

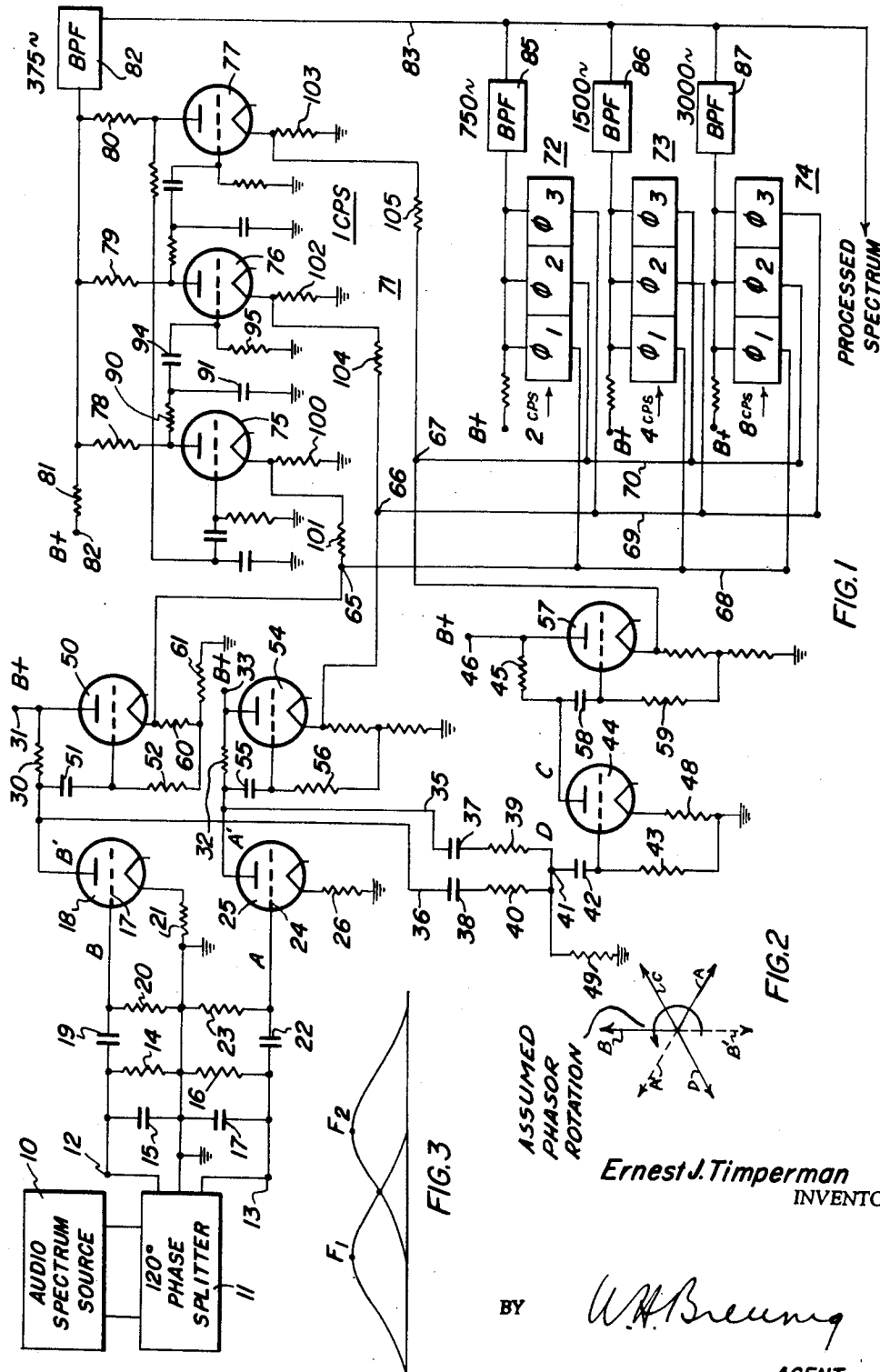
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AUDIO MODULATOR

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AUDIO MODULATOR

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This invention is an improvement of an invention disclosed in an application for United States patent which is filed concurrently herewith, Serial No. 631,650, filed December 31, 1956, in the name of William C. Wayne, entitled Audio Modulation System, assigned to the same assignee as is the present application.

The present invention relates generally to systems for achieving ensemble effect in music by processing a band of audio frequencies subsisting in a communication channel, by translating the frequency spectrum so that it is either sharp or flat in controllable degree over its entire extent, or is in part flat and in part sharp, and to frequency shift circuits useful in such systems. A frequency spectrum processed in accordance with the invention may be audibly combined with the frequency spectrum as it existed prior to processing, as by transducing the processed and unprocessed spectra in, preferably, space separated loud-speaker systems, to provide desirable musical effects.

It is not sufficient, however, to shift the frequencies of an audio band identically, i.e., by the same shift frequency, for the purposes of the present invention, but rather the frequency shift must be different for different portions or sub-bands of the audio frequency spectrum, and specifically the higher audio frequencies must be shifted in greater degree than are the lower audio frequencies. The reason is that it is desired to generate a subjectively differentiable spectrum, by processing an originally available spectrum. In accordance with the present invention, the audio band which is to be processed is frequency shifted by different amounts, in separate frequency-shift modulators. Sub-bands are then selected from the frequency shifted audio bands, such that each selected sub-band has a desired percentage frequency shift. The percentage frequency shift may be equal for all the sub-bands, although this is not essential, and it is advantageous and economical to select the sub-bands each to be approximately one octave in extent. However, the percentage frequency deviation selected may differ for the several sub-bands, and one or more, or all the sub-bands may extend for more or less than an octave.

While the above-identified Wayne application for Audio Modulation Systems relates generally to the same subject matter as does the present invention, the present application discloses and relates to improvements in circuitry over the system disclosed in the Wayne application, as well as to system improvements which lead to differences in character of the processed frequency spectrum produced by the system.

The traditional pipe organ consists of many ranks of pipes which are somewhat out of tune. Certain ranks of pipes, referred to as celestes, are purposely detuned by a considerable amount to produce a rich ensemble effect in the composite tone, which is especially desirable for use in ecclesiastical music. It is one function of systems according to the present invention to provide for

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electrically processing a musical spectrum, from whatever source that spectrum may be derived, so as to achieve a processed frequency spectrum which simulates the ensemble effect of pipe organs, and more particularly the celeste effect, but which is more flexible in respect to the variety of ensemble effects made available than is the traditional pipe organ.

According to the general principles of the present invention, as related to a specific embodiment thereof, in order to derive a plurality of frequency shifted spectra having different shifts, a plurality of wide-band single side-band frequency shift modulators is employed, each of which continuously shifts the phase of a wide-band audio spectrum in such sense as to introduce a desired phase shift of the entire frequency spectrum continuously in a given direction. This continuously changing phase shift is equivalent to a frequency shift of the entire spectrum, and the direction of shift may be either flat or sharp, i.e., negative or positive in accordance with the algebraic sign of the rate of change of phase shift, i.e., if phase shift is continually decreasing, or increasing in a negative sense, a frequency shift in a negative direction results, while for continually increasing phase shift, or for phase shift occurring in a positive sense, the frequency shift is positive.

In order to accomplish an objective of the invention, i.e., to produce a continuous phase shift, in one direction or another, of an entire audio frequency spectrum, the spectrum is divided into three separate spectra, which are identical except in respect to phase. The phases of the several spectra are, in accordance with the specific embodiment of the invention herein described, separated by 120°. The principles of the invention are such that other equally spaced phase separations may be employed. However, separations of 120° between corresponding frequencies of the several spectra is particularly convenient because this is the smallest number of duplicate spectra which may be employed, i.e., involves the greatest phase separation between adjacent phases, of which the principles of the invention admit.

In the practice of the invention, and discussing the invention as employing three-phase modulation, it is required to modulate the amplitudes of the three-phases of an audio frequency spectrum in proper phase sequence, in response to three phases of a sub-audio modulating signal, such that an effective frequency shift of the audio frequency spectrum is accomplished equal to the frequency of the modulating signal. This is accomplished in accordance with the present invention, in a three phase oscillator-modulator which is particularly economical and readily constructed. To that end the oscillator-modulator employs one tube per phase, that tube being employed both as an amplitude modulator for one phase of the audio spectra and also as a component of the oscillator.

Various problems exist in accomplishing frequency shift in accordance with the principles of the present invention, particularly when it is sought to apply the invention to equipment fabricated on a mass production basis. These problems are in part involved in the correlation of sources of phase shifted audio spectra with any one sub-audible oscillator-modulator, but also derive from the fact that common sources of phase separated audio spectra must be commonly coupled to a plurality of oscillator modulators, each of which oscillates at a different sub-audible frequency, so that inter-coupling between the oscillator-modulators by way of the channels carrying the phase separated audio signals must be avoided.

The necessity for a plurality of sub-audio oscillator-modulators derives, as has been hereinabove explained, from a requirement that adjacent octaves or other sub-bands of the original frequency band be shifted in op-

posite directions frequencywise, and by a further requirement that there obtain at least approximately a constant percentage frequency deviation for the several shifted frequencies, in certain applications of the invention. This implies that the audio octaves of lower frequency require a smaller shift, and accordingly must be processed in an oscillator-modulator of lower modulation frequency than is true of octaves of higher frequency. In accordance with the present invention, in the specific embodiment herein illustrated and described, the three phase-separated audio bands are frequency shifted in four frequency-shift channels, each of which includes a three-phase oscillator-modulator, alternate ones of the oscillator-modulators being arranged to produce frequency shifts in opposite sense. From the outputs of the several oscillator-modulators are selected these octaval sub-bands which have the desired frequency deviations, and in the particular embodiment herein considered the selected octaval sub-bands so derived are centered on the frequencies 375 c.p.s., 750 c.p.s., 1500 c.p.s. and 3000 c.p.s., and the frequency shifts are +1 c.p.s., -2 c.p.s., +4 c.p.s. and -8 c.p.s., respectively.

Several specific features contribute in preponderant extent to the efficiency and reproducibility of the present system. Audio frequency signal is derived at three channels from cathode-follower circuits, so that the audio frequency voltage is supplied to the several oscillator-modulators from sources of low impedance. The oscillator-modulator stages are driven by the audio frequency spectra at their cathode circuits, which constitute loads which are of relatively low resistance. A D.C. coupling network is established between a cathode of an audio channel and a cathode of an oscillator-modulator stage, in which is included an isolating resistance which is high with respect to both the output impedance of the cathode follower and the cathode resistance of an oscillator-modulator.

Cathode circuits of corresponding location in the several oscillators are D.C. coupled with a single source of audio spectrum, according to the present invention, but each such cathode is decoupled from the others by the presence of the isolating resistances used to couple between the cathode of an audio source and the cathode of an oscillator-modulator stage. In traversing a path from the cathode of one oscillator-modulator stage to the cathode of another oscillator-modulator stage, two of the isolating resistances are traversed, and in view of the relative resistance values of the isolating resistors as against the resistance values of the cathode resistors, isolation of the order of 80 db is achieved, without requiring complex circuitry and without the circuit difficulties which might be introduced were coupling condensers resorted to.

Oscillator-modulators of the ring type, having RC phase-shift circuits between stages, are employed. Each of the stages of any given oscillator-modulator operates to amplitude modulate one audio frequency band, phase separated from the remaining audio frequency bands. Each stage of the oscillator-modulator employs its own unby-passed cathode resistor, according to the invention, which is employed to couple audio signal into the oscillator-modulator. There is thus provided for each of the oscillator-modulator tubes an individual and independent cathode or negative feedback impedance, which stabilizes the operation of the particular tube, and which makes it unnecessary to select tubes for the oscillator-modulator. While employment of negative feedback is in broad principle well known in the art, in accordance with the present invention the cathode resistances perform dual functions, i.e., they are utilized as input resistances for the separate oscillator-modulator stages and also serve to stabilize each of the several stages independently of the others.

Still further, however, a component of bias voltage for each tube of the oscillator-modulator is developed across

its own cathode resistance, while by reason of the D.C. coupling between the cathode of each oscillator stage and a cathode of an audio output stage, the D.C. cathode voltage of the audio stage is transferred in part to the cathode circuit of the oscillator stage, and assists in maintaining its bias at a positive value with respect to ground, so that the grid voltages of the oscillator stages, which are inter-coupled within the oscillator in part by means of conventional capacitor and grid leak combinations, can never be positive with respect to the cathode before oscillation commences in the oscillator-modulator. Each stage of the oscillator is, accordingly, provided with bias by a combination of voltages available across a grid leak and across a cathode resistance, and cathode bias voltage otherwise developed across each oscillator stage is supplemented by a component of cathode bias voltage derived from the cathode circuit of an audio signal stage.

In the above-identified application filed in the name of Wayne, and entitled Audio Modulation System, desired subbands are filtered from the several frequency shifted wide audio bands by means of band-pass filters which have relatively sharp cut-off regions. In accordance with the present invention, and in distinction to the Wayne disclosure, the band-pass filters employed to separate out the desired sub-bands from the several frequency shifted wide audio bands have gradually sloping sides, and the selectivity characteristics of filters which pass adjacent sub-bands are arranged to cross at points about 2 db down from the peak response. It follows that a large proportion of the wide audio frequency band is passed to the output channel of the system by two, or even more, of the band-pass filters. Any given audio frequency in the original audio spectrum suffers different frequency shifts prior to application to the input circuits of the several filters. Multiple responses of different frequency separation from the original frequency, are thus passed to the output channel, which may have high relative amplitudes. Moreover, the band-pass filters introduce phase shifts at the skirts thereof, so that the signals in the output channel, deriving from a given frequency in the original audio band are randomized in respect to relative amplitudes and relative phases for the several frequency shifts which occur.

It is, accordingly, a broad object of the present invention to provide a system for producing frequency shifts of a wide audio frequency band by means of circuitry which is readily reproducible on a mass production basis, without requiring component or tube selection.

It is another object of the present invention to provide a simple oscillator-modulator of the ring type, in which the signal to be modulated may be inserted at the cathodes of the tubes constituting the stages of the oscillator-modulator.

A further object of the present invention resides in the provision of a novel oscillator of the ring type, employing phase shift circuits between stages, in which each stage is individually biased by voltage developed in its cathode circuit, as well as by means of a grid leak.

Still another object of the invention resides in the provision of a system for coupling modulator signal to a plurality of oscillator-modulators in parallel, while providing isolation between the oscillator-modulators, the isolation and coupling networks consisting of simple resistance combinations.

A further object of the invention resides in the provision of a system for supplying a signal to a modulator tube by means of a connection between the cathode of the modulator signal source and the cathode of the modulator tube.

A further object of the invention resides in the provision of a system for supplying modulator signal from a vacuum tube source to a modulator stage which comprises a vacuum tube, by means of a D.C. circuit employing no coupling capacitors, to provide an extremely wide band response and zero phase shifts.

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As a further feature of the invention, portions of the audio frequency spectrum which have been subjected simultaneously to plural frequency shifts, in opposite senses, are selected by employing band filters, for the several octaval sub-bands, which have extensive overlaps.

The above and still further features, objects and advantages of the present invention will become apparent upon consideration of the following detailed description of a specific embodiment of the invention, especially when taken in conjunction with the accompanying drawings, wherein:

Figure 1 is a circuit diagram of the invention, partly in schematic form, and partly in block diagram form;

Figure 2 is a phasor diagram employed in explaining the operation of the system of Figure 1; and

Figure 3 is a frequency response curve for certain band selector filters employed in the practice of the invention.

Referring now more particularly to the accompanying drawings, the reference numeral 10 denotes a source of an audio frequency spectrum, which may derive from an electronic organ or from a movie sound track or other reproducer of recorded music, or from any other source of sound or music known to the art. The audio frequency spectrum supplied by the source 10 is passed through a 120° phase-splitter 11, which may be constituted of any suitable circuit capable of providing at output terminals 12 and 13 audio frequency spectra which duplicate the spectrum provided by the source 10 in respect to at least that portion of the frequency spectrum which is of interest in the present system, so that the total phase difference between any common frequency at the terminals 12 and 13 equals 120°. In general, for the purposes of the present system, it is not essential that the 120° phase-splitter 11 be capable of accomplishing these specified phase shifts over the entire audio frequency spectrum supplied by the source 10, since in processing music according to the present invention, it is not normally essential to process either extremely low frequencies or extremely high frequencies within the audio band, and this consideration makes possible a simpler design and less stringent requirements for the phase-splitter 11, as well as for other elements of the system, than would otherwise be the case. More specifically, as will appear as the description proceeds, it is desired in a specific embodiment of the present invention to process four octaves of the musical spectrum only, those four octaves being the octaves centered on 375 c.p.s., 750 c.p.s., 1500 c.p.s., and 3000 c.p.s. It is to be understood, however, that the invention is not limited to the specific octaves specified, nor to the specific number of octaves specified, but it may be understood that if the specified octaves are processed desirable musical effects will be accomplished. The parallel resistance 14 and capacitor 15, and the parallel resistance 16 and capacitor 17, constitute terminating impedances for the phase-splitter 11, and the junction point of the resistances 14, 16 is located at reference or ground potential. The voltage developed across the resistance 14 is transferred to the grid 17 of triode 18 via a conventional RC coupling network consisting of a series capacitor 19 and a grid bias resistance 20. The triode 18 is connected in a plate loaded configuration, including an unby-passed cathode resistance 21. Similarly a coupling capacitor 22 and a grid lead resistance 23 are connected in conventional fashion across the resistance 16 and supply signal to the grid 24 of a triode 25. The latter is connected in plate loaded configuration and includes an unby-passed cathode resistance 26. Triode 18 is plate loaded by a resistance 30, and supplied with plate voltage from a B+ source represented as a terminal 31. Similarly the triode 25 is plate loaded by a resistance 32 and is supplied with plate voltage from a B+ terminal 33. It will be realized that the terminals 31 and 33 may be supplied from a common source, as is usual in electronic circuit design. The triodes 25 and 18 provide a gain at their anodes, which are connected by means of

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leads 35 and 36, respectively, and through blocking capacitors 37 and 38 and isolating resistance 39 and 40, respectively to a common load resistance 49, at terminal 41, the other end of the resistance 49 being grounded. The resistances 39 and 40 are selected to have sufficiently high values that interchange of signals between the anodes of the triodes 18 and 25 is minimized, and the presence of the triodes in the coupling circuits assures isolation between the halves of the lattice network which is in fact employed as a 120° phase-splitter 11 in a specific embodiment of the invention, as more specifically described in Wayne, Audio Modulating System, above referred to. The terminal 41 is connected in series with a coupling capacitor 42 and a grid leak resistance 43 which constitute the input circuit of the triode 44. The triode 44 is plate loaded by a resistance 45 and supplied with plate voltage from a B+ terminal 46. The triode 44 includes a cathode circuit consisting of an unby-passed resistance 48 which is returned to ground.

It will be recalled that the signal at the terminals 12 and 13 are, for any single frequency separated in phase by 120°, as indicated in Figure 2 of the accompanying drawings by the phasors A and B. (Corresponding reference letters in Figure 1 show where phasors are located.) The sum of the phasors A and B would then be a phasor C, and would have a phase intermediate that of the phasors A and B. Plate loaded triodes 18 and 25 serve to reverse the phases of the inputs applied thereto, so that at the anodes of these tubes are the phasors A' and B', respectively, rather than the phasors A and B. The sum of the latter is then the inverse of the phasor C, i.e., is displaced with respect to the latter by 180° and is illustrated at D. It is this sum (i.e., phasor D) which is developed across the grid leak resistance 43 of the triode 44. The triode 44 introduces a further phase shift of 180°. It follows that at the anodes of the triodes 18 and 25, and at the anode of the triode 44 appear three voltages, one for each triode, which are displaced in phase by 120°, and correspond with A', B', C.

The signal available at the anode of the triode 18 is coupled to the control grid of a further triode 50, by means of a conventional RC coupling network consisting of capacitor 51 and grid leak resistance 52. Similarly the signal available at the anode of the triode 25 is coupled to the grid of a triode 54 by means of a conventional RC coupling network consisting of a capacitor 55 and a grid leak resistance 56. The signal available at the anodes of the triode 44 is likewise transferred to the grid of a triode 57 via a conventional RC coupling network consisting of a capacitor 58 and a grid leak resistance 59. The triodes 50, 54, and 57 are connected in cathode follower configuration, including two cathode resistors in each case, connected in series. Since the cathode arrangements for the several triodes 50, 54 and 57 are identical, the description will be restricted to the cathode circuits for the triode 50, which consists of resistances 60 and 61.

The grid leak 52 returns to the junction of the cathode resistances 60 and 61. Resistance 60 is small relative to the resistance 61, by a factor of approximately 10 to 1. Resistance 60, being common to the grid circuit of the triode 50, serves to develop bias for the cathode follower. The series combination of resistances 60 and 61 serves as a partial output load resistance for the triode 50. The circuits of triode 50, 54 and 57 do not introduce phase reversals, and accordingly there is available at the terminals 65, 66 and 67 the separate phases of a three-phase replica of that portion of the audio signal which has been transferred by the several coupling components existent between the audio spectrum source 10 and the terminals 65, 66 and 67.

The terminals 65, 66, and 67 constitute connections to a set of three leads or buses 68, 69 and 70, to which are connected an array of oscillator modulators 71, 72, 73

and 74. The several oscillators are generally similar in configuration and in theory of operation, but oscillate each at a different sub-audio frequency. It follows that the circuit components for the several oscillators will not be identical, but will be suitable for the frequencies required to be generated. Nevertheless in view of the similarity of the oscillators, specific description will be restricted to one of these, i.e., 71, and the remaining oscillators are illustrated in block form.

It has been previously explained that a relatively wide audio band is supplied to a plurality of oscillator modulators in parallel and that from the output of each oscillator modulator is selected approximately 1 octave of the original band. Selection is accomplished by means of filters, which may be of particularly simple character and in fact may consist essentially of a parallel tuned circuit. The filters are designed, in accordance with one feature of the present invention, so that their peaks fall on the center of the selected octaves, while their skirts taper gradually. The cross-over points for adjacent filters may occur approximately 2 db down from the peaks, and accordingly the filter for any given band passes frequencies from an adjacent octave in considerable amplitude and in fact may pass appreciable signal from an octave twice removed. It follows that certain components of frequency of the original audio band are modulated with more than a single frequency shift, and accordingly with more than a single percentage deviation. This mode of operating has been found to be advantageous in producing enhanced tones, since the result of the multiple treatment of any single frequency results in more or less random phase shifts and amplitude changes, which are analogous to chorus or ensemble effects in pipe organs.

Proceeding now more specifically to describe the phase shift oscillator of the invention, and confining the discussion to a three-phase oscillator-modulator, with the realization in view that the principles of the invention may be extended to two-phase oscillator-modulators or to oscillator-modulators having more than three phases, each phase includes a single triode, the triodes being denoted by the reference numerals 75, 76 and 77. The triodes 75, 76 and 77 have separate anode loads, which are identified by the reference numerals 78, 79 and 80, respectively, and also a common load resistance, 81, connected between a B+ terminal 82 and the several resistances 78, 79 and 80 in parallel. Resistance 81, accordingly, provides a common output load for the three triodes, and to the junction of resistance 81 with resistances 78, 79, and 80 is connected a band-pass filter 82, the output of which is applied to a lead 83. The several oscillators 72, 73 and 74 likewise develop output signal, via separate band-pass filters 85, 86 and 87 respectively, the outputs of all of the latter being connected in parallel to the lead 83. The band-pass filters 82, 85, 86 and 87 have, respectively, center frequencies of 375 c.p.s., 750 c.p.s., 1500 c.p.s., and 3000 c.p.s., and have the band-pass characteristics indicated in approximate form in Figure 3 of the accompanying drawings, where the peaks of the several filter characteristics occur at the centers of the octaval band passed by the filters, and wherein the skirts of the several filters overlap extensively. In a preferred embodiment of the invention, cross-over points occur 2 db down from the peaks of the filters. The particular advantage in systems for processing musical tones or spectra, which is possessed by the filter arrangement hereinabove described has been briefly indicated.

The triode 75 is coupled at its anode to the control grid of the triode 76 by means of a phase shift network consisting of a series resistance 90 and a capacitor 91, one end of which is grounded. Across the capacitor 91 is connected a series combination of a capacitor 94 and a grid leak 95, and the grid of the triode 76 is connected

to the above-ground end of the grid leak resistance 95, in conventional fashion. The grid leak resistance 95 has a high ohmic resistance in comparison with the resistance 90 of the phase-shift circuit, so that the grid leak circuit will not of itself introduce appreciable phase shift, and the configuration of the circuit is such that the grid leak circuit, insofar as it introduces any phase shift at all, introduces a phase shift in opposite sense to that of the phase shift circuit consisting of resistance 90 and capacitor 91. Identical phase shift circuits are utilized to intercouple the three stages of the oscillator in ring fashion, and accordingly further discussion of the interstage coupling networks is dispensed with.

The several oscillator-modulators 72, 73 and 74 have been illustrated as wired to have the same internal phase sequence as does the oscillator-modulator 71. The connection between the buses or leads 68, 69 and 70 is the same for oscillator-modulators 71 and 73, but in reverse phase sequence for oscillator-modulators 72 and 74. Accordingly, the direction of frequency shift produced by the modulator 71 and by the modulator 73 is in the same sense, i.e., positive, while the frequency shift produced by the oscillator 72 and 74 is in the opposite sense, i.e., negative. Frequency of oscillation of the oscillator 71 may be selected to have a value of 1 c.p.s., while the oscillators 72, 73 and 74 may have frequencies of oscillation respectively equal to 2, 4 and 8 c.p.s.

There is, accordingly, provided on the lead 83 a processed audio spectrum, consisting of a frequency shifted duplicate of the unprocessed spectrum, the frequency shift having approximately a constant percentage value.

The effect of the system on a single tone, made up of a fundamental and harmonics, is instructive. We may assume that the fundamental frequency of the unprocessed tone is 375 c.p.s. The fundamental frequency of the processed tone is 376 c.p.s., of the first harmonic is 748 c.p.s., of the third harmonic is 1129 c.p.s., and of the fourth harmonic is 1492 c.p.s. There is thus introduced an inharmonicity of tonal content, which may have been absent in the original unprocessed tone, and which is musically interesting.

The effect is accentuated by the filters 82, 85, 86, 87, which have overlapping pass-bands. For example, the filter 85 passes not only the frequency 748 c.p.s., in the above example, but also in reduced amplitude the frequency 373 c.p.s., i.e., an original 375 c.p.s. component reduced in frequency by 2 c.p.s. The filter 86, moreover, may pass in some degree 379 c.p.s., i.e., 375 c.p.s.+4 c.p.s.

Accordingly, the employment of filters 82, 85, 86, 87, having considerable overlap contributes materially to musical interest. It also is the case that the desired filter characteristics are readily obtained by employing a simple LC filter, which contributes to economy of manufacture of systems according to the invention.

A further advantage of the particular pass-band arrangements employed is that different tonal components are differently treated by the system. So, a tonal component frequency falling mid-way between the peaks of two filters is passed in equal amplitude through both, while a tonal component which falls elsewhere in the filter response curves is passed in unequal amplitudes through both filters. This property of the system imparts a certain desirable randomness to the processed tone.

The triode 75 includes a cathode resistance 100, and the cathodes of triodes 75 and 50 are D.C. coupled through a high isolating resistance 101. Similarly, the triode 76 includes a cathode resistance 102, and the triode 77 a cathode resistance 103. The cathodes of triodes 76 and 54 are D.C. coupled through a large isolating resistance 104, the cathodes of triodes 77 and 57 through a large isolating resistance 105. Similar coupling devices are employed for the several oscillator-modulators 72, 73 and 74.

It follows that isolation exists between any pair of oscillator-modulator stages, having the same position in the phase sequence of the audio signal, and therefore connected commonly to a single one of triodes 50, 54, 57. The path from one cathode to the other passes through two isolating resistances, and by selecting the isolating resistances to have sufficiently high value relative to the cathode load resistances employed for the stages of the oscillator-modulators, 80 db of isolation may be readily obtained.

The fact that each of triodes 75, 76 and 77 employs a separate cathode load implies that the bias on any one tube is not affected by the gain or other operating parameter of another of the tubes. The cathode loads serve to stabilize the stages individually, as well as to serve as input circuits and assure that no one of the tubes will be subjected to high grid current flow due to the characteristics of the grid leak and capacitor interstage coupling circuits. Moreover, the positive D.C. potentials developed at the cathodes of the audio output triodes, as 50, 54, 57, is in part transferred to the cathodes of the oscillator-modulator stages, assisting in reducing the possibility of grid current flow in the latter.

Stability and reproducibility of the oscillator-modulator stages is particularly important in frequency shift systems, since the theory of operation of such systems requires that each stage of the oscillator-modulator vary its audio frequency output from unmodulated value, to zero, and then to twice unmodulated value, in sequence. Should the stages cut-off, or distort in any way, there will be generated frequencies other than those desired, or the processed spectrum will be amplitude modulated at the sub-audible modulating frequencies. The audio signals as modulated appear in different phase at the anodes of the several stages of the oscillator-modulator. It is, therefore, required that the several stages, at their anodes be isolated from one another for audio frequencies above the respective modulating frequency. To this end the audio channels between the triodes of the oscillator-modulators may be so designed that the audio frequencies, falling in the octave centered on the band-pass frequency, are radically attenuated. Isolation between stages of the oscillator-modulators is then accomplished by design of suitable low-pass phase shift and coupling networks within the oscillator-modulators. Discussing a typical stage, the capacitor 91 is made relatively large and the resistance 90 an appropriate value. Thus, little audio signal appears across capacitor 91, but the amplitude of the sub-audio signal so appearing is relatively large. The capacitor 94 and the grid leak 95 are designed conventionally, to pass the sub-audio frequency with little phase shift, and hence do not materially affect the amplitudes of the sub-audio frequencies. It is, then, the sub-audio low-pass RC phase-shift circuits which are required to provide audio-frequency isolation between stages of the oscillator-modulators, and the RC phase shift circuits accordingly perform a double function, i.e., they introduce an accurate phase shift at the sub-audio modulating frequency and introduce interstage isolation of perhaps 50 to 60 db between stages of the oscillator-modulator for audio frequencies.

It will be clear that the separate oscillator-modulator stages will require different design parameters, in respect particularly to RC phase shift networks, since the oscillation frequencies are different radically (on a percentage basis) for the several oscillator-modulators.

While I have described and illustrated one specific embodiment of my invention, it will be clear that variations of the general arrangement and of the details of construction which are specifically illustrated and described may be resorted to without departing from the true spirit and scope of the invention as defined in the appended claims.

What I claim is:

1. An oscillator-modulator, comprising an n -phase

ring oscillator, each phase of said ring oscillator comprising a vacuum tube having an anode, a cathode and a control electrode, a cathode resistance in the cathode circuit of each of said vacuum tubes, and means for applying individual phases of an n -phase signal to individual ones of said cathodes.

2. An n -phase ring oscillator comprising a plurality of n vacuum tubes, each having an anode, a cathode and a control grid, a separate resistive load circuit in series with each of said anodes, a coupling circuit between the anode of each vacuum tube and the control grid of the vacuum tube adjacent in phase sequence, said coupling circuits each adapted to introduce phase shift around the oscillator ring sufficient to provide regeneration at the desired sub-audio oscillator frequency, and each coupling circuit including in series a resistor and a capacitor, one end of said resistor connected directly to an anode, and the junction of said resistor and capacitor coupled by a network to a control grid, said network including a grid leak and a coupling condenser connected between said junction and a control grid the other end of said capacitor being connected to an audio-frequency ground potential, said resistors having a resistance value sufficiently high and said capacitors having a reactance value sufficiently low to achieve substantially complete isolation between anodes and control grids of vacuum tube adjacent in phase sequence, for frequencies greater by at least an order of magnitude than the oscillatory frequency of said oscillator wherein said coupling circuit including in series a resistor and a capacitor is arranged and adapted to introduce relatively large phase shift and wherein said grid leak and coupling condenser are arranged and adapted to introduce negligible phase shift, both at the frequency of said oscillator.

3. The combination according to claim 2, wherein said networks comprise a grid leak, connected between each of said control grids and a point of reference potential, and a coupling capacitor connected between the grid end of said resistor and the junction between said first mentioned resistor and capacitor.

4. An n -phase ring oscillator-modulation system comprising an n -phase source of wide band audio carrier signals, each phase including an output vacuum tube having at least an anode, a cathode and a control electrode, a cathode resistance load in the cathode of each of said vacuum tubes, an n -phase self-oscillator, each phase of said self-oscillator including an oscillator vacuum tube having at least an anode, a cathode and a control electrode, a separate input cathode resistance in the cathode circuit of each of said oscillator vacuum tubes, and a connection between each cathode of said output vacuum tubes and one of said oscillator vacuum tubes.

5. The combination according to claim 4, wherein said connection includes an isolating resistance having a value greater than the value of any of said cathode resistances.

6. The combination according to claim 4, wherein said oscillator vacuum tubes have a common anode load resistance.

7. The combination according to claim 4, wherein n is greater than 2.

8. The combination according to claim 4, wherein said connection includes an isolating resistance having a value greater than the value of any of said cathode resistances.

9. The combination according to claim 4 wherein said oscillator vacuum tubes have a common anode load resistance.

10. A frequency shift modulation system, including an n -phase source of wide band audio carrier signals, each phase including an output vacuum tube having at least a cathode, a cathode resistance load in the cathode circuit of each of said output vacuum tubes, a plurality of n -phase sub-audio oscillators each oscillating at a different frequency and each including n oscillator vacuum tubes, said oscillator vacuum tubes each having at least

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an anode, a cathode and a control electrode, a cathode input resistance in the cathode circuit of each of said oscillator vacuum tubes, and circuits for driving said cathodes of said oscillator vacuum tubes in polyphase sequence in response to said output vacuum tubes, said circuits each including an isolating resistance connected between a cathode of one output vacuum tube and a cathode of one oscillator vacuum tube in each of said oscillators.

11. The combination in accordance with claim 10, wherein each of said oscillators includes a phase shift coupling circuit between each pair of said oscillator vacuum tubes of adjacent phase sequence, said phase shift circuits coupling an anode of one oscillator vacuum tube to a control electrode of another oscillator vacuum tube, said phase shift circuits including only resistance and capacitance and being arranged to provide isolation for said wide band audio signals.

12. The combination according to claim 11, wherein is provided a separate anode load resistance for each of said oscillator vacuum tubes and a common anode load resistance for all the oscillator vacuum tubes of each oscillator.

13. A system for generating three phase broad band signals in response to a single phase signal having a plurality of frequencies in a relatively wide spectrum, comprising a source of said single phase signal, means for deriving from said single phase signal two further broad band signals having each said plurality of frequencies, wherein each corresponding pair of said plurality of frequencies differs in phase by 120° , means for combining said two further broad band signals in a common load, and an output lead connected to said common load.

14. A system for generating three phase wide band audio signals comprising, a source of single phase wide band audio signals, first means for deriving from said single phase wide band audio signals a pair of wide band audio signals corresponding frequency components of which are separated by substantially 120° , second means for deriving from said pair of wide band audio signals a third wide band audio signal having said frequency components phase separated from corresponding frequency components in either of said pair of wide band audio signals by 120° , a load circuit for said third wide band audio signal, isolating impedances, said second means comprising circuitry for applying said pair of wide band audio signals in parallel to said load circuit via said isolating impedances.

15. An n -phase sub-audio ring oscillator comprising a plurality of n control devices, each of said control devices including a control electrode, an output electrode and a common electrode, a separate resistive load connected in series between each of said output electrodes and a source of energizing voltage, means interconnecting each of said output electrodes with a control electrode of a control device adjacent in phase sequence, each means for intercoupling including a phase shift network introducing a phase shift in one sense of greater than

$$\frac{360^\circ}{n}$$

and consisting of resistance and capacitor, one end of the series resistance being connected directly to an output electrode and one end of said capacitor being connected to ground, said resistance and capacitor being connected in series between the output electrode and ground, said means for intercoupling further including a coupling circuit providing relatively large coupling and negligible phase shift at the frequency of said oscillator, the negligible phase shift being opposite to said one sense, said capacitor having negligible impedance at audio frequencies.

16. A system for processing a band of audio frequencies, comprising means for frequency shifting said band of audio frequencies by a first frequency increment,

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means for frequency shifting said band of audio frequencies by a second and different frequency increment, first means for filtering from the first frequency shifted band a first sub-band of frequencies, second means for filtering from the second frequency shifted band a second sub-band of frequencies, said first and second means for filtering having pass-bands which overlap over a major portion of the pass bands of the means for filtering, wherein said means for frequency shifting includes an oscillator-modulator, comprising an n -phase ring oscillator each phase of said ring oscillator including a vacuum tube having an anode, a cathode, and a control electrode, a cathode resistance in the cathode circuit of each of said vacuum tubes and means for applying individual phases of an n -phase signal to individual ones of said cathodes.

17. The combination according to claim 16 wherein the point of cross-over of the response curves of said first and second means for filtering occurs at points approximately 2 db down on the pass characteristics of said means for filtering.

18. The combination according to claim 16 wherein said sub-bands are of the order of one octave in width.

19. A system for processing a band of audio frequencies, comprising means for frequency shifting said band of audio frequencies by a first frequency increment, means for frequency shifting said band of audio frequencies by a second and different frequency increment, first means for filtering from the first frequency shifted band a first sub-band of frequencies, second means for filtering from the second frequency shifted band a second sub-band of frequencies, said first and second means for filtering having pass-bands which overlap over a major portion of the pass bands of the means for filtering, wherein said means for frequency shifting said band of audio frequencies includes an n -phase source of said band of audio frequencies, each phase including an output vacuum tube having at least an anode, a cathode and a control electrode, a cathode resistance load in the cathode of each of said vacuum tubes, an n -phase self-oscillator, each phase of said self-oscillator including an oscillator vacuum tube having at least an anode, a cathode and a control electrode, a separate input cathode resistance in the cathode circuit of each of said oscillator vacuum tubes, and a connection between each cathode of said output vacuum tubes and one of said oscillator vacuum tubes.

20. A system for processing a band of audio frequencies, comprising means for frequency shifting said band of audio frequencies by a first frequency increment, means for frequency shifting said band of audio frequencies by a second and different frequency increment, first means for filtering from the first frequency shifted band a first sub-band of frequencies, second means for filtering from the second frequency shifted band a second sub-band of frequencies, said first and second means for filtering having pass-bands which overlap over a major portion of the pass bands of the means for filtering, wherein said means for frequency shifting includes an n -phase source of said band of audio frequencies, each phase including an output vacuum tube having at least a cathode, a separate cathode resistance load in the cathode circuit of each of said output vacuum tubes, a plurality of n -phase sub-audio oscillators each oscillating at a different frequency and each including n oscillator vacuum tubes, said oscillator vacuum tubes each having at least an anode, a cathode and a control electrode, a cathode input resistance in the cathode circuit of each of said oscillator vacuum tubes, and circuits for driving said cathodes of said oscillator vacuum tubes in polyphase sequence in response to said output vacuum tubes, said circuits each including an isolating resistance D.C. connected between a cathode of one output vacuum tube and a cathode of one oscillator vacuum tube in each of said oscillators.

21. A system for processing a band of audio frequencies, comprising means for frequency shifting said band of

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audio frequencies by a first frequency increment, means for frequency shifting said band of audio frequencies by a second and different frequency increment, first means for filtering from the first frequency shifted band a first sub-band of frequencies, second means for filtering from the second frequency shifted band a second sub-band of frequencies, said first and second means for filtering having pass-bands which overlap over a major portion of the pass bands of the means for filtering, wherein said means for frequency shifting includes an n -phase source of said band of audio frequencies, each phase including an output vacuum tube having at least a cathode, a separate cathode resistance load in the cathode circuit of each of said output vacuum tubes, a plurality of n -phase sub-audio oscillators each oscillating at a different frequency and each including n oscillator vacuum tubes, said oscillator vacuum tubes each having at least an anode, a cathode and a control electrode, a cathode input resistance in the cathode circuit of each of said oscillator vacuum tubes, and circuits for driving said cathodes of said oscillator vacuum tubes in polyphase sequence in response to said output vacuum tubes, said circuits each including an isolating resistance D.C. connected between a cathode of one output vacuum tube and a cathode of one oscillator vacuum tube in each of said oscillators, wherein each of said oscillators includes a phase shift coupling circuit between each pair of said oscillator vacuum tubes of adjacent phase sequence, said phase shift circuits coupling an anode of one oscillator vacuum tube to a control electrode of another oscillator vacuum tube, said phase shift circuits including only resistance and capacitance and being arranged to provide isolation for said wide band audio signals.

22. A system for processing a band of audio frequencies, comprising means for frequency shifting said band of audio frequencies by a first frequency increment, means for frequency shifting said band of audio frequencies by a second and different frequency increment, first means for filtering from the first frequency shifted band a first sub-band of frequencies, second means for filtering from the second frequency shifted band a second sub-

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band of frequencies, said first and second means for filtering having pass-bands which overlap over a major portion of the pass bands of the means for filtering, wherein said means for frequency shifting includes an n -phase source of said band of audio frequencies, each phase including an output vacuum tube having at least a cathode, a separate cathode resistance load in the cathode circuit of each of said output vacuum tubes, a plurality of n -phase sub-audio oscillators each oscillating at a different frequency and each including n oscillator vacuum tubes, said oscillator vacuum tubes each having at least an anode, a cathode and a control electrode, a cathode input resistance in the cathode circuit of each of said oscillator vacuum tubes, and circuits for driving said cathodes of said oscillator vacuum tubes in polyphase sequence in response to said output vacuum tubes, said circuits each including an isolating resistance D.C. connected between a cathode of one output vacuum tube and a cathode of one oscillator vacuum tube in each of said oscillators, wherein each of said oscillators includes a phase shift coupling circuit between each pair of said oscillator vacuum tubes of adjacent phase sequence, said phase shift circuits coupling an anode of one oscillator vacuum tube to a control electrode of another oscillator vacuum tube, said phase shift circuits including only resistance and capacitance and being arranged to provide isolation for said wide band audio signals, wherein is provided a separate anode load resistance for each of said oscillator vacuum tubes and a common anode load resistance for all the oscillator vacuum tubes of each oscillator.

References Cited in the file of this patent

UNITED STATES PATENTS

1,898,366	Lewis	Feb. 21, 1933
2,024,489	Van der Pol	Dec. 17, 1935
2,460,790	Jarvis	Feb. 1, 1949
2,623,200	Watson	Dec. 23, 1952
2,714,697	Small	Aug. 2, 1955
2,778,940	Sulzer	Jan. 22, 1957