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[54] **DIGITAL TONE GENERATOR**

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[51] **Int. Cl.**[2] **G10H 1/06;** G10H 5/06

[58] **Field of Search** 84/1.01, 1.03, 1.11, 1.19, 84/1.22–1.25

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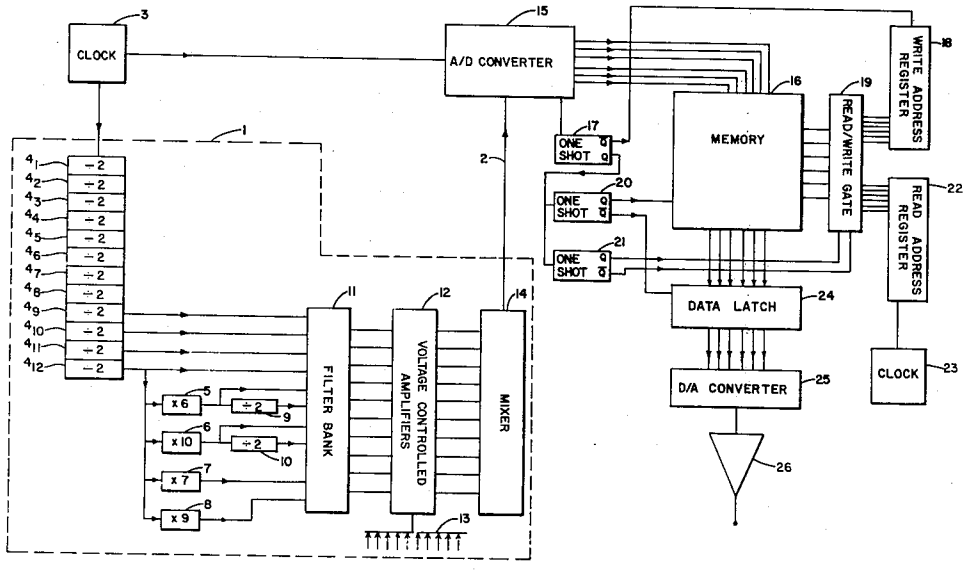
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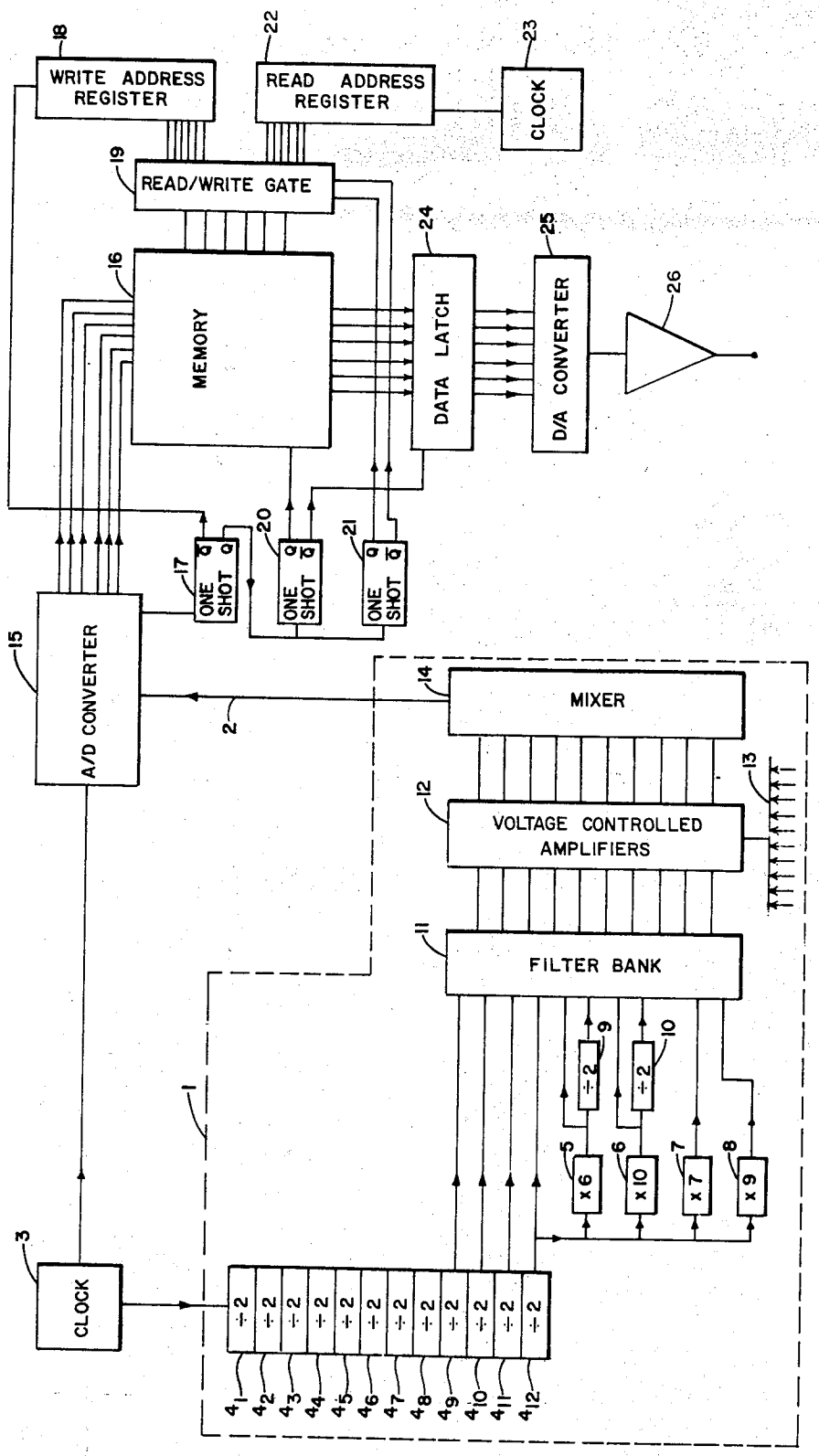
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[57] **ABSTRACT**

In musical instruments as well as as other arts, it is desirable to have a simple generator which is capable of producing signals or tones having continuously variable harmonic spectra at selectable frequencies. This invention provides a tone generator wherein a predetermined number of harmonically related signals are individually amplitude controlled and then mixed to provide a continuously variable waveform signal. This signal is digitized and written into a random access memory at a fixed rate. The memory is simultaneously read at a selectable rate to provide an output tone which has a waveform near identical to the variable input waveform, at a frequency related to the selected reading rate.

7 Claims, 1 Drawing Figure




WRITE ADDRESS REGISTER
READ ADDRESS REGISTER
CLOCK
READ/WRITE GATE
MEMORY
DATA LATCH
D/A CONVERTER
ONE SHOT
ONE SHOT
ONE SHOT
A/D CONVERTER
MIXER
VOLTAGE CONTROLLED AMPLIFIERS
FILTER BANK
÷2
÷2
x6
x10
x7
x9
CLOCK
÷2 ÷2 ÷2 ÷2 ÷2 ÷2 ÷2 ÷2 ÷2 ÷2 ÷2 ÷2
18
22
23
19
16
24
25
26
17
20
21
15
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13
11
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8
3
4 1 4 2 4 3 4 4 4 5 4 6 4 7 4 8 4 9 4 10 4 11 4 12

DIGITAL TONE GENERATOR

This invention relates to a digital tone generator and in particular to a tone generator for an electronic instrument in which the harmonic spectrum of the generated tone may be varied from instant to instant for a continuous single note.

Early electronic instruments were found to be too "mechanical" when compared with the traditional orchestral instruments. Among other things, the harmonic spectrum was too constant during the production of one note, and the means provided for changing it were too cumbersome to make spectrum variation accessible to the performer from instant to instant. The transient variations in spectrum produced on an instrument such as the pipe organ, while not lending themselves to easy variation by the performer were seen to by a musically valuable part of organ tone. Later electronic instruments have used voltage controlled variable filters to impose transient tonal variations on the standard fixed harmonic spectrum tone generators. The effects so obtained have been widely acclaimed by musicians as a significant improvement on the older stationary electronic tones, however, the effects obtainable with a variable filter are clearly limited with respect to the tonal trajectories obtainable and with respect to the variation of the tone with pitch over the compass of the instrument.

As a further advance in the art, Ralph Deutsch describes a Digital Organ in U.S. Pat. No. 3,515,792 issued on June 2, 1970 and assigned to North American Rockwell. In this system, a digital representation of an organ pipe wave shape is stored in a memory. A manual or pedal key activates a clock source to produce clock pulses at a frequency Nf, where f is the frequency of the note selected, and N is the number of sample points in the stored wave shape. The digitized wave shape is read out repetitiously at the generated clock frequency and converted to analog form to produce a musical note having a wave shape corresponding to that stored in the memory.

Periodic or musical tones are normally considered to be tones in which the form of one cycle is more or less the same as the next over short lengths of time, that is lengths of time which are long enough for the ear to establish "tone colour" or "timbre" of the sound. The time it takes for the ear to perceive tone-colour lies between 50 milliseconds and 150 milliseconds. The shortest notes usually are between 50 and 100 milliseconds long. Thus, a significant tone-colour change should be made within 100 to 200 milliseconds at the fastest rate. The course of the tone-colour during a single note is often called the "tonal trajectory". A note is conventionally described to have three main parts; the transient or starting part, the steady or running part and the end part. It has been determined that these three parts of the note usually differ substantially in terms of intensity or amplitude, as well as, harmonic structure. Most prior art devices are capable of reconstructing only the amplitude or intensity variable of the note.

However, true tone-colour cannot be specified by one variable alone since at least the first nine harmonics each have a distinctive character and the presence or absence of all the harmonics above the ninth in various proportions can at times also be detected. It is thus clear that there are many different courses which the tone-colour may follow between two fixed limits. This

invention relates to a new means of defining the courses which makes it feasible and practical to provide the performer with a much wider choice than previously known.

It is therefore an object of this invention to provide a generator which can produce a tone having a continuously variable harmonic spectrum at any given frequency.

It is another object of this invention to provide a generator which can produce tones at selectable frequencies.

It is a further object of this invention to provide a generator in which the frequency and the harmonic spectrum of the output tone may be varied independently.

It is yet another object of this invention to provide a simple, reliable digital tone generator.

These and other objects are achieved in the novel digital tone generator in accordance with the invention. A fixed frequency source provides a signal, having a continuously variable harmonic spectrum, to an analog to digital converter. The conversion rate is controlled by a signal from a first clock source of fixed frequency. The digital represention of the signal waveform are written into a random access memory. Simultaneously, a second clock having a selectable frequency, controls the read-out from the memory at a rate which may be equal to or different from the write-in-rate. The digital representations read out of the memory are converted back to analog form, thus providing an output tone having selectable fundamental frequency, and a waveform the harmonic spectrum of which is near identical to that of the input signal source. As the harmonic spectrum of the input signal can be continuously varied, and as each cycle is successively written into the memory, the harmonic spectrum of the output tone will also be continuously variable.

In the drawings;

The FIGURE is a schematic diagram of one embodiment of tone generator may take in accordance with the invention.

The tone generator will be described primarily as a generator of periodic or musical tones for a musical instrument, however it also has many other uses since its fundamental output frequency can be set at any frequency in the audio range as well as frequencies above this range.

The FIGURE illustrates one possible embodiment of the tone generator in accordance with the invention. A variable waveform signal source **1** provides a signal having a fixed fundamental frequency *f* on its output line **2**. The source may be of any known type which will produce a signal that includes a harmonic spectrum wherein the number of harmonic as well as their amplitudes may be readily varied. The source **1** shown in the FIGURE is one such device. It provides an output signal of frequency *f* (32 hz), with harmonics **1** to **10** of variable amplitude. The particular frequency and these particular harmonics are not essential to the operation of the tone generator. The number of harmonics and the frequency will depend on a particular application. These have been chosen as examples only to simplify the understanding of the invention.

The source **1** receives clock pulses at a frequency Sf, where S is a whole number, from a clock **3**. These pulses are fed into a series of dividers 4_1, 4_2 . . . 4_9, 4_{10}, 4_{11} and 4_{12}. Outputs are taken from dividers 4_9, 4_{10}, 4_{11},

and 4_{12} to provide the 8^{th}, 4^{th}, 2^{nd} and 1^{st} or fundamental frequency respectively. The output from divider 4_{12} is fed into a four multiplier circuits: **5** which multiplies by 6 and provides the 6^{th} harmonic, **6** which multiplies by 10 and provides the 10^{th} harmonic, **7** which multiplies by 7 and provides the 7^{th} harmonic, and **8** which multiplies by 9 and provides the 9^{th} harmonic. Multipliers **5** and **6** further feed divide by 2 circuits **9** and **10** to provide the 3^{rd} and 5^{th} harmonics respectively. As an example, clock **3** may have a frequency of 8192 hz yielding a fundamental frequency of 32hz from divider 4_{12} and harmonics having frequencies of 64 hz, 128 hz . . . 256 hz, 288 hz and 320 hz. The 10 harmonics are fed, through a filter bank **11** having 10 individual channels, to 10 individual voltage controlled amplifiers **12.** The amplifiers **12** are individually controlled by 10 input leads **13** shown schematically, by which the amplitude of each harmonic is controlled to form a particular harmonic spectrum. The amplifiers are connected to a mixer circuit **14** which combines the ten harmonics into a signal having a particular waveform on the output line **2.**

The output line **2** is connected to the analog input of an analog to digital converter **15.** The function of the A/D converter **15** is to translate the analog signal on line **2** which has a fundamental frequency *f* into a series of S digital words. On receiving a pulse from clock **3,** converter **15** samples the instantaneous amplitude of the signal on line **2** and provides an output digital word which is representative of that amplitude. In addition, an end conversion pulse is provided to the single shot **17.** In this particular embodiment, the signal on line **2** has a fundamental frequency of 32 hz and the clock **3** has a frequency of 8192 hz, and therefore the analog signal on line **2** to the input of converter **15** is sampled at 256 successive points during each cycle, and the converter **15** provides a succession of 256–6 bit words on its output, which represent the waveform of the signal on line **2.** Each successive cycle of the signal on line **2** is thus sampled and converted to digital representations by converter **15** and therefore if the signal waveform is changed as by varying the harmonic spectrum in source **1,** the following sequence of 256–6 bit words at the output of converter **15** will represent the new waveform. One such analog to digital converter which may be used is the Datel Systems Inc. ADC-Econoverter described in their Bulletin 231117110K Rev. A.

The digital word representations of the S sample points on the analog waveform of the signal on line **2** which are produced by the A/D converter **15,** are sequentially stored in a conventional random access memory **16.** Memory **16,** which in this embodiment has the capacity to store all sample points for one cycle of the signal on line **2,** i.e. 256 × 6 bits, may include six memories of the type described in the Intel Corporation publication 7136/2 on MOS LS/256 Memory 11-1A, 1101A1, tied together in the appropriate manner. The memory may be larger so as to store sample points for two or more cycles, however the storage of one cycle is sufficient. Thus as each consecutive cycle of the signal is digitized, it is successively stored in the memory to update the memory. Any change in the signal waveform will therefore be immediately stored in the memory. In using clock **3** to control both the source **1** and the A/D converter **15,** the digital word representations of one complete cycle of the signal will always be stored in memory **16,** and therefore the word representations will be stored in the same address sequence.

The writing into the memory **16** of digital words received from the A/D converter **15** and the reading out of this information is controlled by one-shot multivibrators **17, 20, 21,** write address register **18,** read address register **22** and read/write gate **19.** The read/write gate, which is made up of standard TTL 7400 series logic circuits, functions to connect the address register in memory **16** to the write address register **18** or to the read address register **22** when a pulse is received on a first control terminal or second control terminal respectively. In this case these terminals are connected to terminals $\overline{Q}$ and Q respectively of one-shot **21.**

Write address register **18** consists of 2–4 bit binary ripple through counters in cascade to form an 8 bit binary address system. On receiving pulses on its input terminal, in this case from one-shot **17,** the counters sequentially count from 0 to 255 and return to 0, 1 count at a time. The write address register is connected to the address register in memory **16** and is capable of advancing the address registers through all 256 memory locations. Texas Instruments' TTL 7493 series binary counters may be used in this register. Read address register **22** is identical to write address register **18** and is identically connected to the address register in memory **16** through read/write gate **19.** However, read address register **22** receives input pulses from a variable clock **23.**

In operation, on converting the amplitude of a sample point on the waveform of the signal on line **2** to a 6 bit word, the A/D converter provides an end of conversion pulse. This pulse drives one-shot **17** which provides a pulse on terminal $\overline{Q}$. Terminal $\overline{Q}$ is connected to write address register **18** and the pulse on $\overline{Q}$ advances the count in the write address register **18** by **1.** One shot **17** then provides a pulse on terminal Q which is connected to the inputs of one-shot multivibrators **20** and **21.** A pulse is thus generated on one-shot **21** terminal $\overline{Q}$ which controls read/write gate **19** to connect the address register in memory **16** to the write address register **18,** and simultaneously one-shot **20** generates a write command pulse on terminal Q which is connected to memory **16** such that the 6 bit word at the input of memory **16** is stored in the memory at the appropriate address governed by the count in write address register **18.** This write sequence is repeated at the frequency of clock **3,** however since each write sequence is completed in approximately 1 μ sec, the time remaining between each conversion by A/D converter **15** may be used to read out memory **16.** At the end of the write sequence, read/write gate **19** disconnects the address register in memory **16** from write address register **18** and connects it to read address register **22** which receives input pulses from clock **23** to advance its count through the **256** address positions. The memory **16** is therefore read continuously at the clock **22** rate except when the read address register **22** is disabled during a write sequence. The 6 bit words read out of memory **16** are then converted in an D/A converter and the original waveform is reconstructed having a fundamental frequency which is dependent on the read-out rate. The rate at which the memory is read is selectable and controlled by a variable frequency clock **23** which provides pulses at a frequency RSf where R is smaller equal to, or greater than 1, to the read address register **22.** The output tone frequency will therefore be Rf. For exam-

ple, if an output tone frequency of approximately 1046 hz is desired, the read clock frequency will be set at RfS or 1046.5 × 256 which is 267.904 khz. Clock **23** may be continuously variable to provide a continuously variable tone frequency, however if used as a musical instrument tone generator, the clock **23** may vary in frequency steps to provide output tone frequencies which correspond to musical notes.

As memory **16** is addressed by read address register **22,** information on the output memory **16** is transferred to a data latch **24.** As each address is advanced, the information at the input of data latch **24** is transferred to the output of the data latch until the next memory address advance. In addition, during the write sequence in memory **16,** a signal from the $\bar{Q}$ output terminal of one-shot **20** inhibits the data latch ouput information from changing while a new word is being written into memory **16.** This prevents the possibility of unpleasant discontinuities on the output tone. A standard Texas Instruments TTL 7475 series integrated circuit bistable latch may be used for this purpose. The data latch output is fed into a digital to analog (D/A) converter **25** where the digital representation of the waveform is converted to analog steps. These analog steps form a tone having a harmonic spectrum which corresponds to the original waveform from source **1** and the frequency of the tone is determined by clock **23.** This tone is fed through an amplifier **26** to a sound transducer or other device (not shown).

The system described above allows for the generation of a tone having any desired harmonic structure since the digital representations of the waveform are continuously renewed in the memory, and simultaneously read out of the memory. If a tone having a fixed harmonic structure is desired for an indefinite length of time, the system may include a means for disabling the A/D converter if no changes are detected in waveform structure, thus storing the waveform only once and reading it out repetitively. However in the preferred embodiment each consecutive cycle of the input signal is successively written into the memory, immediately registering any changes in the waveform, and simultaneously read out of the memory at a selectable rate. It is clear, that at any one instant, the memory does not receive both the write and read signal, however, reading of the memory may be considered to be simultaneous, since the write sequences, which are very short, are periodically inserted into read sequences. The output may have minor discontinuities which are not detectable after the output has been filtered.

A 256 × 6 random access memory is used in the above described tone generator, however both the capacity of the memory and the code may differ. Memory capacity however should be large enough to store the digital representations of one complete cycle of the input signal *f* or any multiple thereof. Consequently if better resolution is desired memory capacity will have to be increased to store the increased number of sample points.

As used in a musical instrument, the pitch of the tone generator is controlled by the read clock **23** through the use of manual keys, a sliding control or any other conventional manner. The tone colour or harmonic content is provided by the waveform generator **1** through control inputs **13.** The output envelope such as attack, decay, rhythm, etc. is controlled by conventional circuits which are connected to the output of amplifier **26.**

Finally, though described as a monophonic tone generator, i.e. one which produces a single tone output, it would appear to be within the scope of the invention to modify the generator in any known way to produce a polyphonic output.

I claim:

1. A generator for producing a signal (having a varying waveform) at a selectable frequency comprising:
- first means adapted to provide a series of digital representations of a (fixed frequency varying waveform) continuous analog signal having a fixed fundamental frequency and a variable harmonic spectrum);
- (read/write) random access memory means having the capacity to store the digital representations for one cycle of said analog signal at one time;
- second means for continuously writing said digital representations into said memory means to update said memory means for successive cycles of said signal;
- third means for simultaneously reading out said stored digital representations at a selectable rate so as to provide an output signal having (said varying waveform at a selected frequency) a selectable fundamental frequency and a correspondingly variable harmonic spectrum.

2. A generator as claimed in claim **1** wherein said first means comprises:
- signal generator means for generating (a) said continuous analog signal (having a fixed fundamental frequency and a variable harmonic spectrum); and
- analog to digital converter means connected to said signal generator means and adapted to amplitude sample said continuous analog signal at a predetermined fixed rate and convert said samples to digital representations to be stored in said memory means.

3. A generator for producing a (variable waveform) tone at a selectable frequency comprising:
- means for generating a continuous analog signal having a fixed fundamental frequency *f* and a (variable waveform) variable harmonic spectrum;
- first means connected to said signal means and adapted to convert each cycle of said signal to a predetermined number S of amplitude sample representations;
- memory means connected to said first means for receiving and storing said representations;
- means for simultaneously reading out said representations from said memory at a selectable rate; and
- second means for converting said representations read from said memory means to an analog tone, said tone having (said variable waveform and) a fundamental frequency related to said selectable read rate and a correspondingly variable harmonic spectrum.

4. A tone generator as claimed in claim **3** wherein said memory means includes nS address positions where n is a whole number, for storing representations of one or more complete cycles of said analog signal.

5. A tone generator as claimed in claim **3** in which said signal means comprises:
- means for providing a predetermined number of harmonically related output signals;
- means adapted to selectably control the amplitudes of each of said output signals; and

means for mixing said amplitude controlled output signals to provide said analog signal.

6. A generator for producing a tone at a selectable frequency comprising:

means for generating a continuous analog signal having a fixed fundamental frequency *f* and a variable harmonic spectrum;

first means connected to said signal means and adapted to convert each cycle of said signal to a predetermined number S of amplitude sample representations;

memory means connected to said first means for receiving and storing said representations;

means for simultaneously reading out said representations from said memory at a selectrable rate;

second means for converting said representations read from said memory means to an analog tone, said tone having a fundamental frequency related to said selectable read rate and a correspondingly variable harmonic spectrum; and

means adapted to disconnect said memory means from said first means when successive cycles of said signal are identical.

7. A generator for producing tone at a selectable frequency comprising:

means for generating a continuous analog signal having a fixed fundamental frequency *f* and a variable harmonic spectrum;

first means connected to said signal means and adapted to convert each cycle of said signal to a predetermined number S of amplitude sample representations;

memory means connected to said first means for receiving and storing said representations;

means for simultaneously reading out said representations from said memory at a selectable rate;

second means for converting said representations read from said memory means to an analog tone, said tone having a fundamental frequency related to said selectable read rate and a correspondingly variable harmonic spectrum;

first clock means having a fixed frequency S*f*, said first clock means adapted to control the rate at which the sample representations are written into said memory means; and

second clock means having a selectable frequency RSf wherein R may be smaller, greater or equal to 1, said second clock means adapted to control the rate at which the sample representations are read out of said memory means.

* * * * *