Introduction to Adjustable Voltage-Range Current-Controlled Trapezoidal Waveform Generators

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Abstract — **The paper review series of circuits operating as trapezoidal waveform generators. All presented circuits share same rule of operation but offer different possibilities of their functionality enhancements. Enhanced versions provide ability to control voltage-range and differ slew-rates of rising and falling edges of output voltage waveform. Schematics, way of operation, and simulation results are presented.**

Index Terms — **Trapezoidal waveform generator, voltage-range limitation, slew-rate control.**

I. Introduction

TRAPEZOIDAL signal generation is a task useful in various analog [2] and some digital-related applications. There are numerous manners of generation of such signals. Some of them offer interesting features mainly due to untypical, namely current mode of processing leading to voltage-type output waveform. To change from current to voltage some kind of converter is required.

Usually what is recognized as a most obvious device of such type is simply a resistor. However, presented applications use a capacitor to integrate charge and produce proper voltage signal. Such approach is simple and enable various modifications, expanding original functionality over original operation principle.

II. Circuit Operation Overview

In practice this idea is known in various versions [1] and can be described as consecutive charging and discharging process of a load capacitor with two current mirrors consecutively sinking and sourcing current to and from this capacitor (Fig. 1).

Practically, current mirror output stages are use as current sources. Usage of constant value currents produces trapezoidal voltage patterns with constant slew-rate values. Voltage-range of generated voltage signal is limited by ground and supply voltage levels of feeding current mirrors.

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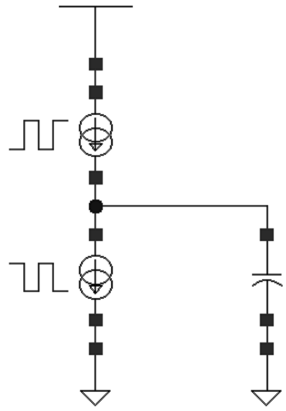

Fig. 1. Waveform generation idea

As shown earlier, trapezoidal waveform generator considered as a black box, on its output side should be seen as output sides of two switched current mirrors, both connected to a load capacitor or load capacitors. Such functionality may be obtained with wholly different internal structures. Differences between their internals are cause of various limitations of produces voltage patterns. Some structure can be simply reuses of subcircuits usually recognized as parts of quite different functional block.

III. OTA-based Generator

It can be argued that typical OTA amplifier (Fig. 2), due to current mode of inside signal transmission, can be used as a part of trapezoidal waveform generator [4].

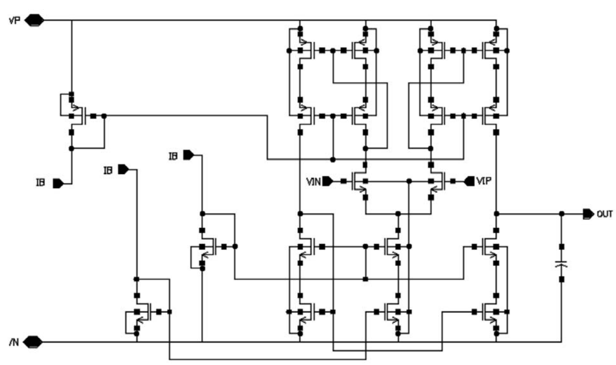

Fig. 2. OTA amplifier as a core of simple trapezoid generator

OTA is here used in open-loop configuration and its differential pair transistors are used as current switches. Such setup ensures that same current is consecutively sunk into and sourced from the output node. Capacitor presence at this node ensures proper operation of an OTA amplifier and produces trapezoidal waveform pattern on such capacitor.

Waveform produced by such structure is quite fixed in its shape (Fig. 3). Always one of the output current mirrors is on. Exception are conditions that working mirror is extinguished at its output side, or all the OTA is disabled. Also, both rising and falling signal edges slew-rate is same (Fig. 4). Any important changes in signal shape require hardware modifications inside or outside the OTA, like in [3], where additional external circuitry produces currents fed inside the OTA to produce modified output voltage signal.

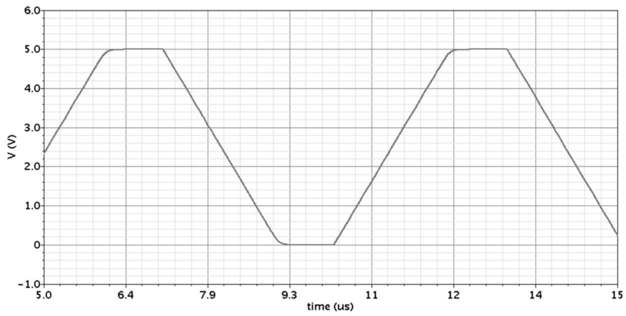

Fig. 3. Signal generated by simple current-controlled generator
Magnetization as a function of applied field

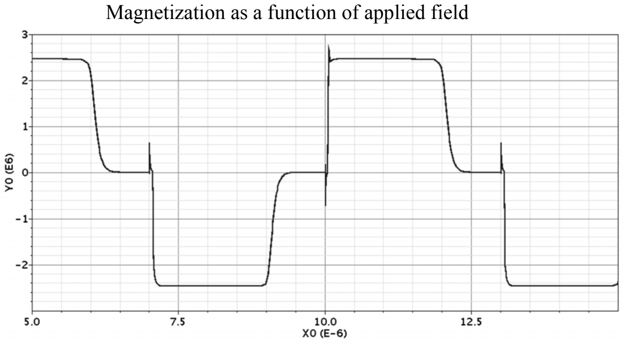

Fig. 4. Derivatives of signal presented in Fig. 3

As it is mentioned earlier, OTA is just one of possible solution of current feeding circuitry. As it is specialized for quite different applications, it is better to compose other circuitry providing both basic functionality and possibility of its expansion.

IV. Non-OTA Functional Equivalent

In general, current-controlled trapezoidal waveform generator may consist of only current mirrors and switches, formed into various structures. Exemplary structure [4] is presented in Figure 3.

This structure copies one input current to two complementary output mirrors. The current flow inside is driven with current switches. This structure is functionality similar to OTA with one noticeable exception. Inside the OTA a current flow never stop and always there is one conducting differential-pair transistor. Only during switching operation there can be short moment when none of differential-pair switches does not conduct current. This can be amended by means of shortly overlapping driving input signals.

In case of circuitry presented in Figure 5 switching process causes current mirrors preceding switches to go off completely, so when switch starts conducting again, the mirrors must regain proper operation mode. Apart from taking time it makes power consumption alter according to clock signal.

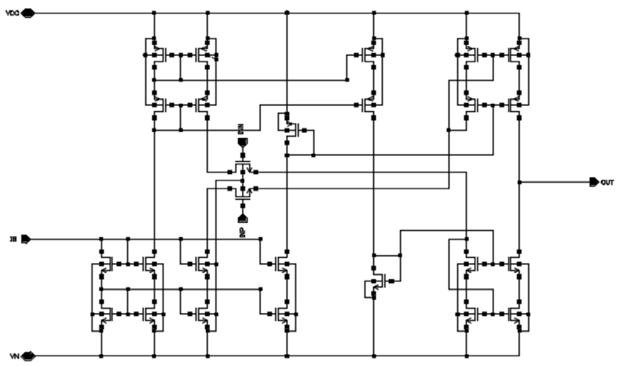

Fig. 5. Generator core with mirrors and current-blocking switches
Magnetization as a function of applied field

Exemplary improvement to this effect is shown in Figure 6. Here the currents inside the circuit are not extinguished but redirected. Power consumption stability is improved, though still there might happen moments when none of switches conducts. Overlapping driving signal can solve this problem as well as in case of OTA-based circuitry.

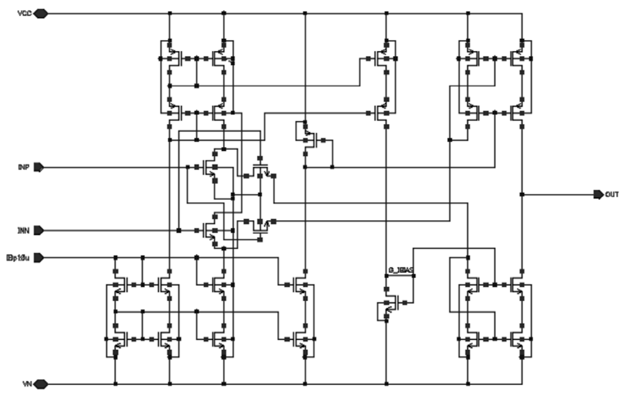

Fig. 6. Generator core with additional current-passing switches

V. Functionality Enhancements

Another approach to switching process is presented in Figure 7, here current flow is also controlled by switches, but here are no current-blocking switches. The switches works as current mirror input bypassing devices. When switch at the input of current mirror is off, current is copied to the output side of the mirror. Is switch is turned on, it both bypass current mirror input, as a very low impedance circuitry and switches the mirror off due to shorting gate terminal of memory transistor to adjacent power net.

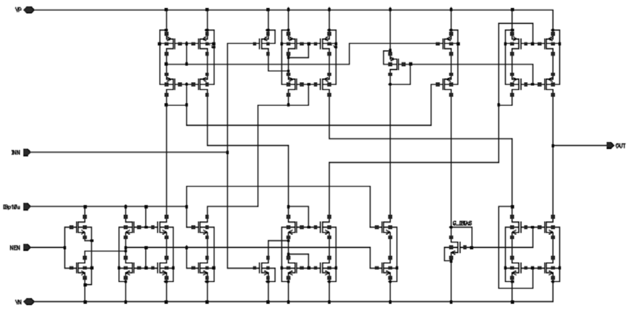

Fig. 7. Generator core with current-bypassing switches

Now, current flow inside the circuitry is uninterrupted, there are no time intervals during which there are no current receivers inside the circuit. There is always at least one way for current flow, at time there are two. Such mode of operation enable usage of only one driving signal.

All discussed, after some modifications, enable generation of waveform having different slew-rate values for rising and falling output signal edges. OTA-based circuits use one source of current, which is redirected according to switch operation.

In an OTA case, additional current adding circuitry should be added to achieve such functionality. In case of non OTA-based solutions, there is possibility of first producing or providing two current flows for distinct defining of slew-rate values and then proper directing of these DC currents to the output capacitor stage.

Also, placing the switching devices further away from the output stage enables utilization of another advantage related to current-mode signal transmission. Namely, the output current mirror stage can be supplied with different voltage levels. Thus, output signal voltage-range can be easily limited. Only piece of circuitry needed for this task is two simple voltage regulators. They can be based solely on OPAMPS, due to very limited power consumption of output stage power consumption of the waveform generator.

Fig. 8 circuitry is an enhancement of Fig. 7 waveform generator. It is equipped with two independent driving signals and two current inputs for output signal slew-rate definition, separately for rising and falling signal edge.

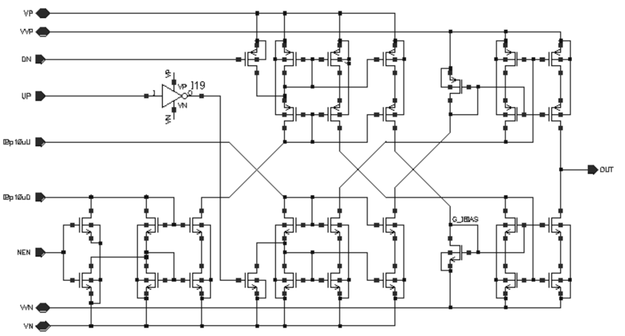

Fig. 8. Enhanced version of Fig. 7 circuit

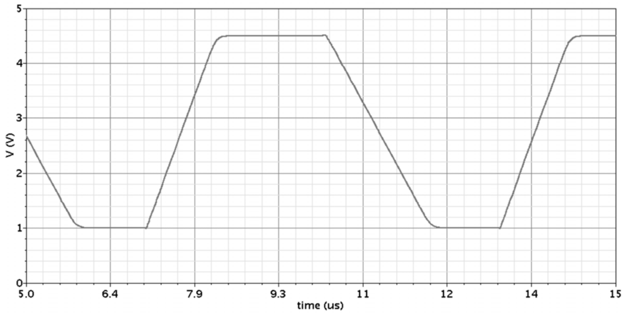

Fig. 9. Waveform produced with circuit from Fig. 8

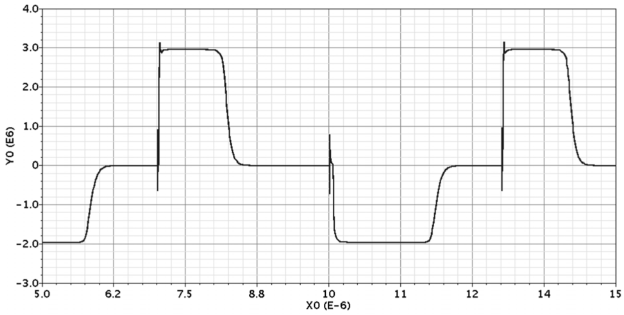

Fig. 10. Derivatives of waveform produced with circuit from Fig. 8 and presented in Fig. 9

Its output stage can be powered with different ground and supply voltage levels. All that is needed to enable this latest functionality is just to redraw the schematic in proper way and cut power nets at specific points.

This circuitry can be driven with two uncorrelated digital inputs and thus both output current mirror stages can be on same time. This feature can be very handy in some applications. For example there can be necessity of generation of signals having very low slew-rate during some time duration. This can be obtained by both enlarging the load capacitor and by minimizing current flow at the capacitor node. However, usually integrated capacitor value and shape is fixed and is not adjustable during circuitry operation. If it is, is poses other problems, big capacitance means big capacitor, which is not good situation in an integrated circuit. On the other hand circuit operation with very small current value makes current signal quality deteriorate during processing process. Noise, disturbance and current coping errors become relatively more pronounced as compared to the proper current signal.

The solution is both using high-quality current mirrors and providing two reasonable value currents to the very load capacitor. As one current is sunk in to capacitor and the other is sourced from there, we have simple current retraction operation, which can produce small current flow to and from the load capacitor. Fig. 9 shows exemplary signal produced by circuitry presented in Fig. 8. Two different slew-rates can be observed. Fig. 10 shows derivatives of the output signal.

What can be observed in generated waveforms presented so far, is rounded shape of the output voltage signal as it approaches its limit voltage. It is caused by fact, that voltage-range limitation is obtained by means of extinguishing output stage current mirror, which happens gradually. Current mirror transistors leaves the saturation region, passes through linear region and then finally go off. The shorter transistor channel length the more abrupt current flow transition and less rounded output waveform signal. Unfortunately, shorter channel length means worse stability of current produced by the mirror against change of output waveform voltage level.

The situation can be bettered by using other means of voltage-limit functionality implementation. Such modification way is possible by means of output voltage control and comparison to required limit level. In case when limit voltage is reached, the capacitor loading current is switched-off, which is much faster operation then current-mirror self-extinguishing process. Simulation showing shape of output waveform produced this way is presented in Fig. 11.

Figure 12 presents derivative of Fig. 11. It can be seen that when generator output waveform reaches its lower voltage limit, its slew-rate (derivative) value changes to zero in much more rapid way than in situation observed when output waveform reaches its upper voltage limit. The first process is realized by voltage level control and loading current removal, the latter is performed by a process of current mirror self-extinguishing. Improvement in circuits performance can be easily noticed.

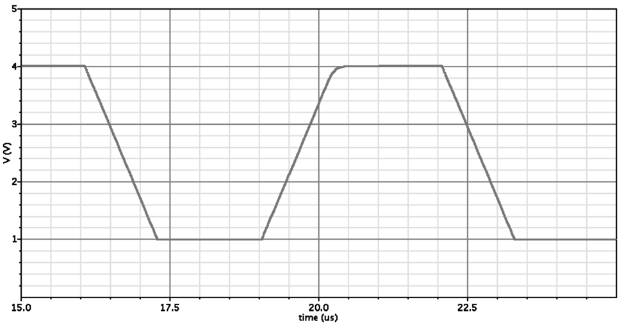

Fig. 11. Waveform created with modified way of voltage-control

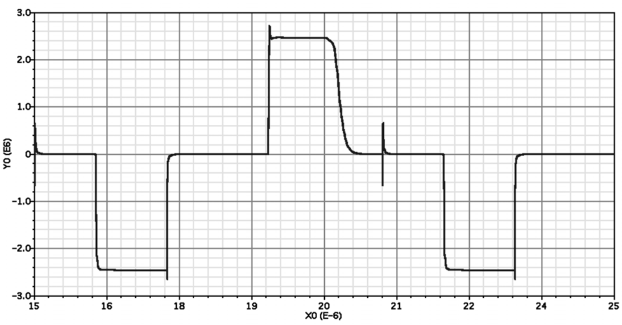

Fig. 12. Derivative of waveform presented in Fig. 11

VI. Conclusion

In the paper set of trapezoidal waveform circuits has been shown. All they operate using same simple principle. Proper choice of internal structure enables additional functionality enhancements being achieved without important drawbacks.

Number of possible enhancements in connection with still simple and consistent internal structure, widens field of application for such circuits.

References

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