Definition of a Ring Oscillator

Introduction

As technology changes and new technology is born, the language used to understand and communicate concepts must also change and new concepts will need new words. To be skilled in the state of the art of electronics, in this case electronic oscillators, or better yet, integrated circuit electronic oscillators, one needs to learn and understand the language of this subject in order to effectively communicate, learn, and understand ideas, concepts, and the direction of future growth to remain skilled and competent.

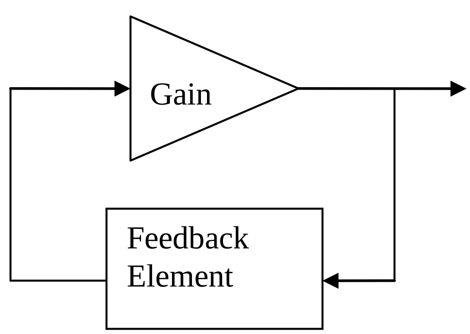
There are many ways to learn this language; the easiest is to use Wikipedia.org; type in the subject – electronic oscillators – into Google and select wikipedia.org to begin. In each subject area there are lists of references.

The emphasis in what follows is to discover the conventions for naming oscillators, why they are named the way they are. In some cases it is the inventor's names which have become known to imply a unique set of feedback structures or operational concepts. It is these feedback ideas and in some cases operational physics that classify the types of oscillators.

Most of what is included here is a direct copy of pertinent sections of the Wikipedia literature. The background, '366, and Talbot sections are not copies.

Background: Electronic oscillators and the criteria for sustainable oscillations.

An electronic oscillator has a gain element and a feedback element.



The gain element adds energy to the oscillator to compensate for losses in the other elements and to provide output power.

The **Barkhausen stability criterion** is a mathematical condition to determine when a linear electronic circuit will oscillate. It was put forth in 1921 by German physicist Heinrich Georg Barkhausen (1881–1956). It is widely used in the design of electronic oscillators.

Stability condition one: the gain around the loop must be larger than one.
For oscillation enough energy must be available to overcome the losses.
Stability condition two: the phase shift around the loop must be 2 π.
For linear feedback oscillators this is true, for relaxation oscillators it is π.

When it oscillates, it meets these criteria.

Electronic oscillators.

There are two main types of electronic oscillators: the linear or harmonic oscillator and the nonlinear or relaxation oscillator.

The **linear oscillator** produces a sinusoidal output. The basic form is an electronic amplifier connected in a feedback loop with its output fed back into its input through a frequency selective electronic filter to provide positive feedback. These linear oscillator circuits can be classified according to the type of frequency selective filter they use in the feedback loop:

- Armstrong oscillator: feedback is magnetic coupling between two coils
- Hartley oscillator: feedback is inductor divider in parallel with capacitance
- Colpits oscillator: feedback is capacitance divider in parallel with inductance
- Clapp oscillator: feedback is same as Colpits but with additional capacitance in series with inductance
- Delay line oscillator: feedback is a delay line
- Pierce oscillator: feedback uses a crystal along with capacitors
- Phase-shift oscillator: feedback uses resistors and capacitors to provide phase shift of 180 degrees
- RC oscillator (Wien Bridge and “Twin-T”): feedback uses two sets of RC networks
- Cross-coupled LC oscillator: common source CMOS transistors cross coupled with LC network
- Vackar oscillator: feedback is same as Colpits but with additional capacitance divider added
- Opto-Electronic oscillator: uses laser light as the communication medium

The **nonlinear or relaxation oscillator** produces a non-sinusoidal output, such as a square, sawtooth, or triangle wave. It contains an energy-storing element (a capacitor) and a nonlinear switching circuit (a latch, Schmitt trigger, or negative resistance element) that periodically charges and discharges the energy stored in the storage element thus causing abrupt changes in the output waveform.

Square wave relaxation oscillators are used to provide the clock signal for logic circuits.

Ring oscillators are built of a ring of active delay stages. Generally the ring has an odd number of inverting stages, so that there is no single stable state for the internal ring voltages. Instead, a single transition propagates endlessly around the ring.

Types of relaxation oscillator circuits include:

- multivibrator: two emitter coupled transistors connected with a feedback loop of two RC networks
- ring oscillator: odd number of inverters connected in a chain; the output of the last inverter is feed back into the first
- delay line oscillator: feedback uses a delay line
- rotary traveling wave oscillator: uses a time to digital converter

It is important to note that the names of oscillators are determined by:

- the type of frequency selective filter they use in the feedback loop
- or the type of energy storage element that is periodically charged and discharged in the feedback loop
- or the time delay mechanism in the feedback loop.

Delay Line Oscillator

A delay line oscillator is a form of electronic oscillator that uses a delay line as its principal timing element.

The circuit is set to oscillate by inverting the output of the delay line and feeding that signal back to the input of the delay line with appropriate amplification. The simplest style of delay line oscillator will oscillate with period exactly two times the delay period of the delay line.

The delay line may be realized with a physical delay line (such as an LC network or a transmission line). In contrast to a Phase-shift oscillator in which LC components are lumped, the capacitances and inductances are distributed through the length of the delay line. A ring oscillator uses a delay line formed from the gate delay of a cascade of logic gates.

Voltage-Controlled oscillators or VCOs

VCOs can be generally categorized into two groups based on the type of wave form produced: 1) harmonic oscillators, and 2) relaxation oscillators.

Harmonic oscillators generate a sinusoidal waveform.

Relaxation oscillators can generate square waveforms. They are commonly used in monolithic integrated circuits (ICs). Relaxation oscillator VCOs can have three topologies: 1) grounded-capacitor VCOs, 2) emitter-coupled VCOs, and 3) delay-based ring VCOs. The first two of these types operate similarly. The amount of time in each state depends on the time for a current to charge or discharge a capacitor. The delay-based ring VCO operates somewhat differently however. For this type, the gain stages are connected in a ring. The output frequency is then a function of the delay in each of the stages.

It is to be recognized that grounded-capacitor VCOs operate on a different principle than delay-based ring VCOs and are therefore not ring oscillators.

Ring Oscillators

The ring oscillator is a member of the class of time delay oscillators. The ring oscillator is a distributed version of the delay oscillator. The ring oscillator uses an odd number of inverters to give the effect of a single inverting amplifier with a gain of greater than one. Rather than having a single delay element, each inverter contributes to the delay of the signal around the ring of inverters, hence the name ring oscillators.

Changing the supply voltage changes the delay through each inverter, with higher voltages typically decreasing the delay and increasing the oscillator frequency. If each inverter has a voltage controlled current source between it and the power source then the ring oscillator becomes a VCO. By changing the current through the each inverter the delay time can be controlled and hence the frequency of oscillation. (See Miyazaki, IEICE TRANS. Electron.,Vol.E88-C, No.3 March 2005)

Ring oscillators are included as part of the wafer scribe line test structures. They are used during wafer testing to measure the effects of manufacturing process variations, effects of voltage and temperature on a chip.

‘336 Patent

Ring oscillators form the simplest test structure that provides measured feedback on the effects of manufacturing process variations, voltage and temperature. It reflects the general state of the operating environment on the, in this case, the speed of all of the circuits on the same chip it is part of. The ring oscillator is, then, the best structure to control the chip clock because it measures the oscillation frequency of an inverter set directly. The clock should run at a frequency slightly lower then the frequency of the slowest signal path through the portion of the chip that needs to be clocked. The elegance of the ring oscillator becomes obvious; the ring design uses just enough inverters in the chain to insure that the clock runs at this preferred frequency.

Talbot US Patent 4,689,581

The VCO (12) shown in figure 1 and its two embodiments are shown in figures 3 and 4. In both figures and the describing text items 50 in figure 3 and items 64 and 66 in figure 4 are grounded-capacitor VCO configurations. This means that the time delay is set by the charge and discharge time of the capacitors and NOT by the delay time of each inverter in a ring, indeed there is no ring, hence these VCOs are not ring oscillators.

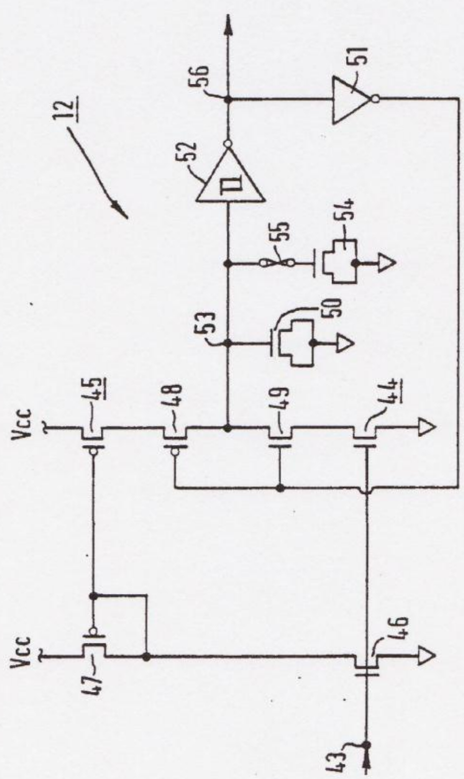


FIG. 3

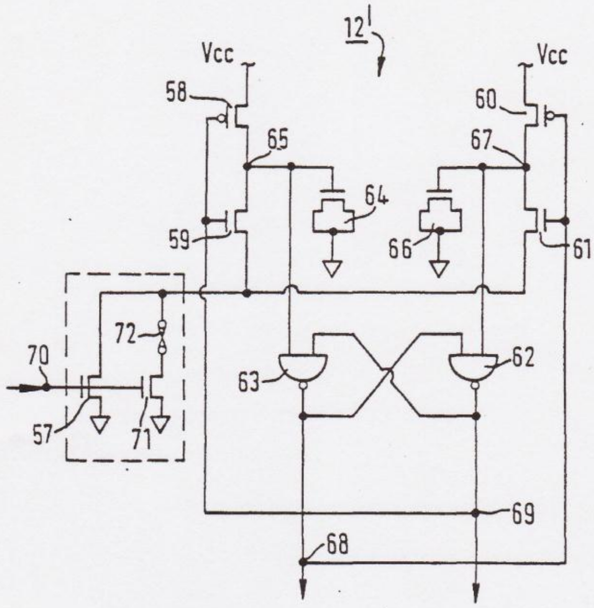


FIG. 4