United States Patent

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[54] **SPEECH SYNTHESIS FROM A SPECTROGRAPHIC TRACE**

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[52] **U.S. Cl.** ....**179/1 SA,** 179/1 VS

[51] **Int. Cl.** **G10l 1/00,** G10l 1/12

[58] **Field of Search**.................179/1 SA, 1 SB, 1 US; 340/146.3, 148, 149, 146.3 C, 146.3 F; 35/35 A

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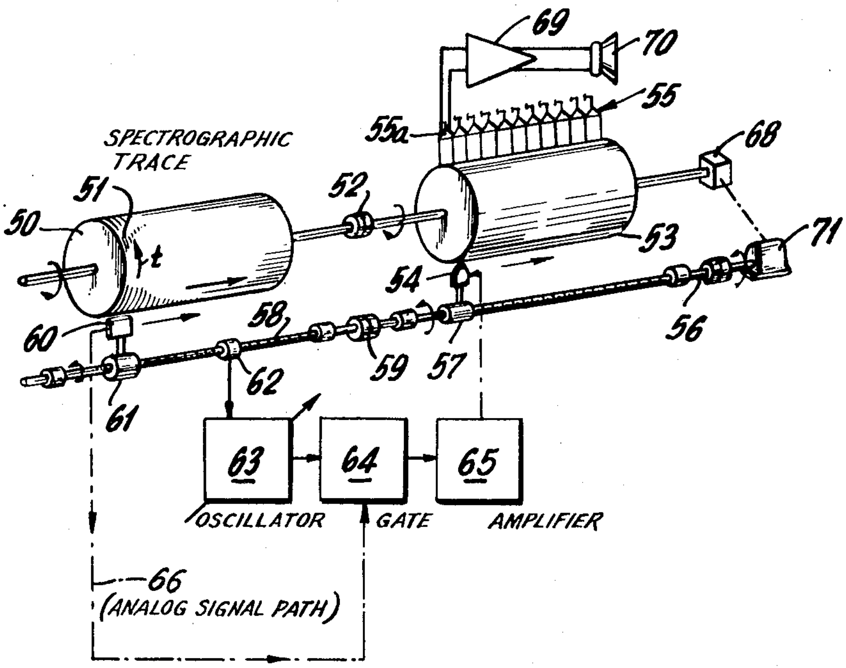
[57] **ABSTRACT**

A voice synthesis system using a sound spectrogram, showing the spectrum in the form of a plot of frequency against time with intensity being represented by the variable density of the plot. The spectrogram is scanned and analog signals are produced the amplitude of which is a function of the density of the spectrogram plot. Synchronously with the production of the analog signals oscillation signals are produced at the respective scanning frequencies and are amplitude modulated by the analog signal. The amplitude modulated oscillation signals are stored and summed and subsequently reproduced thereby synthesizing an acoustic signal.

23 Claims, 12 Drawing Figures



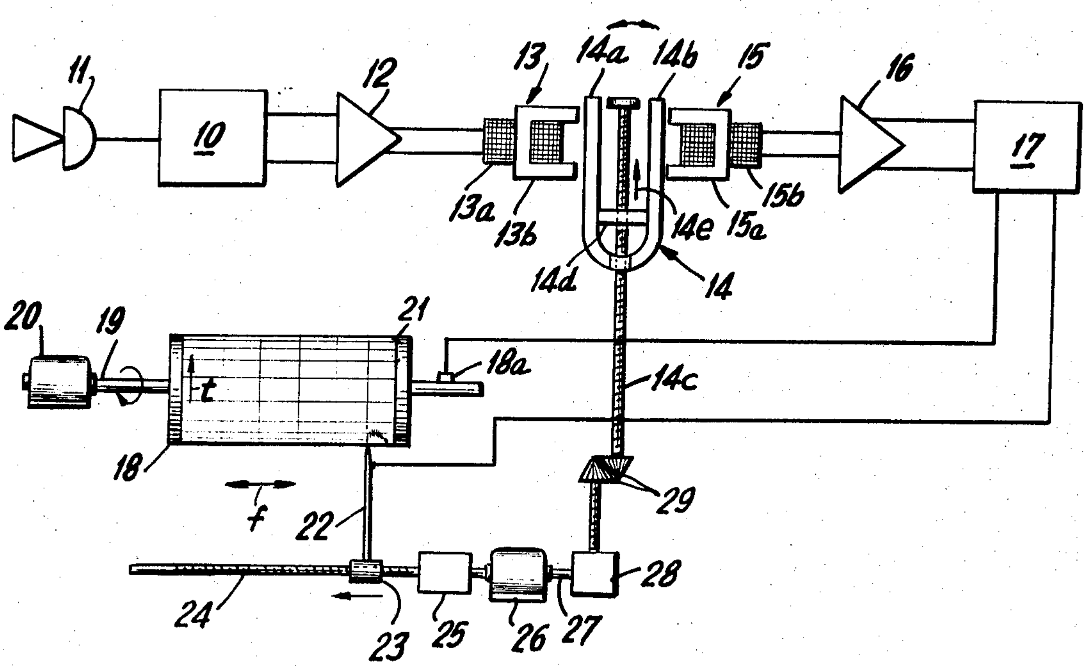


FIG.1

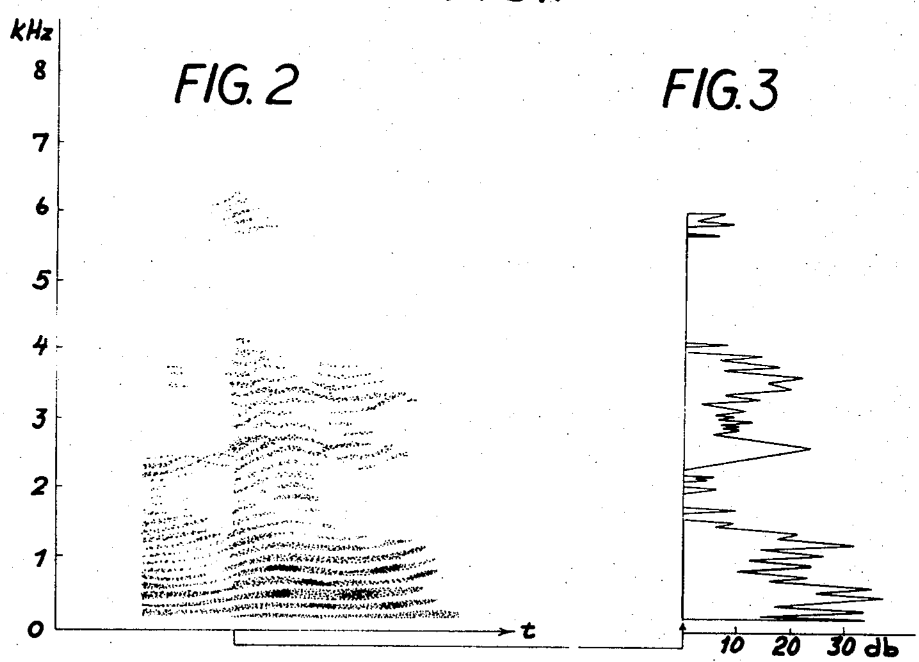


FIG. 2

FIG. 3

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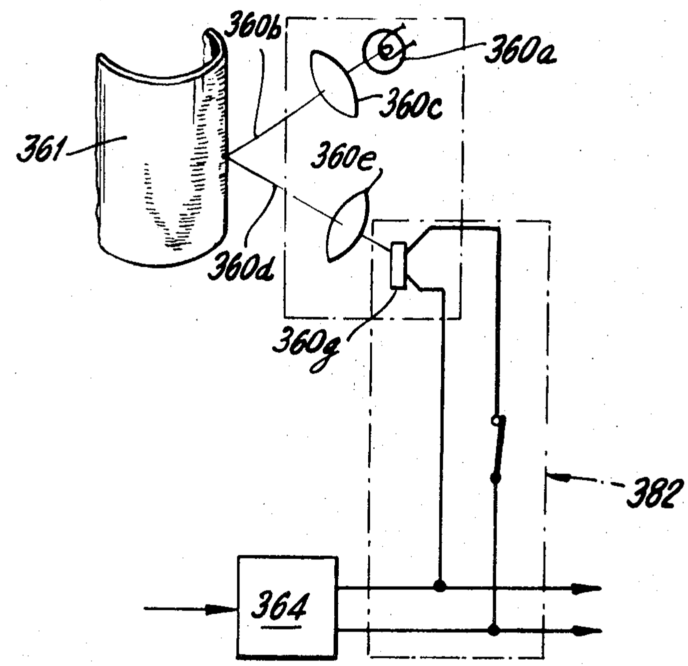

FIG. 7

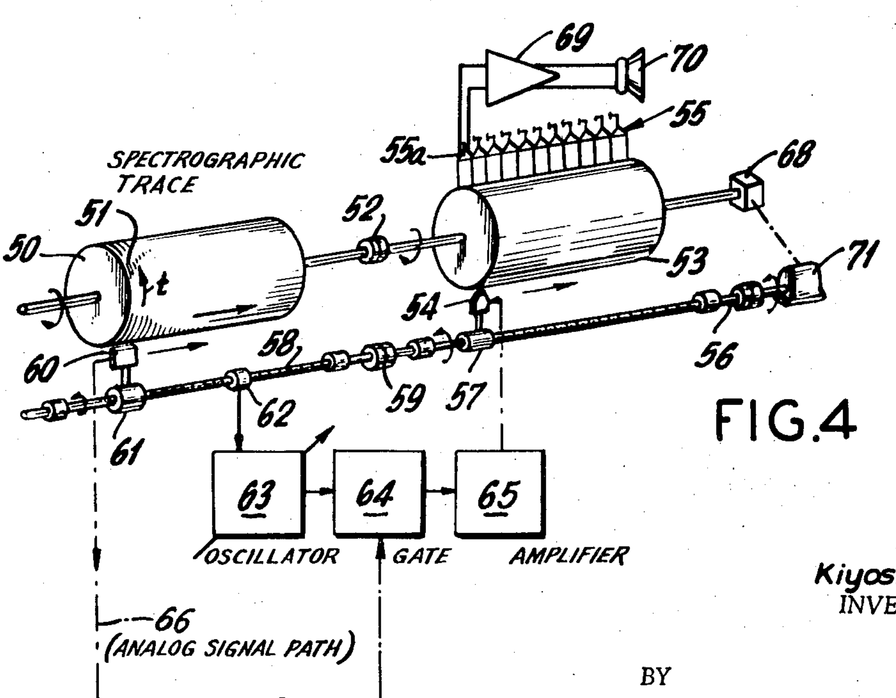

FIG. 4

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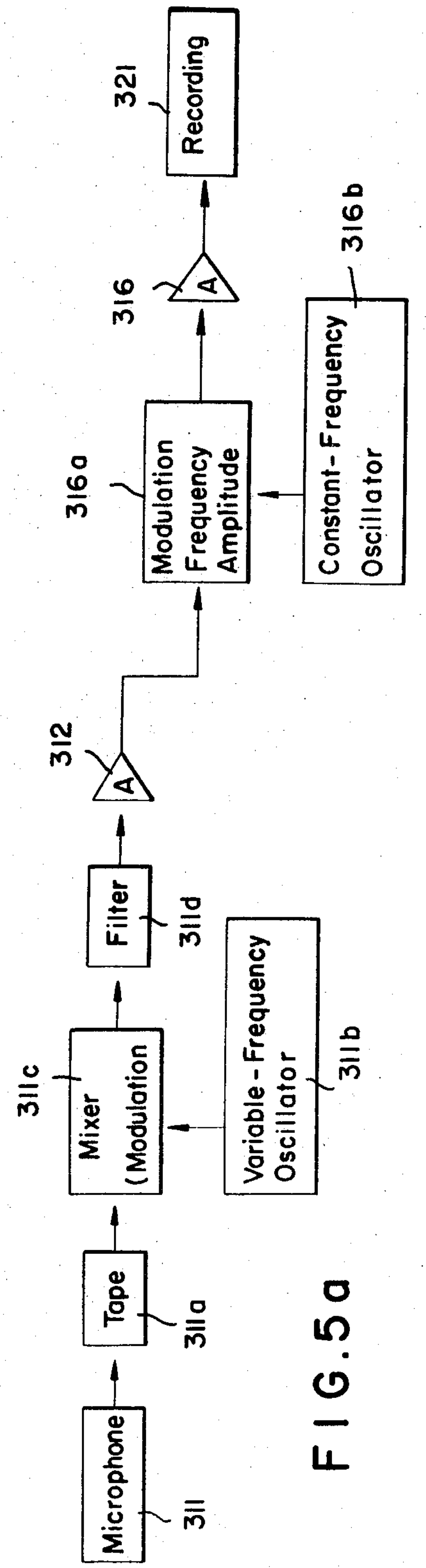

FIG. 5a

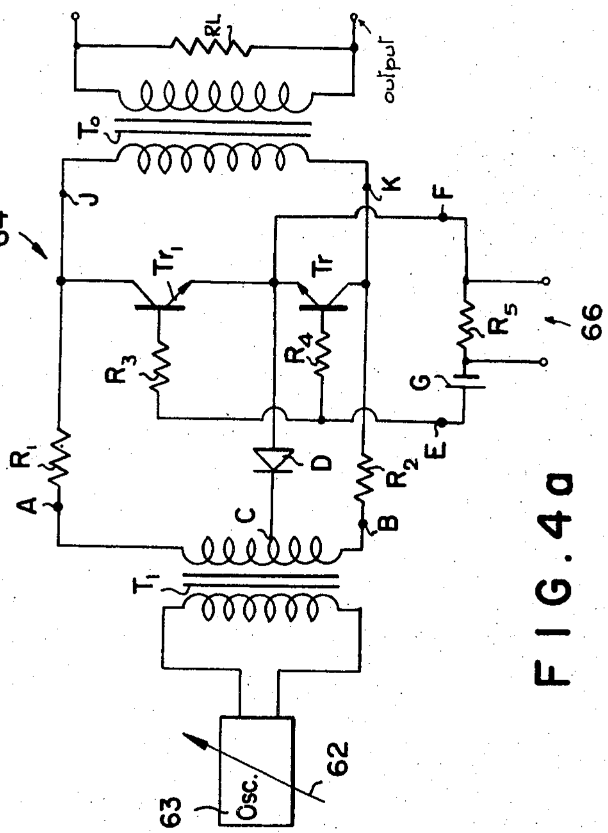

FIG. 4a

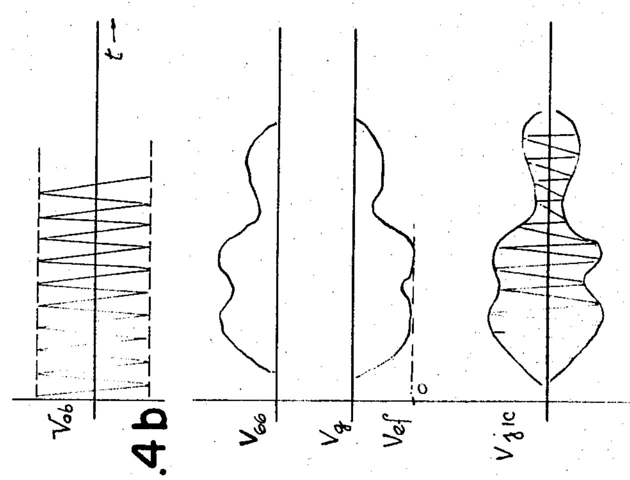

FIG. 4b

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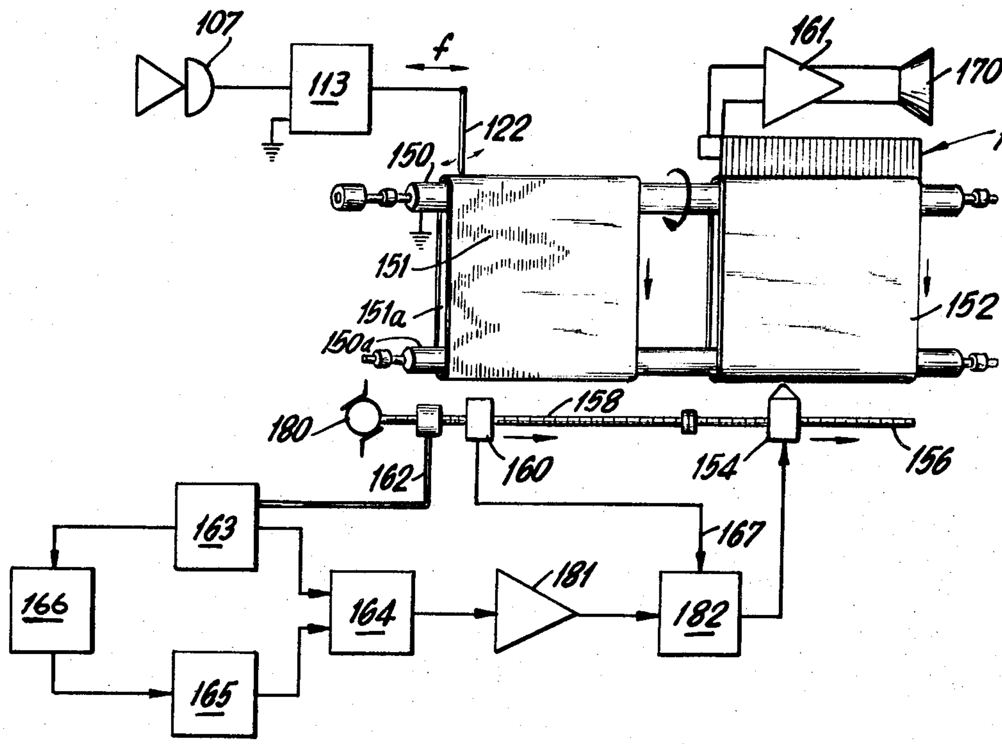

FIG. 5

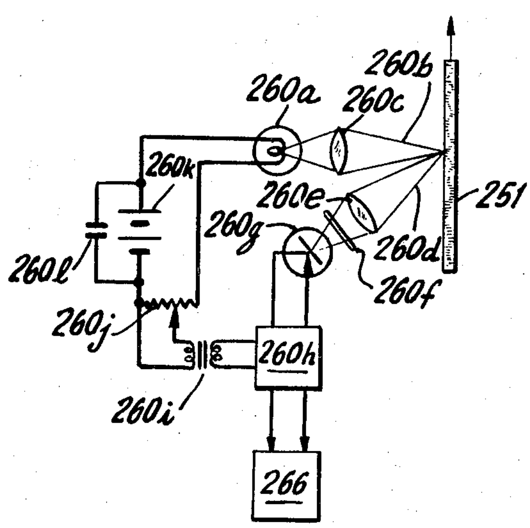

FIG. 6

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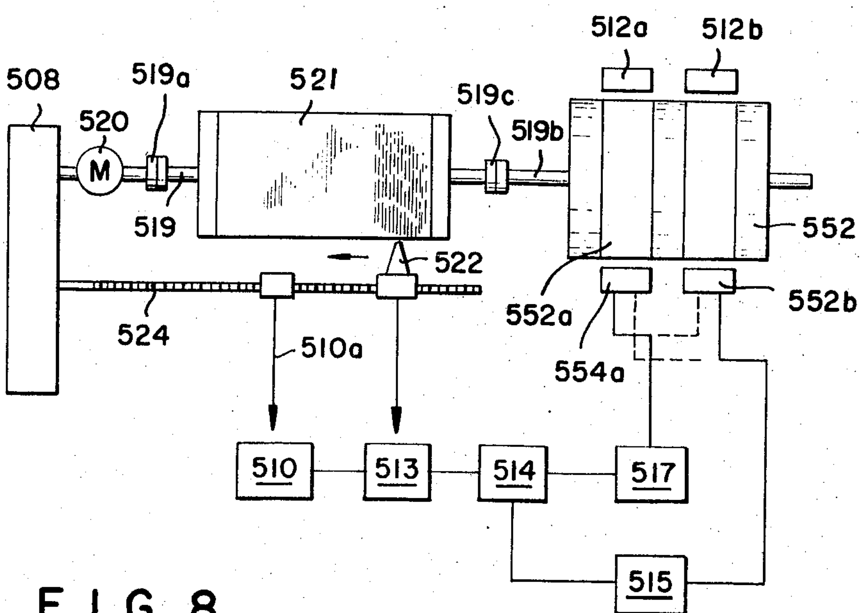

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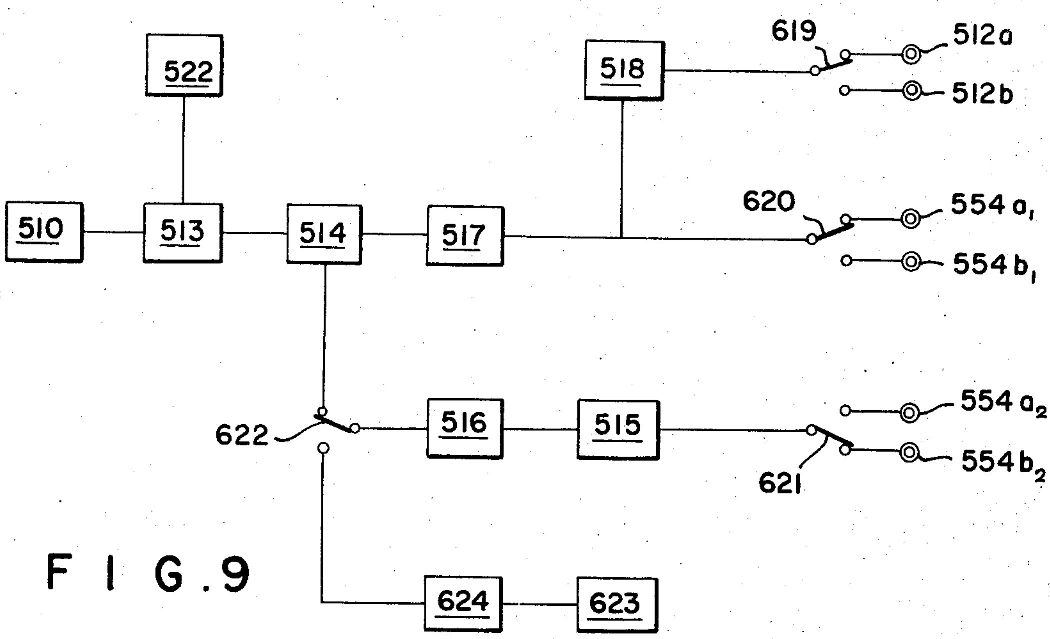

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SPEECH SYNTHESIS FROM A SPECTROGRAPHIC TRACE

FIELD OF THE INVENTION

My present invention relates to sound analysis and synthesis and, more particularly, to the analysis or synthesis of voice signals as well as acoustical signals from other sources using a form of spectrographic recordal and breakdown.

BACKGROUND OF THE INVENTION

Sonic analysis can be carried out by recording an acoustic signal or an acoustical waveform to enable subsequent analysis of the recorded waveform, based upon Fourier transforms, into a spectrum consisting of a series of component waves which are commonly shown in graphic form as a printed diagram or sound spectrogram.

A sound spectrum, according to the principles to be applied here, therefore, is a representation of the breakdown or analysis of a composite acoustical signal, from whatever source, into its frequency components, the frequency increments of the spectrum being chosen in accordance with the desired resolution of the spectral analysis.

The spectrogram, then, is a diagram of the spectrum in which time may be plotted along the abscissa while frequency is plotted along the ordinate. Furthermore, the amplitude or relative intensity of the respective frequency components is indicated by the relative density of the plot so that, for example, the absence of a trace represents lack of a signal of the particular frequency whereas a light trace represents a low-amplitude component of the particular frequency and a relatively dark trace represents a relatively high amplitude of the frequency component under discussion.

Spectrographic techniques of this type, wherein acoustical signals are "analyzed" or dissected to yield the components making up the composite signal, provide valuable information on the sound for various purposes. For example, vocal sounds may be analyzed in speech research to identify characteristic patterns of component frequencies, known as formants, or phonemes, and are also concerned with formant changes as a result of context, intonation and stress of spoken words or sentences. These analyses are highly desirable in the evaluation of defective speech patterns, in the identification of the oral actions leading to particular formant characteristics, and even in the standardization of speech.

The resultant body of information on vocal sounds, therefore, is extremely valuable since it enables an understanding of the complicated phenomena of speech production and enables the design of new modes of speech transmission so as, for example, to provide automatic speech recognition, automatic speech transmission and automatic sound synthesis. All of these automatic results are most desirable to facilitate the interaction of man and machine at so-called "-man/machine interfaces," e.g., as computer inputs and readouts.

Another function of sound spectrograms of the type described above and especially voice spectrograms, is identification of the speaker, it having been found that considerable differences exist in the spectrograms produced by different individuals speaking the same or similar words, these differences being a consequence not only of different speaking habits and accents but also to significantly distinct functional and structural differences in the vocal organs of these individuals. It thus has been proposed to provide so-called "voice prints" or "voice signatures" and analysis thereof to aid in criminal investigations or otherwise enable mechanized identification of selected individuals by comparing a present input with a previously recorded or stored reference.

Spectrograph analysis is also recognized as a source of information permitting evaluation of various functional disorders in any organism generating or responding to acoustic waves or signals which can be converted to such waves without introducing additional variables. Thus, for example, a diseased heart or a malfunctioning engine can be spectrographically evaluated and the existence of the defect and/or the nature of the defect diagnosed spectrographically.

In all of the foregoing applications and in diverse other fields making use of acoustic analysis and acoustic synthesis, it is convenient to synthesize or recompose an acoustic signal from the spectrographically reproduced data. Thus acoustic synthesis may be significant when the analyst wishes to work with an audible signal or when modification of the recorded data is desired in, say, systems analysis. In the latter case it may be desired to subtract, to add or to modify a portion of the data recorded in a spectrogram to eliminate background noise, or even to isolate a particular signal. Furthermore, this reproduced acoustical signal may even form the input of an analysis system following the basic step previously set forth of recording the amplitudes of the various frequency components against time.

OBJECTS OF THE INVENTION

It is the principal object of the present invention to provide a simple, economical and yet reliable method of and system for the synthesis of acoustical signals or the reproduction thereof from spectrographic data resulting from analysis.

Another object of the invention is to provide an improved sonic-analysis system enabling a wider range of investigation of acoustical inputs than has been possible heretofore and capable of producing results in sonic analysis which are of greater practical and theoretical significance than earlier systems.

Still another object of the invention is to provide a sonic analysis and synthesis system capable of making available more information as to the nature of analyzed sound signals than has been obtainable from prior analysis systems.

It is yet another object of my invention to provide a synthesis system for generating artificial yet recognizable speech sounds for use at man/machine interfaces of the character described and for communication purposes.

It is also an object of the invention to provide a general-purpose sonic-analysis system yielding significant results on objective and subjective levels which is capable of providing objectively significant engineering and like data, but which can consider subjective factors as well.

Still another object of the instant invention is to provide an improved system for breaking down sound waves into components thereof.

SUMMARY OF THE INVENTION

These objects and others which will become apparent hereinafter, are attained, in accordance with this invention, with a novel sound-synthesis and sound-analysis system and method, based upon the recognition that it is possible to further derive, from a spectrographic breakdown of an acoustical signal, a further signal in which incremental frequencies are scanned and an analog output is formed, based upon the amplitudes of each frequency increment such that the analog signals are combined, composed or synthesized into an acoustical output and/or an electrical or other signal representing same.

Thus, the present invention in generic terms makes use of a spectrographic trace of any acoustic input, as will be prepared by conventional techniques or special apparatus described hereinafter, in which the component waves of the acoustic signal are plotted as incremental frequency bands (i.e., individual frequency components), against time, with the amplitude of the particular function being represented by varying density of the particular plot. If the frequency distribution of the acoustic signal is considered to be a function of time and overall amplitude is a function of time, it will be seen immediately that each component frequency may also be viewed as a function of time.

In the breakdown of the input signal, the value of the signal for each of a multiplicity of component frequencies or frequency bands is ascertained and plotted against time in a spectrographic trace which generally makes use of visible indicia, although invisible traces (e.g., magnetic recordings) may also be employed. The intensity (amplitude) of the component frequency or component frequency band is therefore indicated by some parameter of the trace, generally a passage from relatively light to relatively dark as amplitude increases when optical traces are considered. Any form or registry using the same principle is, however, contemplated within the terminology used here of high density and low density, which may identify optical lightness and darkness, spreading or narrowing of a recorded component signal, greater recording depth or shallowness, etc.

The expression "spectrographic trace" is used to denote any trace or recordal of spectrographically analyzed signals in which a composite or mixed sonic input is broken down, dissected or analyzed to yield the respective frequencies and the relative amplitudes of these component frequencies can be ascertained, preferably in an instantaneous manner or as a function of time. The spectrographic trace may be created from an acoustical signal of any form and any source and practically any machine, individual or system capable of producing sound material constitute an input from which a spectrographic trace is taken. The input may be used for investigation or for any of the other purposes mentioned earlier and may be derived for voice analysis, speech sound analysis, musical sound analysis, noise analysis, acoustical signals associated with the detection, diagnosis and evaluation of dysfunction of organic or mechanical systems, or acoustical signals from individuals, machines and systems for purposes of identification.

The term "spectrographic trace" is used herein not only to refer to an original trace or spectrogram of the raw acoustic input, but also to refer to modified traces, traces which have been copied, traces which have been partly canceled or selectively evaluated or traces which have been produced by a previous sonic synthesis using, for example, the techniques described in greater detail hereinafter.

According to the principal feature of the present invention, a spectrographic trace of the character described is scanned successively for incremental frequencies to derive analog outputs or signals whose amplitudes vary in proportion to the intensities or densities of the respective plots of the component or analyzed frequencies.

It must be noted here, to avoid confusion, that many acoustical signals will provide a continuum of component frequency, while other acoustical signals will consist of relatively pure tones, relatively pure or simple overtones and mixtures of such tones, overtones and harmonics. Still other signals will be revealed as having one or more continuum-type frequency bands together with one or more pure tones, pure overtones, etc. Thus, when reference is made herein to "component frequencies," it should be understood that not necessarily every frequency of a particular sound signal is to be recorded individually and thereafter scanned. It has been found that it is frequently practical to record frequency bands of a band width which will depend upon the purpose of analysis. On the other hand, for some purposes it may be desirable to make use of extremely narrow bands or practically pure component frequencies or to space the component frequencies to be derived more or less from one another. When voice analysis is contemplated, it may be sufficient to record substantially contiguous component frequency bands of a band width between 10 and 200 Hz, for example.

Synchronously with the respective scanning steps, isolation signals are generated at the respective scanning frequencies and amplitude modulated by the analog signals, the amplitude-modulated signals being recorded for subsequent playback in the synthesis stage of the invention.

In accordance with one aspect of this invention, the amplitude-modulated signals are recorded in parallel but coincident and co-ordinated tracks of a single recording medium and, upon complete recording, a synthesized output is produced by combining the recorded signals as they are reproduced as a function of time.

It has also been found to be possible to reduce the number of tracks and therefore the densities of the recording medium by a system which may be described in terms of a "seesaw" effect. In accordance with this technique, each incrementally scanned signal is recorded as scanned but each subsequent scan and recordal combines the previously recorded signal so that the signal recorded at the second scan will contain two components while that recorded at the third scan will contain three components, etc. In other words, the scanning step is combined with a mixing step so that only a single track is finally required to record the synthesized signal. In this arrangement, therefore, a pair of narrow recording media, e.g., magnetic tapes, can be used. On a first of these tapes, I record the amplitude-modulated oscillation signal corresponding to one of the incremental frequency scans. This signal is then reproduced and mixed with the amplitude-modulated oscillation signal of the next scan to provide a resultant or mixed signal which is recorded upon the second tape while the first tape is erased. During the next scan, the mixed signal of a second tape is combined with a fresh amplitude-modulated oscillation signal of the third scan while the second tape is erased and the tripartite mixed signal is applied to the first tape. In this manner a mixed signal of increasing complexity is recorded first on one and then on the other tape and may be played back as the completely synthesized signal from the final tape.

According to another aspect of this invention, the spectrograph is produced by an improved and highly sensitive recordal system having pickup means with a mechanical resonance element, preferably a tuning fork and means for continuously varying the resonant frequency of this device. The resonant system thus serves as a variable-frequency monochromatic pass filter or regulator capable of isolating the particular frequency to which the resonance element has been set and thereby enabling a recording device to be energized with an input corresponding to the time-variation of the amplitude of this particular frequency. More specifically, the variable-frequency monochromatic signal isolator comprises a tuning fork having a tuning member movable by a lead screw or the like between the shanks of the tuning fork, which is energized at one of its shanks by an electric signal derived from an acoustical signal by mechanical-electric transducer. The other shank co-operates with a mechanical-electrical transducer feeding an amplifier or output device to generate an electrical signal which is proportional to the amplitude of the resonant frequency of the tuning fork at the particular instant and the specific setting thereof.

BRIEF DESCRIPTION OF THE FIGURES

The above and other objects, features and advantages of the present invention will become more readily apparent from the following description, reference being made to the accompanying drawing in which:

FIG. **1** is a diagrammatic representation, partly in block form, of a spectrographic, recording system for use with the system of the present invention;

FIG. **2** is a sound spectrogram (or trace simulating a sound spectrogram) or visible recording as made of the speech sound or word ("hallow") by the system of FIG. **1**, in which the frequency (*f*) is plotted along the ordinate and time (*t*) is plotted along the abscissa with the intensity (I) being indicated by visually ascertainable plots;

FIG. **3** is a graph showing the frequency-amplitude relationship of the component waves taken at a certain instant of said speech sound (corresponding to the double-L sound of "Hallow");

FIG. **4** is a partly perspective view, in diagrammatic form, of a sound-synthesis system embodying the principles of the present invention;

FIG. **4*a*** is a circuit diagram of an amplitude-modulation and gate system which can be incorporated in the synthesis system of the present invention;

FIG. **4*b*** is a graph representing the signal of FIG. **4*a***;

FIG. **5** is a diagrammatic view of another system according to this invention generally similar to the system of FIG. **4**;

FIG. **5*a*** is a block diagram of an input device with a conventional electrical heterodyne system;

FIG. **6** is a circuit diagram of a self-intensifying optical scanner according to this invention;

FIG. **7** is a view of another circuit useful for control of a switching device according to this invention;

FIG. **8** is a diagram generally similar to that of FIG. **2** but illustrating a seesaw recording method, according to the invention; and

FIG. **9** is a block diagram illustrating the switching of the recording and play-back devices of the latter system.

SPECIFIC DESCRIPTION

In FIG. **1**, I show a spectrograph or registering system for preparing a spectrogram of a recorded acoustic input in which component waves are plotted incrementally in coordinate form of which ordinate represents frequency and abscissa represents time, the intensity of the component waves being indicated by relative darkness of the plots.

In this system, an audio input is picked up by a microphone, stethoscope, electroacoustic transducer, strain gauge, geophone or other sonic pickup **11** and recorded in a tape recorder **10**. The recorded sound signal is repeatedly iteratively reproduced as an electrical signal which is transmitted via the usual amplifier **12** to an electromechanical transducer **13** of the electromagnetic type.

The system **13, 14, 15**, described in detail hereinafter, constitutes a mechanical filter adapted to sweep the frequency spectrum of any acoustic source and register the intensity (generally time-varying) of the component waves individual to each of these frequencies. To this end, the scanning means includes a tunable vibratile element such as a tuning fork whose legs **14*a*** and **14*b*** tend to vibrate upon electromagnetic energization at the tuned frequency with an amplitude proportional to the electromagnetic energization amplitude.

Thus, the electromechanical vibrator **13** can include a magnetic yoke **13*b*** energizable by a coil **13*a*** connected across the amplifier **12** and juxtaposed with the leg **14*a*** of the tuning fork. The other leg **14*b*** of the tuning fork is juxtaposed with an electromagnetic pickup **15** whose yoke **15*a***, of the magnetic-carriage meter type, cooperates with a coil **15*b*** to respond to vibration of the leg **14*b***. The flux changes in the core **15*a***, which are proportional to the amplitude and velocity of vibration of the leg **14*b***, induce an electrical output which is amplified at **16** and delivered at **17** to the recording unit.

While substantially any pen, stylus or electrode recorder may be used for the present purposes, the description with respect to FIGS. **1–4** will be confined to stylus-type recording devices adapted to produce an electric discharge between the stylus **22** and a substrate in the form of a recording paper or sheet **21**, wound around an electrically conductive drum **18**, to plot the component wave with darkness proportional to the intensity. A suitable recording sheet may compose of carbon substrate coated with a thin layer of a metal oxide such as titanium oxide, the amplitude-responsive discharge effecting breakdown of this dielectric layer to expose the carbon substrate with intensity or density proportional to the amplitude or intensity contribution of the scanned frequency.

In the system of FIG. **1**, the recorder consists of the drum **18** carried by a shaft **19** and driven at a constant speed by motor **20** for each frequency scanning. The output from the recorder circuit **17** to the stylus **22** is applied between the latter and the drum **18** via a brush **18***a* bearing on the shaft **19** of this drum.

The stylus assembly **22** is shiftable upon its carriage **23** by a leadscrew **24** driven via a transmission **25** and a motor **26** synchronously with the tuning means to provide incremental frequency scans as represented at *f* in FIG. **1**.

The incremental frequency-scanning shift is effected via an output shaft **27** of motor **26** and a transmission **28**, **29** which drives a leadscrew **14***c* adapted to shift a tuning block **14***d* in the direction of arrow **14***e* between the legs **14***a* and **14***b* of the tuning fork. In the system illustrated, the frequency spectrum is scanned from the lower frequency end to the higher frequency end, although the reverse scanning may be desired from time to time. It will be understood that the stylus **22** generates spark discharge on the recording sheet **21** with intensity of breakdown which represents the intensity of the particular frequency to which the fork is tuned and at the particular instant. The overall result of the scan is represented by the spectrogram in FIG. **2**. FIG. **3** represents the frequency-intensity relationship or weighted frequency distribution of the component waves at a selected instant of time.

In accordance with the principles of this invention, an acoustic output is synthesized or reproduced from a spectrogram as shown in FIG. **2** or its modified or copied form. The system of FIG. **4** thus can comprise a drum **50** carrying a spectrographic trace **51** as indicated. The drum **50** is mechanically coupled, via a clutch **52**, with the drum **53** carrying a recording sheet such as a magnetic, electrostatic or optical recording sheet adapted to cooperate with a recording head **54** and a multiplicity of pickup heads or a unitary head **55** whose function will be described in greater detail hereinbelow.

The drums **50** and **53** are jointly driven at an identical angular velocity by a transmission **68** from a constant-speed motor **71**. Another output of the latter drives a leadscrew **56** whose carriage **57** supports the head **54** for movement along a generatrix of the drum **53**. A further leadscrew **58** is coupled with leadscrew **56** via the slip clutch **59** and shifts a scanning head **60** upon the carriage **61** along a generatrix of drum **50**. The leadscrew **58** also displaces a frequency-shift member **62** of a variable-frequency oscillator **63** (e.g., the movable member of a tuning condenser of a Hartley oscillator) adapted to generate the corresponding frequency oscillation signal to be fed to an amplitude-modulation gate **64**. The latter receives from the pickup head **60**, which can be of the optical type illustrated in FIG. **6** or FIG. **7**, a control signal (analog signal) **66** as a function of the intensity of the component wave registered on the spectrogram **51**, thereby delivering the amplitude-modulated oscillation signal upon amplification by amplifier **65** to the recording head **54**.

In operation, the spectrographic trace **51** is applied to the drum **50** and this drum, synchronized with the recording drum **53**, is set in rotation at the peripheral displacement rate at which the original sound was recorded or the synthesis sound is to be produced. The pickup head **50** adapted to effect step movement synchronous with the recording head, scans each incremental frequency of the trace **51** and produces an output at **66** whose amplitude is a function of the time-variable intensity of the respective component wave represented by darkness of the time-frequency plots and provides at the output of the gate **64** the amplitude-modulation signal to be amplified by the amplifier **65** and energizes the head **54** to record this amplified signal upon the drum **53** for reproducible manner.

Upon completion of one frequency scan, the pickup head **50**, the frequency-shift member **62** and the recording head **54** are set to the next incremental frequency position; the above-mentioned scanning and recording operation is repeated until the entire frequency range is translated from the visual spectrographic trace to the reproducible recording media. It will be understood that, depending on the purpose of the analysis and synthesis, a selected portion of the spectrographic trace may be canceled from the record of the data; in this case a corresponding blocking signal may be applied to the gate **64**. The synthesized sound will not have the eliminated portion of the spectrum.

The translated record upon recording drum **53** is synthesized into a sound signal, in accordance with this invention, by reproduction head **55** which can be composed of a multiplicity of pickup heads as shown arrayed along a common generatrix of the drum or an elongated unitary pickup head spanning the generatrix, and connected to an amplifier **69** whose output energizes a loudspeaker **70** or otherwise is magnetically recorded for direct acoustic reproduction.

When the synthesized output is to be modified by suppression or augmentation of the selected frequencies at this stage, the head **55** which in this case is a multiplicity corresponding in number to the incremental frequencies are connected via respective variable-gain amplifiers **55***a* to the common output amplifier **69** and the individual amplifiers adjusted accordingly. Furthermore, the relative weights of the respective frequencies or of a portion thereof can be evaluated by tapping the magnetic heads **55** selectively. Inasmuch as the head or heads **55** pick up the entire frequency spectrum simultaneously, the output at **70** corresponds essentially to the input at **11** (FIG. **1**) when no modification is entered in the spectrogram or the scanning stage and when the peripheral speed of drum **53** is identical to the peripheral speed of the recording drum **18**.

In FIG. **4***a*, there is shown a circuit specifically designed for use as amplitude-modulation gating means **64** of FIG. **4**. This circuit includes an input transformer T_i whose primary winding is energized by the constant-voltage, variable-frequency oscillator **63** whose output frequency is regulated by the shift member **62** as previously described.

The transformer T_i has its secondary winding divided into two sections by a center tap *c*, the end terminals of this secondary winding being connected across a high-impedance primary winding of an output transformer T_o via high-ohmic resistors R_1 and R_2, respectively, as shown. Across the secondary winding of the output transformer T_o is provided a load resistor RL at which an amplitude-modulated oscillation appears as will be described. The circuit further includes a pair of NPN transistors Tr_1 and Tr_2 having their respective emitter electrodes interconnected at a junction connected via a diode D of the indicated conduction orientation to the centertap *c* of the secondary winding of the input transformer T_i. Collector electrodes of these transistors are tied to the line connecting the high-ohmic resistor R_1 to the one terminal of the primary winding of the output transformer T_o and the line connecting the other high-ohmic resistor R_2 to the other terminal, respectively. The resistors R_1 and R_2 are of an identical ohmic value. Base electrodes of the transistors Tr_1 and Tr_2 are connected via their respective base resistors R_3 and R_4 commonly to one terminal E of an analog input while the common emitter junction of these transistors is connected to the other terminal of this analog input.

The input comprises a battery G of a fixed bias voltage and an input resistor R_5 across which is applied an analog signal **6** of the opposing polarity to the fixed voltage G and detected by the pickup head **60** as described earlier.

Let it be assumed that no signal appears across the input resistor R_5; then the transistors Tr_1 and Tr_3 are in conduction because of the fixed bias voltage G. Since the primary winding of the output transformer T_o is designed to be high-impedance as mentioned earlier, the positive and negative cycles of a transformed input alternating current V_{ab} (see FIG. **4***b*) appearing across the terminals A–B are both short-circuited through the conducting transistors Tr_1 and Tr_2 and the resistors R_1 and R_2, respectively, and through the common line of the diode D with the result that substantially no signal appears across the output transformer T_o, hence at the output resistor RL.

In scanning operation, let it be assumed that an input signal of waveform V**66** shown in the graph **2** appears at the resistor R_5; then terminal voltage V_{ef} will assume the voltage waveform of the graph **3** of FIG. **4***b* as the difference between the fixed bias voltage V_g and the input voltage waveform V_{66} which causes the collector-emitter impedance of the respective transistor Tr_1 and Tr_3 to vary in inverse proportionality to the net voltage V_{ef} across the terminals E–F. As the result, it will be readily appreciated that the amplitude-modulated oscillation signal as shown V_{jk} in the graph **4** appears at the terminal J–K of the output transformer T_o and the corresponding waveform signal at the output resistor RL.

In FIG. **5**, I show a system generally similar to that of FIG. **4** wherein, however, the spectrographic trace **51** of frequency/amplitude against time is generated by a stylus such as that shown at **22** in FIG. **1** and here represented at **122**. The block **113**, of course, represents the audio input and circuitry of the recording means of FIG. **1** or the similar device which may have the conventional construction with an electrical heterodyne system as shown in FIG. **5***a* and is energized by a microphone, stethoscope or like pickup means **107**.

In this embodiment, the recording drum is replaced by a roller **150** around which the belt **151***a* passes, an idler roller **150***a* being spaced from the roller **150**. A magnetic recording belt **152** likewise passes over the rollers **150** and **150***a* for recording the frequency/amplitude vs time scan. In this system, the recording and translating means are provided in one apparatus, the stylus assembly **122** being step-shifted in the direction of arrow *f* accomplishing each incremental frequency scan by a leadscrew assembly of the type illustrated at **23–28** of FIG. **1**.

In this case, the leadscrew of the stylus assembly **122** may be coupled with the motor **180**. The motor **180** drives a leadscrew **56, 156, 158** along which the optical pickup head **160** is shiftable jointly with the magnetic recording head **154**. An array of closely spaced narrow-band playback heads **155** (or a single elongated head) is provided along a generatrix of the belt **153** and connected by independent variable-gain amplifier (not shown) to the common amplifier **161** and loudspeaker **170**.

In this system, the variable-frequency oscillator **163** is regulated by a control member **162** driven by the lead-screw **156, 158** so that the frequency supplied to mixer **164** is tuned to the frequency band with which the pickup head **160** is aligned. A constant-frequency oscillator **165**, for generating the carrier frequency for the recording head **154**, is also connected to the mixer **164** which feeds an amplifier **181** and an electric switch **182**. A synchronizer synchronizes the output signal of the variable-frequency oscillator **163** with that of the constant-frequency oscillator **165**.

The electronic switch or gate **182** which may be that shown in FIG. **4***a* is controlled by the output from head **160** as represented at **167** and illustrated in FIG. **7**. The system of FIG. **5**, of course, operates essentially in the manner described with reference to FIG. **4**.

The input system illustrated in FIG. **5**a and energized by a mechanical-electrical transducer, includes the microphone **311** which feeds a magnetic tape recorder **311***a*. The variable frequency-oscillator **311***b* provides the carrier frequency which is modulated by the taped input at a mixer **311***c* before passing via a filter **311***d* to the amplifier **312**. Recording is done at **321** by stylus or the like, energized via the amplifier **316** which is fed by an amplitude-modulation network **316***a* to which a base signal is supplied by the constant frequency oscillator **316***b*.

In FIG. **6**, I show a pickup circuit with a self-intensifying feedback for use at **60** or **160** in the systems of FIGS. **4** and **5**, for example, and for general use in analyzing optically sensed traces of the present recording system. The system of FIG. **6** comprises a light source **260***a* which focuses a beam **260***b* of illumination upon the recording medium **251** via an optical system **260***c*. A reflected beam **260***d* is picked up by an optical system **260***e* and focuses via an iris-type diaphragm **260***f* upon the audio-optically sensitive transducer **260***q*. The latter may be a phototransistor connected to an amplifier circuit **260***h* with the reflected beam **260***d* forming the control element or base of the transducer.

In a simple version of this circuit, the phototransistor **260***q* is connected in series with a source of electric current, a load and a current transformer **260*i*** whose output is applied across a resistor **260*j***. The latter is connected in series with a d-c source **260*k*** shunted by an a-c passing capacitor **260*l*** in series with the filament of the lamp **260*a***.

The output of amplifier **260*h***, upon phase reversal, is delivered to the recording system **266** etc. as described in connection with FIGS. **4** and **5** (i.e., to the gate **64**, **182**). Thus the output received at **260*q*** is proportional to the optical recording upon layer **251** and delivers the appropriate control signal to the recorder **266**, while simultaneously intensifying this signal by applying an augmented current to the lamp **260*a***. This positive feedback ensures heightened contrast even with relatively light traces upon the recording medium **251**.

In the system of FIG. **7**, a nonintensifying arrangement is illustrated and here the lamp **360*a*** produces a beam **360*b*** which is directed at the recording medium **361** via an optical system **360*c***, the reflected beam **360*d*** being picked up by the optical system **360*e*** and focused upon a photoresistor **360*q*** connected in shunt across the output side of the variable frequency oscillator or the mixer **364** as described earlier. The switching system is represented diagrammatically at **382** and is here designed to short-circuit the frequency output **364** so that an output is delivered to the recording head **54** or **154** only when the reflected beam is of diminished intensity because of absorption at the spectrographic plots and, yet with an amplitude of the output oscillation signal proportional to the relative darkness of the plots.

In FIG. **8**, I have shown a sound-synthesis system in which a motor **520** drives a shaft **519** on which is mounted a first drum **521**, via a clutch **519*a***. The drum **521** carries a record sheet, e.g., a visible sound spectrogram, which is scanned by the optical scanner **522**.

The drum is mechanically coupled with a second drum **552** carrying a pair of magnetic tapes **552*a*** and **552*b***, the drums being rotated in synchronism and at a constant speed via the shaft **529*b*** and a magnetic clutch **519*c***. The record sheet is provided with a spectrographic trace **504*a*** of a given sound in which component frequency waves are plotted incrementally against time with the intensity of the component waves being represented by optically ascertainable conditions, preferably relative darkness of the plots. A spectrogram of this type has been illustrated in FIG. **2**.

The drum **521** is rotated to sweep each component frequency past the scanner in a particular "time position " of the latter. Parallel to the generatrix and axis of the spectrogram trace, I provide a shaft **524** which is driven by the motor **520** via a transmission represented at **508**. The carriage of the optical scanner **522** is mounted upon the leadscrew formed by the shaft **524** so that the optical scanner can be shifted continuously or stepped in the direction of the arrow shown in FIG. **8** (to the left) upon each rotation of the drum **521** or upon the completion of each complete frequency scan in the direction of the time axis.

A variable-frequency oscillator is provided at **510** and has an output frequency tuned to the frequency scanned by the optical scanner **522**, the tuning being effected by a frequency-control lever **510*a*** shifted by the leadscrew **524** synchronously with the optical sensor **522**.

Adjacent the drum **552** and along a generatrix thereof, I provide a pair of magnetic tape heads **554*a*** and **554*b*** confronting the respective magnetic tapes **552*a*** and **552*b***, the tapes extending around the drum **552**. The tape heads **554*a*** and **554*b*** each operate alternately as a recording and reproducing head as will be apparent hereinafter. In juxtaposition with tapes **552*a*** and **552*b***, I also provide respective erasers or cancelation heads **512*a*** and **512*b*** designed to clear previously recorded signals from each of the tapes.

At **513** there is provided a gate-type modulator at which the signal from the oscillator **510** may be amplitude modulated by a control or switching signal received from the optical sensor **522** and representing the instantaneous intensity of the frequency-time plots of the trace **504*a***. An amplitude modulated signal is then fed to a mixer **514** which may be supplied, via the reproducing stage **515** of the tape play-back system, with a reproduced signal from one of the magnetic tapes **552-*a*** or **554*b*** as derived by the head **554*a*** or **554*b*** which operates in the reproduced or play-back mode. The other head, of course, simultaneously operates in the record mode. A filter **516** (See FIG. **9**) may be provided to remove background noise or selectively modify the acoustical signal delivered to the mixer from the tape **552*a*** or **552*b***. The mixed signal is magnetically recorded on the previously erased tape **552*a***, **552*b***, by a recorder **517**. An oscillator **518** is provided to supply to the recorder **517** an alternating bias current for magnetic recording and also to supply a canceling signal to the erase head **512*a***, **512*b*** via a switch **619**. A switch **620** selectively connects the output of the recorder **517** to one of the recorder circuits of the respective heads **554**a_1, **554**b_1 while a switch **621** selectively connects one of the reproducing circuits **554**a_2 and **554**b_2 of the heads with the reproducer **515**. A further switch **622** can switch the output of a filter **516** into an electrical-acoustic transducer **623** via an amplifier **624** for reproduction of an acoustic output.

In operation, let it be assumed that the switches **619**, **620**, **621** and **622** are in the respective positions indicated in FIG. **9** for scanning of frequency F1. Then, the output frequency of the oscillator **510** is set in F1 by the lever **510*a*** and this output signal is amplitude-modulated at the gate **513** in the manner previously described. The amplitude-modulated oscillation signal is fed to the mixer **514** and, in the absence of any input from the reproducer **515**, directly to the recorder **517** which then energizes the recording head **554**a_1 to magnetically record said signal on the recording tape **552*a*** on which any previous recording if present has been canceled by the erase head **512*a***.

When the optical head **522** completes the frequency F1 scan of the spectrographic trace as the drum **518** accomplishes one rotation, the drive **520** is temporarily stopped or continuously shifts the head **522** to the next frequency-scanning position F2, while shifting the output frequency of the oscillator **510** to F2 via the lever **510*a***. At the same time, switches **519**, **520** and **521** are thrown into positions **512*b***, **554**b_1 and **554**a_2, respectively. In this step, the prior recording of frequency F1 registered on the tape **552*a*** in the preceding step is erased by head **512*a***, but the signal is reproduced via the head **554*a*** serving now as a reproducing or playback head, the reproducer **515** and the filter **516**, and is fed to the mixer **514** while the tape **554*b*** receives a recording signal from the head **554*b*** serving in this step as a recording head.

Thus, upon commencing scan, an amplitude-modulated signal of frequency F2 is derived at the output of the gate circuit **513** and combined at the mixer **514** with the reproduced signal of frequency F1, the resultant mixed signal F1+F2 being recorded on the tape **552*b*** via the recorder **517** and the recording head **554b** as the optical scanner proceeds in the scanning of component frequency F2 on the spectrographic trace.

Subsequently, for scanning the next frequency component F3, the switches **519**, **520** and **521** are returned to the indicated positions and the frequency of the oscillator **510** is shifted to F3 with the scanning head **522** shifted to the position corresponding to F3. An amplitude-modulated oscillation signal of frequency F3 is generated under control of the optical scanner **522** and fed to the mixer **514** which also receives the reproduced signal F1+F2 from the tape **552*b***.

The resultant mixed signal F1+F2+F3 is recorded on the tape **552*a*** while the previously recorded signal F1+F2, being presently reproduced, is erased from the tape **522*b*** by the head **512*b***.

With the above-mentioned steps repeated, the overall frequency spectrum or any interesting portion thereof is recorded finally either on the tape **552*a*** or **552*b*** for reproduction into an acoustic wave. For reproduction, the switch **522** is thrown to connect the reproducing head **554*a***$_2$ or **554*b***$_2$, depending on which has the final recording, to the audio amplifier **624** and the speaker **623**.

I claim:

1. A method of synthesizing an acoustical signal from a spectrograph trace in which component frequency portions of sound are incrementally plotted against time over a predetermined time period with the intensity of the components being represented by varying density of the plots at corresponding frequency-time points, said method comprising the steps of:

scanning said trace successively for said incremental frequency portions over said period and deriving analog signals of amplitude as a function of the density of the plot of the respective frequencies;

synchronously with the scanning of the trace generating oscillation signals at the respective scanning frequencies during said period and amplitude-modulating said oscillation signals by the analog signals of amplitude to produce amplitude-modulated oscillation signals;

recording said amplitude-modulated oscillation signals upon a medium in a multiplicity of tracks;

scanning said medium and generating automatically in response to the scanning of the medium a reproduction of the recorded signals to produce a synthesized acoustic signal corresponding to a summation of the amplitude-modulated signals.

2. The method defined in claim **1** wherein said signals are additively combined by simultaneously reproducing signals from all of the recorded trace.

3. The method defined in claim **1** wherein the acoustical signal reproduced from the recording of said amplitude-modulated oscillation signals is substantially identical to the acoustical input forming said spectrographic trace.

4. The method defining in claim **3**, further comprising the step of subtracting a part of the acoustical signal represented by said spectrographic trace prior to reproducing the recorded amplitude-modulated oscillation signals.

5. The method defined in claim **4** wherein said spectrographic trace is a voice spectrogram of the pronunciation of an individual.

6. The method defined in claim **1**, further comprising the steps of preparing said spectrographic trace prior to the scanning thereof, by plotting component waves of an acoustical input along incremental frequency bands against time over said period while recording the intensity of the component waves as relative lightness and darkness of the respective plots at the corresponding frequency-time points; and

modifying at least a portion of the plotted information prior to the scanning of the spectrographic and trace acoustically comparing the synthesized acoustic signal with the original acoustic input.

7. The method defined in claim **6** wherein a further spectrographic trace is produced from the spectrographic trace as first prepared by modifying information relating to at least some of the component frequencies, said further spectrographic trace being subjected to the scanning step.

8. The method defined in claim **6** wherein the component waves of the acoustic input are plotted successively in said incremental frequency bands.

9. A method of synthesizing an acoustical signal from a spectrographic trace in which component frequency portions of sound are incrementally plotted against time over a predetermined time period with the intensity of the components being represented by varying density of the plots at corresponding frequency-time points, said method comprising the steps of:

scanning said trace successively for said incremental frequency portions over said period and deriving analog signals of amplitude as a function of the density of the plot of the respective frequencies;

synchronously with the scanning of the trace generating oscillation signals at the respective scanning frequencies during said period and amplitude-modulating said oscillation signals by the analog signals of amplitude to produce amplitude-modulated oscillation signals;

recording said amplitude-modulated oscillation signals upon a medium; and

scanning said medium and generating automatically in response to the scanning of the medium a reproduction of the recorded signals to produce a synthesized acoustic signal corresponding to a summation of the amplitude-modulated signals, each amplitude-modulated oscillation signal but the first being combined with a previously recorded amplitude-modulated oscillation signal during a previous scan whereby the final recording represents a summation of all of said amplitude-modulated oscillation signals on a single track.

10. The method defined in claim **9** wherein said trace is a visible spectrogram and said density is the relative darkness of parts of the trace.

11. The method defined in claim **9** wherein said spectrographic trace is formed from an acoustical input.

12. The method defined in claim 9 wherein said spectrographic trace is prepared artificially based upon analysis of related sound.

13. A method of analyzing an acoustic input, comprising the steps of:

a. detecting successive incremental frequency bands of the acoustic input and resonating a mechanical element at the band frequency with an oscillation amplitude representing the intensity of the corresponding frequency band;
b. recording for each incremental frequency band detected in step (a), a visible plot with the amplitude of the corresponding frequency band at each instant of time during a time interval represented by a corresponding degree of darkness of the plot, thereby forming a spectrographic trace in which component frequency waves of the acoustic input are incrementally plotted against time over a given time period with the intensity of the component waves indicated by relative darkness of the plots at the corresponding frequency-time points;
c. optically scanning said trace successively for said incremental frequencies and deriving an electrical output of an amplitude varying with time in accordance with the relative darkness of the plot of the corresponding frequency;
d. generating an electrical oscillation of a frequency corresponding to each of the scanned frequencies in step (c) and amplitude modulating the electrical oscillation with the corresponding electrical output of step (c) to form amplitude-modulated oscillation signals;
e. electrically combining the amplitude-modulated oscillation signals of step (d) for the incremental frequencies; and
f. automatically converting the combined amplitude-modulated oscillation signals of step (e) into an acoustic output.

14. The method defined in claim 13 wherein said amplitude-modulated oscillation signals are combined in step (e) by recording the first amplitude-modulated oscillation signal upon one recording track, recording the next amplitude-modulated oscillation signal and the previously recorded amplitude-modulated oscillation signal upon another recording track while cancelling the previously made recording, and repeating the recordal and cancellation steps until one of said tracks carries a recording of the combined amplitude-modulated oscillation signals.

15. The method defined in claim 13 wherein said amplitude-modulated oscillation signals are combined by recording them individually upon a single recording medium.

16. An apparatus for the synthesis of an acoustic output from a spectrographic trace in which component frequency portions of an original sound are incrementally plotted against time over a predetermined time period with the intensity of the components being represented by varying density of the plots at corresponding frequency-time points, said apparatus comprising:

scanning means for repetitively scanning said trace successively for said incremental frequencies and deriving for each of the scanned frequencies analog signals of an amplitude varying with the time in proportion to the density of the plots of the respective component frequencies;

oscillator means operatively connected with said scanning means for producing respective oscillation signal corresponding to each of the scanning frequencies;

amplitude-modulating means connected with said scanning means and with said oscillator means for producing an amplitude-modulated oscillation signal as a function of time for each of the scanned frequencies;

means for combining at least some of said amplitude-modulated oscillation signals; and

electroacoustic transducer means for producing an acoustical output corresponding to the combined amplitude-modulated oscillation signals.

17. The apparatus defined in claim 16 wherein said trace is visible and the varying density of said plots is represented by different degrees of darkness, said scanning means including an optical scanner adapted to sweep said trace and provided with a source of illumination trained at said plots successively and optically sensitive pickup means receiving reflected light from said plots for detecting the degree of darkness thereof.

18. The apparatus defined in claim 16 wherein said means for combining said amplitude-modulated oscillation signals includes a single recording medium and means for recording said amplitude-modulated oscillation signals successively on separate tracks of said medium.

19. The apparatus defined in claim 16 wherein said scanning means includes a drum carrying said trace and rotatable about an axis parallel to the time axis of said trace and a scanning head displaceable parallel to a generatrix of said drum, said oscillator means comprising a variable-frequency oscillator having a frequency-selection member and means operatively connecting said head with said member.

20. An apparatus for the synthesis of an acoustic output from a spectrographic trace in which component frequency portions of an original sound are incrementally plotted against time over a predetermined time period with the intensity of the components being represented by varying density of the plots at corresponding frequency-time points, said apparatus comprising:

scanning means for repetitively scanning said trace successively for said incremental frequencies and deriving for each of the scanned frequencies analog signals of an amplitude varying with the time in proportion to the density of the plots of the respective component frequencies;

oscillator means operatively connected with said scanning means for producing respective oscillation signal corresponding to each of the scanning frequencies;

amplitude-modulating means connected with said scanning means and with said oscillator means for producing an amplitude-modulated oscillation signal as a function of time for each of the scanned frequencies;

means for combining at least some of said amplitude-modulated oscillation signals; and electroacoustic transducer means for producing an acoustical output corresponding to the combined amplitude-modulated oscillation signals, said means for combining said amplitude-modulated oscillation signals including

a pair of synchronously driven recording tracks,

recording means associated with each of said tracks,

playback means associated with each of said tracks,

cancellation means associated with each of said tracks, and

switch means operable to connect the recording means of one of said tracks to said amplitude-modulating means and the playback means of the other of said tracks to said recording means of said one of said tracks to record the amplitude-modulated oscillation signal of the frequency currently scanned by said scanning means upon said one of said tracks concurrently with a previously recorded amplitude-modulated oscillation signal from said other track, while cancelling the recorded signal on said other track.

21. An apparatus for the synthesis of an acoustic output from a spectrographic trace in which component frequency portions of an original sound are incrementally plotted against time over a predetermined time period with the intensity of the components being represented by varying density of the plots at corresponding frequency-time points, said apparatus comprising:

scanning means for repetitively scanning said trace successively for said incremental frequencies and deriving for each of the scanned frequencies analog signals of an amplitude varying with the time in proportion to the density of the plots of the respective component frequencies;

oscillator means operatively connected with said scanning means for producing respective oscillation signals corresponding to each of the scanning frequencies;

amplitude-modulating means connected with said scanning means and with said oscillator means for producing an amplitude-modulated oscillation signal as a function of time for each of the scanned frequencies;

means for combining at least some of said amplitude-modulated oscillation signals;

electroacoustic transducer means for producing an acoustical output corresponding to the combined amplitude-modulated oscillation signals;

sound-analyzing means for producing said trace and including vibratory means having a resonance-shifting member, means responsive to an acoustical input for energizing said vibratory means; and

means responsive to the amplitude of vibration of said vibratory means at successive resonant frequencies thereof for forming said trace.

22. The apparatus defined in claim **21** wherein said sound analyzing means includes a recording head adapted to sweep a recording medium for producing an electrical discharge forming visible marks thereon.

23. The apparatus defined in claim **21** wherein said vibratory means includes a tuning fork, said member being shiftable between the arms of said fork, said input means constituting a first electromagnetic transducer co-operating with one of said arms and said output means constituting a second electromagnetic transducer co-operating with the other of said arms.

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