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Design and Construction of a Signal Generator

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ABSTRACT

This study examines the process of designing a signal generator, to generate three types of wave forms which include sinusoidal wave, triangular wave, and square wave. Change the amplitude of the generated signal over a wide range. Measure both the frequency and amplitude of the selected signal and display them on the LCD. To carry out a computer aided simulation. This work is intended to build a low costing function generator from simple components available in laboratory, the frequency and amplitude of the generated signal can easily be tuned on a LCD, this eliminates the need for other devices, to measure or display the amplitude and the frequency of the signal. Typically, this signal generator type will produce waveforms or functions such as sine waves, saw tooth waveforms, square and triangular waveforms. But in this work, we are considering a square waveform. To achieve the objectives of the function signal generator project, hardware components and software tools are employed and used after they have been selected among other alternatives due to various reasons and circumstances. We also focus the design consideration that should be achieved on completion of this project, followed by a brief discussion about the overall circuit diagram, various blocks that constructs the function generator, and subsequently sections investigate these blocks by details.

Keywords: wave forms, low cost, wide range, signal generator

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1. INTRODUCTION

Signal Generator (function Generator) is a device which generates various types of wave forms like sin wave, the triangular wave, the square wave, the saw-tooth wave, the cosine wave etc. in a repeating or non-repeating signal in either the Analogue or the digital domain.

The signal generator is exactly what its name implies: a generator of signals used as a stimulus for electronic measurements. These electronic signals are either repeating or non-repeating as per the requirements and field of applications. Signal generators in all their forms are widely used within test and development systems, being used with other test instruments.

When looking at what a signal generator is, it will be seen that they come in many forms - there are many signal generator types, each one being used to provide a different form of signal. Some provide RF signals, others audio signals, some can provide different shapes of waveform and others may provide just pulses.

Signal generators have been used for many years. Early types were very basic by the standard of today's different types of signal generator. Performance levels as well as the variety of facilities that are available have increased and improved.

There are different types of signal generators with different levels of capability and functionality. All the signal generators have different designs, different dimensions, and parameters. So, the variety of generators serves different purposes and covers a range of applications. The signal generators are used in designing, repairing of electronic devices, and in troubleshooting. Every versatile signal generator can create unlimited number of signals to meet the debug challenges. You can vary the output of the signal generator by setting the amplitude and frequency of the output signal while a simulation is in the process.

Today's electronic system requires many signal waveforms shapes. Common waveforms are the square wave, triangular wave since wave and single pulse wave with fixed duration. Fixed duration pulses are used in communication and control systems. Square waves are used as a clock per digital systems. Triangular waves are used per scanning an electron beam on a cathode ray tube (CRT) screen in precise measurement and in time modulation.

With the development of modern technology, the function Generator with independent control Amplitude and frequency play an important role in applied electronics, communications, instrumentation, and signal processing application. And it is measurement with a long history, it has been produced in 1920 with the development of communication technique and radar technique. In 1940, the signal generator was used to test standard signal of various receiver appeared, this improvement changes the signal generator form a qualitative investigation test instrument to a quantitative analysis measuring instrument.

In education, communication, industrial and control fields, an electronic system known as signal generator is normally required to provide periodic signals with different waveforms, and frequencies, the measurement of wave forms and how to display this measurement is not fast and simple and need some other devices such as oscilloscope, when this device is not available then it can cause some of damage for sensitive components in the circuits if the input signal is applied without measurement.(Thiessen, Arthur 1965). There are many specialized function generators available, some costing hundreds to thousands of dollars to provide input signals with different waveforms and frequencies.

Signal generators have been used for many years. Early types were very basic by the standard of today's different types of signal generator. Performance levels as well as the variety of facilities that are available have increased and improved. The frequency control of a signal generator controls the rate at which the output signal oscillates. Integrated circuits used to generate waveforms may also be described as signal generator ICs. These signal generator projects are used to provide some circuits and how to change the magnitude and frequency of the signal then how to measure and display this change.

The signal generator is an instrument which provides several different output forms including sine wave, triangular wave, square wave, pulse train and amplitude modulated development and troubleshooting. In history, the signal generator is a measurement equipment with long history, it has been produced in 1920. With the development of its communication technique and radar technique, in 1940, the signal generator used to test standard signal of various receiver appeared, this improvement changes the signal generator from a qualitative investigation testing instrument to a quantitative analysis measuring instruments. At the same time, the pulse function generator to measure the pulse circuit or modulate the pulse has been made. The mechanical structure of the function generator was very complex in early time, which led to the slow evolution of the function generator. (Jouko Vankka 2001)

Till 1964, the first function generators with whole transistors were created. As a commonly used signal source, function generator is the most extensive used of general instrument in the modern test area. To research, production, testing and maintenance each electronic component, units and the machine equipment, the signal source are needed. It produces voltage signal and current signal with different frequency and waveform and added to the device or equipment which being measured, then observe and measuring the output response of the measured instrument to analyze and identify their performance parameters.

“Signal Generator” is the most basic and widely used electronic instrument in the electronic measurement field. It has not only been applied in the domains of education, scientific research, production and engineering, but also have some advantages such as continuous phase transformation, frequency stabilization and so on; it is useful in simulate various complex signal and dynamic control the values, such as frequency, amplitude, phase and waveform; the function generator can also communicate with other equipment’s to constitute automatic test system (ATS), so it can also applied in the domains of communication, ATS, instrument and met”.

The signal generator is unique for several reasons. A signal generator provides an excitation to the electronic measurement system and processing circuits which coverts various outputs into useful data. The excitation provided by signal generator may be a constant dc voltage or current or even stable AC signal.

In some cases, it is important to vary the frequency as well as the amplitude of excitation and the purpose is served by a signal generator. In various instrumentation systems, the signal at frequency is generated using an oscillator which provides fixed frequency signal. Some other frequency oscillator is available.

There are different types of signal generator. But the requirements are common to all the types; The output frequency of signal should be variable. The amplitude of the output signal generator should be controllable from low values to relative values. The amplitude of the output signal must be stable. The harmonic content in the output should be as low as possible. The output signal should be distortion free. The signal generator should provide very lowtheurious; that means effect of hum, noise, jitter, and modulation should be negligible.

In most measurement and instrumentation systems, the input signal required is a periodic signal, such as signal generated using an oscillator. An oscillator is a circuit that generates a signal with constant amplitude and constant desired frequency using positive feedback. It generates an output waveform at a desired frequency in the range from few hertz to several gig hertz. Thus, an oscillator is a circuit that acts as a generator which generates output using positive feedback.

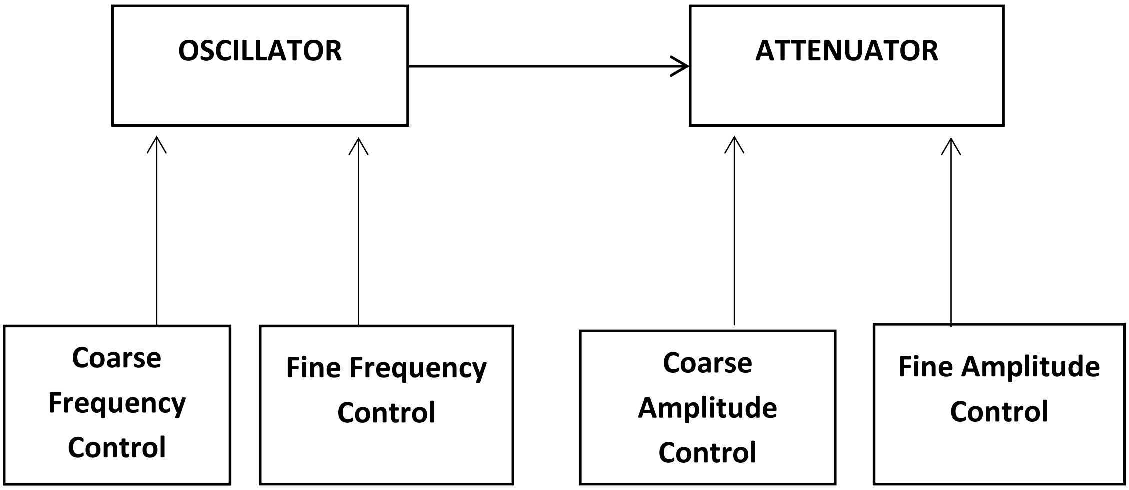

Figure 1. A block diagram of simple signal generator

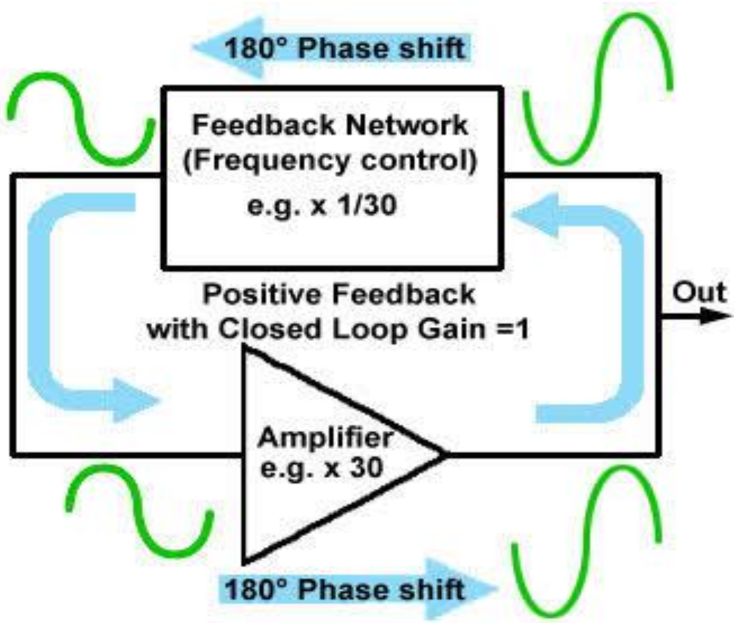

Figure 2. Schematic Illustration of the Working Principle for Oscillation

A signal generator consists of two important blocks as shown in figure 1, which are the oscillator and Attenuator. Generally, the oscillator uses an active device such as an operational amplifier, the output is fed back in phase with input and the positive feedback causes regeneration action resulting in an oscillation. Oscillator will be discussed in the next section of this signal generation project. While the attenuator provides amplitude control. Basically, the attenuator is a device that reduces or attenuates the power level of the signal by a fixed amount. The proper performance of a signal generator depends on the performance of an oscillator and attenuator. (Eva Murphy 2004). Thus, discussions below further highlight the oscillator as the fundamental block of the Signal Generator.

Oscillator – Periodic phenomena are pervasive, manifesting themselves at various microscopic and macroscopic levels. An electron revolving around the nucleus in an atom, clock arm rotating in constant pace, or a planet in the solar system rotating around the sun, all represent familiar examples of oscillation. For many centuries the study of oscillation has fascinated mankind and continues to be an active area of research in many scientific fields.

Figure 2 shows the Schematic Illustration of the Working Principle for Oscillation. Oscillators are a circuit that produces periodic waveforms, with the only input requirement being D.C power supply. By their nature, oscillators are unstable systems in which the poles of the systems lie in the imaginary axis. There are many types of oscillators and the most operate in basic history.

When electronic circuits are activated, there are electrical noises present that span the electrical frequency spectrum. If the noise is amplified and the output of the amplifier is connected to positive feedback is designed to select a signal at one frequency. This signal is coupled back to the input in proper phase, so it reinforces the signal present at the input. As this process of amplifying and positive feedback continues, the selected frequency becomes the dominant signal in the circuit. Figure 2 shows the three essentials for the oscillator to function: an amplifier, a frequency network and positive feedback.

Amplification is required to transform DC power energy into signal energy and overcome circuit losses so that selected signal can be sustained. It should be noted that an oscillator does not generate energy but only transforms DC supply energy to signal energy. The frequency of oscillation is determined by the selection network. The stability of oscillation is determined by how the network can select a given frequency. Positive must be present support oscillation while negative feedback is used in oscillator circuit to stabilize and prevent oscillation. (Johan Van Der Tang 2003)

Oscillators are classified based on the following: the nature of output waveform – Under this, oscillators are classified as sinusoidal and non-sinusoidal oscillators. The circuitry and its parameters – The oscillators using components resistor(R), capacitor(C), are called RC OSCILLATORS, While the oscillators using the components inductance (L) AND CAPACITOR(C), are called LC oscillators. In some oscillators, crystal is used, which are called crystal oscillators. In this project RC oscillator was used. The range of frequencies – If the oscillators are used to generate the oscillation at audio frequency range which is 20Hz to 100-200 kHz, then oscillators are classified as low frequency (L.F) or audio frequency (R.F) oscillators. While the oscillators used at the frequency range of more than 200-300 kHz up to gigs hertz (GHz) are classified as high frequency (H.F) or audio frequency (R.F) oscillators. Discussing further, the SINUSOIDAL OSCILLATOR is an electronic device that generates sinusoidal oscillation as output. This section discusses the basic principles of sinusoidal oscillators. THE OSCILLATORS' FEEDBACK LOOP is a property which allows to feedback the part of the output, to the same circuit as its input. Such feedback is said to be positive whenever the part of the output that is fed back to the amplifier as its input is in phase with the original input signal applied to the amplifier (). If we consider non-inverting amplifier as with the voltage gain A as shown in Figure 3.

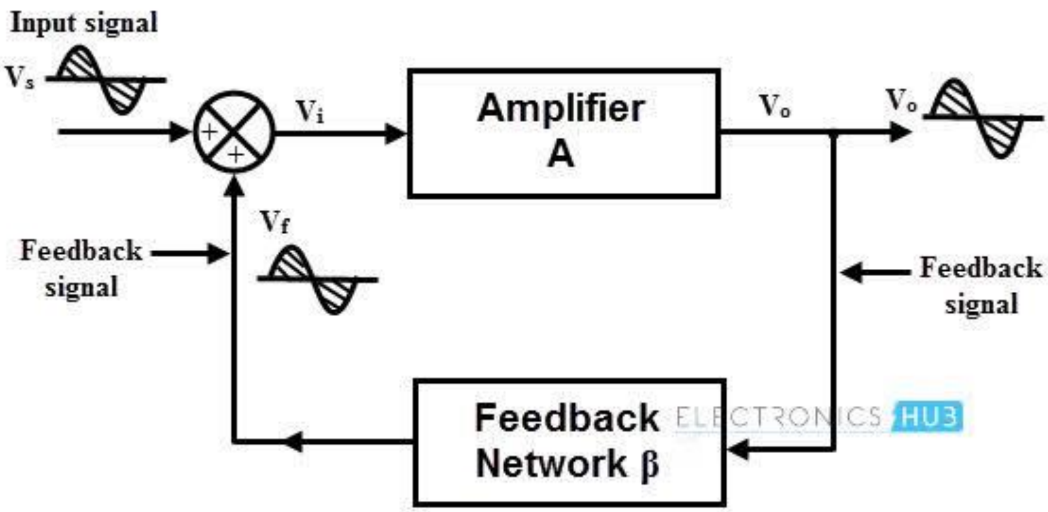

Figure 3. Schematic illustration of the concept of positive feedback

Assume that a sinusoidal input signal (voltage) Vs is applied to the circuit. As amplifier is non-inverting, the output voltage Vo is in phase with the input Vs. the part of the output is fed back to the input with the help of network feedback. How much part of the output is to feed back is get decided by the feedback gain β no phase change is introduced by the feedback voltage V_f. is in phase with the input signal Vs.

The amplifier gain is A i.e., it amplifies its input A to produce output V_0

$$A = \frac{Vs}{Vi} \qquad (1)$$

This is called open loop gain of the amplifier.

For the overall circuit, the Input supply voltage V_S and net output is V_0 the ratio of the output $V_0$the input V_i considering effect of feedback is called closed gain of the circuit or gain with feedback denoted as given by

$$Af = \frac{A}{(A-A\beta)} \qquad (2)$$

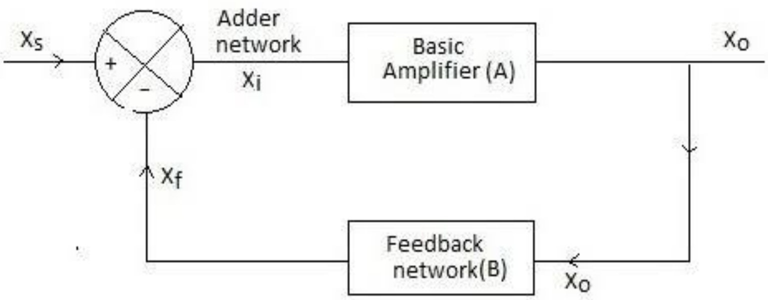

Figure 4. An amplifier having a gain of A and a feedback fraction of β

An oscillator circuit is basically an amplifier, but positive feedback from its input to the output enables it to sustain the output without the need of an external signal. Figure.4 illustrates an amplifier with a gain of A and a feedback amplifier with feedback fraction of β.

If an input signal V_i is applied to the amplifier then its output V_0 will be given by;

$$V_0 = V_1 A \tag{3}$$

Now if the feedback network is connected to the amplifier as shown in the figure and somehow the input is made equal to the output of the feedback network so that they have identical magnitude, phase and frequency, then the circuit will not need an external signal, In other words the circuit will act as an oscillator if:

$$V_i = \beta V_0 \tag{4}$$

Substituting from (3) into (4):

$$V_i = \beta V_i A \tag{5}$$

$$A\beta = 1 \tag{6}$$

The above relationship is known as Barkhuizen Condition. Thus, the magnitude of the loop gain should be unity and the phase shift of the loop gain should be 0° or a magnitude of 360° of the frequency of interest.

Applying these results to equation (2) yields:

$$A_f = \frac{A}{(1-a)} = \infty \tag{7}$$

A gain of infinity implies that there is an output voltage even if no input signal is present, i.e., the circuit oscillates.

Many circuits that generate sinusoidal output are available, they are classified according to their frequency determining components. The three basic types of sinusoidal oscillators are LC oscillators, RC oscillators and crystal oscillators. In this project one of the practical oscillator circuits utilizing op-am and RC network known as Wien-Bridge is used to obtain the sinusoidal signal. (B.-G. Goldberg 1999).

The Wien- Bridge oscillator is a type of bridge that was developed by Max Wien in 1891, it is a simple, stable, and popular RC oscillator configuration. Its identifying features are a set of two RC combinations called a lead-lag network. A series RC combination is connected in series with the feedback path, and a parallel RC combination in parallel with the feedback path. Another unusual feature that is uses a non- inverting instead of the unusual inverting configuration. (B.-G. Goldberg 1999).

Features of Wien Bridge Oscillator; The DC power supply is the $_{+}V_{CC}$ connection. The frequency determining element of the oscillator is the lead-lag RC network composed of C_1, R_1, C_2, and R_2. Amplification is provided by the op-amp circuit. Positive feedback is accomplished by the connection from the output of the op-amp, through the RC network as shown in figure 5, the non-inverting input (+) of the op-am. The important property of this kind of RC network is that the signal fed back from the output of the amplifier under does a phase shift of 0° at the oscillation frequency. Because the lea-lag network causes a zero-phase shift at the operating frequency, the amplifier must be a non-inverting type to enable a 0°-phase shift as well.

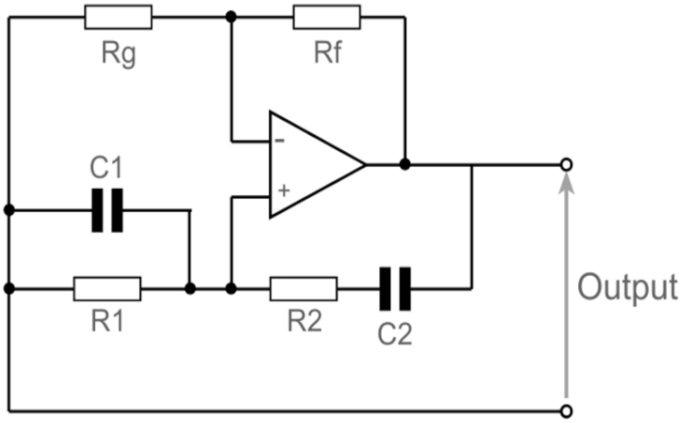

Figure 5. Wien- bridge oscillator

Frequency is the number of occurrences of a repeating event per time. It is also referred to as a temporal frequency. The period is the time duration of `one cycle in a repeating event, so the period is the reciprocal of the frequency. For cyclical processes, such as rotation, oscillations, or waves, frequency is defined as the number of cycles per unit, In S.I unit of frequency is the hertz, named after the German physicist Heinrich Hetz: 1Hz means that an event repeats once per second. The previous name for this unit was cycles per second. A traditional unit of measure used to rotate mechanical devices is revolutions per minute, abbreviated RPM. 60 RPM equals 1 hertz. (B.-G. Goldberg 1999). The period, usually denoted by T, is the length of time taken by one cycle, and is the reciprocal of the frequency F:

$$T = \frac{1}{f} \tag{8}$$

The SI unit for period is the second.

The frequency of a signal can be measured by the used of two ways to discuss in the following sections: the oscilloscope displays waveforms on graph that shows the shape, voltage, and frequency os an electrical signal. When it displays a wave, the scope can measure its frequency by using the graph on the screen and SEC/DIV control located in the horizontal section of the oscilloscope face.

Higher frequencies are usually measured with a frequency counter. This is an electronic instrument which measures the frequency of an applied repetitive electronic signal and displays the result in hertz on a display. By writing a software code microcontroller can be used to measure the frequency and display the result on LCD. Amplitude is the magnitude of change in the change in the oscillation variable with each oscillation within an oscillation system. If a variable undergoes regular oscillators and a graph of the system is drawn with oscillating variable as the vertical axis and time as the horizontal axis, the amplitude is usually represented by the vertical distance between the extreme of the curve and the equilibrium value.

There are two ways that are used to measure the amplitude of the signal: By oscilloscope – One important function of the oscilloscope is to make voltage measurement. The scope is capable of measuring both ac and dc voltage. Voltage is determined by using vertical grids on the display. Each square on the grid is called a division. Just as a voltmeter has a rage switch, so does an oscilloscope. This switch selects volts per division by voltage counter – By writing a software code microcontroller can be used to measure the amplitude and display the results LCD.

2. MATERIALS AND METHODOLOGY

This work was aimed at designing a signal generator that satisfies the consideration of low cost, ease of use as the function generator should easily be sued to provide a stable signal with different waveforms that can be used as an in input to electronic circuits. The generated signal must also have a pure shape with low levels of distortion to satisfy user requirements, the amplitude and the frequency of output signal should be easily changed over a wide range. The function generator should also give accurate measurements for the amplitude and frequency of the signal.

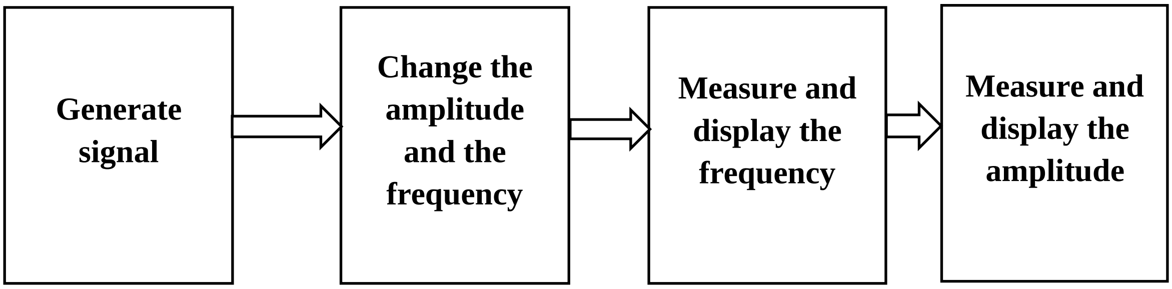

Figure 6. Block diagram of function generator

In Figure 6, the block diagram illustrates the high-level design of the function generator, which consists of several blocks: A generator: to generate different types of signals. An electronic circuit to change the amplitude and frequency. Microcontroller to measure and display the frequency. Microcontroller to measure and display the amplitude.

Tools: To implement this project software and hardware tools were used: NI Multisim 10: to simulate the electronic circuit.PIC C Complier: to compile the C code that measures and displays the frequency. Micro C pro for Pic: to compile the C code which measures and displays the amplitude. Proteus ISI professional: to simulate both microcontroller circuits that measure the amplitude and the frequency. AVR code vision: to compile the C code which generates the signal. Pic programmer: To load the frequency and amplitude code in microcontrollers. Pic Microcontrollers: To measure the frequency and the amplitude of the generated signal. LCD: To display the measured frequency and amplitude of the signal. Pic development kit model FEPSPI: to implement the microcontroller circuits. Resistors, Capacitors, Diodes and Op-Amps: to implement the electronic circuits.

Materials: LM324 Op amp chip,10KΩ resistors(2) ,100KΩ resistors (4), 22KΩ resistor, 220KΩ resistor, 555 Timer, 1µF ceramic capacitor, Lead light, 33nF ceramic capacitor,10nF ceramic capacitor,100KΩ potentiometer,4 IN4007 diode, 470µf capacitor(2), 240AC source transformer, Computer, Lead, Vero boar, Soldering iron, Digital Multimeter, Jumper wire.

Different function generators have different techniques in producing waveforms, hence different circuit components of now days have these components,

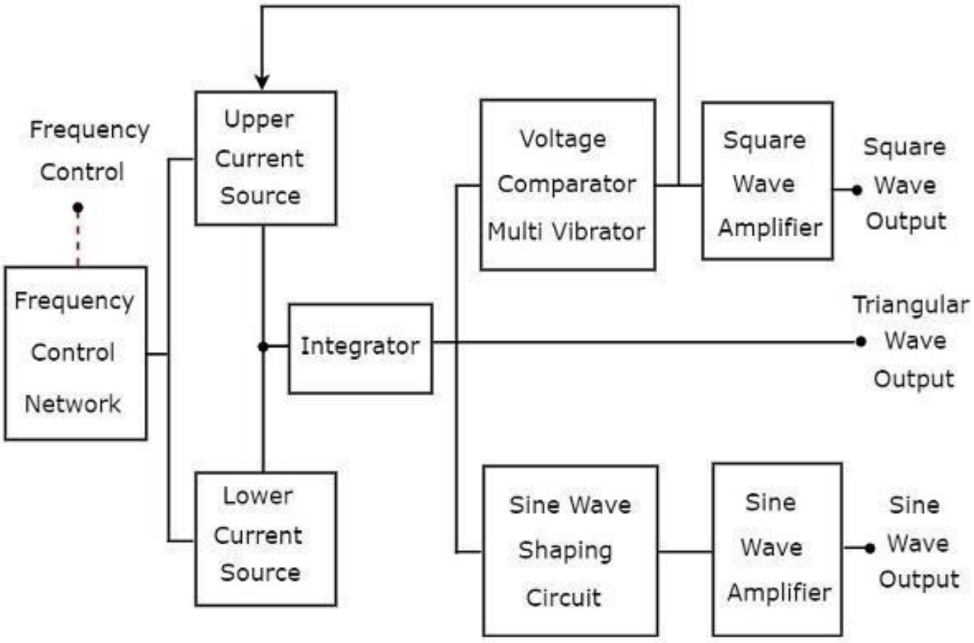

Figure 7. Schematic Block Diagram of a Signal Generator

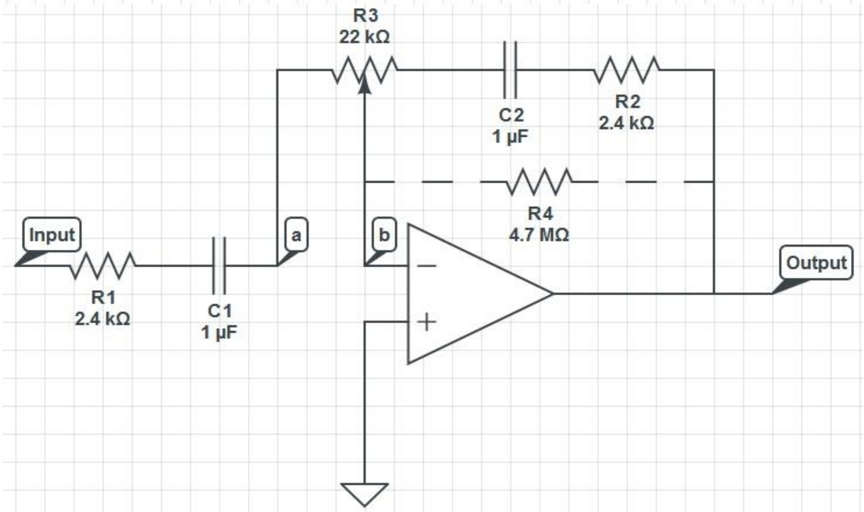

Figure 8. Frequency Network Control System

The first step in using a function generator is to adjust its frequency. Figure 8 shows a basic frequency control network. The input to this network is a DC current source. When C1 and C2 are charging, the output of this network is going to be zero. Then, when they are both fully charged, the resistors tend to dissipate the charge and conduct a current at the output. How frequent this process happens depends on the value of the resistor R3, which is an adjustable resistor.

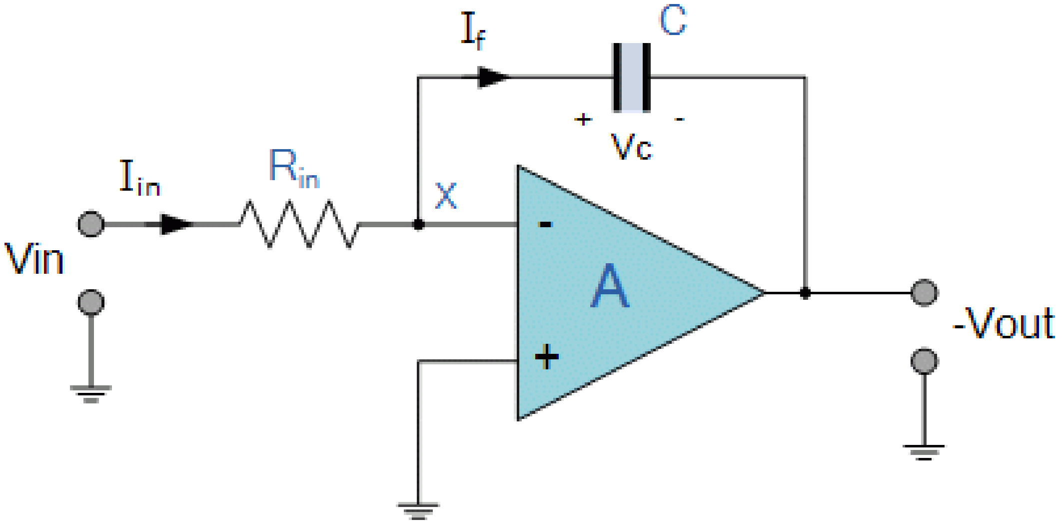

Figure 9. An integrator circuit.

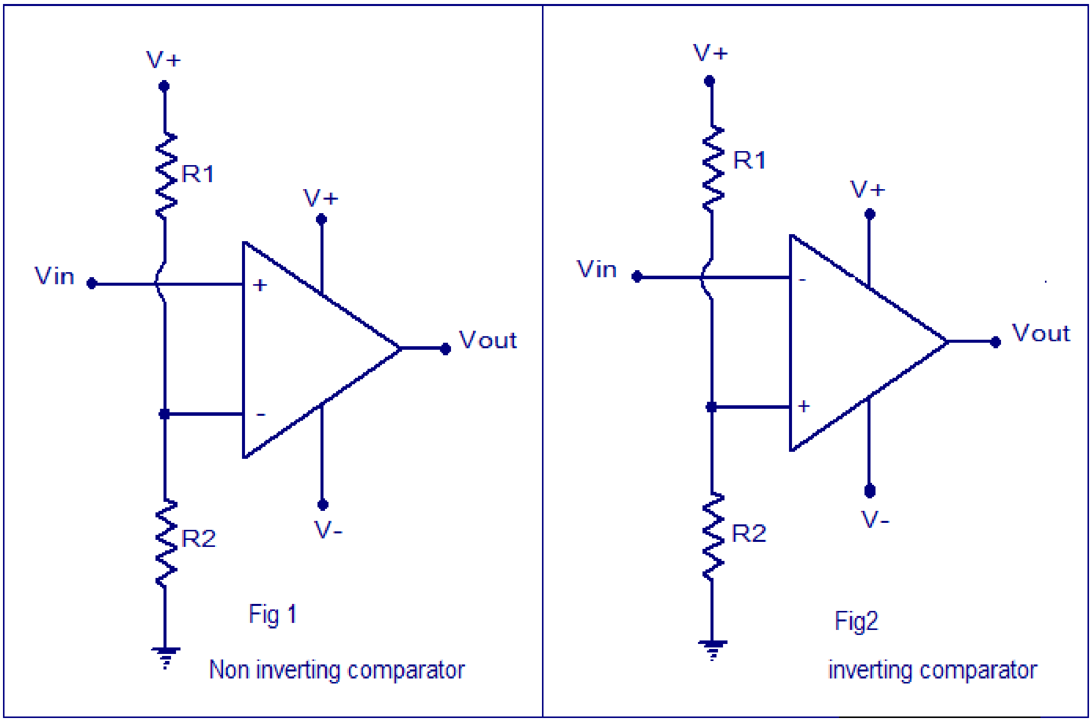

Figure 10. None and inverting voltage comparator

After adjusting the frequency of the current supplies**,** the integrator comes into play. Its main function is to produce a triangular waveform that is going to be directly used or converted to a sin or a square wave as seen in Figure 9. It basically performs a mathematical integration to its input signal, which is a constant DC current. Hence, produces an output voltage that rises linearly with time.

In other words, the output is going to be a triangular waveform. The slope of the waveform depends linearly on the magnitude of the constant current supply source. If the current supply is positive, the output is going to be a rising line. In contrast, if it was negative, the output is going to be a falling line. The Frequency Control Network controls the polarity of the current sources.

The voltage comparator is used to produce a square waveform. The comparator is a circuit that compares an input voltage to a fixed reference voltage as shown in Figure 10. The comparator is supplied with two voltage constant voltage sources, V+ and V-, that have the same magnitude but different signs. If the input voltage (The output of the integrator) is larger than the reference voltage (Usually 0), it outputs the value of the V+ source. However, if the input voltage is smaller than the reference voltage, it outputs the value of the V- source. Since the V+ and V- have constant values, the output will switch between the value of V+ and V-, which will produce a square wave.

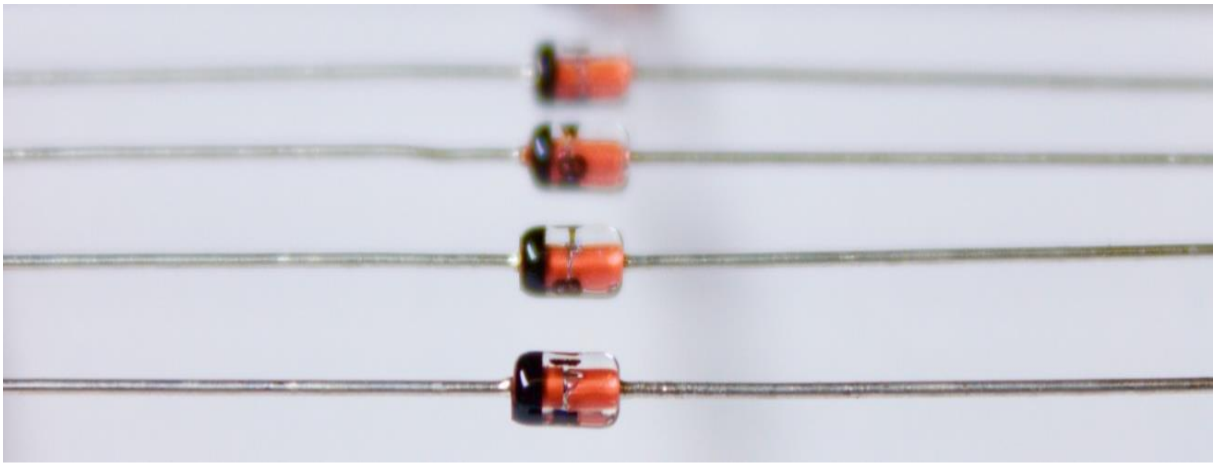

Figure 11. Shaping Resistance Diode

The resistance diode network changes the slope of the triangular wave as its amplitude changes and produces a sinusoidal wave with less than 1% distortion. It has a very complicated operation that is hard to explain in few parts.

3. RESULTS AND DISCUSSION

The LM324 is a quad operational amplifier IC that is used to build this signal generator and it is a 14-pin chip IC, the pins are studied very well to connect the pins properly. Below are the pins of the LM324 op amp

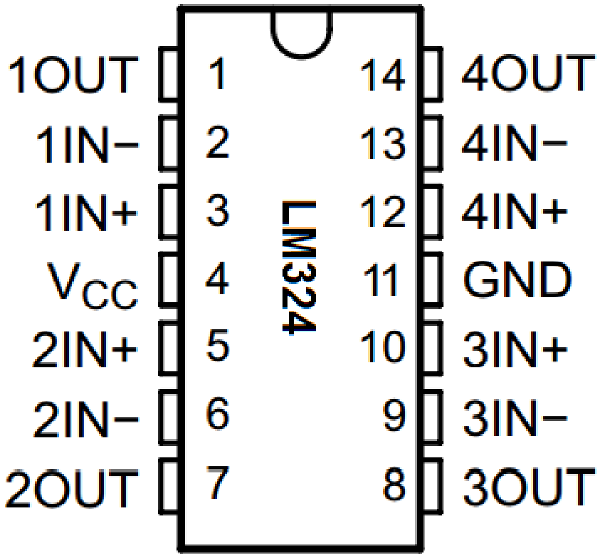

Figure 12. LM324 Operational amplifier pin description

From Figure 12, the pin outs are relatively straight forward, and it has two (2) power pins, pins 4 and 11. Pin 4 is the positive voltage power supply, V_{cc}, Pin 11 labeled GND, is the negative voltage power supply and it establishes the negative DC rails from the AC. Through these two pins positive and negative DC rails from the AC signal can swing. LM324 can take up to 30V to pin 4, $V_{cc.\ While}$ all the 12 pins are the inputs or output of each of the operational amplifier. There are 4 operational amplifiers within the chip; each op amp has two inputs and one output.

The 100 KΩ potentiometer allows the advantage of varying the frequency of the circuit. And its way of adjusting the frequency of the output signal in which Wien bridge oscillator are of high stability and low distortion and the oscillator will oscillate at the frequency

$$f_o = \frac{1}{2\pi RC} \qquad (9)$$

where

F= frequency of osculation in Hertz
C= Capacitance in farad
R=Resistance in ohms

When:

$$:\frac{R1}{R2} \geq 2 \qquad (10)$$

For oscillation to start, the value R_2/R_1 should be made slightly greater than 2
Then, Determining the frequency of oscillation of the Wien bridge oscillator if

R = 100 kΩ and

$C = 0.1\ \mu\text{F}$

Solution

$$f_o = \frac{1}{2\pi RC} = \frac{1}{(100)(0.1)\mu\pi} = 8.885\ \text{kHz},$$

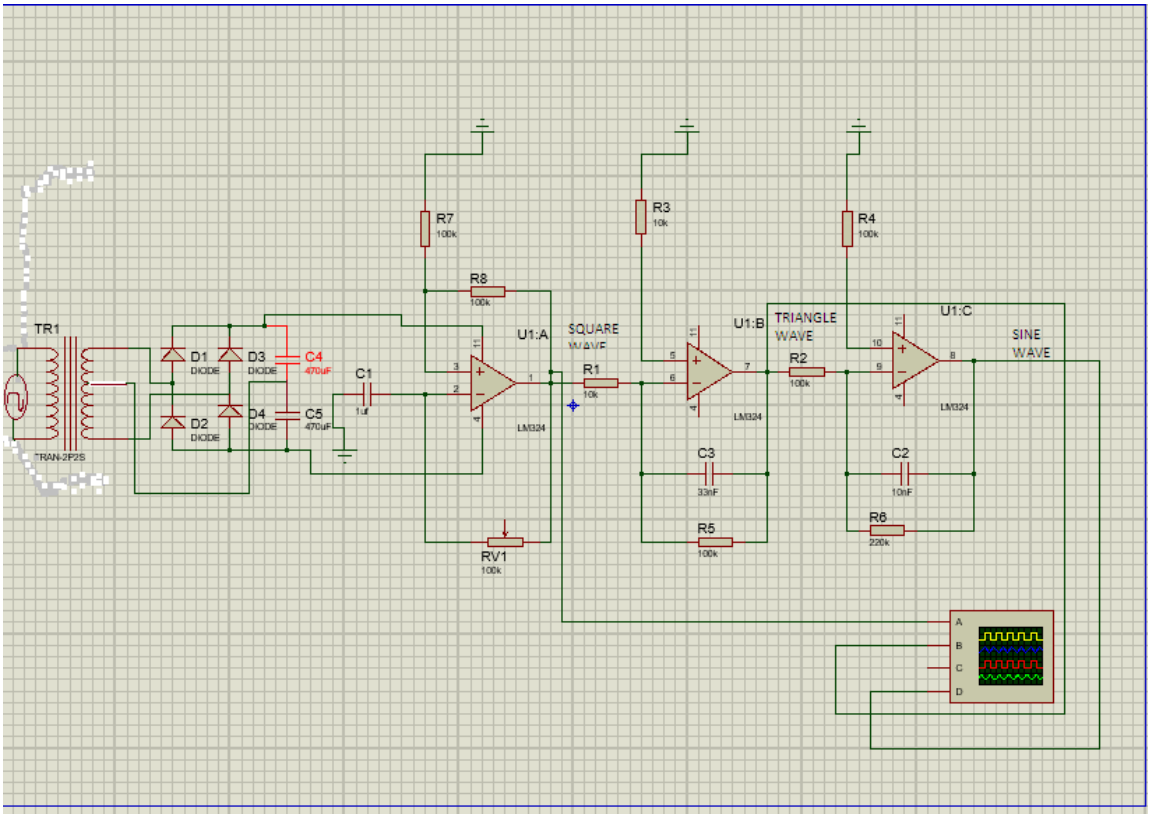

Figure 13. Circuit Diagram of a Signal Generator

By integrating the various parts of signal generator, the overall design was obtained, the generated signal after setting its frequency to the desired one is applied to the switch to select one the three types of waves, then the selected signal is applied to the non-inverting op-am configuration. Then using the formula to calculate the output voltage of a potential divider network, we can calculate the closed-loop voltage gain (A_V) of the Non-inverting Amplifier as follows: Once the basic waveform is defined, other operations, such as filtering and sequencing, can be applied to modify or extend it, respectively.

Filtering allows you to remove selected bands of frequency content from the signal. For example, when testing an analog- to-digital converter (ADC), it is necessary to ensure that the analog input signal, which comes from the signal generator, is free of frequencies higher than half the converter's clock frequency. This prevents unwanted aliasing distortion in the DUT output, which would otherwise compromise the test results. Aliasing is the intrusion of distorted conversion by-products into the frequency range of interest. A DUT that is putting out an aliased signal cannot produce meaningful measurements.

One reliable way to eliminate these frequencies is to apply a steep low-pass filter to the waveform, allowing frequencies below a specified point to pass through and drastically attenuating those above the cutoff. Filters can also be used to re-shape waveforms such as square and triangle waves. Sometimes it's simpler to modify an existing waveform in this way than to create a new one. In the past, it was necessary to use a signal generator and an external filter to achieve these results. Fortunately, many of today's high-performance signal generators feature built-in filters that can be controlled.

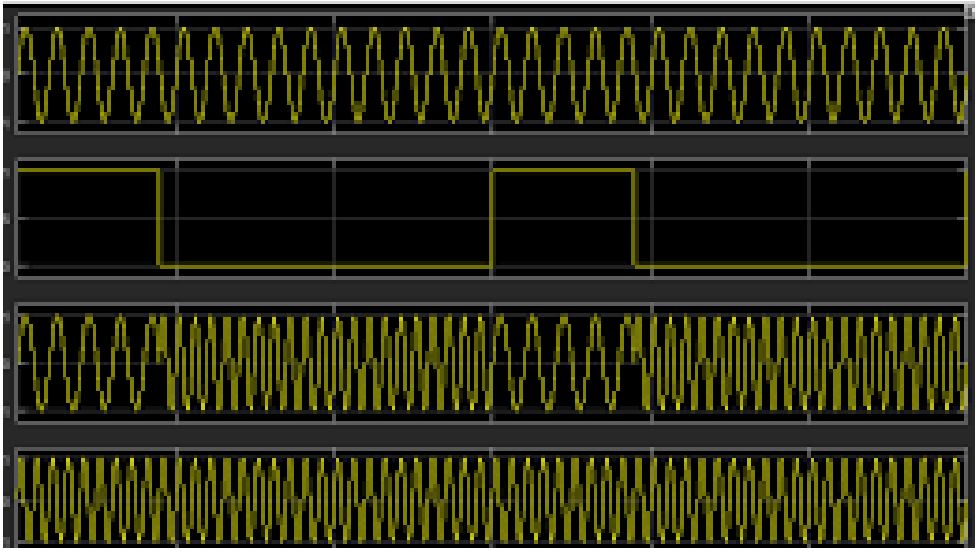

Figure 14. Sample Wave Forms Generated

Waveform Characteristics: The term "wave" can be defined as a pattern of varying quantitative values that repeats over some interval of time. Waves are common in nature: sound waves, brain waves, ocean waves, light waves, voltage waves, and many more. All are periodically repeating phenomena. Signal generators are usually concerned with producing electrical (typically voltage) waves that repeat in a controllable manner. Each full repetition of a wave is known as a "cycle." A waveform is a graphic representation of the wave's activity — its variation over time. A voltage waveform is a classic Cartesian graph with time on the horizontal axis and voltage on the vertical axis. Note that some instruments can capture or produce current waveforms, power waveforms, or other alternatives. In this document we will concentrate on the conventional voltage vs. time waveform.

Amplitude is a measure of the voltage "strength" of the waveform. Amplitude is constantly changing in an AC signal. Signal generators allow you to set a voltage range, for example, —3 to +3 volts. This will produce a signal that fluctuates between the two voltage values, with the rate of change dependent upon both the wave shape and the frequency.

Frequency is the rate at which full waveform cycles occur. Frequency is measured in Hertz (Hz), formerly known as cycles per second. Frequency is inversely related to the period (or wavelength) of the waveform, which is a measure of the distance between two similar peaks on adjacent waves. Higher frequencies have shorter periods.

In theory, the placement of a waveform cycle is relative to a 0-degree point. In practice, phase is the time placement of a cycle relative to a reference waveform or point in time. Phase is best explained by looking at a sine wave. The voltage level of sine waves is mathematically related to circular motion. Like a full circle, one cycle of a sine wave travels through 360 degrees. The phase angle of a sine wave describes how much of its period has elapsed.

Two waveforms may have identical frequency and amplitude and still differ in phase. Phase shift, also known as delay, describes the difference in timing between two otherwise similar signals, Phase shifts are common in electronics. The amplitude, frequency, and phase characteristics of a waveform are the building blocks a signal generator uses to optimize waveforms for almost any application. In addition, there are other parameters that further define signals, and these too are implemented as controlled variables in many signal generators.

Edge transition times, also referred to as rise and fall times, are characteristics usually ascribed to pulses and square waves. They are measures of the time it takes the signal edge to make a transition from one state to another. In modern digital circuitry, these values are usually in the low nanosecond range or less. 90º Phase shift (also known as delay), describes the difference in timing between two signals. Phase is usually expressed in degrees as shown, but a time value may be more appropriate in some circumstances. Both rise and fall times are measured between the 10% and 90% points of the static voltage levels before and after the transition (20% and 80% points are sometimes used as alternatives). At a lower sample rate, this same waveform would look much "square". In some cases, rise and fall times of generated pulses need to be varied independently, for example when using generated pulses to measure an amplifier with unsymmetrical slew rates, or controlling the cool down time of a laser spot welding gun.

Pulse width is the time that elapses between the leading and trailing edges of a pulse. Note that the term "leading" applies to either positive-going or negative-going edges as does the term "trailing." In other words, these terms denote the order in which the events occur during a given cycle; a pulse's polarity does not affect its status as the leading or trailing edge. The positive-going edge is the leading edge. The pulse width measurement expressed the time between the 50% amplitude points of the respective edges.

Another term, "duty cycle," is used to describe a pulse's high and low (on/off) time intervals. To cite a tangible example of a duty cycle, imagine an actuator that must rest for three seconds after each one-second burst of activity, to prevent the motor from overheating. The actuator rests for three seconds out of every four - a 25% duty cycle.

Sine waves are perhaps the most recognizable wave shape. Most AC power sources produce sine waves. Household wall outlets deliver power in the form of sine waves. And the sine wave is almost always used in elementary classroom demon- stations of electrical and electronic principles. The sine wave is the result of a basic mathematical function — graphing a sine curve through 360 degrees will produce a definitive sine wave image. The damped sine wave is a special case in which a circuit oscillates from an impulse, and then winds down over time.

Square and rectangular waves are basic forms that are at the heart of all digital electronics, and they have other uses as well. A square wave is a voltage that switches between two fixed voltage levels at equal intervals. It is routinely used to test amplifiers, which should be able to reproduce the fast transitions between the two voltage levels (these are the rise and fall times explained earlier). The square wave makes an ideal timekeeping clock for digital systems — computers, wireless telecom equipment, HDTV systems, and more.

A rectangular wave has switching characteristics like those of a square wave, except that its high and low time intervals are not of equal length, as described in the earlier “duty cycle” explanation. Shows examples of square and rectangular waves. Sawtooth and triangle waves look very much like the geometric shapes they are named for. The sawtooth ramps up slowly and evenly to a peak in each cycle, then falls off quickly. The triangle has more symmetrical rise and fall times. These wave- forms are often used to control other voltages in systems such as analog oscilloscopes and televisions. Figure 10 shows examples of sawtooth and triangle waves.

4. CONCLUSIONS

This paper presents a compact and simple design of adjustable triangular, sine, sawtooth and square wave functional generators employing fundamental cells fabricated on a single integrated circuit (IC) package. Two solutions have electronically tunable repeating frequency. The linear adjustability of repeating frequency was verified in the range between 17 and 264 kHz. The main benefits of the proposed generator are the follows: A simple adjustment of the repeating frequency by DC bias current, Schmitt trigger (threshold voltages) setting by DC driving voltage, and output levels in hundreds of mV when the complementary metal-oxide semiconductor (CMOS) process with limited supply voltage levels is used. These generators are suitable to provide a simple conversion of luminance to frequency of oscillation that can be employed for illuminance measurement and sensing in agriculture applications. Experimental measurements proved that the proposed concept is usable for sensing illuminance in the range from 1 up to 500 lx. The change of illuminance within this range causes driving of bias current between 21 and 52 μA that adjusts repeating frequency between 70 and 154 kHz with an error up to 10% between the expected and real cases.

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