ON VARIOUS OSCILLATORS AND POWER AMPLIFIERS DESIGN METHODS EMPLOYED FOR THE DEVELOPMENT OF POWER INVERTERS

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ABSTRACT

Electricity is central to the existence of human being such that a country's electric power generating capacity is equated with its level of development. Several Nigerians have lost their lives from inhaling (fuel type electric) generator fumes due to the inability of the federal government to provide stable electric power. Scientists and engineers have suggested the use of power inverters as the alternative to the fuel type electric generators. An inverter is an electronic device that has the ability to convert the direct current, dc, from the battery or solar cells (panels) to alternating current, ac, which is the convectional form that powers many electrical appliances. Many inverters ranging from low wattages to high wattages are now found in homes and offices across Nigeria. Majority of these inverters can not be used to adequately power some electrical appliances due to the poor design techniques employed by the designers. This paper discussed the main building blocks of the power inverters: the oscillators and the power amplifiers design techniques. The merits and demerits of various design techniques available for the development of different types of power inverters were spell out.

Keywords: Electricity, Inverter, oscillator, power amplifier, circuit design.

1. INTRODUCTION

What would life be without electricity? The need for electricity in the modern social life especially in the operation of all daily activities is highly becoming insatiable by the public electricity power supply company in Nigeria. For a business, home or office, a reliable electricity power supply source is inevitable for operation of electrical and electronic systems. Nigerians are now paying the price for embracing fuel type electric power generators, which have become a nightmare in the environment in many ways. Besides the huge sums of money they spend to acquire and maintain generators, Nigerians are experiencing untold agony over the inability of the federal government to provide stable electric power. For instance, over the years, several people have lost their lives by inhaling noxious, toxic fumes from generators.

Scientists have suggested the use of nonfuel, soundless power inverters as the alternative to the fuel type, noisy, electric generators. An inverter is an electronic device that has the ability to convert the direct current, dc, from the battery or solar cells (panels) to alternating current, ac (Figure 1), which is the convectional form that powers many electrical appliances [1, 2]. Many inverters ranging from low wattages (500VA/1kVA) to high wattages (10kVA) are now available in the Nigeria markets, and are used in homes and offices across the country. Majority of these inverters can not be used to adequately power some electrical appliances such as laser jet printers, tomatoes/papers grinding machine, fans and some medical equipment, just to mention a few. It is because in the market of power inverters, there are many choices. They range from the very expensive to the very inexpensive, with varying degrees of quality, efficiency and as previously mentioned, power output capability along the way. High quality combined with high efficiency is very important features of power inverter regardless of the cost [1, 2, 3].

In this paper, the challenges facing the development of low noise, high efficient power inverters are recognized as the poor design techniques employed by the designers. In particular, most student researchers at the undergraduate and postgraduate levels face the dilemma of the actual design technique to employ for development of power inverters. The main building blocks of the power inverters are the oscillators and the power amplifiers; these constitute the various types of the power inverters available and of course the various inverters' design techniques. The other features are the transformers. This paper discussed various design techniques, their merits and demerits, available for the development of different types of power inverters.

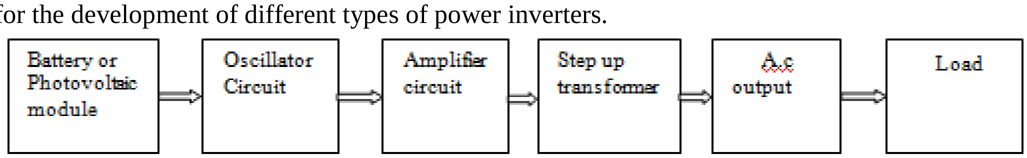

Figure 1: Schematic diagram of the inverter system for generation of electricity.

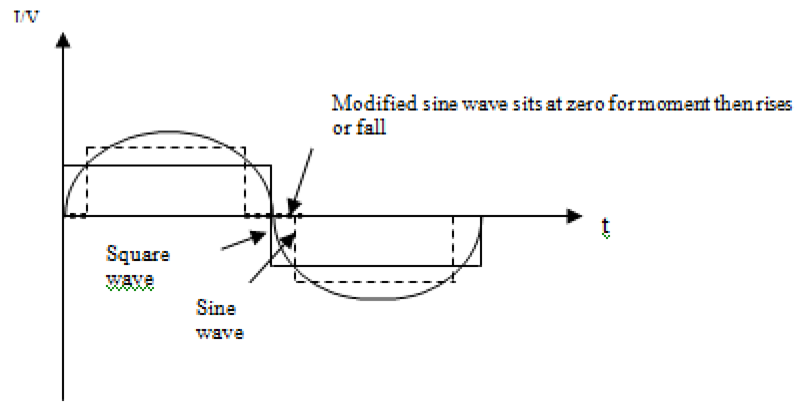

Figure 2: Showing a.c output of the sine wave, square wave and modified sine wave inverters.

2. OSCILLATORS EMPLOYED FOR DESIGN OF POWER INVERTERS

An oscillator is an electronic device that converts dc power supply to ac power having the desired characteristics. Power inverters come in a wide variety of power capacities and they are distinguished primarily by the wave shape (sine or cosine, square and others as shown in the figure 2) of the alternating current they produced from the oscillator employed for the design. The major types are: 1. Pure sine-wave inverter, 2. Square wave inverter, and 3. Modified sine-wave inverter [3, 4, 5, 6,]. The basis of the oscillation in an electric circuit is the positive feedback. Oscillator falls into the following classes; Positive feedback (RC and LC networks), Negative resistance, and Relaxation type. The discussion of the oscillators in this paper will be focused on the low frequency oscillators that can be employed for the design of power inverters operating at 50/60Hz.

2.1 Pure Sine wave Inverters

Pure or perfect sin wave inverters produce sine wave outputs (Figure 2) identical to the power coming out of the electrical outlet (national grid). These devices are able to effectively run more sensitive devices (and inductive loads) that square wave and modified sine wave inverters may cause damage to such as: laser printers, laptop computers, grinding machine, digital clocks and medical equipment. The power supplied by utility companies and engine generators is a true sine waveform. This is the most reliable waveform for household use. True sine wave power passes from the upper and lower peak voltage in a smooth curved wave, rather than the stair-step of the modified sine wave. Pure sine wave inverters produce AC voltage with low total harmonic distortion, THD (normally below 3%). True sine wave inverters produce AC power as good as or better than utility power, ensuring that even the most sensitive equipment are run properly. They are used where there is need for clean sinusoidal output for electrical and electronic equipment and appliances [2, 3, 5, 6, 7, 8, 9, 10].

2.1.1 Advantages:

The advantages of the pure sine wave inverters outweigh its disadvantages over the square wave and modified sine wave inverters:

(i) A pure sine wave inverter’s output voltage waveform is a perfect sine wave with very low harmonic distortion and clean power like utility- supplied electricity.

(ii) Inductive loads like microwave ovens and motors run faster, quieter and cooler with the pure sine wave inverter.

(iii) A pure sine wave inverter reduces audible and electrical noise in fans, fluorescent lights, audio amplifier, TV, Game consoles, Fax and answering machines.

(iv) A pure sine wave inverter prevents crashes in computers, weird print out, and glitches and noise in monitors.

(v) A pure sine wave inverter can produce reliably power for effective operation of the following devices that will normally not work well with the square wave and modified sine wave inverters:

- Laser printers, photocopies, magneto-optical hard drives,
- Certain laptop computers,
- Some fluorescent lights with electronic ballasts,
- Power tools employing “solid state” power or variable speed control,
- Some battery chargers for cordless tools,

- Some new furnaces and pellet stoves with microprocessor control,
- Digital clocks with radios,
- Sewing machines with speed/ microprocessor control,
- X-10 home automation system,
- Medical equipment such as oxygen concentrators,

2.1.2 Disadvantages:

One disadvantage of pure sine wave inverters is that they are considerably more expensive but the additional cost may be worth it, if the inverter is to be used frequency or if maximum performance is essential.

2.2 Types of sine waves oscillator

At low frequencies, RC oscillators can be employed to produce perfect sine waves. These low-frequency oscillators use Integrated Circuits (and op-amps), or transistors (preferably MOSFET because of its power handling capability), and RC resonant circuits to determine the frequency of oscillation. The examples of such oscillators that can be employed to produce pure sine wave inverters among are; Phase shift oscillators, Wien bridge oscillators, Twin-T oscillators and Bubba oscillators. Others are Quadrature oscillators, Triangle-Driven Break-Point Shaper, Triangle-Driven Logarithmic Shaper, DAC-Driven Logarithmic Shaper, and ROM-Driven DAC [2, 3, 5].

2.2.1 Phase-shift oscillators

Phase shift oscillators are the terms given to the particular oscillator circuit topologies that use the RC networks in the feedback loop of the amplifiers to generate the required phase shift at a particular frequency to sustain oscillation In order to sustain an oscillation at a particular frequency, a circuit must have a gain higher than unity, and a total phase shift around loop of 360^0 (which is equivalent to 0^0, or positive feedback). When used with a single stage inverting amplification element, such as a transistor, or inverting op-amps configuration, the amplifier itself provides 180^0 of phase shift (a gain of –A, where A is the gain of the amplification stage). The remaining 180^0 of phase shift necessary to provide a total of 360^0 is provided by an external network of resistors and capacitors to sustain oscillations.

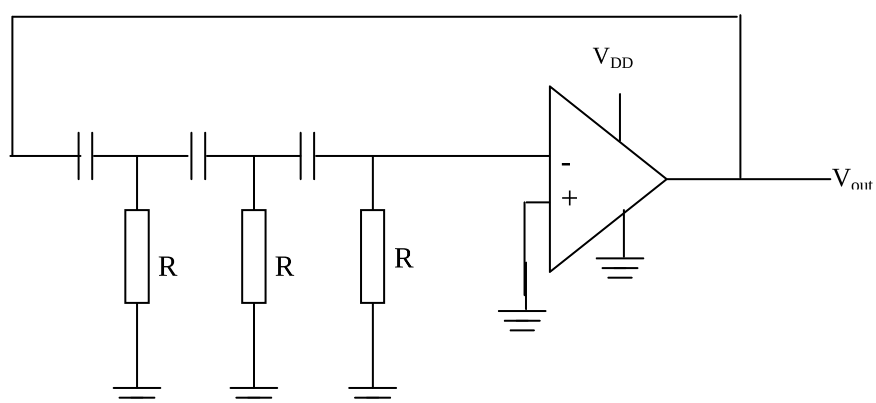

Figure 3: Phase –shift oscillator with three lead circuits.

Figure 3 shows a schematic diagram of a typical phase shift oscillator with three lead circuits. The phase shift elements are C_1/R_1, C_2/R_2 and C_3/R_3. Three of these phase lead networks contribute a total of 180^0 of phase shift at the oscillation frequency. Note that a phase shift oscillator could also be built using four or more phase shift elements, with each element contributing less overall phase shift at the oscillation frequency. Normally there is no need to do this, as it takes extra components. A minimum of three phase shift networks is required, however, because the maximum theoretical phase shift available from any one RC network is 90^0, and the actual phase shift approaches this value asymptotically.

A phase shift oscillator can also be made using three phase lag networks shown the Figure 2b, which are obtained by swapping the positions of the R and C. The operation is similar. The amplifier produces 180^0 of phase shift, and the lag circuits contribute $–180^0$ at some higher frequency to get a loop phase of 0^0. If A is greater than unity at this frequency, oscillation can start. The typical frequency range of operation of the phase shift oscillators is 10Hz to 1MHz [3, 10].

Oscillation frequency: The frequency of oscillation of the phase shift oscillators is given by the formula:

$$f_O = \frac{1}{2\pi RC\sqrt{6}} \qquad (1)$$

$R_1 = R_2 = R_3 = R$, $C_1 = C_2 = C_3 = C$

Advantages: Phase shift oscillators are moderately stable in frequency and amplitude, very cheap, and easy to design and construct. They have quick starting and settling.
Disadvantage: The main problem with the circuit is that it cannot be easily adjusted over a large frequency range.

2.2.2 Wien bridge oscillators

The Wien bridge oscillator is one of electronic oscillators that generate sine waves. It is the standard RC oscillator circuit for low to moderate frequencies in the range of 5Hz to 1MHz. A typical Wien bridge oscillator circuit is shown in the Figure 4. The bridge circuit comprises of four resistors and two capacitors. Its characteristic feature is the RC network consisting of R and C in series with a parallel combination of R and C, as shown the Figure 3. The resistors and capacitors can be different in value, but it is much simpler to make them equal, and nothing of value is lost [4, 5, 10].

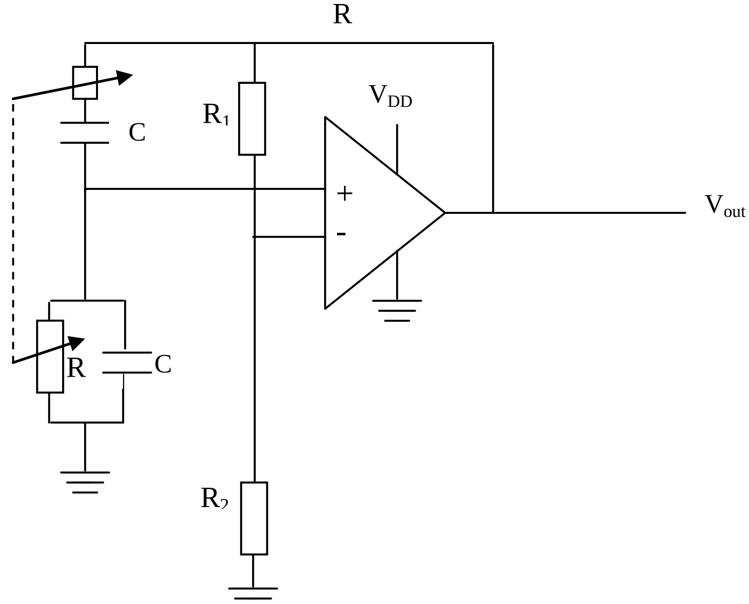

Figure 4: Wien-bridge oscillator circuit.

Oscillation frequency: The Wien bridge is an ac version of the well-known Wheatstone bridge and the bridge is balanced at a frequency given by the formula:

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

Advantages: One major advantage of the Wien bridge oscillator is the simplicity of tuning which can be achieved by a means of a two-track (double-ganged) potentiometer. It also has extremely low distortion and high amplitude stability.
Disadvantages: Its major disadvantage is slow settling after a step change in the frequency or amplitude.

2.2.3 Twin – T oscillators

Twin- T oscillator uses two “T” RC circuits operated in parallel as shown in the figure 5. One circuit is an R-C-R “T” which acts as low pass filter. The second circuit is a C-R-C “T” which operates as a high pass filter. Together, these circuits form a bridge which is tuned at the desired frequency of oscillation. The signal in the C-R-C branch of the Twin-T filter is advanced, and in the R-C-R- is delayed, so they may cancel one another for the oscillation frequency f_o. As a guide, R_2/R_1 is in the range of 10 to 1000. This forces the oscillator to operate at a frequency near the notch frequency f_o [3].

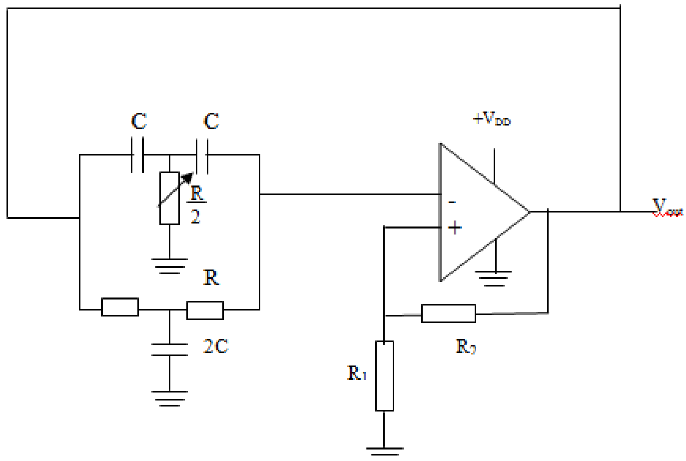

Figure 5: Twin-T oscillator circuit.

Oscillation frequency: The frequency of oscillation of the Twin-T oscillator is given by the formula:

$$f_o = \frac{1}{2\pi RC} \tag{3}$$

Advantages: The Twin-T oscillator works very well at one frequency.
Disadvantage: The main problem with the circuit is that, unlike the Wien-bridge oscillator, it cannot be adjusted over a large frequency range.

2.2.4 Bubba oscillator

The Bubba oscillator is a variety of phase shift oscillator circuit that provides a filtered sine wave of any frequency the user desires based upon the configuration of resistors and capacitors in the circuit. The circuit completes this task with four operational amplifiers (e.g. LM348) that either buffer or amplify the signal (Figure 6). However, unlike other phase shift varieties that require phase shifts of 90^0 or more, the bubba oscillator only requires a 45^0 shift in order to function. This is because of the four op-amps, that when placed in series, produce a total 180^0 shift. Four identical RC filters phase shift the signal 45^0 each. This causes a 180^0 phase shift which is then returned to a zero degree phase shift with the inverting amplifier placed across the first operational amplifier [2].

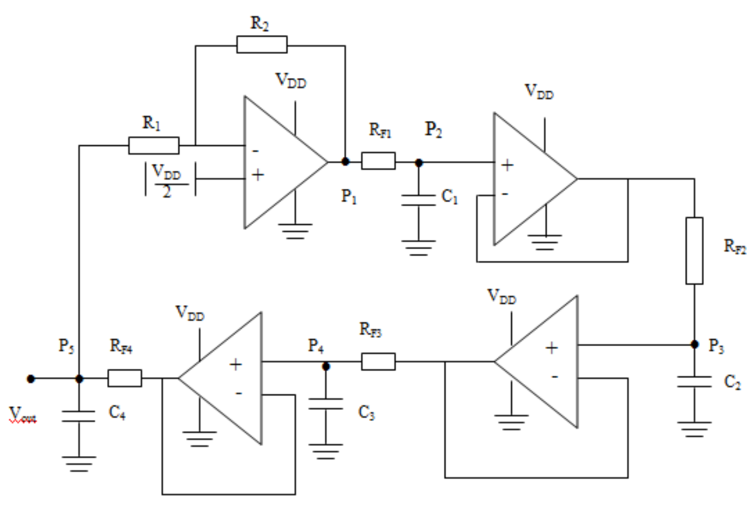

Figure 6: Bubba oscillator circuit.

Oscillation frequency: The frequency of oscillation of the Bubba oscillator is given by the formula:

$$f_O = \frac{1}{2\pi RC\sqrt{6}} \tag{4}$$

$R_1 = R_2 = R_3 = R_4 = R$, $C_1 = C_2 = C_3 = C$

Advantages: The bubba oscillator offers a few features that other oscillators cannot; the biggest factor is that the frequency stability holds while still giving a low distortion output. The reason for this involves the four filters that the signal passes through, providing a clear and stable signal at point p5, as shown in the Figure 6.
Disadvantage: The main problem with the circuit is the side effect of the filtering leading to the attenuation of the output signal, which is so big that the signal must be amplified so that the oscillator works.

2.3 Square wave Inverters

The model of power inverter depends on the oscillator employed in the design of the inverter. Square wave inverters produce square wave outputs, as shown in the figure 2, not identical to the power coming out of the electrical outlet (national grid). The output power of a square wave inverter can be used to run electric bulbs and some other non induction coil devices effectively. The square wave inverter is the simplest, the least expensive type, and they are commonly available in the market. However, the Fourier analysis of square waves shown that the waveforms composed of many harmonics of the fundamental frequencies, and the rich harmonics contents make the square wave inverters in particular not useful for the operation of induction coil devices [2, 4, 9, 10].
There are so many types of oscillators that can be employed to produce square wave inverters, amongst are; Op-amps square wave oscillator (Relaxation oscillator), Blocking oscillator, Integrated circuit astable multivibrator, JFET Chopper, and Gated CMOS oscillator [2, 4, 9].

2.3.1 Op-amps square wave oscillator (Relaxation oscillator)

One of the electronic circuits that generate square waves is shown in the Figure 7. With positive feedback (feedback resistor, R) square wave oscillators can be built using the op-amps as shown in the Figure 6. The output of the circuit is a rectangular signal that swings between $-V_{sat}$ and $+V_{sat}$. If the output is in the positive saturation ($+V_{sat}$), the capacitor, C will charge exponentially toward $+V_{sat}$. But the capacitor voltage never reaches $+V_{sat}$ because the voltage crosses the *upper trip point* (UTP). As a result, the output square wave switches to $-V_{sat}$, and the capacitor discharges. When the capacitor voltage crosses through zero, the capacitor starts charging negatively toward $-V_{sat}$. But the capacitor voltage never reaches $-V_{sat}$ because the voltage crosses the *lower trip point* (LTP). As a result, the output square wave switches back to $+V_{sat}$. The cycle then repeats. Because of the continuous charging and discharging of the capacitor, the output is a rectangular wave with a duty cycle of 50% [3, 4].

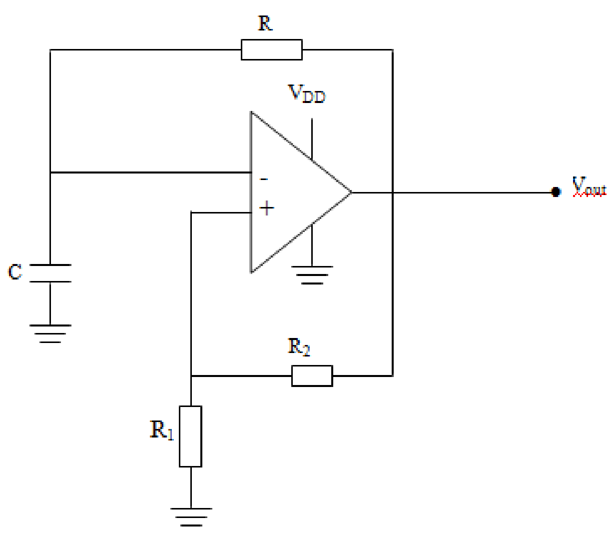

Figure 7: Relaxation oscillator circuit.

Advantages: The major advantage of this design technique is its simplicity.
Disadvantages: The disadvantages of this oscillator are its slow settling to the lower frequency and output duty cycle not more than 50%.
Oscillation frequency: The frequency of oscillation of Op-amps square wave oscillator is given by the formula:

$$f_o = \frac{1}{2RC \ln\left(1 + \frac{2R_2}{R_1}\right)} \quad (5)$$

2.3.2 Blocking oscillator

At first sight the blocking oscillator might be mistaken for the LC oscillator, however, the operation is completely different. A typical blocking oscillator circuit is drawn in the figure 8. The sequence starts with the timing capacitor, C, charged negative and transistor TR_1 turned off. The timing resistor, R, charges C and the base voltage starts to rise towards V_{cc}. At about 0.5 V, TR_1 turns on, and current flows through the primary of the transformer. This couples back into the base, causing more current to flow. Regenerative action takes place, and the increased base current flows through C, driving the RC junction quickly negative, cutting TR_1 off. The sequence now starts again.
The output consists of short negative pulses (with width determined by the transistor and transformer) occurring at regular intervals (with time determined by RC) [4].

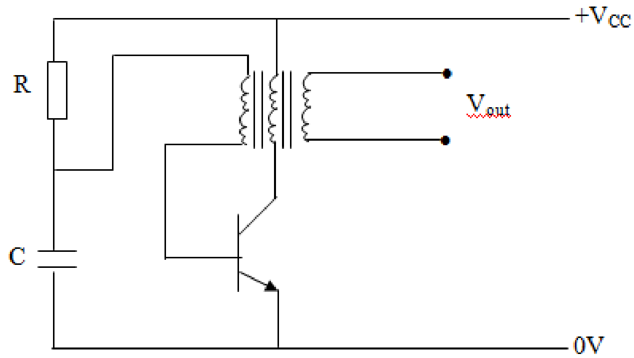

Figure 8: Blocking oscillator circuit.

Oscillation frequency: The frequency of oscillation of Blocking oscillator is determined by the transistor, transformer, resistor and capacitor in the circuit and can be given by the formula:

$$f_o = \frac{1}{RC} \quad (6)$$

Advantages: The major advantage of this design technique is its simplicity.
Disadvantages: The transformer can radiate noise (spikes) in rf fashion and it can be a serious problem particularly in digital circuits. However, the manufacturers have dealt with the problem through careful transformer design and construction and package shielding. The designer of the oscillator can introduce filters into the oscillator's output to reduce the noise.

2.3.3 Integrated circuit astable multivibrator

An integrated circuit such as IC555 timer (or op-amps; LM555 or CA555 or MC1455) can be used as an astable multivibrator, an oscillator, with times from a few microseconds to hours. It works on any d.c. supply from 3 to 15V and can supply (source) or accept (sink) a current of up to 200mA. This means that it can drive devices such as lamps and relays directly.
The circuit for the oscillator is shown in the Figure 9. Pin 2 of the IC (chip) is connected to pin 6, so as soon as pin 6 returns pin 7 to ground this low voltage is fed back to pin 2, which then retriggers the IC. A second resistor, R_2 is added between pins 6 and 7 to slow down the discharge of the capacitor and hence the oscillation is sustained [4, 8].

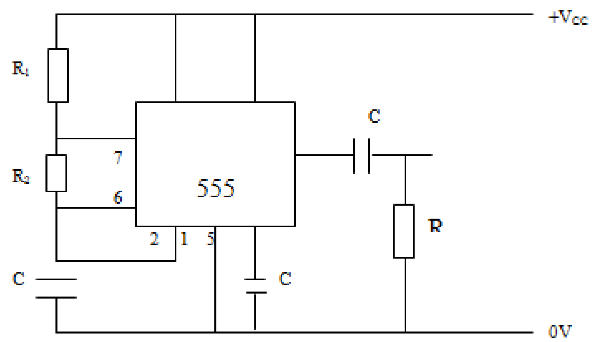

Figure 9: Integrated Circuit (using 555 timer) Astable Multivibrator oscillator.

Oscillation frequency: The frequency of oscillation of Integrated circuit astable multivibrator is given by the formula:

$$f_o = \frac{1.45}{(R_1 + 2R_2)C} \qquad (7)$$

Advantages: The major advantages of this design technique are the simplicity of design and possibility of high output duty cycle (more than 50%).
Disadvantages: The main disadvantage of this oscillator is its slow settling to the lower frequency.

2.3.4 JFET Chopper

JFET Chopper can be used either in shunt or series switch mode to convert a d.c. input voltage to a square wave output as shown in the Figure 10 [3].

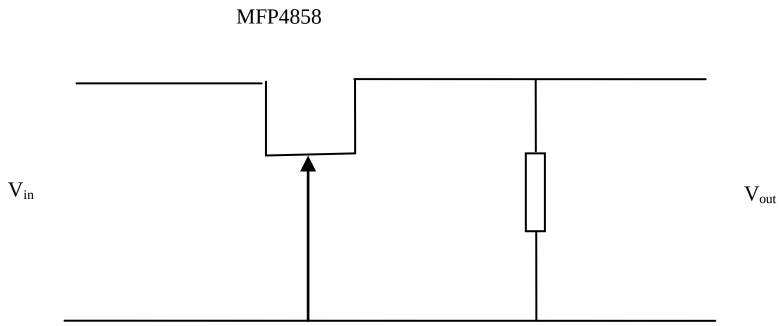

Figure 10: JFET Chopper oscillator circuit.

Oscillation frequency: The frequency of oscillation is determined by the transistor, resistor and capacitor making up the circuit.
Advantages: The oscillator circuit is low noise.
Disadvantages: The frequency of oscillation is difficult to adjust

2.3.5 Gated CMOS oscillator

Most of the square wave oscillators are noisy. An oscillator circuit in which noise is reduced is the gated CMOS oscillator shown in the Figure 11 [4].

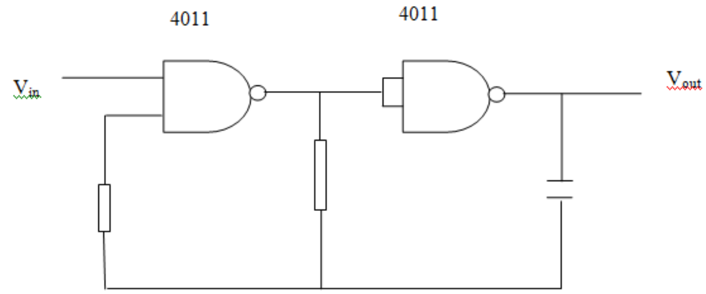

Figure 11: Gated CMOS oscillator circuit.

Oscillation frequency: The frequency of oscillation is determined by the CMOS (MOFET), resistor and capacitor making up the circuit.
Advantages: The oscillator circuit is low noise.
Disadvantages: The frequency of oscillation is difficult to adjust

2.4 Modified Sine wave Inverter

The modified sine wave topologies, which are actually similar to square waves, supply square waves with some dead spots between positive and negative half-cycles (Figure 2). They are suitable for many electronic loads, although their THD is about 25%. Modified sine wave models are the most popular low-cost inverters on the consumer market today, particularly among car inverters. If the description of a model does not state that it is a pure sine wave type, then most likely it is a modified sine wave inverter. Note that output voltage waveform conventional modified sine wave DC-AC circuits has only two levels: zero and peak voltage. By adding another voltage level, the THD can be reduced typically from 25% to 6.5%. Periodically connecting the output to a special voltage level with proper timing can produce a multiple-level waveform which is closer to a sine wave than conventional modified sine wave. Modified sine wave inverter will run many household appliances such as televisions, radio and micro-waves with occasional minor electrical "noise" present. Sensitive equipment like battery chargers, tools with variable speed motors, laser printer and certain heating controllers will run erratically or not at all with modified sine wave power [2].

Advantages: Modified sine wave inverters are relatively cheaper than the pure sine wave inverters and can be used to run electric bulbs and some other non induction coil devices effectively
Disadvantages: Sensitive equipment like battery chargers, tools with variable speed motors, medical equipment, computers, laser printer and certain heating controllers just to mention a few will run erratically or not at all with modified sine wave power.

3. POWER AMPLIFIER (DRIVER) STAGE

The output voltage and current of the oscillator stage are normally reduced due to the heat loss during modulation. As a result it is necessary to design a power amplifier which delivers adequate power to a load. The design criteria for power amplifiers employed for inverters include frequency, output power level, efficiency, gain, linearity, size, and cost. It is always difficult to simultaneously maximize all the criteria at the same time. Thereby tradeoffs must be made, and only a subset of the requirements can be satisfied, for instance linearity versus efficiency [11, 12].
Power amplifiers are generally divided into two types: transconductance power amplifiers and switching-mode power amplifiers. Transconductance power amplifiers include Class A, Class AB, Class B, and Class C amplifiers according to the bias condition of the output stage. Switching-mode power amplifiers include Class D, Class E, and Class F amplifiers. The classic tradeoff between the transconductance power amplifiers and switching-mode power amplifiers are linearity and efficiency. While transconductance power amplifiers are the most linear power amplifiers, they can not achieve maximum efficiency of 100%. Switching-mode power amplifiers can achieve an ideal efficiency of 100%, but they are strongly nonlinear amplifiers, and so they can only be used in applications that can tolerate a high degree of nonlinearity, or they have to be used with careful linearization techniques which translate into complex circuits, costly and difficult to implement [2, 3, 10, 11, 12].
This paper is focused on the transconductance power amplifier design (Figure 12). They are widely used in the inverter circuits and today wireless transmitters and have been discussed in detail in several books [2, 3, 10, 11, 12]. The simplest circuit diagram of a transconductance power amplifier design is shown in figure. The circuit is single ended, and the ideal rf choke, dc-coupling capacitor and the filter are assumed. The easy way to distinguish the

transconductance power amplifiers is the conduction angle. Class A amplifiers have a conduction angle of $\theta_c = 2\pi$ and biased at the middle of the load line as shown in the Figure 13; Class AB amplifiers have a conduction angle of $\pi < \theta_c < 2\pi$; Class B amplifiers have a conduction angle of $\theta_c = 2\pi$; Class C amplifiers have a conduction angle of $0 < \theta_c < \pi$.
The Class A amplifier is the most linear and the best behaved amplifier. However, the biggest drawback of the Class-A amplifier is the ideal maximum efficiency of 50%. The Class AB amplifier has the efficiency greater than 60%. The Class B amplifier which is the transition between the Class AB and the Class C has the efficiency of about 78.5%. The Class C amplifiers are high efficiency amplifiers, with an ideal efficiency of about 100%. The major drawback of the Class C amplifier is that its linearity is poor. It has to be used with linearity technique. For instance, a tuned Class C amplifier is usually a narrowband amplifier. The input signal in a Class C is amplified to get large output power with an efficiency approaching 100%. The universal formulas for all classes of the transconductance power amplifier design are listed as [3]:

$$G = \frac{P_{out}}{P_{in}} \qquad (8)$$

$$\mathrm{P_{out}} = \frac{V_{out}}{8R_L} \qquad (9)$$

$$\mathrm{P_{out(max)}} = \frac{MPP^2}{8R_L} \qquad (10)$$

$$\mathrm{P_{dc}} = V_{CC} I_{dc} \qquad (11)$$

$$\eta = \frac{\mathrm{P_{out}}}{\mathrm{P_{dc}}} \times 100\% \qquad (12)$$

Where, G is the Power gain; P_{out} is the ac output power; $P_{out(max)}$ is the maximum ac output power; P_{dc} is dc input power; η is the efficiency; *MPP* is the maximum peak-to-peak output voltage; V_{out} is the output voltage; V_{CC} is the supply voltage; I_{dc} is the direct current and R_L is the load.
It is the duty of the power driver (amplifier) stage to supply the transformer with the current and voltage it demands (Figure 1). The power driver stage is driven by the core oscillator and alternately switches the direction of the current through the transformer at a rate determined by the core oscillator.In order to create ac, current must be constantly switched from one direction through the transformer windings to the order. There are many ways to accomplish this, (H-Bridges are a fantastic way to achieve this, but they require considerably more complex circuitry.

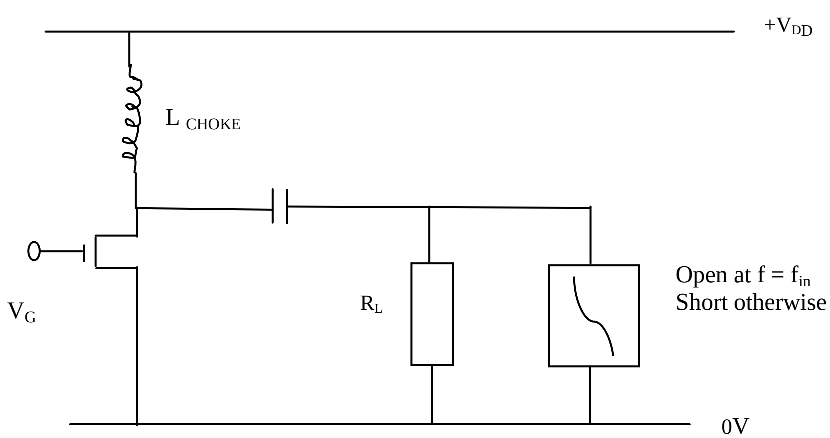

Figure 12: Showing simple circuit diagram of a transconductance amplifier.

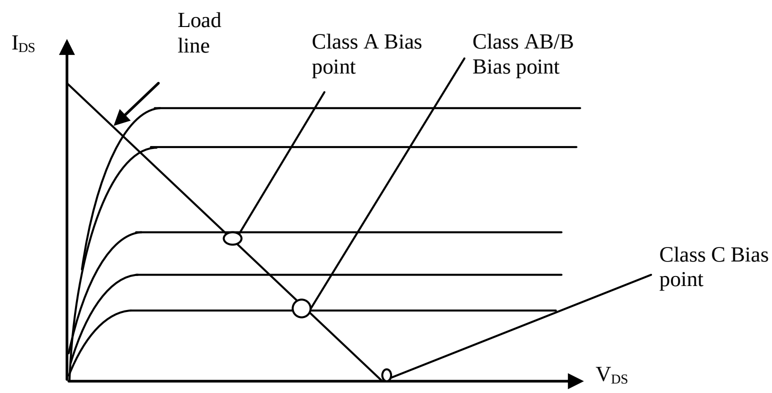

Figure 13: Showing the operation of transconductance amplifier classes

4. CONCLUSIONS

Scientists have suggested the use of nonfuel, soundless power inverters as the alternative to the fuel type, noisy, and costly electric generators. An inverter is an electronic device that has the ability to convert the direct current, dc, from the battery or solar cells (panels) to alternating current, ac, which is the convectional form that powers many electrical appliances. Many of these inverters can not be used to adequately power some electrical appliances such as laser jet printers, tomatoes/papers grinding machine, fans and some medical equipment. In particular, most student researchers at the undergraduate and postgraduate levels face the dilemma of the actual design technique to employ for development of power inverters. This paper reviewed the various design techniques employed for the development of power inverters. The main building blocks of the power inverters which are the oscillators and the power amplifiers are discussed.

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