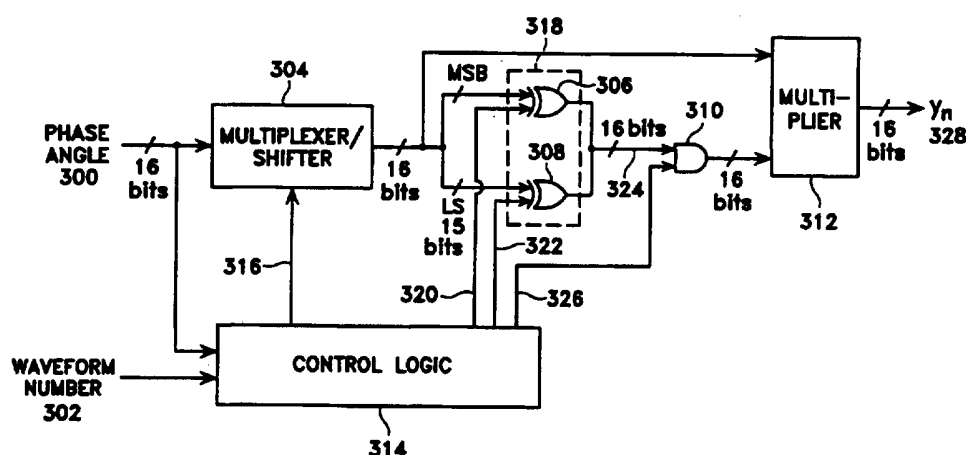




## INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

(51) International Patent Classification <sup>6</sup> : <b>G10H 5/10</b>	<b>A1</b>	(11) International Publication Number: <b>WO 96/31868</b> (43) International Publication Date: 10 October 1996 (10.10.96)
<p>(21) International Application Number: PCT/IB96/00398</p> <p>(22) International Filing Date: 5 April 1996 (05.04.96)</p> <p>(30) Priority Data: 08/418,518 7 April 1995 (07.04.95) US</p> <p>(71) Applicant: CREATIVE TECHNOLOGY LTD. [SG/SG]; 67 Ayer Rajah, Crescent #03-18, Singapore 139950 (SG).</p> <p>(72) Inventor: ROSSUM, David, P.; 102 Las Lomas Drive, Aptos, CA 95003-3221 (US).</p> <p>(74) Agents: SALTZBERG, Robert, A. et al.; Morrison &amp; Foerster L.L.P., 755 Page Mill Road, Palo Alto, CA 94304-1018 (US).</p>	<p>(81) Designated States: AL, AM, AT, AU, AZ, BB, BG, BR, BY, CA, CH, CN, CZ, DE, DK, EE, ES, FI, GB, GE, HU, IS, JP, KE, KG, KP, KR, KZ, LK, LR, LS, LT, LU, LV, MD, MG, MK, MN, MW, MX, NO, NZ, PL, PT, RO, RU, SD, SE, SG, SI, SK, TJ, TM, TR, TT, UA, UG, UZ, VN, ARIPO patent (KE, LS, MW, SD, SZ, UG), Eurasian patent (AM, AZ, BY, KG, KZ, MD, RU, TJ, TM), European patent (AT, BE, CH, DE, DK, ES, FI, FR, GB, GR, IE, IT, LU, MC, NL, PT, SE), OAPI patent (BF, BJ, CF, CG, CI, CM, GA, GN, ML, MR, NE, SN, TD, TG).</p> <p><b>Published</b> <i>With international search report.</i> <i>Before the expiration of the time limit for amending the claims and to be republished in the event of the receipt of amendments.</i></p>	

(54) Title: METHOD AND APPARATUS FOR CREATING DIFFERENT WAVEFORMS WHEN SYNTHESIZING MUSICAL SOUNDS



## (57) Abstract

In one embodiment, the invention provides a multiplexer/shifter (304) which modifies the phase angle input (300) according to the particular waveform desired. Boolean logic gates (306, 308, 310) further modify the multiplexer/shifter output based on the two most significant bits of the phase angle input (300) and according to the particular waveform desired. Finally, a multiplier (312) multiplies the multiplexer/shifter output with the output of the Boolean logic gates to produce the desired waveform. The invention may employ banks of exclusive OR gates and AND gates as the Boolean logic. Another embodiment of the invention provides a waveshaping method where a desired waveform is generated from a phase angle input. The phase angle input is multiplexed/shifted based on the particular waveform desired. The results of the multiplexing/shifting are then modified by Boolean logic gates, based on the two most significant bits of the phase angle input and according to the particular waveform desired. The results of the multiplexing/shifting and the Boolean logic are then multiplied together to produce the desired waveform.

**FOR THE PURPOSES OF INFORMATION ONLY**

Codes used to identify States party to the PCT on the front pages of pamphlets publishing international applications under the PCT.

AM	Armenia	GB	United Kingdom	MW	Malawi
AT	Austria	GE	Georgia	MX	Mexico
AU	Australia	GN	Guinea	NE	Niger
BB	Barbados	GR	Greece	NL	Netherlands
BE	Belgium	HU	Hungary	NO	Norway
BF	Burkina Faso	IE	Ireland	NZ	New Zealand
BG	Bulgaria	IT	Italy	PL	Poland
BJ	Benin	JP	Japan	PT	Portugal
BR	Brazil	KE	Kenya	RO	Romania
BY	Belarus	KG	Kyrgyzstan	RU	Russian Federation
CA	Canada	KP	Democratic People's Republic of Korea	SD	Sudan
CF	Central African Republic	KR	Republic of Korea	SE	Sweden
CG	Congo	KZ	Kazakhstan	SG	Singapore
CH	Switzerland	LI	Liechtenstein	SI	Slovenia
CI	Côte d'Ivoire	LK	Sri Lanka	SK	Slovakia
CM	Cameroon	LR	Liberia	SN	Senegal
CN	China	LT	Lithuania	SZ	Swaziland
CS	Czechoslovakia	LU	Luxembourg	TD	Chad
CZ	Czech Republic	LV	Latvia	TG	Togo
DE	Germany	MC	Monaco	TJ	Tajikistan
DK	Denmark	MD	Republic of Moldova	TT	Trinidad and Tobago
EE	Estonia	MG	Madagascar	UA	Ukraine
ES	Spain	ML	Mali	UG	Uganda
FI	Finland	MN	Mongolia	US	United States of America
FR	France	MR	Mauritania	UZ	Uzbekistan
GA	Gabon			VN	Viet Nam

METHOD AND APPARATUS FOR CREATING DIFFERENT  
WAVEFORMS WHEN SYNTHESIZING MUSICAL SOUNDS

5

Field of the Invention

The present invention relates to a method and apparatus for creating different waveforms when synthesizing musical sounds.

10

Background of the Invention

In digital music synthesis, one of the basic functional units is the phase increment oscillator. A phase increment oscillator generates a "phase sawtooth," and then employs a "wveshaper" to shape the phase sawtooth into a sine wave, or other desired waveform. In most early hardware implementations, a lookup table in RAM or ROM was used to transform the phase sawtooth into the desired waveform. That approach had the virtues of generating waveforms of arbitrary shapes and being relatively cost effective compared to other means available, at least at that time. Because of these virtues, that approach remains common today.

20  
25

However, in the maturing of the digital music synthesizer, certain waveforms have become standard, thus obviating the need for arbitrary waveform generation. For example, the popular Yamaha Corporation "OPL3" synthesizer chip has eight standard waveforms. Because the "OPL3" chip is used in Creative Technology Ltd's "SOUND BLASTER" sound card for IBM-compatible PCs, the popularity of those sound cards has made those eight waveforms a standard for compatible FM music synthesis.

30

Additionally, in the field of VLSI, the speed of computational circuits has increased by orders of magnitude.

This enables the use of computational methods of generating waveforms as an improvement (in some cases) to the lookup  
5 table methods previously used, particularly where the size of the table must be relatively large to minimize inaccuracies and distortion.

For example, the well-known Taylor expansion for the cosine function:

$$10 \quad \cos(x) = 1 - x^2 / 2! + x^4 / 4! - x^6 / 6! \dots$$

provides a basis for a computational approximation to a stored sine waveform, shifted in phase by  $\pi/2$ .

Unfortunately, to achieve sufficient accuracy of less than a few percent total harmonic distortion (which is adequate for  
15 low cost music synthesis), several terms of this equation must be implemented when the required range is from  $-\pi$  to  $\pi$  (a single cycle of the cosine). Because each additional term requires an additional multiplication and addition, this approach becomes computation intensive, and thus  
20 costly.

Accordingly, while computational approaches such as these have been used instead of lookup tables, they require fairly complicated multiplications, additions and other functions. This in turn requires complex logic, if  
25 the logic is hardwired, or places a significant burden on a microprocessor, if a microprocessor is used instead. The tradeoff has been, therefore, between using large amounts of memory, as with a lookup table, or large amounts of computational capacity, as with a computational approach.

30

Summary of the Invention

This invention provides a new circuit and method for generating waveforms from a phase angle input when synthesizing musical sounds. In one embodiment, the invention provides a multiplexer/shifter which modifies the phase angle input according to the particular waveform desired. Boolean logic gates then further modify the multiplexer/shifter output signal based on the two most significant bits of the phase angle input and according to the particular waveform desired. Finally, a multiplier multiplies the multiplexer/shifter output signal with the output signal of the Boolean logic gates to produce the desired waveform. The invention may employ banks of exclusive OR gates and AND gates as the Boolean logic.

Another embodiment of the invention provides a waveshaping method where a desired waveform is generated from a phase angle input. The phase angle input is multiplexed/shifted based on the particular waveform desired. The results of the multiplexing/shifting are then modified by Boolean logic gates, based on the two most significant bits of the phase angle input and according to the particular waveform desired. The results of the multiplexing/shifting and the Boolean logic are then multiplied together to produce the desired waveform.

Brief Description of the Drawings

The objects, features and advantages of the present invention will be apparent to one skilled in the art in light of the following detailed description in which:

Figure 1 shows a signal flow diagram of a known phase increment oscillator.

Figure 2 shows graphically the basis of the present invention.

Figure 3 shows graphically the creation of the eight "OPL3" waveforms using the present invention.

Figure 4 shows a block diagram of a hardware implementation of the present invention.

5 Figure 5 shows the relationship of signals in the present invention for the eight "OPL3" waveforms.

#### Detailed Description of the Invention

Before the present methods and apparatuses are  
10 described, it is to be understood that this invention is not limited to the particular apparatuses or methods described as such, which those of skill in the art can, of course, vary. It is also to be understood that the terminology used herein is for the purpose of describing particular  
15 embodiments only, and is not intended to be limiting as to the scope of the present invention, which will be limited only by the appended claims.

It should be noted that, as used in this specification and the appended claims, the singular forms  
20 "a", "an" and "the" include the plural referents unless the context clearly dictates otherwise.

Unless defined otherwise, all technical and scientific terms used herein have the same meaning as commonly understood by one of ordinary skill in the art to  
25 which this invention belongs. Although any methods and materials similar or equivalent to those described herein can be useful in the practice or testing of the present invention, preferred methods and materials are described below. All publications and patents mentioned herein are  
30 incorporated herein by reference.

As noted above, the Taylor expansion of the cosine function provides a basis for a computational approximation to a stored sine waveform, but it requires

several terms (and the necessary multiplications and additions) to achieve sufficient accuracy through a range of  $-\pi$  to  $\pi$ . It can be seen through analysis, however, that if the range is limited from  $-\pi/2$  to  $\pi/2$ , that a single term of the Taylor expansion can be appropriately modified and used, using a quadratic spline method. Specifically,

$$\cos(x)[- \pi / 2 \leq x \leq \pi / 2] \approx 1 - (2x / \pi)^2$$

One can visualize this function over the specified interval as an inverted parabola, intersecting the points  $(-1,0)$ ,  $(0,1)$ , and  $(1,0)$ . One can then extrapolate to a "parabolic wave" approximation to a cosine wave based on this interval linked appropriately with other copies of the same interval, inverted and translated appropriately.

The above formula clearly requires at least one multiplication. However, it is not obvious that the remainder of the formula can be adequately approximated entirely by Boolean logic, without requiring an adder or "carry chain" logic. This means that the operation to produce this sinusoid-like waveform can be performed by a few hundred gates of logic (at the cost of a few cents on a modern VLSI circuit), plus a single multiplication operation.

Because a phase increment oscillator requires a multiplication operation for scaling of the amplitude of the output signal, a multiplier is already required in this application. With the speed of digital circuitry today, implementing a second multiplication by time domain multiplexing this multiplier does not significantly change the cost of the circuitry for many modern implementations.

Those skilled in the art will recognize from the above description that the present invention suffers from approximately 2% harmonic distortion. However, the

alternative approach of a table lookup oscillator can suffer from more objectional forms of distortion when implemented for low cost by the use of a small table, because the resulting waveform will have a "stairstep" quality. This is  
5 much more objectionable than the smooth output signal that the present invention produces. Thus, the present invention, despite its distortion, has a perceived fidelity advantage over previous low cost approaches.

In short, therefore, the present invention  
10 provides an efficient, low cost alternative to waveform memory storage in producing standard waveforms from a phase increment oscillator. It also offers improved audio fidelity at low cost.

Various embodiments of the present invention are  
15 illustrated in Figures 1 through 5. Figure 1 shows, in signal flow diagram form, the well known phase increment oscillator. While many variations of this oscillator exist, including in particular numerous connection topologies for implementing various FM patches, the fundamental core of the  
20 oscillator remains unchanged.

In Figure 1, an adder 12 adds a phase increment ( $\omega_n$ ) input 10 to the value of the previous phase, which was stored by the delay operator 22. A modulo operator 14 then takes the sum modulo  $2\pi$ , and the resulting new phase is  
25 output to both a waveshaper 16 and to the delay operator 22, which stores it for use during the computation of the next sample. A multiplier 18 then multiplies the output signal of the waveshaper 16 by an amplitude envelope ( $A_n$ ) input 24 to produce the oscillator's output signal ( $Y_n$ ) 20.

30 As will be easily seen by those skilled in the art, when the phase increment ( $\omega_n$ ) input 10 is a constant much less than  $2\pi$ , the signal at the output of the modulo operator 14 will be a "sawtooth" waveform increasing slowly



with constant slope from zero to  $2\pi$ , then jumping suddenly back to zero to begin rising again. Hence this signal is commonly referred to as a "phase sawtooth." This is shown graphically in row 2a of Figure 2.

5                   The present invention performs the function of the waveshaper 16 in Figure 1. Figure 2 shows pictorially the generation, according to the present invention, of an inverted sine waveform. Although for clarity the example of a standard phase sawtooth being input to the waveshaper 16  
10 is sometimes used in the detailed description of the present invention, it will be evident to those skilled in the art that the phase angle input need not be limited to a standard phase sawtooth; any phase angle input may be used.

Row 2a of Figure 2 shows several cycles of the  
15 standard phase sawtooth, with time varying over the horizontal axis and amplitude varying from -1 to +1 on the vertical axis. Note that the vertical axis has been scaled and a fixed offset added to the standard view of the phase sawtooth varying from 0 to  $2\pi$ ; this is of course of no  
20 audible consequence.

Row 2b shows the standard phase sawtooth with a phase offset of  $\pi$  added to it. In other words, the phase sawtooth has been shifted 180 degrees along the horizontal axis. Row 2c shows the absolute value of the signal in  
25 Figure 2b. Row 2d shows the signal, in this case simply  $y(t)=1$ , which according to the present invention is to be ANDed with Row 2c. Row 2e shows the results of that ANDing. Finally, Row 2f shows the end results of the present invention, obtained by multiplying the signal in  
30 Row 2a with that in Row 2e, which can be seen to approximate an inverted sine waveform of amplitude ranging from  $-\frac{1}{2}$  to  $\frac{1}{2}$ . This is an inverted form of the first standard "OPL3" waveform, obtained according to the present invention.

Figure 3 shows pictorially the method, according to the present invention, for forming each of the eight standard "OPL3" waveforms (Waveforms #0 to #7). Each of the steps of the method shown pictorially in Figure 3 will be  
5 discussed in greater detail below when describing the operation of the hardware embodiment of the present invention.

Column 3a of Figure 3 shows one cycle, from 0 to  $2\pi$ , of each of the eight waveforms. Column 3b shows the  
10 first modification, if any, to the input phase sawtooth required by the present invention. This first modification results in either the original phase sawtooth (for Waveforms #0 to #3), the original phase sawtooth doubled in frequency (for Waveforms #4 and #5), and in one case, also  
15 halved in amplitude (for Waveform #7), or the signum of the original phase sawtooth, also halved in amplitude (for Waveform #6).

Column 3c shows the modified phase sawtooth shifted in phase, if required, and its absolute value taken,  
20 if required, in both cases according to the present invention. Column 3d shows the function which, according to the present invention, is ANDed with the modified phase sawtooth of column 3c, and column 3e shows the results of the ANDing of columns 3c and 3d. Finally, column 3f shows  
25 the results of the final step of the present invention, multiplying column 3b by column 3e. Note that the vertical scale of column 3e is from  $-\frac{1}{4}$  to  $\frac{1}{4}$ , while the vertical scale of the other columns is -1 to 1.

From Figure 3, it can be seen that all eight  
30 "OPL3" waveforms can be approximated according to the present invention. This is accomplished by appropriately combining, according to the present invention, the steps of modifying the original phase sawtooth input, shifting the

result in phase, taking an absolute value, ANDing the result with certain phase sawtooth bits, and finally a single multiplication. Note that the polarity of the approximated waveforms is treated as being insignificant, as it does not  
5 affect the sound or harmonic content of the waveform. However, as will be seen below, with minor modifications to the circuitry described even the polarity can be corrected, if desired.

Figure 4 shows a detailed hardware implementation  
10 of the present invention. A phase angle input 300 provides an input to both a multiplexer/shifter 304 and control logic 314. The phase angle input 300 is a 16-bit unsigned value representing the phase taken modulo  $2\pi$ . Thus, a phase of zero is hexadecimal 0000, and a phase of almost  $2\pi$  is  
15 hexadecimal FFFF.

The multiplexer/shifter 304 is a multiplexer wired as a modified barrel shifter. The control logic 314 drives the multiplexer/shifter 304 through a control  
20 signal 316. In this embodiment, the control signal has two bits for representing the four possible multiplexer/shifter functions. However, as will be evident to those skilled in the art, the control signal 316 can have more than two bits if desired to optimize the logic of the circuit.

The steps for generating each of the standard  
25 "OPL3" waveforms will now be described. First, the multiplexer/shifter 304 operates on the phase angle input 300, as described in detail below. The output signal of the multiplexer/shifter 304 for each waveform is shown in column 3b of Figure 3.

30 In Figure 4, when the control logic 314 sends a control signal 316 of binary 00 to the multiplexer/shifter 304, the multiplexer/shifter 304 outputs a 16-bit signal identical to the 16-bit phase angle input 300 it

received. This produces the output signal shown in rows #0 to #3 of column 3b of Figure 3.

When the control signal 316 to the multiplexer/shifter 304 is binary 01, it shifts the 16-bit phase angle input 300 left one bit, shifts off and ignores the most significant bit ("MSB"), sets the new least significant bit ("LSB") to 0, and inverts the new MSB. Mathematically, this is equivalent to adding  $\pi/2$  to the phase angle input 300, multiplying the result by two, and then taking the result modulo  $2\pi$ . This produces the output signal shown in rows #4 and #5 of column 3b.

When the control signal 316 to the multiplexer/shifter 304 is binary 10, it outputs a fixed hexadecimal 3FFF. This produces the output signal shown in row #6 of column 3b.

Finally, when the control signal 316 to the multiplexer/shifter 304 is binary 11, it outputs the fourteen LSBs of the 16-bit phase angle input 300 unchanged, and sets the two MSBs of the output signal both to the inverse of the next to the most significant bit, i.e. bit 14, of the original input signal. In other words, it outputs the fifteen LSBs of the 16-bit phase angle input 300 plus  $\pi/2$ , sign extended. This produces the output signal shown in row #7 of column 3b.

Next, a bank 318 of exclusive OR gates further modifies the 16-bit output signal of the multiplexer/shifter 304. The exclusive OR bank 318 consists of two sections. The first section of exclusive OR gates 306 acts only on the MSB of the multiplexer/shifter 304 output signal, while the second section of exclusive OR gates 308 acts on the other fifteen LSBs.

The exclusive OR bank 318 performs two functions, phase shifting and a functional approximation to the absolute value function, or a combination of both, or neither (a pass-through). The output signal of the  
5 exclusive OR bank 318 for each waveform is shown in column 3c of Figure 3.

When two control signals 320 and 322 received by both sections of the exclusive OR bank 318 are both a logical "0", no change occurs. This pass-through operation  
10 is used to produce part of the output signal shown in rows #6 and #7 of column 3c of Figure 3.

When the first control signal 320 is logical "0" and the second control signal 322 is logical "1", the output signal 324 of the exclusive OR bank 318 is the one's  
15 complement of the multiplexer/shifter 304 output signal plus  $\pi$ . In this case, the one's complement is only one LSB away from the two's complement, which is, to the accuracy required, the same result as obtained by multiplying by -1. Accordingly, taking the one's complement can be used to  
20 produce a functional approximation to the absolute value function. This phase-shifting and absolute value operation is used to produce part of the output signal shown in rows #0 and #4 of column 3c.

When the first control signal 320 is a  
25 logical "1" but the second control signal 322 is a logical "0", the output signal 324 of the exclusive OR bank 318 is the sum of the multiplexer/shifter 304 output signal and  $\pi$ , since the MSB has significance  $\pi$ . Accordingly, this operation can be used to shift a signal  
30 by  $\pi$ . This operation is used to produce all of the output signal shown in rows #1, #2, #3 and #5 of column 3c, and part of the output signal shown in rows #0 and #4.

When the two control signals 320 and 322 are both a logical "1", the output signal 324 of the exclusive OR bank 318 is the one's complement of the output signal of the multiplexer/shifter 304. As discussed above, this operation  
5 is a functional approximation to the absolute value function. This operation is used to produce part of the output signal shown in rows #6 and #7 of column 3c of Figure 3.

Next, a bank 310 of AND gates further modifies  
10 the 16-bit output signal 324 of the exclusive OR bank 318. A control signal 326 to the AND bank 310 can force its 16-bit output signal to hexadecimal 0000, or leave it unchanged. This performs the ANDing of each of the signals shown in column 3c of Figure 3 with the corresponding signal  
15 shown in column 3d, with the output signal of the bank 310 for each waveform shown in column 3e.

It should be noted that all of the Boolean logic described up to this point is parallel in nature, and does not require any addition operations or other logic, such as  
20 a carry chain, that requires each higher order bit to be processed as a result of logical operations on lower order bits. Thus, the processing of this data involves only a few gate delays and can be accomplished within a single clock cycle.

25 A 16-bit by 16-bit signed two's complement multiplier 312 then receives both the 16-bit output signal of the multiplexer/shifter 304, unmodified (as shown in column 3b of Figure 3), and the 16-bit output signal of the AND bank 310 (as shown in column 3e), and multiplies them  
30 together. Because most current audio applications use just 16-bit signals, only the sixteen MSBs of the multiplier 312 output signal are needed, so an abbreviated form of the multiplier can be used. The results of this multiplication

for each waveform are shown in column 3f of Figure 3. This completes the processing needed to form each of the standard "OPL3" waveforms.

As will be evident to those skilled in the art, depending on the size of the available multiplier, it may be desirable to have either or both of the arguments of the multiplier be less than 16 bits, since that would have only a minor impact on the waveform fidelity. Moreover, it will also be evident that any type of multiplier could be used, such as a full parallel multiplier, a serial multiplier, or a hybrid parallel/serial multiplier, to accomplish this function.

In addition, the multiplier 312 output signal never reaches more than one fourth of its theoretical maximum output value, since the peak values occur when its inputs are each at an absolute value of half of full scale. The multiplier 312 output signal 328 should be scaled to account for this.

As is evident from the above step-by-step description, the four control signals 316, 320, 322 and 326 output by the control logic 314 must be set appropriately to form the eight "OPL3" waveforms. These control signals 316, 320, 322 and 326 are determined by the waveform number 302 and the two MSBs of the phase angle input 300. These control signals 316, 320, 322 and 326 then appropriately control the multiplexer/shifter 304, the exclusive OR bank 318, the AND bank 310 and the multiplier 312 to create the desired waveform from the phase angle input 300.

Based on the waveform number 302 and bits 15 and 14 of the phase angle input 300, the control logic 314 sets the control signals 316, 320, 322 and 326 to the values shown in the truth table, Table 1, below. In Table 1, PHn indicates the nth bit of the phase angle input 300, so that,

for example, PH15 is the most significant bit. ! indicates logical complement, and ^ indicates an exclusive OR.

Table 1

5 Control Signal Truth Table

Waveform	Control Signals:			
Number	316	320	322	326
#0	00	PH15	!PH15 1	
10 #1	00	1	0	PH15
#2	00	1	0	1
#3	00	1	0	!PH14
#4	01	PH14	!PH14 PH15	
#5	01	1	0	PH15
15 #6	10	PH15	PH15	1
#7	11	!PH14	!PH14 PH15^PH14	

Figure 5 shows in graphical form the various steps, described in detail above, for producing each of the eight "OPL3" waveforms. Column 5a shows the output signal of the multiplexer/shifter 304, column 5b shows the output signal 324 of the exclusive OR bank 318, column 5c shows the output signal of the AND bank 310, and column 5d shows the output signal 328 of the multiplier 312. Note that the vertical scale of column 5d is from -¼ to ¼, while the vertical scale of the other columns is -1 to 1.

As can be seen in column 3f of Figure 3 and column 5d of Figure 5, all of the output waveforms, when created as described above, are simply inverted in polarity from the desired "OPL3" waveforms. Inverted polarity has no audible impact on the sounds of these waveforms. However, the precise waveform, correct in phase and polarity, can be produced by taking the complement of the output waveform.



This can be done at a variety of locations in further signal processing circuitry, as part of the multiplier 312, or by an additional circuit. As will be evident to those skilled in the art, a one's complementing of the output signal may  
5 be sufficient to accomplish this inversion to the accuracy of the approximations herein described.

Figure 4 provides circuitry, or hardware, which embodies the invention. However, as will be evident to those skilled in the art, the invention can also be embodied  
10 in firmware and software.

As can be seen from the detailed description of the present invention above, it enables each of the standard "OPL3" waveforms to be produced without requiring large amounts of memory or intensive computation. Accordingly,  
15 for applications where the waveform can be an approximation, and high accuracy in the waveform is not required, the waveshaper of the present invention provides advantages over the prior art.

What is claimed is:

1. A circuit for generating a predetermined waveform from a phase angle input comprising:
  - a multiplexer/shifter for modifying the phase  
5 angle input to produce an output;
  - combinatorial logic circuitry for modifying the output of the multiplexer/shifter to produce an output; and
  - a multiplier for multiplying the output of the multiplexer/shifter with the output of the combinatorial  
10 logic circuitry to produce the waveform.
2. The circuit of claim 1 wherein the combinatorial logic circuitry comprises banks of exclusive OR gates and banks of AND gates.
3. The circuit of claim 2 wherein the banks of  
15 AND gates follow the banks of exclusive OR gates.
4. A method for generating a predetermined waveform from a phase angle input comprising the steps of:
  - multiplexing/shifting the phase angle input;
  - modifying the results of the  
20 multiplexing/shifting step, using combinatorial logic; and
  - multiplying the results of the multiplexing/shifting step and the modifying step to produce the waveform.
5. The method of claim 4 wherein the step of  
25 multiplexing/shifting comprises carrying out a null operation.
6. A method for generating a predetermined waveform from a phase angle input comprising the steps of:
  - multiplexing/shifting the phase angle input;
  - 30 modifying the results of the multiplexing/shifting step, using combinatorial logic, without performing an addition operation or any operation which requires a carry chain; and

multiplying the results of the  
multiplexing/shifting step and the modifying step to produce  
the waveform.

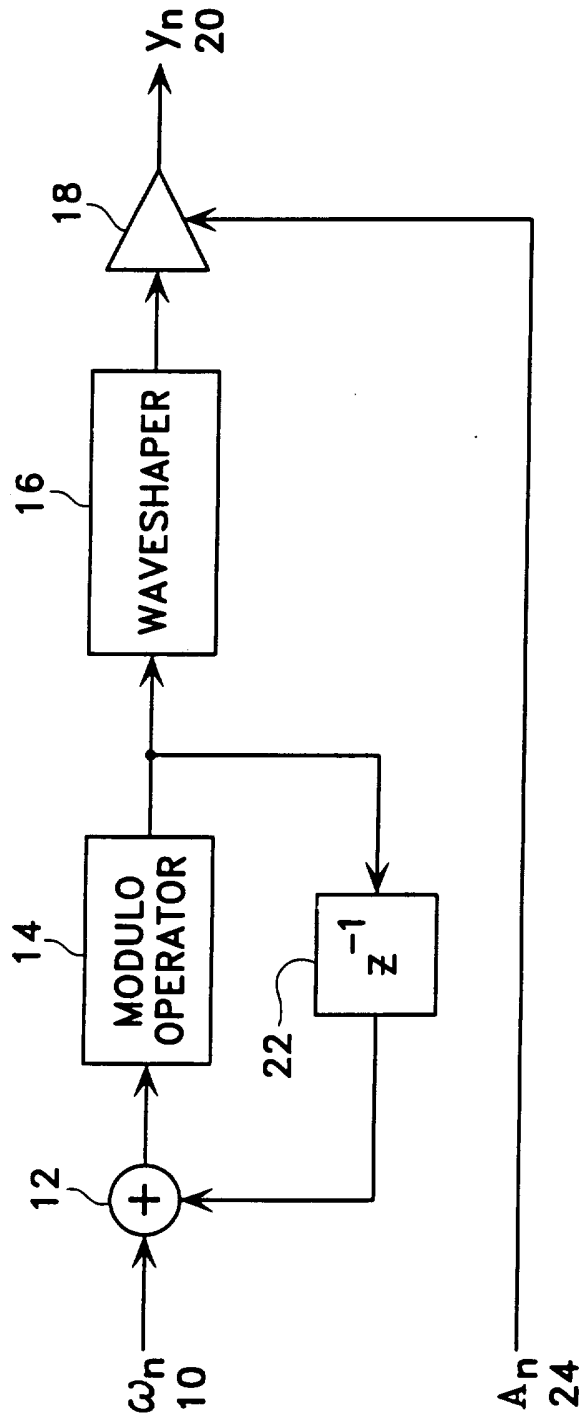


FIG. 1

2/5

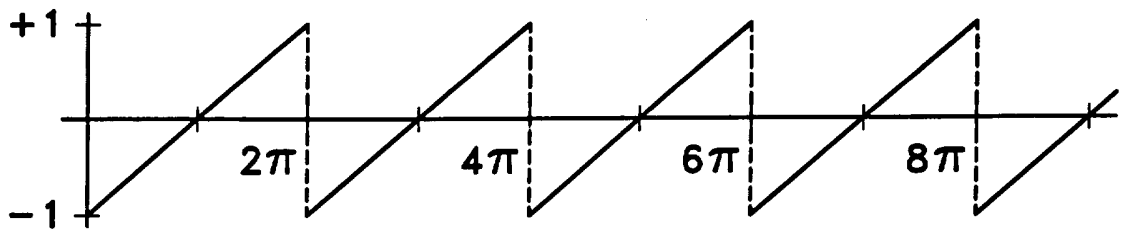


FIG. 2a

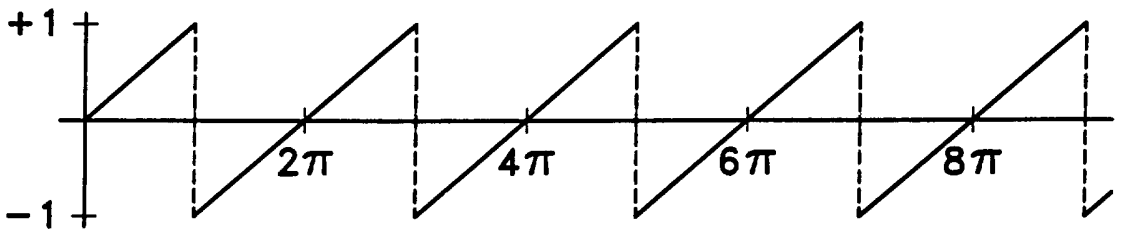


FIG. 2b

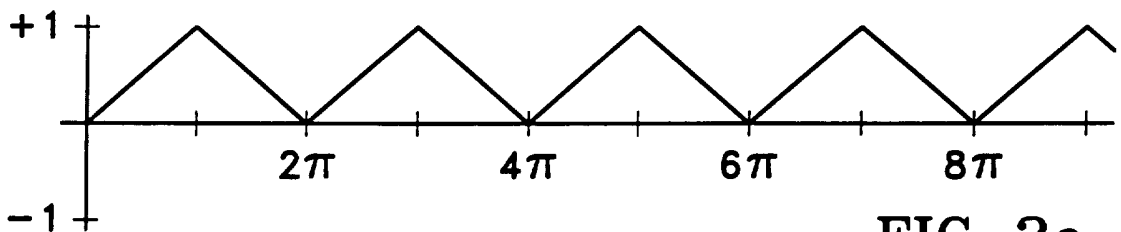


FIG. 2c

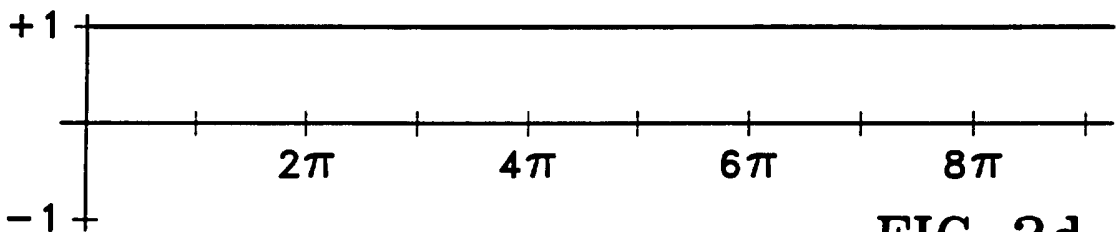


FIG. 2d

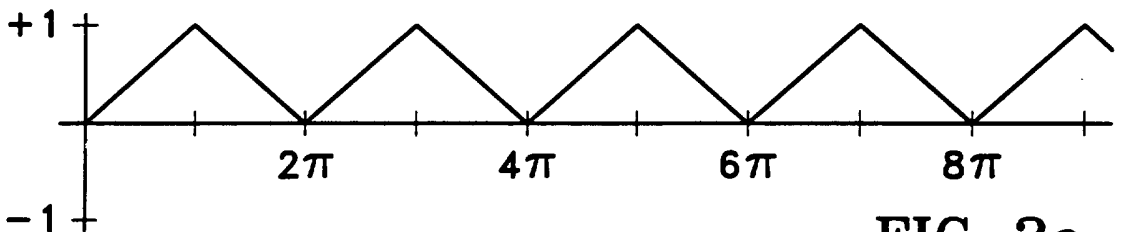


FIG. 2e

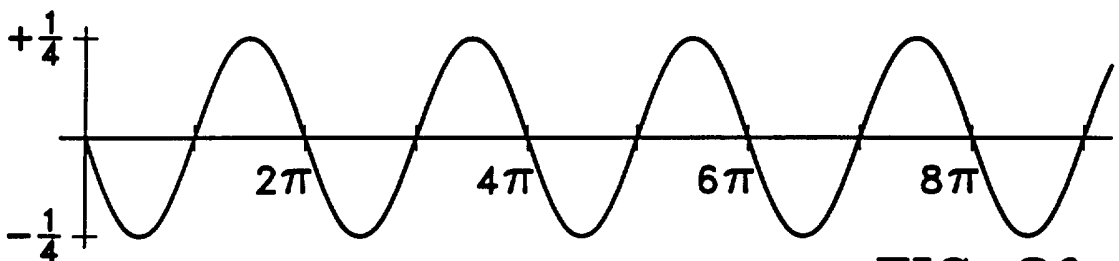
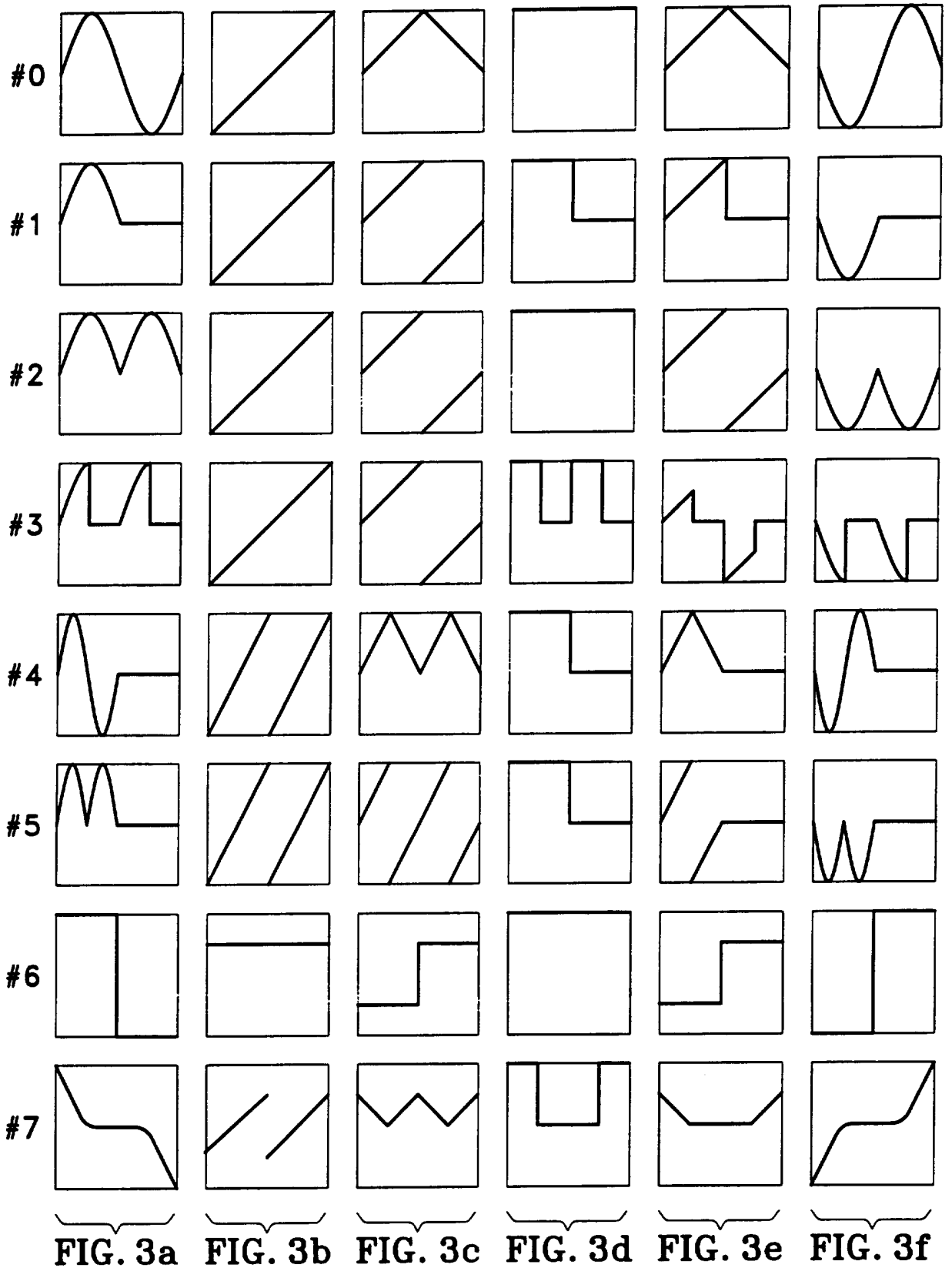


FIG. 2f



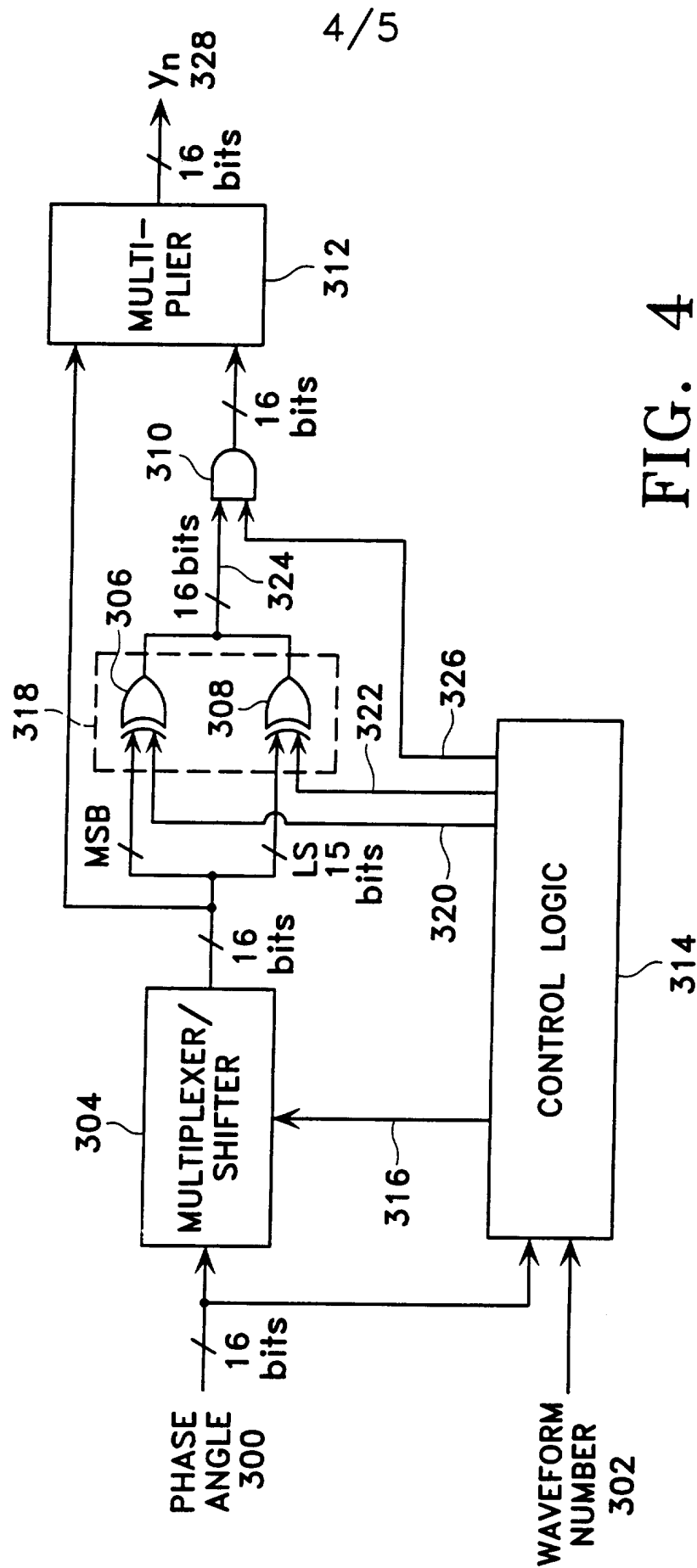
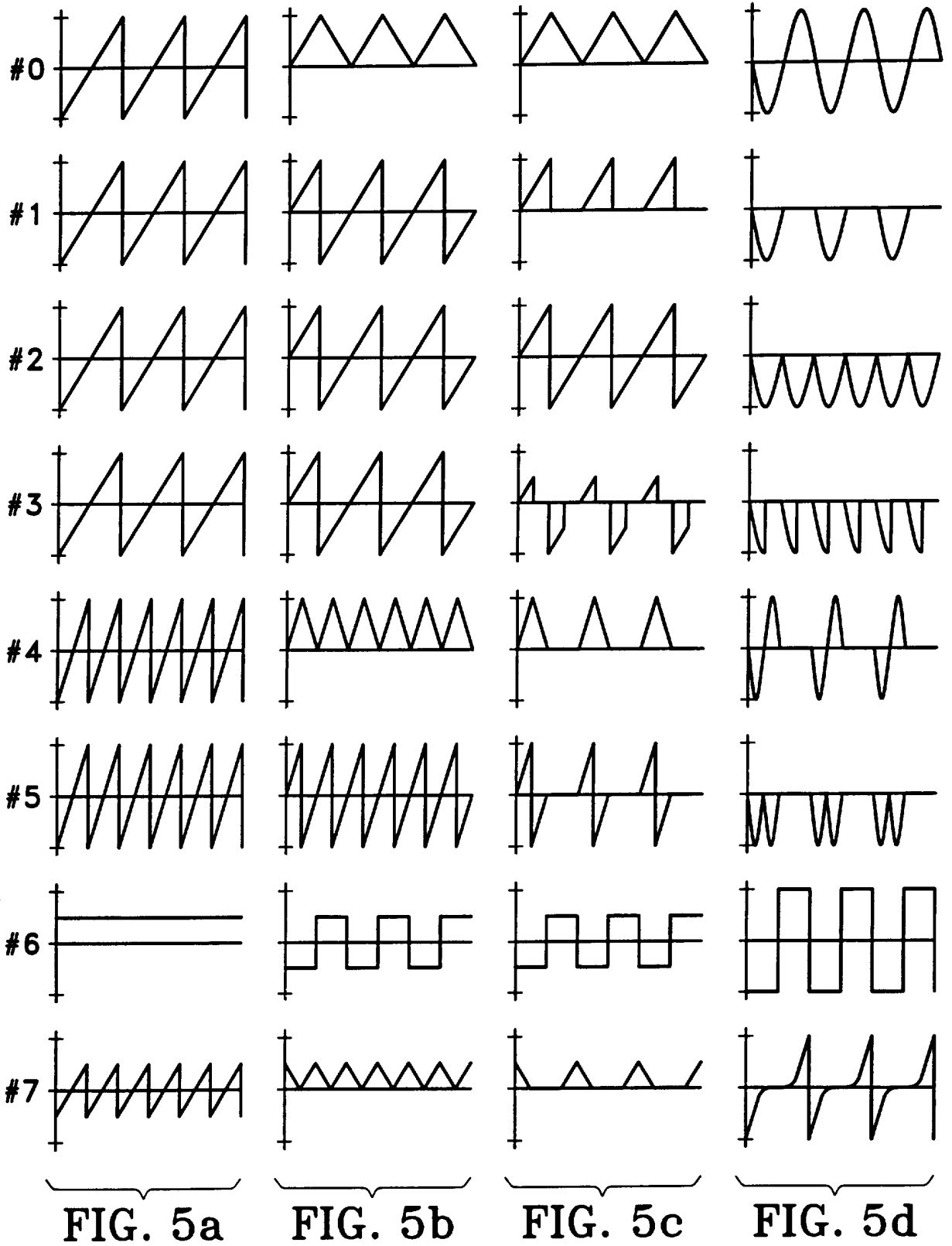


FIG. 4





INTERNATIONAL SEARCH REPORT

International Application No  
PCT/IB 96/00398

A. CLASSIFICATION OF SUBJECT MATTER  
IPC 6 G10H5/10

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)  
IPC 6 G10H

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practical, search terms used)

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category *	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	EP,A,0 484 048 (IBM) 6 May 1992 see column 6, line 2 - column 7, line 1; figures 2,3A-3E	1,4
A	EP,A,0 454 047 (CASIO COMPUTER CO LTD) 30 October 1991 see page 9, line 1 - page 10, line 10; figures 7A-7G,8	1,2,4
A	US,A,4 259 888 (GROSS GLENN M) 7 April 1981 see column 12, line 14 - column 14, line 2; figures 9-12G	1,4,6

Further documents are listed in the continuation of box C.

Patent family members are listed in annex.

\* Special categories of cited documents :

- \*A\* document defining the general state of the art which is not considered to be of particular relevance
- \*E\* earlier document but published on or after the international filing date
- \*L\* document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)
- \*O\* document referring to an oral disclosure, use, exhibition or other means
- \*P\* document published prior to the international filing date but later than the priority date claimed

- \*T\* later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention
- \*X\* document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone
- \*Y\* document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art.
- \*&\* document member of the same patent family

Date of the actual completion of the international search

21 August 1996

Date of mailing of the international search report

- 6. 09. 96

Name and mailing address of the ISA

European Patent Office, P.B. 5818 Patentlaan 2  
NL - 2280 HV Rijswijk  
Tel. (+31-70) 340-2040, Tx. 31 651 epo nl,  
Fax (+31-70) 340-3016

Authorized officer

Pulluard, R

## INTERNATIONAL SEARCH REPORT

Information on patent family members

International Application No

PCT/IB 96/00398

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
EP-A-0484048	06-05-92	US-A- 5194684	16-03-93
		CA-A,C 2052770	02-05-92
		JP-A- 4234795	24-08-92
		JP-B- 6103438	14-12-94
EP-A-0454047	30-10-91	JP-A- 4005692	09-01-92
		JP-A- 4060693	26-02-92
		JP-A- 4060694	26-02-92
		KR-B- 9405988	30-06-94
		US-A- 5340938	23-08-94
US-A-4259888	07-04-81	NONE	