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Pulse Generator with Quartz Stabilization of the Frequency

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Introduction

The large-scale application of integrated circuits in computing technology, in measurement equipment and in data processing systems has led to the solution of technical problems on a qualitatively higher level. In addition to the functions for which they are designed, the standard NAND gates can be interconnected to form various pulse generator circuits. In view of the requirements existing in the above fields as regards the stability and reliability of the pulse generators, increasingly frequent use has been made of circuits with highly stable delay lines or quartz resonators as time-setting elements.

This paper describes the operation and analyzes the characteristics of a pulse generator circuit with quartz stabilization of the frequency, which has been realized with standard two-input TTL NAND gates. The circuitry proposed avoids some of the shortcomings of the familiar circuitries (difficulties in the oscillations of the quartz resonator, oscillations of higher harmonics, and strong influence of variations in the supply voltage) and offers certain advantages (variable duty ratio of the output pulses, oscillation of the quartz resonator to the frequency of the serial resonance, and possibility of varying the frequency within narrow limits).

General Considerations Related to the Quartz Stabilization of the Pulse Generators

By the inclusion of a quartz resonator in the circuitry of the pulse generator, under thermostatic conditions of the resonator and of the electronic elements, it is possible to obtain instability of the frequency generated over a long period of time within the limits of 10^{-6} to 10^{-9} [2].

The equivalent electrical circuitry of the quartz resonator is approximately of the following type [2-4] — Fig. 1.

(1) $\omega_1=\frac{1}{\sqrt{L_Q C_Q}}$ frequency of the serial resonance.

(2) $\omega_2 \cong \omega_1(1+0.5\ m)$ frequency of the parallel resonance,

(3) $m=\frac{C_Q}{C_O} \ll 1$ coefficient of incorporation of the quartz in the circuitry.

The circuitry proposed makes use of in-series control of the quartz crystal which is more efficient than the parallel one [3] and offers the following advantages:

— Lower tendency to parasitic oscillatons;

— Smaller change of the equivalent resistance controlling the generator upon deviation from the stabilized frequency;

— In-series control makes it possible to operate close to the frequency of the serial resonance.

For the excitation of the quartz resonator in the circuitry of the pulse generator it must be connected between points in the circuitry which show great variation in the potential difference during operation [1, 2]. On the other hand, it is desirable for the quartz crystal to participate in the feedback circuit; this condition is not complied with in most practical circuits, but an additional condition is introduced, namely, that the period of the free oscillations generated (when the quartz resonator is not included in the circuitry) shall be 1.2 to 1.5 times smaller than the period of the stabilized oscillations [1, 3].

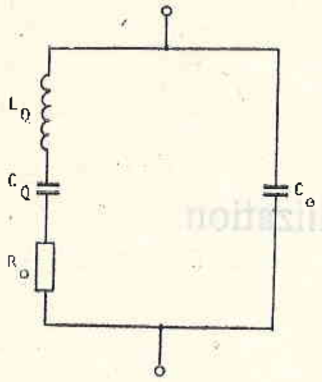

Fig. 1

L_Q — self-inductance of quartz; C_Q— self-capacitance of quartz; R_o—resistance of quartz at f_o; C_o — capacitance of quartz contacts

Operation of the Circuitry

On application of the supply voltage the circuitry begins generating free oscillations with a frequency $f_0=(1.2—1.5)\ f$, the quartz resonator playing the role of a capacitor. After about 100 ms [4] the resonator is excited and begins to oscil-

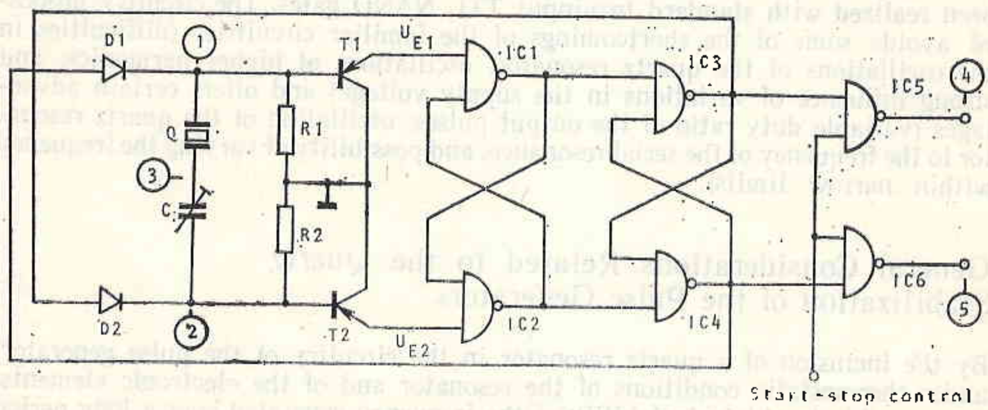

Fig. 2

late with a steadily growing amplitude. Upon reaching the rated amplitude of the oscillations, the pulse generator is synchronized with the frequency of the quartz resonator (Fig. 2).

Let us take the moment in which the voltage at point 1 of the circuitry changes with a jump from a "low" into a "high" level as the initial moment in the time-diagram. At the same moment the change of the voltage in point 2 is equal to the sum of the change in point 1 and the voltage applied on the quartz resonator.

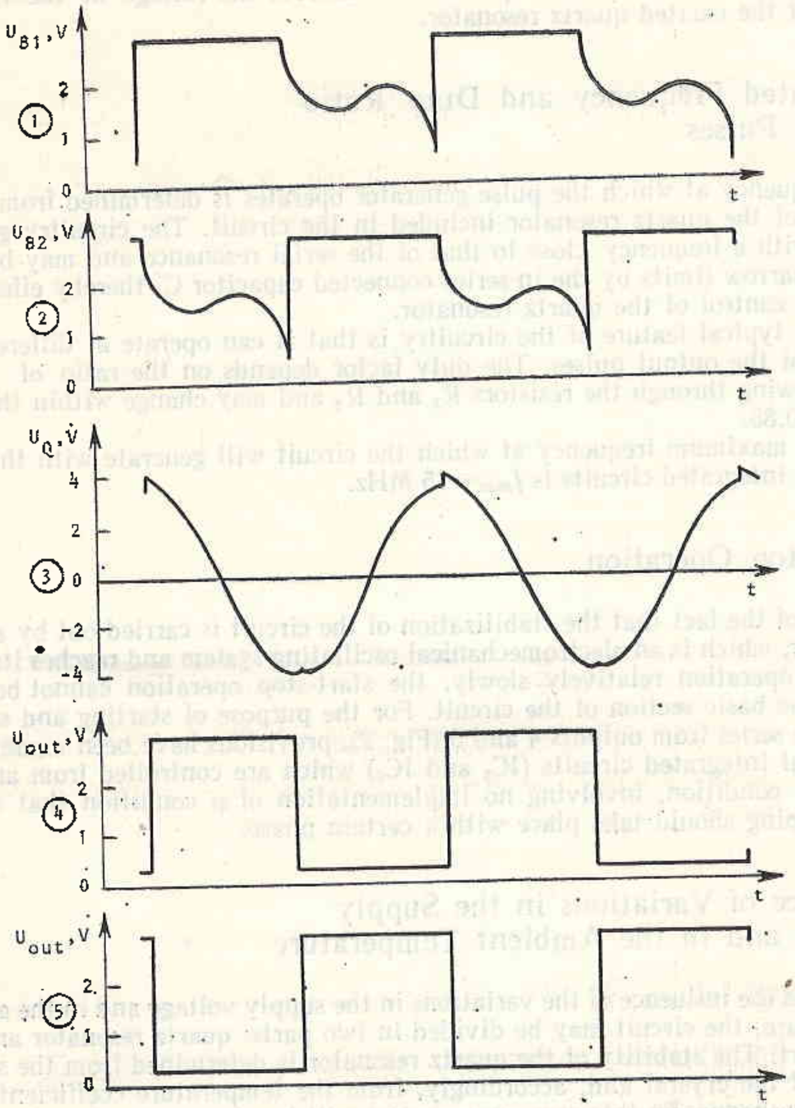

Fig. 3

The diode D_2 is reverse biased and is cut off, and the current of the excited quartz crystal begins to flow through the resistor R_2. At the moment when the voltages across the oscillating circuit (composed of the quartz crystal and of the in-series connected capacitor) becomes equal to 0, determined by the period of the serial circuit, the current begins to flow in the opposite direction through the diode D_1 and the resistor R_2. Upon reaching the threshold level 0.8 V (U_E=1.5 V) of the integtated circuit IC_1, the state of IC_1 and IC_2 (IC_3 and IC_4, respectively) changes and the voltage at point 2 changes with a jump to a "high" level. The process continues its development without stopping in the other branch of the system, the potentials at the respective points changing into the opposite ones. Figure 3 shows the voltages at typical points of the circuit, as a function of time. At point 3 of the circuit it is possible to observe the voltage of the first harmonic of the excited quartz resonator.

Generated Frequency and Duty Ratio of the Pulses

The frequency at which the pulse generator operates is determined from the frequency of the quartz resonator included in the circuit. The circuitry generates pulses with a frequency close to that of the serial resonance and may be varied within narrow limits by the in-series connected capacitor C, thereby effecting an in-series control of the quartz resonator.

One typical feature of the circuitry is that it can operate at different duty factors of the output pulses. The duty factor depends on the ratio of the currents flowing through the resistors R_1 and R_2 and may change within the limits of 0.15-0.85.

The maximum frequency at which the circuit will generate with the use of standard integrated circuits is $f_{max}=15$ MHz.

Start-Stop Operation

In view of the fact that the stabilization of the circuit is carried out by a quartz generator, which is an electromechanical oscillating system and reaches its steady state of operation relatively slowly, the start-stop operation cannot be realized in the basic section of the circuit. For the purpose of starting and stopping the pulse series from outputs 4 and 5 (Fig. 2), provisions have been made for two additional integrated circuits (IC_5 and IC_6) which are controlled from an external logic condition, involving no implementation of a condition that starting and stopping should take place with a certain phase.

Influence of Variations in the Supply Voltage and in the Ambient Temperature

As regards the influence of the variations in the supply voltage and in the ambient temperature, the circuit may be divided in two parts: quartz resonator and electronic part. The stability of the quartz resonator is determined from the selected section of the crysral and, accordingly, from the temperature coefficient of the frequency change. In this case an appraisal will be given only about the stability of the electronic part of the circuitry.

The summary influence of the changes in the supply voltage and in the ambient temperature (in the entire working range $U_c=+5$ V$\pm5\%$, $T_a=0\div70$°C) is expressed as instability of the frequency $\leqslant10^{-7}$ (at a duty ratio for the output pulses $\delta=0.5$) [2] and tests of the circuitry under real conditions.

Practical Realization of the Circuitry of the Pulse Generator with Quartz Stabilization of the Frequency

Several variants have been realized of the examined circuitry, use being made of high-stability quartz resonators of the C. E. P. E. Company (Italy) and of the following electronic elements: SN74OON, SN74HOON, SN54OON, 1N914, 1N916, BAY71, BAY74, 2N2907, and BSX29. At a frequency of the quartz resonators 50 kHz and 100 kHz, of stabilized supply voltage and duty ratio of the pulses $\delta = 0.5$, without taking any measures for temperature stabilization of the circuitry, an instability of 5×10^{-8} was measured for a period of 1 hour under laboratory conditions.

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Импульсный генератор с кварцевой стабилизацией частоты

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(Р е з ю м е)

В связи с широким применением интегральных схем и требованиям к стабильности и надежности импульсных генераторов в системах обработки информации предлагается схема импульсного генератора с кварцевой стабилизацией частоты.

В работе описано действие и анализируются особенности предлагаемой схемы импульсного генератора. Данная схема лишена некоторых недостатков известных схем, а именно: отсутствуют трудности, связанные с возбуждением кварцевого резонатора, с возбуждением на высших гармониках и с влиянием напряжения питания. Показаны также преимущества данной схемы — переменный коэффициент заполнения выходных импульсов, возбуждение резонатора на частоте серийного резонанса, возможности изменения частоты в некоторых пределах.

Приводятся полученные результаты при практической реализации схемы импульсного генератора с кварцевой стабилизацией частоты.