

- [54] **ELECTRONIC MUSICAL INSTRUMENT MASTER OSCILLATOR WITH PROVISION FOR FREQUENCY CONTROL**
- [72] Inventors: **Alexander J. Borrevik**, Babylon, N.Y.; **Charles J. Tennes**, Palatine, Ill.
- [73] Assignee: **Hammond Corporation**, Deerfield, Ill.
- [22] Filed: **Jan. 11, 1971**
- [21] Appl. No.: **105,309**
- [52] U.S. Cl. **331/44**, 84/1.25, 84/DIG. 11, 331/60, 331/74, 331/117 R, 331/177 V, 331/178
- [51] Int. Cl. **G10h 5/06**, H03b 3/04, H03b 23/00
- [58] Field of Search. 331/36 C, 44, 60, 74, 76, 117 R, 331/117 V, 178; 84/1.03, 1.04, 1.25, DIG. 11; 307/225 R

[56] **References Cited**

UNITED STATES PATENTS

R25,256 10/1962 Schweitzer.....331/177 V

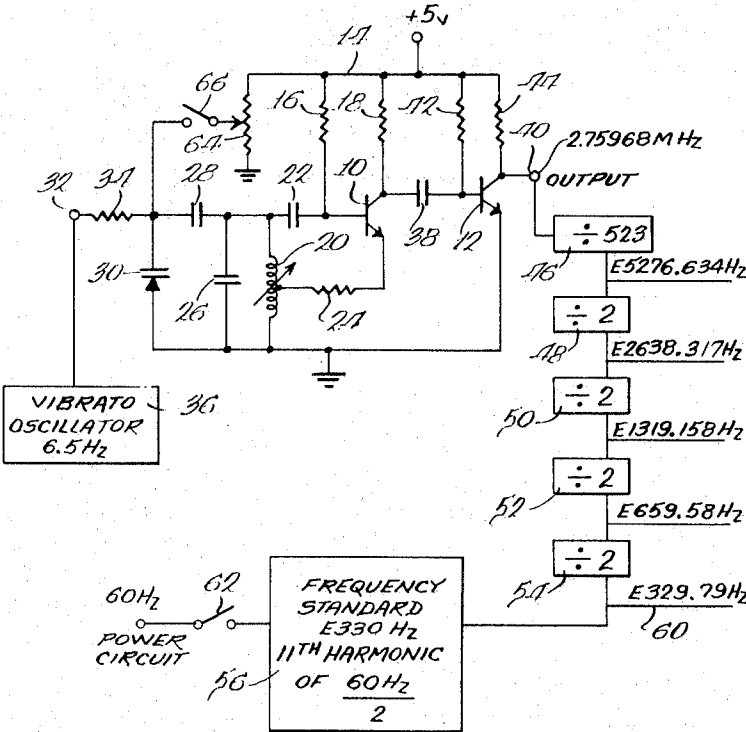
2,936,428	5/1960	Schweitzer.....	331/177 V
3,499,094	3/1970	Hoshino	84/1.25
2,719,232	9/1955	Ehrlich.....	331/44
3,601,518	8/1971	Hill.....	84/1.01

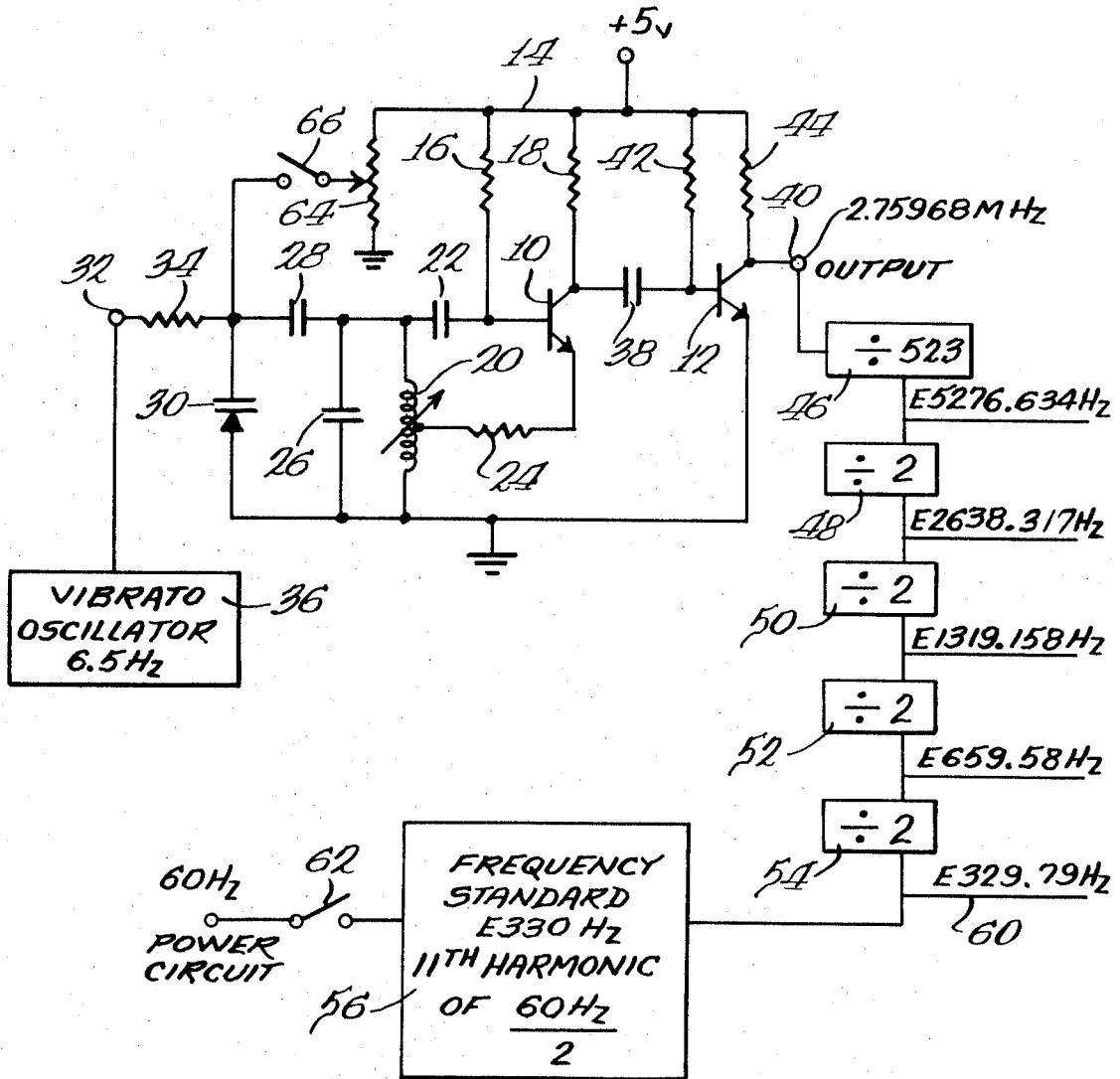
Primary Examiner—Roy Lake
Assistant Examiner—Siegfried H. Grimm
Attorney—Gradolph, Love, Rogers & Van Sciver

[57] **ABSTRACT**

A master oscillator operating in the MHz range for supplying a signal suitable for providing the notes of the musical scale, the various note signals being arrived at by frequency division of the master frequency. The oscillator has a high order of frequency stability together with ease of control for shifting the frequency to supply vibrato, portamento, trill, transposition features and the like. Control is exercised by incorporating a voltage-variable capacitance diode, "Varicap," as an effective element in the oscillator tank and varying the diode bias. Features provide for isolation of the bias voltage from the main tank circuit, a zero-bias condition at the true frequency, and a novel comparison tuning system using a slightly off-pitch tuning reference standard for obtaining true pitch.

5 Claims, 1 Drawing Figure





Inventors:
 Alexander J. Borrevik
 Charles J. Jenness
 By
 Bradolph Love Rogers & Van Siver
 Attys

ELECTRONIC MUSICAL INSTRUMENT MASTER OSCILLATOR WITH PROVISION FOR FREQUENCY CONTROL

BACKGROUND OF THE INVENTION

1. Field of the Invention

Electronic oscillators for musical instruments for supplying a stable, but easily variable frequency suitable for division to provide signals for the notes of the musical scale.

2. Description of the Prior Art

Electronic musical instruments, of the organ type for instance, require signal sources for all the notes of the musical scale within the compass of the instrument. A common arrangement for accomplishing this is to provide twelve oscillators for the 12 notes of the top octave of the instrument and then to acquire the note signals for the lower octaves by successive divisions by two of each of the top octave oscillator signals.

One of the preferred arrangements for providing vibrato, portamento or other systems which require a shift in the frequencies of all notes is to shift the frequencies of the twelve master oscillators which, of course, shifts the frequencies of all of the note signals derived therefrom. Thus, for vibrato, it is common to cause the frequencies of the master oscillators to shift so as to be slightly sharp and flat on a cyclical basis at a rate of about 6 to 7 Hz. Usually this is accomplished by using master oscillator circuits which are voltage sensitive at a particular terminal and supplying a variable control voltage thereto which causes the frequency to shift with the control voltage variations.

This same general scheme is also used for related effects, such as portamento, since once the voltage controlled variable frequency oscillators are present, many musical effects dependent upon frequency variation can be had without changing the basic system simply by providing any of a number of schemes for supplying a variable control voltage.

An example of an approach to a system of the type just described which will serve as an illustration of the state of the art is Bull et al U.S. Pat. No. 3,376,776. The arrangement there shown provides a voltage sensitive oscillator controlled by a cyclically variable voltage to produce vibrato and by a pulse initiated variable voltage to provide portamento effects.

A problem associated with a system of this character is the difficulty of harmonizing the essentially opposite requirements of providing oscillator frequency stability, or stability about a central frequency in the case of vibrato, on the one hand and of providing frequency sensitivity to a control voltage on the other hand, particularly in view of cost limitations.

SUMMARY OF THE INVENTION

The present system meets the requirement of providing signal sources for the notes of the musical scale in a novel manner. Some portions of the system form no part of the present invention, but will be briefly outlined for purpose of orientation, since the basic system is believed to be unfamiliar to most of those otherwise skilled in the electronic musical instrument art.

The system comprises a single master oscillator rather than twelve, and this single oscillator operates at a selected point in the low MHz range rather than in the upper audio frequency range. The signal from the sin-

gle oscillator is then passed through parallel frequency dividing chains, each of which at its end supplies an appropriate frequency for a note in the top octave of the instrument. Thereafter, the lower octave notes are provided by successive divisions in a well-known manner. As an example of such a system, the master oscillator may operate at 0.7744 MHz and the notes from C 4158.6 Hz to C No. 2213 Hz in half-tone intervals are provided by division in which the divisors for the notes in succession are 185, 196, 208, 220, 233, 247, 261, 277, 294, 312, 330 and 350. This will give the notes for an octave with an error spread of one part in 192, or 8.85 cents based upon A 440 Hz, the generally recognized standard. A more precise result can be achieved if the master oscillator frequency is 2.759680 MHz and the divisors in order are 349, 370, 392, 415, 440, 466, 494, 523, 554, 587, 622 and 659 to give the notes (again on the basis of "middle A" = 440 Hz) from B 7907.393 Hz to C 4187.678 Hz. Here the maximum error spread is one part in 1030, or 1.65 cents.

Each divider chain may consist of a series of cascaded bistable flip-flops modified either by the false count feedback method or by the coincidence reset system. Both of these are well understood in some technologies, but for the benefit of those lacking a familiarity, a brief explanation follows.

The older system is the false count feedback method. Here one uses a cascaded chain of flip-flops having a number of stages equal to a power of two at least as large as the desired divisor. Then by interconnection ("feedback") among the divider stages, one introduces by the feedback false counts in sufficient number to account for the difference between the desired divisor and 2^n , where n is the number of cascaded binary stages. For example, to divide by 10, one would provide 4 cascaded binary flip-flops, each of which has two stable states, and by interconnection, feedback 6 supplementary trigger pulses (false counts) for every 10 input pulses, thereby furnishing the total of 16 input pulses required to complete the counting cycle. For further explanation see "Pulse, Digital and Switching Waveforms," (McGraw Hill, 1965) by Millman and Taub, Chapter 18, for example.

In a reset counter, one arranges a multiple-input logical "AND" function to recognize the particular combination of flip-flop states corresponding to the desired divisor. Fulfillment of the AND requirement provides the output signal, and simultaneously resets the entire divider chain. For example, suppose that one applies triggering impulses to a 4-stage binary chain. Actuation of the first stage away from its reset state occurs at a count of one. Each actuation of the second stage requires two original input pulses. Each actuation of the third stage away from its reset state requires four input pulses. Similarly, actuation of the fourth stage requires eight pulses. Now to divide by 10, one would arrange a 2-input logical "AND" function responsive to simultaneous actuation of the second and fourth stages away from their reset states. Such coincidence would occur first on the second input pulse following tripping of the fourth stage which trips at the eighth pulse. By applying the "AND" function output as a reset signal for the entire divider chain, the circuit effectively starts over at every 10th input pulse. To divide by 11, the coincidence circuit notes simultaneous

flipping of the first, second, and fourth stages, thereby yielding a reset signal every $1 + 2 + 8 = 11$ input pulses.

When quite large divisors are required, the coincidence reset counter usually is preferable, in that its detailed design requirements tend to be less critical. In the present application, the largest required divisor is 659. This number may be represented as the sum of various integral powers of 2, as follows:

$$659 = 512 + 128 + 16 + 2 + 1$$

The total number of required stages is that integral power of 2 required to cover the desired divisor. 659 exceeds $2^9 = 512$, but is contained within $2^{10} = 1024$. Therefore, 10 binary stages are required. The "AND" inputs are arranged to note simultaneous actuation (away from reset state) of the first, second, fifth, eighth and tenth stages, corresponding to $1 + 2 + 16 + 128 + 512 = 659$ input pulses having been received. This output signal also resets the entire flip-flop chain.

When a divisor is not a prime number, it is convenient to subdivide it into its prime factors, and inspect these lesser numbers for commonalities that might be applied to advantage. For example, in the above listed number set, seven of the desired divisors (370, 392, 440, 466, 494, 554, and 622) have 2 as a prime factor. Thus a common divide-by-2 stage could serve that entire group of seven divisors, and permit a saving of six flip-flops. Three divisors (370, 415 and 440) contain the common prime factor 5. Since the division by 5 involves three flip-flops instead of just one, it could be attractive to put 370 and 440 in the divide-by-5 subgrouping instead of the divide-by-2 subgrouping. In the general case, one would make such assignments so as to minimize the total number of flip-flops.

With either the false-count feedback method, or the coincidence reset method, it is advantageous to exploit factorial subgrouping as noted above. Other things being comparable (such as accuracy), a preferred divisor set is one having many common factors, and preferably no prime numbers at all. On the other hand, with some of the newer technologies feasible with MOSFET (Metal Oxide Silicon Field Effect Transistor) integrated circuits, it may be more convenient to arrange completely independent divisors, in which case a prime number is no more troublesome than any other.

Other systems are available for dividing by large primes, but the above will serve as examples of systems using a single high frequency master oscillator as a source for all note signals.

As with the first described arrangement using 12 audio frequency master oscillators, it is also desirable to provide the single master oscillator, operating at 2.759680 MHz as an example, in a form such that it is highly stable while also providing for frequency shifting in response to a control voltage. Such an oscillator is the subject of this invention.

Essentially, the invention comprises applying the control voltage to a voltage variable capacitance diode which is incorporated in the oscillator tank so as to influence the capacity therein, but in such manner as to prevent the variable control voltage from otherwise influencing the characteristics of the tank or other circuit elements. Over-all stability is augmented by operating the oscillator at the true note frequency under condi-

tions of zero D.C. voltage thereby making it unnecessary to have precise D.C. voltage regulation in order to obtain the true frequency. On the other hand, the circuit permits the diode to operate in its essentially linear range, while shifting above and below the true frequency when producing vibrato in response to a variable control voltage.

To provide for ease of tuning the oscillator precisely to its true frequency from time to time as may be necessary, or for checking its frequency, the system provides a novel arrangement for comparing the oscillator frequency with a slightly off-pitch tuning reference standard of complete inherent stability, so as to compensate for the tuning differential between the oscillator and the reference standard without requiring skill on the part of the operator.

BRIEF DESCRIPTION OF THE DRAWING

The FIGURE is a circuit diagram illustrating an oscillator and an associated tuning reference standard incorporating features of the invention.

DESCRIPTION OF THE PREFERRED EMBODIMENT

The oscillator comprises circuits associated with transistor 10, the output of which feeds into a driver stage organized around transistor 12 which supplies the master frequency to the divider systems indicated at the right.

The basic oscillator connections are as follows. The B+ line 14 at a potential of +5v. is connected through resistor 16 to the base of transistor 10 and through resistor 18 to the collector. One end of a slug tuned inductor 20 is connected through a capacitor 22 to the transistor base, the other end being connected to the return circuit, in this instance ground. The transistor emitter is connected through resistor 24 to a tap on inductor 20 and a capacitor 26 bridges the inductor 20. This circuit will oscillate at a frequency determined largely by the values in the tank comprised of the capacitor 26 and inductor 20. The junction between capacitor 22, capacitor 26 and coil 20 is connected through a capacitor 28 to the cathode side of a voltage-variable-capacitance diode 30, the opposite side of which is grounded. Voltage-variable capacitance diodes, sometimes referred to as "varicaps" have the property of acting in the usual diode manner and also change capacity depending upon the voltage impressed thereon. A terminal 32 adapted to receive a variable voltage is connected through a resistor 34 to the junction between the variable capacitance diode 30 and capacitor 28. As shown, a vibrato oscillator 36 is connected to terminal 32. This vibrato oscillator may be of any well known type and supplies a variable voltage at a vibrato rate, that is at a frequency of about 6.5 Hz.

The output of the oscillator, the collector of transistor 10, is connected through coupling capacitor 38 to the base of driver transistor 12. The emitter of transistor 12 is grounded and the collector is connected to an output terminal 40. Resistors 42 and 44 connect the base and collector respectively to the B+ line 14. The driver stage is essentially conventional and is believed to need no specific discussion.

The output terminal 40 which supplies the master signal, in this instance at a frequency of 2.75968 MHz,

is connected to the inputs of the several divider chains. One of these, for some of the E note frequencies, is illustrated. It consists of a basic divider 46 of the type previously described which divides the master frequency by 523 so as to provide a high pitched E note at 5276.634 Hz. This is followed by a cascaded series of binary dividers 48, 50, 52 and 54 which provide the octavely related E notes at 2638.317 Hz, 1319.158 Hz, 659.58 Hz and 329.79 Hz. The divider chain will normally be continued, of course, to provide lower octavely related E notes according to the same plan. The reason for choosing E for purpose of illustration, and for bringing it down to 329.79 Hz, is that this is the note which is compared with the tuning reference standard as will appear presently.

Referring back to the oscillator, the values in the illustrated circuit are as follows.

The diode 30 is type MV 830 or equivalent and has a nominal capacity of 15pf. The transistors are type MPS2369. Coil 20 has 47 turns, tapped at 31, on a Miller 20A000-2 form or equivalent.

Capacitors in pf unless otherwise indicated are:

26 -	28
22 -	20
38 -	100
28 -	.01 μ f

Resistors in ohms are:

34 -	100 K
24 -	82
16 & 42 -	22 K
18 & 44 -	470

With these values, the low frequency, about 6.5 Hz, signal at terminal 32 is effectively blocked by capacitor 28 and, therefore, influences only the capacity of the diode 30. Similarly, the tank, 26-20 is isolated from the D.C. at the base of transistor 10. The capacity of the diode 30 is, however, effectively added to that of the tank main capacitor 26, so far as determining the frequency of oscillation is concerned. The oscillator, therefore, oscillates at a frequency which is variable depending upon the voltage at terminal 32 which in turn affects the capacity at 30.

A feature of the system is that the oscillator is tuned by adjusting tank coil 20 to oscillate at the appropriate frequency under conditions where the potential at 32 is zero. The true frequency of 2.75968 MHz is, therefore, not dependent upon maintaining a precise voltage differential between terminal 32 and ground. It might be thought that this would pose a serious problem, since the diode 30 when at zero potential is completely outside the range at which it responds with a substantially linear capacity change with voltage variation. This is because of the threshold voltage in one direction and the reverse threshold voltage in the opposite direction. On the other hand, the cyclically variable voltage from the vibrato oscillator will most conveniently vary about zero potential on a sine wave basis or according to some wave form similar thereto. Of course, a D.C. potential could be added to the vibrato signal when vibrato was desired so as to cause the diode to operate at a linear portion of its curve, but this would have the unsatisfactory effect of causing the frequency of the instrument at the midpoint of the vibrato to be sharp or

flat. That is, the note frequency would undulate about a frequency displaced from the true frequency.

The circuit overcomes these problems because the oscillator signal at 2.75968 MHz which is applied to the diode is at a potential such that rectification takes place. This rectified signal acts as a bias for the diode and in the circuit shown has essentially the same effect as a +5v bias applied between resistor 34 and capacitor 28. The effect of this is to shift the capacity versus voltage response of the diode to the +5v portion of the curve where the response is essentially straight line. The vibrato voltage applied to terminal 32 in the present instance has a swing from zero of about plus and minus 3v and this is added to the 5v effective bias. Thus, when operating in the vibrato mode, the effective voltage variation on the diode is between +2 and +8 volts which gives a vibrato swing of about 2 to 2.5 percent plus and minus.

The tuning standard is shown at 56 and needs no detailed description since it is the subject of a copending patent application, Ser. No. 18909, in the name of Peter Davidson for "Musical Instrument Tuning Reference Standard." According to that system, the standard power line frequency at 60 Hz is divided by two by means of a bistable flip-flop to provide a square wave at a fundamental frequency of 30 Hz. This square wave is then filtered through a band pass system which extracts the eleventh harmonic at 330 Hz. The 330 Hz signal is then treated to enhance its harmonic structure and applied to a speaker and used as a reference for tuning the E string of guitars for example to zero beat. The true frequency to which the guitar theoretically should be tuned is 329.677, but the difference between 330 and 329.677 is so small as to be of almost no consequence, particularly since the tuning of a guitar will not remain constant in any event.

The advantage of this particular tuning reference standard, even though it is very slightly inaccurate, is that the standard cannot drift or need adjustment, since it is locked to the extremely well regulated power line frequency.

The present oscillator system, however, overcomes this slight inaccuracy and enables adjustment of the oscillator frequency to 2.75968 Hz so that E is 329.79 Hz by tuning to zero beat against the reference standard at 330 Hz. To facilitate this, the output of the reference standard 56 is fed into the line 60 carrying the E signal when the reference standard is turned on by closing switch 62. The signal from the standard and from the organ, for instance, when the appropriate E key is played, are mixed and applied to the same power amplifier and speaker system, not shown. The user can then tune the instrument, by adjusting the coil 20, for the instance, to zero beat. After this has been accomplished, the switch 62 can be open to restore the instrument to its intended use.

So that the oscillator will be properly tuned under these conditions, a very small positive voltage is applied to the point between resistor 34 and capacitor 28 during tuning. This voltage temporarily shifts the frequency of the oscillator just enough so that when it is tuned to E 330 with the voltage applied, it will drop back to E 329.79 when this voltage is subsequently removed.

Although this voltage to be applied during tuning can come from any source, in the interest of completeness a

potentiometer 64 is shown connected between the +5v line 14 and ground with the adjustable tap being connected through switch 66 to the junction between resistor 34, capacitor 28 and diode 30. If desired, switches 66 and 62 can be ganged so that they are opened and closed together by actuation of a single control.

The value of the potential to be applied during tuning is of the order of 0.5v and is easily determined in a particular circuit by whatever is necessary to make the appropriate adjustment.

If desired, of course, the oscillator frequency could be moved up slightly during tuning to match the E 330 standard by cutting out a small capacitor normally connected in parallel with capacitor 26, so as to reduce the capacity in the tank. Other changes similarly could be made to carry out the principle of detuning the oscillator by a specific amount during the period it is being matched against a standard which is slightly off the true frequency. Since the present oscillator is sensitive to the application of a control voltage, however, the scheme first described above for shifting the frequency for tuning purposes is particularly apt.

One advantage of this approach to tuning is that the value of the correction voltage, or of the capacitor in the second example, need not be as precise as might at first thought. This is because the tuning differential to be accommodated is less than one part in 1500, and thus, if the tuning correction is, for instance, as much as twenty percent off the proper value, the final result will be correct to within 20 percent of the amount of the original differential. The result would be an error of no more than one part in 7,000 which is of no consequence.

Although the variable voltage applied to the terminal 32 is for the purpose of producing vibrato and the circuit elements have been selected with this in mind, other types of variable voltage can be applied to achieve other musical effects as previously discussed. In some instances, however, a greater frequency swing will be required than for vibrato. In such instances voltage-variable-capacitance diodes with different characteristics may be used to advantage, or two or more in parallel could be substituted for the one shown at 30, depending, of course, upon the capacity variation required.

We claim:

1. The method of tuning an oscillator having a resonant circuit to a selected frequency comprising providing a reference frequency slightly different from said selected frequency, temporarily changing the effective value of a component of said resonant circuit to shift the frequency of said oscillator by an amount equivalent to the differential between said selected frequency and said reference frequency, tuning said oscillator to said reference frequency and subsequently restoring the component temporarily changed to its original effective value.

2. A system for providing the signals for the notes for a high octave of the musical scale comprising means providing an oscillator operating at substantially a nominal frequency of 2.75968 MHz, means providing twelve divider chains connected for dividing said frequency to provide the twelve notes of said octave, the 12 dividers for said 12 chains being adapted to di-

vide by 349, 370, 392, 415, 440, 466, 494, 523, 554, 587, 622 and 659, and means for shifting the frequency of oscillation of said oscillator by an amount of the order of one to two per cent above and below said nominal frequency at a rate of the order of 6 to 7 Hz.

3. A system for providing the signals for the notes for a high octave of the musical scale comprising means providing an oscillator operating in the low megahertz range, means providing twelve divider chains connected for dividing said frequency to provide the twelve notes of said octave, means responsive to a variable voltage for shifting the frequency of oscillation of said oscillator to provide musical effects dependent upon pitch variation, means for supplying a variable voltage to said voltage responsive means to change the pitch of all said notes simultaneously, and the variable voltage supply means including means for varying said voltage on a cyclical basis at a vibrato frequency.

4. An oscillator having a resonant circuit including a main capacitance element, a voltage-variable-capacitance diode effectively coupled with said main capacitance element, said voltage-variable-capacitance diode being adapted to vary the capacity in said resonant circuit and hence the oscillator frequency depending upon the value of a potential applied to said diode, means for applying a variable control voltage to said diode, means for applying the signal output of the oscillator to said diode at a level such that rectification of said signal by said diode occurs and produces a D.C. potential equivalent sufficient to bias said diode to a level where said diode capacity variation with voltage variation is substantially a linear function throughout a substantial portion of the range of voltage variation of said control voltage, means for tuning said oscillator to a selected frequency under conditions where said control voltage is zero, said tuning means including a source of reference frequency slightly different from said selected frequency, means for temporarily applying an appropriate potential to said diode to alter the capacity of said diode to shift the frequency of the oscillator an amount equivalent to substantially the difference between said selected frequency and said reference frequency, means for tuning to the reference frequency with the last said potential temporarily applied, subsequent removal of the temporary potential shifting the capacity of said diode and the frequency of the tuned oscillator by the amount of said difference.

5. A musical instrument oscillator adapted to have its frequency varied as essentially a linear function of a control voltage which fluctuates relative to ground potential, said oscillator including a main capacitance tuning element, a voltage-variable-capacitance diode effectively coupled with said main capacitance element, said voltage variable capacitance diode having essentially a linear change of capacity with respect to the value of a control voltage applied thereto when said diode is biased to a certain voltage level and said control voltage fluctuates relative to said bias voltage level, means for applying the signal output of said oscillator to said diode for rectification thereby at a level such that the rectified oscillator signal produces a D.C. equivalent sufficient to bias said diode to said certain voltage level, means for tuning said oscillator to a selected frequency when said control voltage is zero, said tuning means including means providing a

9

reference frequency slightly different from said selected frequency, means for temporarily applying an appropriate potential to said diode to shift the frequency of the oscillator an amount equivalent to substantially the difference between said selected frequency and said reference frequency, means for tuning to the

10

reference frequency with the last said potential temporarily applied, subsequent removal of the temporary potential shifting the capacity of said diode and the frequency of the tuned oscillator by the amount of said difference.

* * * * *

10

15

20

25

30

35

40

45

50

55

60

65

UNITED STATES PATENT OFFICE
CERTIFICATE OF CORRECTION

Patent No. 3,701,040 Dated October 24, 1972

Inventor(s) Alexander J. Borrevik and Charles J. Tennes

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

Col. 2, line 8, "C4158.6 Hz" should be --C4168.6 Hz--.

Col. 5, line 25, first line of table "26-28" should be --26-82--.

Signed and sealed this 10th day of April 1973.

(SEAL)
Attest:

EDWARD M. FLETCHER, JR.
Attesting Officer

ROBERT GOTTSCHALK
Commissioner of Patents

UNITED STATES PATENT OFFICE
CERTIFICATE OF CORRECTION

Patent No. 3,701,040 Dated October 24, 1972

Inventor(s) Alexander J. Borrevik and Charles J. Tennes

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

Col. 2, line 8, "C4158.6 Hz" should be --C4168.6 Hz--.

Col. 5, line 25, first line of table "26-28" should be --26-82--.

Signed and sealed this 10th day of April 1973.

(SEAL)
Attest:

EDWARD M. FLETCHER, JR.
Attesting Officer

ROBERT GOTTSCHALK
Commissioner of Patents