United States Patent

[11] **3,579,117**

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[54] **WAVEFORM GENERATOR**
4 Claims, 5 Drawing Figs.

[52] **U.S. Cl.** **328/27,** 328/14, 328/25, 328/30, 328/104, 328/139, 328/154
[51] **Int. Cl.** **H03k 5/08**
[50] **Field of Search** 328/14, 15, 17, 22, 24, 25, 27, 30, 104, 117, 137, 139, 158, 154, 133; 332/23; 329/122; 325/351

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ABSTRACT: A method and apparatus for time-domain generation of an approximation to an ideal waveform for signaling synchronously via a bandlimited transmission facility is disclosed. The method, which consists of serially gating appropriate waveform segments so as to achieve the desired composite waveform, presents the advantage over prior art that time-domain techniques are invoked in the task of waveform generation, to supplement the work of frequency-domain techniques (filtering).

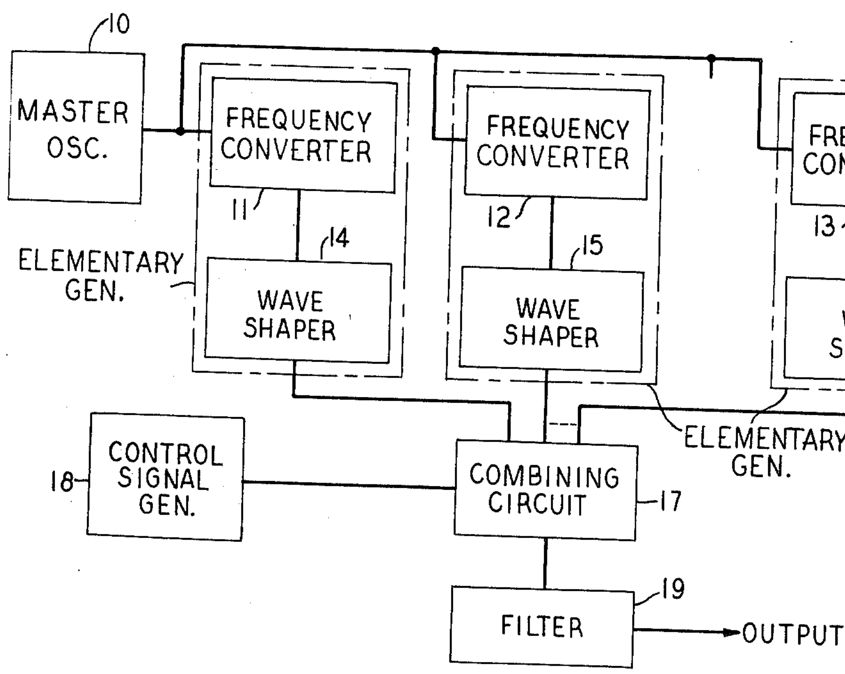


FIG. 1

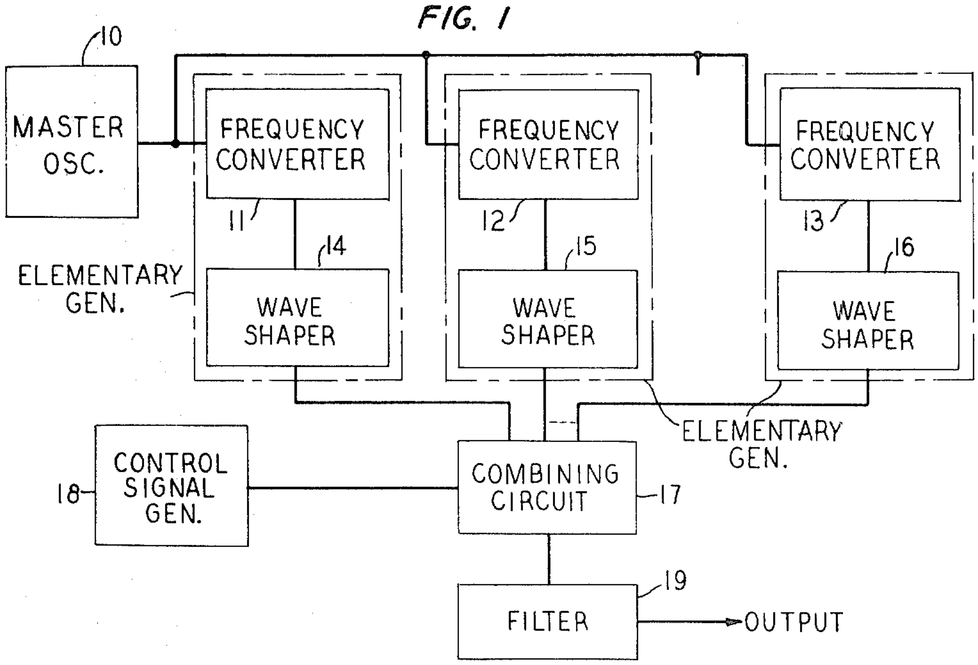
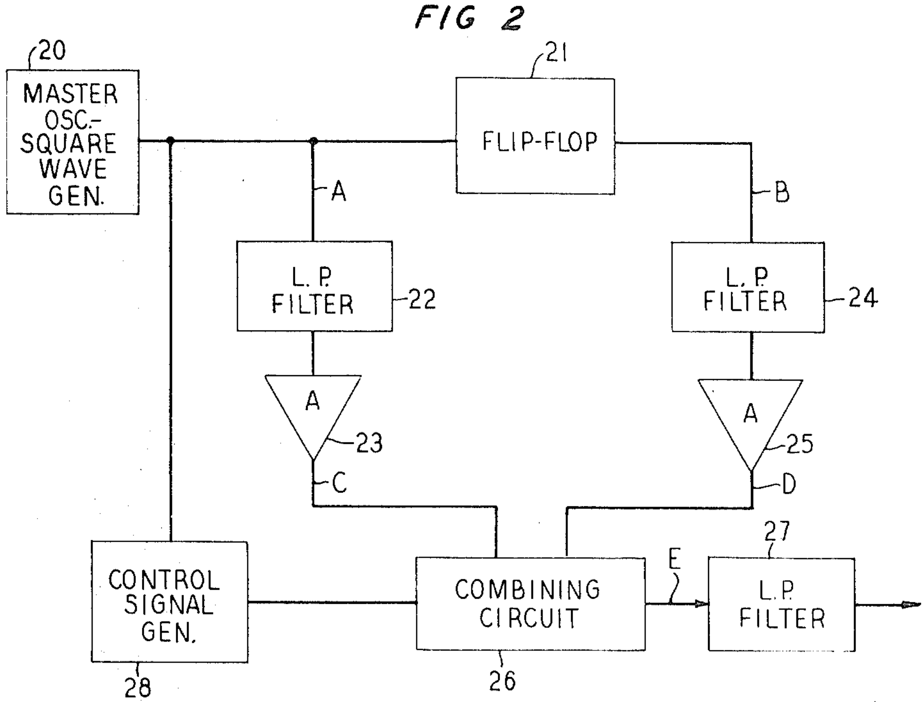


FIG 2



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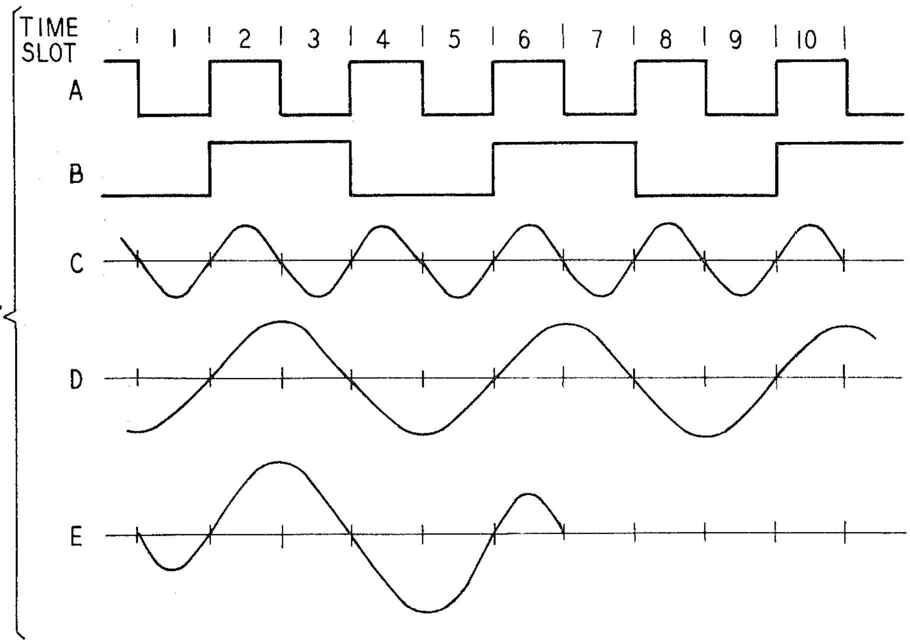
TIME
SLOT
1
2
3
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5
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7
8
9
10
A
B
C
D
E

FIG. 3

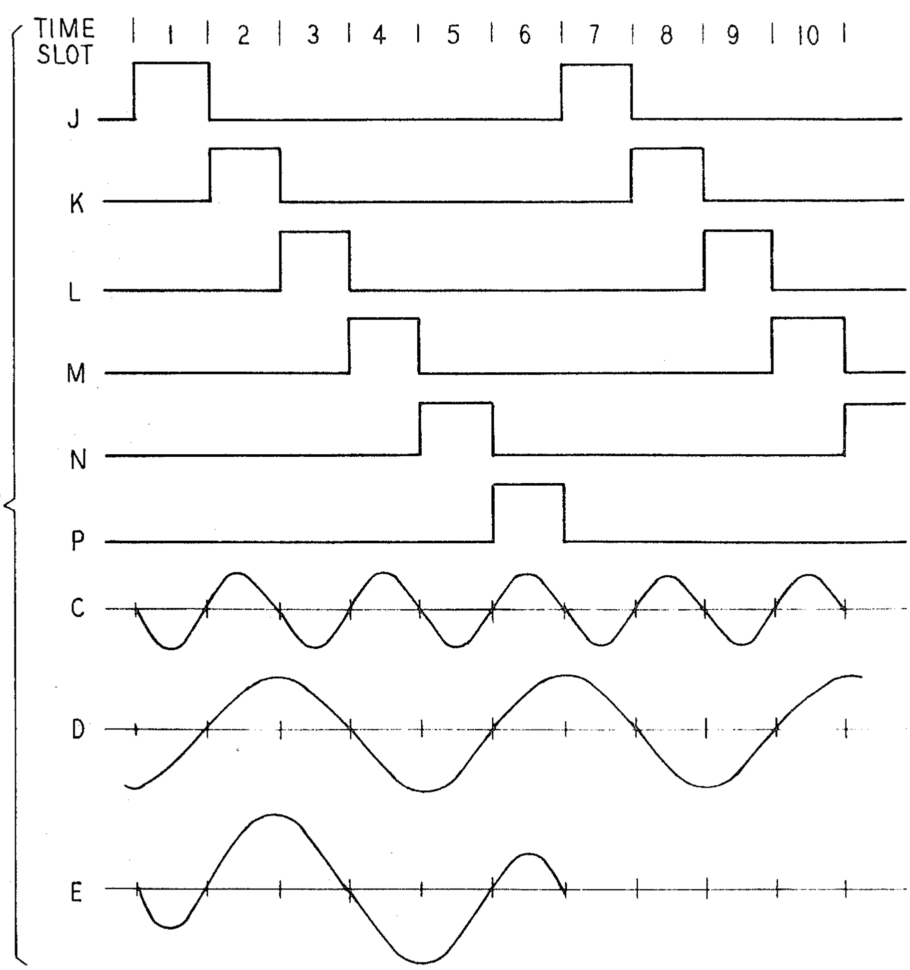
TIME
SLOT
1
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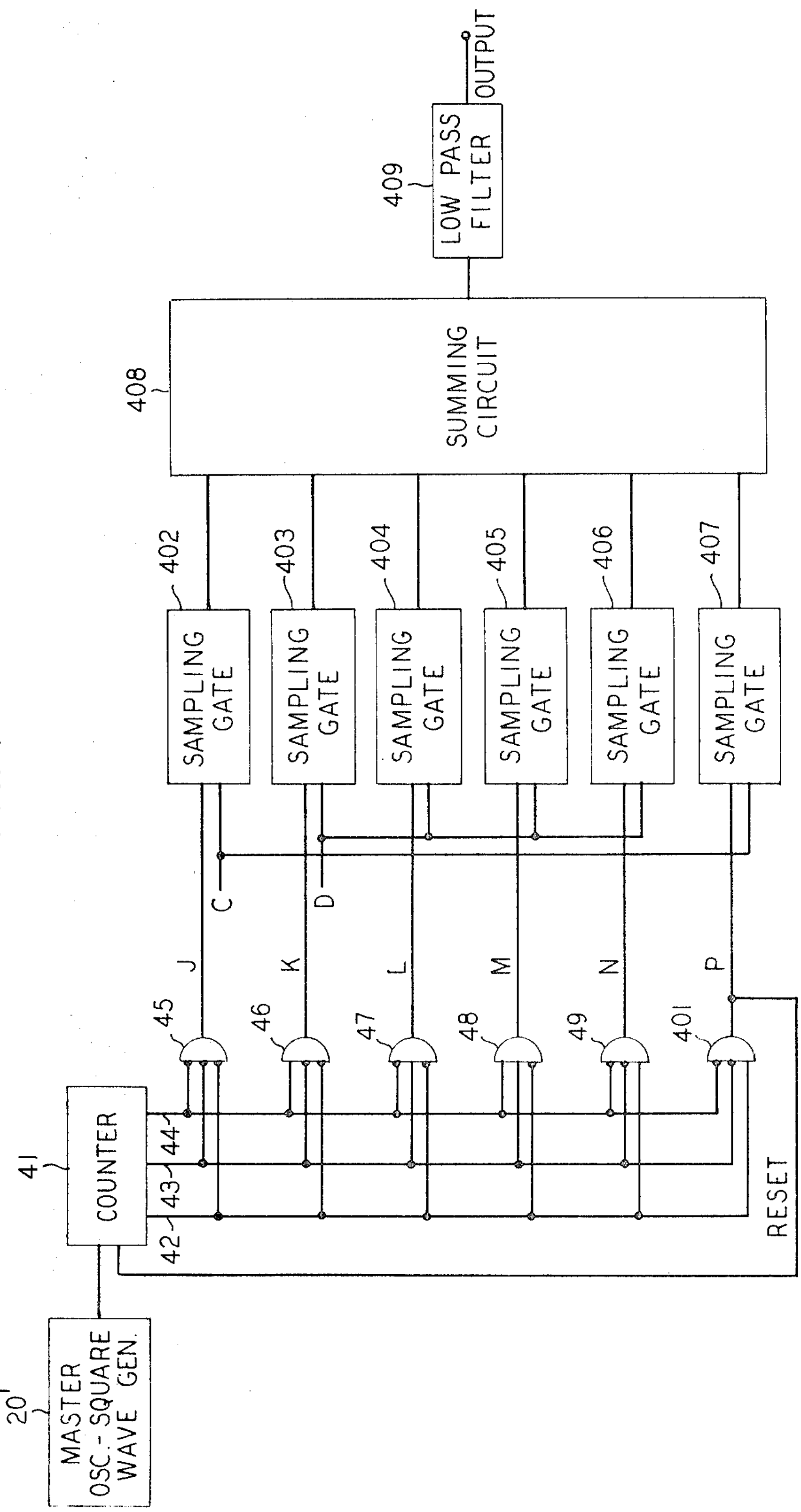
FIG. 5

FIG. 4


OUTPUT
LOW PASS FILTER
409
SUMMING CIRCUIT
408
402
403
404
405
406
407
SAMPLING GATE
SAMPLING GATE
SAMPLING GATE
SAMPLING GATE
SAMPLING GATE
SAMPLING GATE
C
D
J
K
L
M
N
P
45
46
47
48
49
401
COUNTER
41
44
43
42
RESET
MASTER OSC.- SQUARE WAVE GEN.
20'

WAVEFORM GENERATOR

BACKGROUND OF THE INVENTION

This invention relates generally to a waveform generator and, more particularly, to a waveform generator used with a pulse transmission system.

In a pulse transmission system, it has been discovered that the transmission of rectangularly shaped pulses is inefficient and inaccurate because overlap and interference occur between neighboring pulses. This overlap and interference is caused, in part, by the inability of the characteristics of the transmission system and line to accommodate the extremely high frequency components of the rectangular wave. By substituting a pulse having a shape that can be more efficiently accommodated by the transmission system and line, less distorted transmission may take place. One example of such a pulse is the well-known Sinx/x pulse. When it is substituted for a rectangular pulse, the above problems attendant on the transmission of the rectangular pulse are minimized.

While it is clear that a certain type of pulse substituted for the rectangular pulse will result in more efficient transmission, the problem of generating such a pulse may be significant. A waveform generator is required which can generate a pulse having the desired waveshape to be substituted for the rectangular pulse of a digital pulse train. Some prior art waveform generators, whether used with a digital transmission system or not, commonly are cumbersome due to the nature of the filters required to produce the desired waveshape.

Prior art waveform generators which utilize frequency domain shaping techniques (filtering) are physically cumbersome and have limited capabilities with respect to the waveforms which can be produced. For instance, when a null in the spectrum at a specific frequency is created by filtering, the signals in the frequencies contiguous to the specific frequency suffer from undesirable phase shift and amplitude effects.

An object of the present invention is to provide a waveform generator which can produce a complex function in a simple manner.

Another object of the present invention is to utilize time domain shaping techniques in the production of a desired waveform.

Another object of the present invention is to synchronize parts of a combined wave in a simple manner.

Another object of the present invention is to generate a pulse waveform which may be substituted for a rectangular pulse waveform in a simple manner.

Another object of the present invention is to generate a pulse having a waveform suitable for use in a digital transmission system.

SUMMARY OF THE INVENTION

These objects are accomplished in accordance with the present invention by generating a composite waveform which is partitioned into a number of time slots, each of which is seperately filled by a portion of a relatively simple periodic waveform derived from an elementary generator. The composite waveform is formed by selectively combining the generators in the proper sequence such that no discontinuity results in the composite waveform. This discontinuity is avoided by having the elementary generators harmonically related and under the the control of a master clock.

The master clock may be a square wave oscillator which is connected to plural frequency converters.

The output of each frequency converter is passed through a respective waveshaper and the outputs of the waveshapers are selectively combined in accordance with predetermined control signals and passed through a simple filter to provide a desired waveshape. Each combination of frequency converter and waveshaper forms an elementary generator. The predetermined control signals may be selected to provide modulation of the desired waveshape in addition to performing the combining functions. As a feature of the present invention, significant equipment savings may be realized by joining the modulation function with the combining circuit.

As another feature, time domain shaping techniques, in accordance with the present invention, may produce waveforms having special properties which were not readily obtainable with frequency domain shaping techniques. For example, the null unobtainable by frequency domain shaping techniques is easily obtained with the present invention by producing a modified periodic ripple signal in the time domain which, it may be shown, transfers to a null in the frequency domain.

Due to the characteristics of a transmission system an line, rectangular pulses cannot be efficiently accommodated without overlap and interference between neighboring pulses. Replacement of each rectangular pulse with a pulse having a form which may more easily be accommodated by a digital transmission system minimizes the overlap and interference problems. As described above, one such waveform is a Sinx/x pulse. Since a Sinx/x pulse theoretically is nonvanishing over all time, its actual generation is impossible. By duration limiting the Sinx/x pulse, that is, by generating a portion of the waveform over a specified time duration, it may effectively be approximated and used with a digital transmission system.

It has been found that transmission of a Sinx/x duration limited pulse is undesirable in at least one aspect because a DC average level is produced on the transmission line. It would be preferable to provide a pulse for use as a substitute for a rectangular pulse which has a zero average value. In another aspect, an embodiment of the present invention provides a duration limited pulse which resembles the Sinx/x pulse, but has a zero average level and is used as a substitute for the rectangular pulse in digital transmission systems. By sampling this pulse at a positive portion of the waveform, the desired information may be obtained.

The desired duration limited pulse is derived, in an illustrative embodiment of the present invention, for use with a digital transmission system by applying the output of a square wave generator to two tandemly-connected flip-flops which serve as frequency dividers. The output of each flip-flop is passed through a respective simple low-pass filter, and the outputs of the filter are selectively combined in order to provide the desired duration limited pulse.

In another aspect, embodiments of the present waveform generator may be fabricated by integrated circuitry techniques, the benefits of which are well known and significant. The waveshaping devices following each flip-flop may provide some problem for integrated circuitry fabrication, but when they comprise only resistors and capacitors, integrated circuitry techniques may be used.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 is a block diagram of the generalized waveform generator arranged in accordance with the principles of the present invention;

FIG. 2 is a block diagram of an illustrative embodiment of the waveform generator shown in FIG. 1 which is capable of producing an electrical waveform for use with a digital transmission system;

FIG. 3 presents a series of curves representative of electrical waveforms appearing at various points in the function generator shown in FIG. 2;

FIG. 4 is a more detailed block diagram of a control and combining circuit arrangement suitable for use in the waveform generator of FIGS. 1 and 2; and

FIG. 5 presents a series of electrical waveforms appearing at portions of the control and combining circuit arrangement shown in FIG. 4.

DETAILED DESCRIPTION

FIG. 1 is a block diagram of a generalized embodiment of a waveform generator and illustrates the principles of the present invention. The output of master oscillator **10** which has a frequency f_1 is supplied to a number of frequency converters illustratively shown as **11**, **12**, and **13**. Converters **11**, **12**, and **13** may be multipliers or dividers or any combination thereof.

The outputs of frequency converters **11**, **12**, and **13** are connected to waveshapers **14**, **15**, and **16**, respectively, the outputs of which are connected to combining circuit **17**. Each combination of converter and waveshaper forms an elementary generator. Under control of control signal generator **18**, the outputs of waveshapers **14**, **15**, and **16** are selectively combined in combining circuit **17** and passed through filter **19** to provide the desired waveform.

Simplistically, the operation of the waveform generator shown in FIG. **1** may be viewed as an arrangement which permits the piecing together of separately generated pieces and combining them to form a desired waveform by serially gating the outputs of the elementary generators. Clearly, in order to produce a desired waveform exactly by this piecing technique, the number of frequency converters and waveshapers required is infinite. With integrated circuitry, the number of frequency converters and waveshapers which can be practically produced is large, but not infinite. Therefore, time domain shaping accomplished by the elementary generators and combining circuit must be supplemented to produce accurately the desired function. By utilizing frequency in addition to time domain shaping, the desired waveform may be accurately produced. To this end, filter **19** is connected to the output of combining circuit **17** to provide the necessary frequency domain shaping. Filter **19** may be simple since most of the waveshaping has been accomplished by the prior circuitry.

Another feature of the present invention relates to the combined frequency and time domain shaping to produce the desired waveform. In the prior art, waveform generators generally include expensive and complex filters in order to provide a desired waveform. In accordance with the present invention, the waveform is produced by initially using time domain shaping and subsequently frequency domain shaping in order to produce the desired waveform. This latter approach enables the waveform generator to be simply and inexpensively fabricated due to the simplicity of the elementary generators.

FIG. **2** is a block diagram of an illustrative embodiment of the generalized waveform shown in FIG. **1**. The apparatus shown in FIG. **2** produces the desired duration limited pulse for use with a digital transmission system. The master oscillator is illustratively shown as master square wave generator **20** which provides a square wave output to a frequency converter, illustratively shown as flip-flop **21**, which frequency divides the square wave input supplied by generator **20**. Master generator **20**, which may serve as a component in an elementary generator, supplies its output through low-pass filter **22** to amplifier **23**, while the output of flip-flop **21** passes through low-pass filter **24** to amplifier **25**. The outputs of amplifiers **23** and **25** connect to the input of combining circuit **26**, the output of which passes through low-pass filter **27**. Control signal generator **28** connects to combining circuit **26** and controls the selective combination process to be accomplished by the combining circuit by serially gating the outputs of amplifiers **23** and **25**.

Another feature of the present invention which is shown in FIG. **2** relates to synchronizing the pieced portions to avoid significant discontinuities in the resulting waveform. Frequency divider **21** represents one of a series of tandemly connected frequency dividers connected to master oscillator **20** and locked to it, enabling drift in the master oscillator to be sensed in each of the following frequency dividers. Thus, when one segment of the desired waveform drifts in time, the amount of drift in the following segment will be the same so that the two portions connect together without significant discontinuity.

The operation of the waveform generator shown in FIG. **2** may be more easily understood by referring to FIG. **3** which presents a series of waveforms appearing at various points in the function generator shown in FIG. **2**. The output of square wave generator **20** is illustratively shown in FIG. **3** as curve A, while the output of flip-flop **21** (which serves as a frequency divider) is shown as waveform B. Waveforms A and B are passed through filters **22** and **24** respectively and amplifiers **23** and **25** respectively. The outputs of amplifiers **23** and **25** are shown as curves C and D respectively. The desired duration limited waveform is shown as curve E. The proper application of control signals to combining circuit **26** will enable curves C and D to be selectively combined to form curve E.

Curve A is a square wave produced by generator **20** which is frequency divided by flip-flop **21** an the output of flip-flop **21** is shown as curve B. For illustrative purposes, flip-flop **21** is shown to change its output state only in response to a positive going step and provide the desired frequency division, as shown by curves A and B.

For digital transmission, it has been shown above that a waveform having a specified shape will most efficiently serve as a substitute for a rectangular pulse in a digital pulse train. In order to produce the desired waveform, the square waves provided by master generator **20** and frequency divider **21** (curves A and B, respectively) are passed through low-pass filters **22** and **24**. The waveshapers may be designed to transform the square waves into waveforms which may be selectively utilized and combined with other waveforms to produce the desired composite waveshape.

In order to selectively combine the outputs of amplifiers **23** and **25** of FIG. **2**, shown as curves C and D, respectively, control signals are applied to combining circuit **26**. FIG. **4** is a more detailed block diagram of an embodiment of control signal generator **28** and combining circuit **26** which, in accordance with the present invention, produce the desired waveform. The block diagram shown in FIG. **4** is merely illustrative of one of many arrangements which perform the desired combining function.

Since the control signal generator is synchronized with master generator **20** of FIG. **2**, master generator **20** is reproduced in FIG. **4** designated **20′**. The output of master generator **20′** connects to counter **41**, which is arranged to count six input pulses and then reset. Digital counter **41** includes three stages and a feedback path for proper resetting. Leads **42**, **43** and **44** extend from the first, second and third stages, respectively, and to a series of AND gates. Leads **42**, **43** and **44** each connect to AND gates **45**, **46**, **47**, **48**, **49** and **401** so that, as the count in counter **41** changes, one AND gate will be activated to the exclusion of the others. To this end, inverters are utilized at the inputs to the AND gates and illustratively shown. The proper use thereof for sequencing purposes is well known in the prior art. The output of AND gate **45** is connected to one input of sampling gates **402**, **403**, **404**, **405**, **406** and **407**, respectively. The outputs of sampling gates **402**—**407** are connected to summing circuit **408**, the output of which is connected to low-pass filter **409**.

The operation of the control signal generator and combining circuit, illustratively shown in FIG. **4**, may be more fully understood by referring to FIG. **5** which illustrates a series of waveforms found at the inputs and outputs of sampling gates **402**—**407** and summing circuit **408**. FIGS. **3** and **5** are presented on the same sheet of drawings because the waveforms illustratively shown in FIG. **5** are synchronized with the output of the master generator, illustratively shown as waveform A in FIG. **3**. For convenience sake, time slots have been assigned to consecutive portions of the output of the master generator. Ten time slots are shown in both FIG. **3** and FIG. **5**. The operation of counter **41** is well known, and a binary code representing the count in counter **41** is carried on leads **42**, **43** and **44**. These leads **42**, **43** and **44** are connected to AND gates **45** through **49** and **401**, the outputs of each of which are shown as curves J, K, L, M, N, p, respectively. In time slot **1**, leads **42**, **43** and **44** will each carry binary O, and the output of AND gate **45** will be binary **1** during time slot **1** since each binary **0** is inverted at the input to AND gate **45**. The output of AND gate **45** is shown as curve J. For the purpose of illustration, binary **0** is considered to be a low voltage, and binary **1** a high voltage. Other arrangements may be provided for carrying out the same logic functions. In time slot **2**, leads **42** and **43** will carry binary **0**, while lead **44** will carry binary **1**. A binary **1** will appear at the output of AND gate **46** during time slot 2 since the binary 0 appearing on leads 42 and 43, respectively, will be inverted at the input of AND gate 46. The output of AND gate 46 is shown as waveform K in FIG. 5. Similarly, it may be shown that the output of AND gate 47 is a binary 1 during time slot 3, illustratively shown as curve L in FIG. 5. The output of AND gate is a binary 1 during time slot 4, illustratively shown as waveform M in FIG. 5. The output of AND gate 19 is binary 1 during time slot 5, illustratively shown as waveform N in FIG. 5, and the output of AND gate 401 is binary 1 during time slot 6, illustratively shown as waveform P in FIG. 5.

Sampling gates 402 through 407 are two-input devices, one input of which is connected to AND gate 42 through 49 and 401, respectively, while the other input is connected to the output of the waveshaping devices in FIG. 2.

It was shown in FIG. 3 that the output of amplifier 23 is illustratively shown as curve C, while the output of amplifier 25 is illustratively shown as curve D of FIG. 3. Curves C and D are reproduced in FIG. 5. The desired waveform is illustratively shown as curve E in FIG. 3 and is reproduced as curves E in FIG. 5. During time slot 1 the first half cycle of the sinusoid shown as curve C is used to form a part of the desired waveform E. Therefore, during time slot 1, the waveform appearing as curve C is applied to the second input of sampling gate 402 and its output, which is the desired first portion of waveform E, is supplied to summing circuit 408. Similarly, it may be shown that the remaining part of waveform E may be generated by selectively applying the waveforms shown as curve D during time slots 2—5 in FIG. 5 to sampling gates 403—406, respectively, and curve C during time slot 6 in FIG. 6 to sampling gate 407.

The waveform generator shown in FIGS. 2 and 4 illustrates a principle of the present invention which provides a significant advantage over the prior art. If pieces of a desired waveform are improperly synchronized, significant discontinuities would result in the produced waveform. This may be seen by referring to curves C and D in FIG. 5. During time slot 2, it is desired that the waveform shown as curve C not contribute to waveform E, while the waveform shown as curve D contribute to the desired function to be produced. If there is a lack of synchronization between the apparatus which operates during time slot 1 and time slot 2, curve C may contribute during a part of time slot 1. This synchronization problem, therefore, may cause significant error in the produced waveform. By utilizing the principles of the present invention, the synchronization problem is eliminated because the frequency dividers and the control signal generator are sychronized with a master generator.

While the embodiment shown in FIGS. 2 and 4 illustrates the application of the principles of the present invention in a waveform generator, modulation may also be realized by using the principles of the present invention. The process of selectively combining a desired waveform includes the capability to shape a waveform in accordance with digital control signals where the digital control signals represent modulation information. The generalized block diagram of FIG. 1 may be utilized to achieve this modulation.

We claim:

1. A waveform generator comprising:
a source of square wave pulse signals of a first periodicity,
a first waveshaping network connected to receive said pulse signals and convert them to an output signal of frequency f_1,
a square wave pulse generator connected to receive said pulse signals and produce a pulse signal output of a second periodicity,
a second waveshaping network connected to receive the output pulses of said pulse generator and convert them to an output signal of frequency f_2,
a control signal generator connect receive said pulse signals of said first periodicity,
and summing means under control of said control signal generator for selectively combining the outputs of said waveshaping networks.

2. A waveform generator as claimed in claim 1 and further including means for modifying the waveshape of the output of said summing means.

3. A waveform generator comprising:
a source of square wave pulse signals of a first periodicity,
a plurality of elementary wave generators connected in parallel to said source of pulse signals, each of said elementary wave generators comprising a frequency divider and a waveshaping network connected to the output of the frequency divider, the frequency divider of each of said elementary wave generators producing a square wave pulse signal output having a periodicity different from the periodicity of the frequency divider outputs of the other elementary wave generators,
a control signal generator connected to receive pulse signals of said first periodicity from said source,
and summing means under control of said control signal generator for selectively combining the outputs of said elementary wave generators.

4. A waveform generator as claimed in claim 3 wherein each of said waveshaping networks comprises a low pass filter and an amplifier.