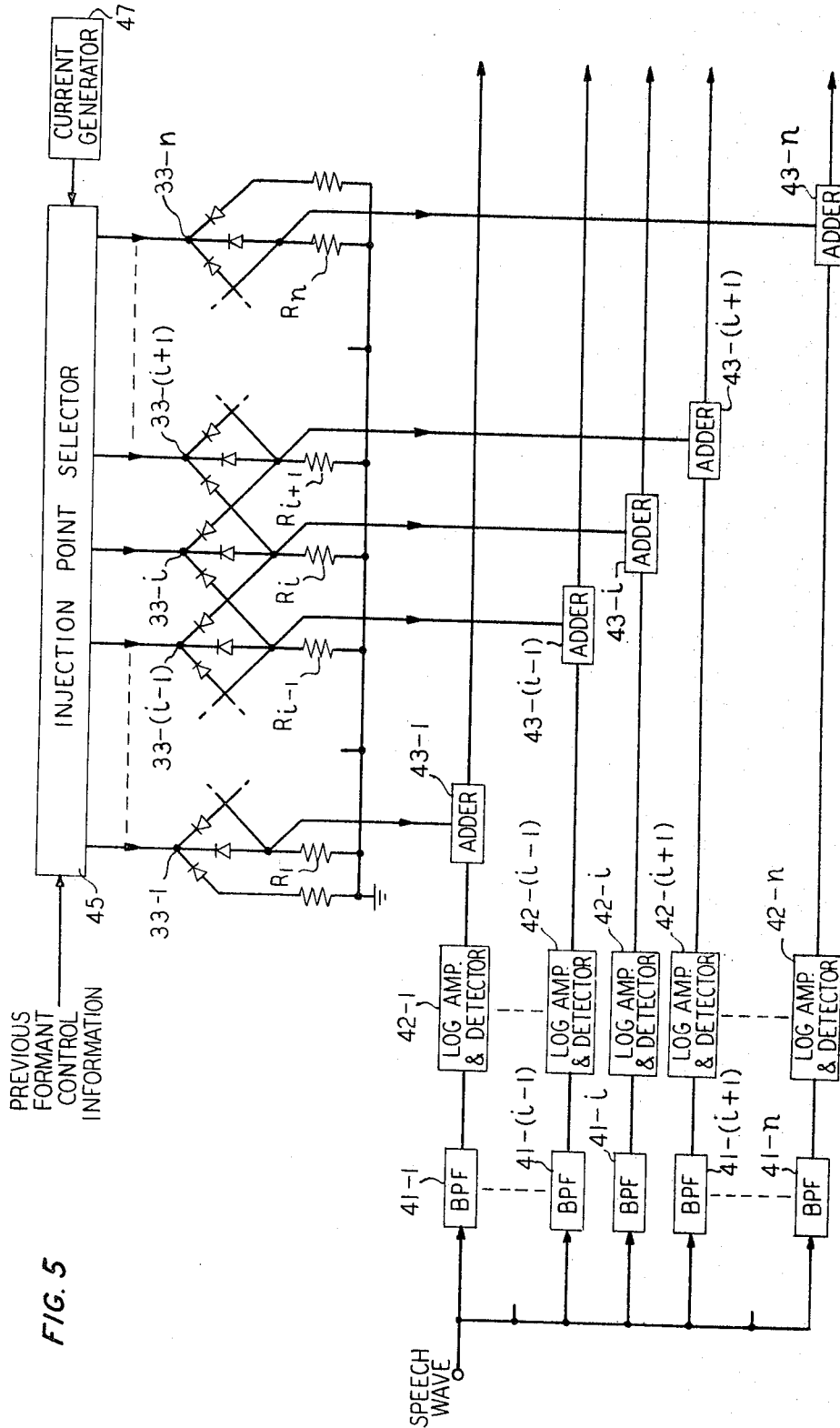
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3,437,757

SPEECH ANALYSIS SYSTEM

Filed June 15, 1966

Sheet 3 of 3



1

3,437,757

SPEECH ANALYSIS SYSTEM

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Int. Cl. H04b 1/66; G101 1/06

U.S. Cl. 179-1

10 Claims

ABSTRACT OF THE DISCLOSURE

In a resonance vocoder, in order to avoid losing track of a formant during brief periods of unvoicing, a pre-emphasis filter is used to accentuate those frequencies in the incoming speech wave which are adjacent the formant frequency. Operation of the filter is delayed at the onset of voicing to allow the vocoder to locate the formants to be tracked.

This invention pertains to the analysis of speech waves and, more particularly, to the analysis of speech waves in bandwidth compression systems.

In order to make more economical use of the frequency bandwidth of speech transmission channels, a number of bandwidth compression arrangements have been devised for transmitting the information content of a speech wave over a channel whose bandwidth is substantially narrower than that required for facsimile transmission of the speech wave itself. Bandwidth compression systems typically include, at a transmitting terminal, an analyzer for deriving from an incoming speech wave a group of narrow bandwidth control signals representative of selected information-bearing characteristics of the speech wave and, at a receiving terminal, a synthesizer for reconstructing from the control signals a replica of the original speech wave.

One well-known bandwidth compression system is the so-called "resonance vocoder." In a resonance vocoder, the distinctive information-bearing characteristics represented by the control signals and reconstructed at the receiving terminal are the frequency locations of selected peaks or maxima in the speech amplitude spectrum. These selected maxima, formants, correspond to vocal tract resonances, that is, they correspond to frequency regions of relatively effective transmission through a talker's vocal tract. Generally, it is the maxima corresponding to the three principal vocal tract resonances which are selected.

In a typical resonance vocoder analyzer, for example, one of the filter-bank, maximum value selector variety, the spectrum of an incoming speech wave is divided into three fixed frequency subbands, and each subband embraces a frequency range within which a particular formant normally occurs. From the speech frequency components lying within a subband there is derived a narrow band control signal representative of the frequency at which a formant peak occurs in that frequency subband of the spectrum. It is an empirical fact that these narrow band control signals, emanating from this type of vocoder, are subject to discontinuous changes to grossly incorrect values of the indicated formant frequencies. Characteristically, these abrupt changes are of short duration and are sometimes attributable to occasional faltering of the glottal excitation of the speaker. Statistically, these discontinuous changes are most likely in error since the nature of speech is such that changes in formant frequency are necessarily continuous with time due to the inertia of the vocal tract. Thus the filter-bank variety of vocoder fails to take into account this natural constraint inherent in speech signals. The above disadvantages partially stem from the fact that the filter-bank vocoder has no provision for comparing present indications of formant loca-

2

tions with previous indications, i.e., the vocoder lacks "memory."

In the feedback, tracking-filter variety of resonant vocoder analyzer, on the other hand, strong use is made of the prior history of the speech signal. This type of vocoder is not sensitive to faltering of the glottal excitation of the speaker, but instead, has a tendency to make errors at the onset of voicing and then to perpetuate these errors in a groping search for the proper formant. Thus, while not subject to discontinuous changes in amplitude, there is a strong possibility that the analyzer will "lock" onto an improper frequency component and continue to do so for a considerable period of time.

In the present invention these shortcomings are overcome by selectively utilizing the advantages of both types of equalizers without incurring their concomitant serious disadvantages. In accordance with this invention, a formant detector is excited by a speech wave altered by a selective filter, responsive to control signals representative of the previous values of formant locations. At the onset of voicing, the selected filter is bypassed to eliminate the possibility of locking onto an improper speech frequency component. After a predetermined interval of time has elapsed and sufficient information is available to determine where the formants have been located in the past, this information is utilized to provide a reliable indication of the vicinity where the formants will be located in the future. Accordingly, the selective filter is controlled by these signals indicative of the past history of the speech signal and responsive thereto the filter characteristics are altered to accentuate or enhance the transmission characteristics of the filter in the probable formant region. Thus, abrupt and discontinuous changes in immediate formant location indications are highly unlikely since there is a predisposition to find a succeeding formant in the region where previous formant have been located. However, if the input speech signal exhibits a maximum value exceeding a predetermined threshold, the detector will select this new value of spectral component. This feature allows the analyzer to abandon a peak in the speech signal if it becomes absurdly small with respect to another peak. The criterion for what is absurdly small is a matter of choice depending on the selected threshold value. Preselected threshold values provide a graduated set of performance characteristics intermediate between vocoders of the filter-bank and tracking-filter varieties. Furthermore, it has been found that the average error rate of the analyzer of this invention is lower than that found in either type of prior art analyzer.

The invention may be more fully understood from the following description of illustrative embodiments thereof, taken in connection with the appended drawing in which:

FIG. 1 is a block diagram of apparatus illustrative of the operation and principles of the present invention;

FIG. 2A is a graphical presentation which is of assistance in explaining the principles of operation of this invention;

FIG. 2B is a graphical presentation which is also of assistance in explaining the principles of operation of this invention;

FIG. 3 is a block diagram showing a complete speech transmission system embodying the principles of this invention;

FIG. 4 is a block diagram of a formant processor and detector utilized in the present invention; and

FIG. 5 illustrates a selective filter utilized in the present invention.

Explanation of the present invention is facilitated by reference to FIGS. 1 and 2. FIG. 2A illustrates the spectral distribution of a speech signal in the vicinity of its first principal speech formant, indicated as F_1 . Assuming for the moment that a speech signal is applied

directly to formant detector 11 of FIG. 1, there would be a strong possibility that the adjoining peak, indicated as F_0 , would be selected as the first principal speech formant. This is because abnormal spectral weighting of the speech signal can cause the peak indicated at F_0 to have, temporarily, more energy than the formant F_1 , and hence a detector of the filter-bank variety would select F_0 as the formant. In accordance with the principles of the present invention, however, the signal applied to formant detector 11 is first processed by selective filter 12. Filter 12 is responsive to control signals which are indicative of the previous locations of the principal speech formant F_1 . In response to these control signals the transmission characteristics of filter 12 are altered in order to accentuate transmissibility in the region of these previous formant locations. As shown in FIG. 2B, the selective filter response is enhanced in the region where previous formants have been located. Thus, there is a tendency for filter 12 to favor the transmission of spectral components in the vicinity of the formant peak F_1 . It is to be noted, however, that it is not a binding constraint that the peak F_1 be transmitted to formant detector 11. If the peak F_0 is larger by a predetermined threshold value, indicated as Δ in FIG. 2B, then the peak F_0 will be selected irrespective of the prefiltering accentuation of filter 12. Thus, as discussed above, this feature allows the system to abandon a peak if it becomes absurdly small as compared to another peak. Experience has indicated that the threshold value, Δ , is optimally $\frac{1}{8}$ to $\frac{1}{4}$ the average Q of the specific formant peak expressed in decibels. The Q of a formant peak is defined in the same manner as that of a resonance curve, namely, the ratio of the bandwidth to the center frequency of the peak. Thus for a peak F_1 whose Q ranges from three to five, corresponding to a range of ten to fourteen decibels, a threshold value of two decibels has been found appropriate.

In the illustrative embodiment of this invention shown in FIG. 3, which incorporates the above principles, an incoming speech wave from source 10, which may be a conventional transducer for converting speech sounds into a corresponding electrical wave, is applied to equalizer 13. Equalizer 13, which may be of the type disclosed in the copending application of C. H. Coker, Ser. No. 322,390, filed Nov. 8, 1963, now Patent No. 3,327,057, serves to adjust the amplitudes of the frequency components of the speech wave in order to approximately optimize the operation of the formant detecting apparatus which follows. The equalized speech wave from equalizer 13 is simultaneously applied to formant processor and detector 14 and to delay element 15. Formant processor and detector 14 derives from a selected frequency subband of the equalized speech wave a first narrow band control signal representative of the location of the speech formant that normally occurs in that subband, for example, the first speech formant. Delay element 15 serves to delay the equalized speech wave from equalizer 13 by an amount sufficient to compensate for the delay, if any, introduced by formant detector 14 in the detection of a speech formant, and the delayed, equalized speech wave from delay element 15 is applied to the input terminal of formant suppressor 16.

Formant suppressor 16, which may have one of the alternative forms shown in the aforementioned copending application Ser. No. 322,390, is controlled by the narrow band control signal from processor 14 to suppress a formant peak by suppressing all of the frequency components in the vicinity of that formant peak in the incoming speech wave which correspond to the formant represented by the narrow band control signal. By suppressing all of the frequency components in the vicinity of a formant peak, before detecting the location of the next formant peak, the frequency subband within which the next formant peak normally occurs will not contain any large amplitude components from the vicinity of

the suppressed formant peak. Since the detection of formant locations is often based upon the frequency location of the largest amplitude components within a particular frequency subband, the suppression of frequency components in the vicinity of one formant peak prevents these components from being mistakenly recognized as indicating the location of another formant.

The output signal of suppressor 16 is also applied to delay element 17 in order to delay the output signal of suppressor 16 by an amount of time sufficient to compensate for the delay, if any, introduced by formant processor and detector 18 in deriving a second narrow band control signal representative of another speech formant location. The second narrow band control signal from processor 18 is applied to the control terminal of formant suppressor 19, while the delayed output signal from suppressor 16 is applied to the input terminal of suppressor 19. Suppressor 19, which functions in a manner similar to suppressor 16, serves to suppress in the output signal of suppressor 16 the frequency components in the vicinity of that speech formant which correspond to the formant represented by the narrow band control signal developed by detector 18. The output signal developed by suppressor 19, and delivered to formant detector 21, therefore has two fewer formants than are found in the original speech wave, so that in the situation where the apparatus is designed to locate the three principal speech formants, the output signal of suppressor 19 contains only one principal formant. The output signal of suppressor 19 is passed to formant processor and detector 21, which derives from this output signal a third narrow band control signal representative of still another speech formant, for example, the third principal speech formant.

The narrow band control signals developed at the output terminals of processors 14, 18 and 21 may be utilized to reconstruct a replica of the original speech wave in a suitable synthesizer 22, where it is understood that synthesizer 22 is to be supplied with the usual additional control signals necessary to specify completely the speech characteristics. A suitable synthesizer is disclosed in H. L. Barney Patent 2,819,341, issued Jan. 7, 1958, and speech sounds may be reproduced from the reconstructed wave by a suitable transducer 23, for example, a loudspeaker of conventional design. It is important to note at this point, however, that in order for synthesizer 22 to reconstruct a replica of the speech wave having formants that occur at the same frequency locations as the formants of the original speech wave, it is necessary that the narrow band control signals from processors 14, 18 and 21 unambiguously identify particular formants of the original speech wave. If the three principal formants are ordered in terms of their relative locations on the frequency scale, then, for a given speech sound, the second formant occurs at higher frequencies than the first formant and lower frequencies than the third formant, and the third formant occurs at higher frequencies than the first and second formants. Although equalizer 13 may be constructed so that the first, second, and third narrow band control signals developed by detectors 14, 18 and 21, respectively, represent the first, second, and third principal speech formants in that order, it is contemplated that other types of equalizers may be employed. In that case, the first, second, and third narrow band control signals respectively developed by the detectors may not necessarily represent the first, second, and third principal formant locations in that order. In the latter event, it is necessary to distinguish between the three narrow band control signals so that the proper narrow band signal may be applied to the proper input point of synthesizer 22, and this may be accomplished by passing the three narrow band control signals through formant ordering circuit 24. Formant ordering circuit 24, which may be of the type disclosed in the aforementioned copending application Ser. No. 322,390, rearranges the narrow band control signals as necessary in order that

the narrow band control signals representative of the formant locations appear in the desired sequence.

Simultaneously with the application of the incoming speech signal to equalizer 13, the speech signal is also applied to a decision making device, e.g., voiced-unvoiced detector 25 which may be of any well-known type. Detector 25 develops a signal indicative of the nature of the applied speech signal, e.g., whether it is voiced or unvoiced. Other criteria may, of course, be used, as desired. The signals developed by detector 25 are utilized to control formant processors and detectors 14, 18 and 21 via conductor 26, as discussed hereinafter. Information regarding the previous history of formant locations is provided by a feedback arrangement via conductor 27 to the formant processors and detectors. This information is developed at the appropriate output terminals of formant ordering circuit 24, as indicated in FIG. 3.

FIG. 4 shows a typical formant processor and detector 14, 18 or 21, utilized in the apparatus of FIG. 3. The input signals to the processor comprise a speech wave, a control signal via conductor 26 from voiced-unvoiced detector 25 and previous formant location information via conductor 27. The speech wave is applied to selective filter 12, which may be of the type shown in FIG. 5 and discussed hereinafter. Selective filter 12 accentuates or enhances the transmission of spectral components in the vicinity of previous formant locations in response to information from signal processor 28, which is responsive to the control signals appearing on conductor 27. In order to remove random fluctuations and irregularities, if any, in the formant information fed back from the output of formant ordering circuit 24 of FIG. 3, apparatus 28 is preferably an optimum prediction device, for example, an extrapolator, as shown and described in the copending application of C. H. Coker, Ser. No. 365,654, filed May 7, 1964, now Patent No. 3,349,180. Of course, if the control signals are not subject to fluctuation, apparatus 28 need not be used. The output signal emanating from processor 28 thus corresponds to an optimum average of the previous formant location information.

In order to avoid improper tracking by selective filter 12 upon the initiation of voicing of the input speech signal, which is usually accompanied by noise, delay element 29 responsive to the control signals emanating from detector 25, activate switch 31 via relay 32. Switch 31 in its normally inoperative position is connected in such a manner that selective filter 12 is bypassed. After voicing has commenced, a control signal applied from detector 25, via conductor 26, to element 29 is delayed by approximately ten milliseconds. This delay allows the control signal to develop into a reliable indication of past formant locations prior to operation of selective filter 12. Thus, after a delay of ten milliseconds, relay 32 is activated, operating switch 31, and connecting selective filter 12 directly to formant detector 11. In this mode of operation, selective filter 12 is continuously altering its transmission characteristics, responsive to the previous formant control information emanating from apparatus 28. Thus, there is a strong predisposition for formant detector 11 to select formant peaks occurring in the vicinity of previous formant locations. Formant detector 11 may be of any well-known construction; a suitable formant detector is described in the copending application of C. H. Coker, Ser. No. 322,389, now Patent No. 3,327,058. Thus, at the onset of voicing or some other predetermined criterion, selective filter 12 is bypassed to eliminate the possibility of locking onto an improper speech frequency component, therefore avoiding the disadvantage of typical tracking-filter analyzers. After a predetermined interval of time, typically 10 milliseconds, selective filter 12, activated by previous formant control information, increases the probability of finding a formant in the vicinity of previous formants, thus avoiding the abrupt and discontinuous changes inherent in analyzers of the filter-bank variety.

A preferable form of selective filter 12 is illustrated in

FIG. 5. An incoming speech signal, for example, the signal from equalizer 13 or formant suppressors 16 and 19 of FIG. 3, is applied in parallel to a bank of contiguous or overlapping bandpass filters 41-1 through 41-n. The pass bands of filters 41-1 through 41-n span the entire frequency range of the incoming signal, so that there is developed at the output terminals of these filters a group of alternating signals representative of the frequency components of the incoming speech wave. Each bandpass filter is followed by a conventional logarithmic amplifier and detector 42-1 through 42-n, respectively. Elements 42-1 through 42-n develop from the group of alternating signals a corresponding group of unidirectional voltages proportional to the logarithms of the amplitudes of the components of the incoming speech wave. The group of unidirectional voltages from elements 42-1 through 42-n is combined in adders 43-1 through 43-n with the output signals of diode-resistor networks 33-1 through 33-n. Diode-resistor networks 33 are controlled through injection point selector 45 and current generator 47, which may be of the type described in the aforementioned copending application of C. H. Coker, Ser. No. 322,390, by an incoming control signal, from processor 28 of FIG. 4, representative of the location of previous formant peaks. At the output points of networks 33 there are developed a group of unidirectional voltages representing the vicinity in the frequency domain where previous formant peaks have been detected. A constant current is injected, via generator 47 and point selector 45, into a predetermined resistor-diode network 33-i, in response to the applied formant control information. This injected current is distributed via the interconnecting diodes of network 33-i and its immediately adjacent networks, 33-(i-1) and 33-(i+1), to load resistors R_{i-1} , R_i and R_{i+1} . The signal voltages developed across resistors R_{i-1} , R_i and R_{i+1} are combined in adders 43-(i-1), 43-i and 43-(i+1) with the signals emanating from the respective logarithmic amplifiers and detectors. Since no current is injected into the other load resistors, R_1 through R_{i-2} , and, R_{i+2} through R_n , the contribution to the respective adders to which they are connected is zero. Accordingly, only the spectral components in channels (i-1) through (i+1) are accentuated by the addition of signal voltages developed across the load resistors. The product of the current flowing in the selected load resistors and the resistive values thereof is selected to provide an accentuation, of the speech components in the vicinity of previous formant peaks, of the order of $\frac{1}{8}$ to $\frac{1}{4}$ of the Q of the formant peaks, as discussed above. The accentuated spectral components and their unaccentuated counterparts are conveyed via the output leads of adders 43-1 through 43-n to formant detector 11 of FIG. 4. Thus, there is a decided predisposition for formant detector 11 to locate a formant peak in the vicinity of previous formant locations.

Although this invention has been described in terms of speech communication systems, it is to be understood that applications of the principles of this invention are not limited to these systems but include such related fields as automatic speech recognition, speech processing and automatic message recording and reproduction. In addition, it is to be understood that the above-described embodiments are merely illustrative of the numerous arrangements which may be devised for the principles of this invention by those skilled in the art without departing from the spirit and scope of the invention.

What is claimed is:

1. Apparatus for accentuating the detection of a selected formant of a speech wave which comprises:
 - a source of an incoming speech wave,
 - means supplied with said speech wave for obtaining a first group of unidirectional signals representative of the amplitudes of the frequency components of said speech wave,
 - a source of a control signal representative of the

previous frequency locations of a selected formant of said speech wave,
 means responsive to said control signal for generating a second group of unidirectional signals representative of the vicinity in the frequency domain of the previous formant locations of said selected formant represented by said control signal,
 and means for combining said first and second groups of unidirectional signals.

2. Apparatus for increasing the probability of detecting a selected formant of a speech wave which comprises:
 a source of an incoming speech wave,
 means supplied with said speech wave for obtaining a first group of unidirectional signals representative of the amplitudes of the frequency components of said speech wave,
 a source of a control signal representative of the previous frequency locations of a selected formant of said speech wave,
 selector means responsive to said control signal and provided with a plurality of output points for delivering a constant current to a selected plurality of said output points in accordance with the magnitude of said control signal,
 means provided with a plurality of input points each connected to a corresponding one of said plurality of output points of said selector means for generating a second group of unidirectional signals representative of the location in the frequency domain of the previous formants represented by said control signal,
 and means for combining said first and second groups of unidirectional signals.

3. Apparatus for determining the frequency locations of selected formants of speech sounds which comprises:
 a source of an incoming speech wave,
 equalizer means supplied with said speech wave for enhancing the relative amplitudes of the high frequency components of said speech wave by predetermined relative amounts and for eliminating selected frequency components of said speech wave, thereby to develop an equalized speech wave,
 first detector means in circuit relation with said equalizer means for deriving from said equalized speech wave a first control signal with a magnitude representative of the frequency location of a formant of said equalized speech wave,
 first suppressor means under the control of said first control signal and responsive to said equalized speech wave for individually suppressing in said equalized speech wave each frequency component in the vicinity of the formant represented by said first control signal to obtain a first suppressed formant speech wave,
 second detector means in circuit relation with said first suppressor means for deriving from said first suppressed formant speech wave a second control signal with a magnitude representative of the frequency location of a formant of said first suppressed formant speech wave,
 second suppressor means under the control of said second control signal and supplied with said first suppressed formant speech wave for individually suppressing in said first suppressed formant speech wave each frequency component in the vicinity of the formant represented by said second control signal to obtain a second suppressed formant speech wave,
 third detector means in circuit relation with said second suppressor means for deriving from said second suppressed formant speech wave a third control signal with a magnitude representative of the frequency location of a formant of said second suppressed formant speech wave,
 formant ordering means supplied with said first, second, and third control signals for arranging said first,

second, and third control signals in a predetermined order,
 means responsive to said ordered control signals for altering the performance of said detector means in accordance with a predetermined schedule to increase the probability of detecting a subsequent formant in the vicinity of the previous formants represented by said control signals,
 means responsive to said incoming speech wave for controlling the operation of said detector means in accordance with predetermined criteria,
 and speech synthesizing means responsive to said first, second and third ordered control signals for reconstructing a replica of said incoming speech wave.

4. Apparatus as defined in claim 3 wherein said altering means comprises:
 means for removing random fluctuations and irregularities in said control signals to establish a signal which corresponds to the optimum estimate of said control signals,
 and selective filter means responsive to said optimum control signals for accentuating the transmission of the speech wave spectral components in the vicinity of previous formant locations established by said optimum control signals.

5. Apparatus as defined in claim 4 wherein said selective filter means comprises:
 means supplied with said speech wave for obtaining a first group of unidirectional signals representative of the amplitudes of the frequency components of said speech wave,
 means responsive to said control signals for generating a second group of unidirectional signals representative of the vicinity in the frequency domain of the previous formant locations of said selected formant represented by said control signals,
 and means for combining said first and second groups of unidirectional signals.

6. Apparatus as defined in claim 3 wherein said controlling means comprises:
 means for developing a signal representative of the voiced or unvoiced nature of said speech wave,
 means for delaying said representative signal,
 and means responsive to said delayed representative signal for energizing said altering means during voiced intervals of said speech wave.

7. Speech equalizer apparatus for determining the frequency locations of selected formants of a speech wave comprising:
 selective filter means responsive to applied control signals representative of previous formant locations of said speech wave for enhancing the transmissibility of the spectral components of said speech wave in the vicinity of said previous formant locations,
 detection means responsive to the signals of said selective filter means for determining the locations of the formants of said speech wave,
 and means responsive to signals representative of the nature of said speech waves for applying said speech waves directly to said detection means for a predetermined interval of time.

8. Apparatus as defined in claim 7 wherein said selective filter means comprises:
 means supplied with said speech wave for obtaining a first group of unidirectional signals representative of the amplitudes of the frequency components of said speech wave,
 means responsive to said control signals for generating a second group of unidirectional signals representative of the vicinity in the frequency domain of the previous formant locations of said selected formant represented by said control signals,
 and means for combining said first and second groups of unidirectional signals.

9. Apparatus for determining the frequency locations

of selected formants of speech sounds which comprises:
 a source of an incoming speech wave,
 equalizer means supplied with said speech wave for
 developing an equalized speech wave,
 first detector means in circuit relation with said equal- 5
 izer means for deriving from said equalized speech
 wave a first control signal representative of the fre-
 quency location of a formant of said equalized
 speech wave,
 first suppressor means under the control of said first 10
 control signal and responsive to said equalized
 speech wave for individually suppressing in said
 equalized speech wave each frequency component
 in the vicinity of the formant represented by said
 first control signal to obtain a first suppressed form- 15
 ant speech wave,
 second detector means in circuit relation with said first
 suppressor means for deriving from said first
 suppressed formant speech wave a second control
 signal representative of the frequency location of a 20
 formant of said first suppressed formant speech
 wave,
 second suppressor means under the control of said
 second control signal and supplied with said first sup- 25
 pressed formant speech wave for individually sup-
 pressing in said first suppressed formant speech wave
 each frequency component in the vicinity of the
 formant represented by said second control signal
 to obtain a second suppressed formant speech wave,
 third detector means in circuit relation with said second 30
 suppressor means for deriving from said second sup-
 pressed formant speech wave a third control signal
 representative of the frequency location of a formant
 of said second suppressed formant speech wave,
 means responsive to said control signals for altering the 35

performance of said detection means in accordance
 with a predetermined schedule to increase the prob-
 ability of detecting a subsequent formant in the
 vicinity of the previous formants represented by
 said control signals,
 means responsive to said incoming speech wave for
 controlling the operation of said detection means
 during predetermined intervals of said speech wave,
 and speech synthesizing means responsive to said first,
 second and third control signals for reconstructing a
 replica of said incoming speech wave.
 10. Apparatus as defined in claim 9 wherein said alter-
 ing means comprises:
 means for compensating for random fluctuations and
 irregularities in said control signals,
 and selective filter means responsive to said compensat-
 ing means for emphasizing the transmission of the
 speech wave spectral components in the vicinity of
 previous formant locations established by said con-
 trol signals.

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U.S. Cl. X.R.

179—15, 55