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IMPLEMENTATION OF TRANSISTOR RECTIFIERS AND COMPARISON WITH DIODE RECTIFIERS

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ABSTRACT
This paper presents a comprehensive comparison of transistor rectifiers with diode rectifiers. In the modern-day electronics, rectifiers are used for the conversion of AC to DC voltages. The present investigation focuses on exploring the various rectifier circuits constructed using a transistor (BC547) instead of rectifier diodes (1N4007). Forward and reverse bias conditions of the diode were realized using a transistor. Half-wave and full-wave rectifiers were constructed using transistors. The obtained output waveforms were compared with rectifier diode waveforms. The calculated values of rectification efficiency are presented.

Keywords: Transistor; Diode; waveforms; Rectification.

1. INTRODUCTION
A device whose output is a direct current voltage when an alternating current voltage is supplied as input is generally known to be a rectifier. An alternating current changes its direction periodically while the direct current maintains a constant voltage in one direction. The voltage obtained at the output is not a perfect constant voltage instead, it varies the voltage periodically in the positive cycle itself. To convert this pulsating dc voltage to a constant voltage a filter is needed. The positive voltage obtained across the output load can be a half-wave or a full-wave. It depends on the design and implementation of the rectifier circuit. In daily life, electronic gadgets used by a lot of people. They require a constant direct current voltage to operate. The direct-current voltage is not available in the power supplies we use frequently. The alternating current is available and for major sources this serves as the power supply. The only way we can get direct current voltage is by converting alternating current voltage. This conversion can be done by using a rectifier and a filter to convert it to a constant voltage [1].

The alternating current changes its polarity and direction which is not suitable for electronic gadgets as they require a constant direct current voltage. The rectifier allows only the positive polarity part of alternating current to pass through the circuit through the load across which output is obtained. The output after the conversion in a rectifier is not a constant direct current voltage, but is a pulsating direct current [2]

The alternating current consists of negative voltage as well as positive voltage changing periodically. At the output of the rectifier if only positive voltages are allowed, then it a half-wave rectifier. The alternating current voltage available in every home is a single-phase supply. The negative voltages are therefore blocked by the rectifier circuit. The negative values are blocked as dc voltage does not consist of negative voltages. The rectifier allows positive voltages to flow resembling that of a step function in mathematics where ramp function provides one and zero for negative voltages. The output rectified voltage consists of only half the voltage compared to ac voltage. If mean voltage is considered then the output marks to be lower when compared to the mean voltage of the ac voltage [1-3].

The rectifier is always provided with an input of a single-phase supply. The filtering process for the full-wave is less compared to half-wave because fewer harmonics from the output needs to be eliminated. A full-wave rectifier accepts the input waveform and converts it to a constant positive polarity waveform at the output. A full-wave rectifier resembles that to a function in mathematics known as the absolute value function. The full-wave rectifier converts the negative polarity wave into a positive polarity wave while the half-wave rectifier blocks the negative polarity wave [3,4].

2. MATERIALS AND METHODS

2.1. Component description

The rectifier circuit for various applications was constructed using 1N4007 diode and BC547 transistor. Various components used to analyze the rectifier circuit were resistors (1K to 10K) and center-tapped transformer 12V-0-12V. The waveform measurements and the comparison were done in the digital storage oscilloscope.

1N4007 is a PN junction unidirectional rectifier diode consisting of two terminals. 1N4007 comes from the family of 1NXXXX devices. 1N4007 consists of a p-type anode and n-type cathode. The cathode is represented by the silver cylindrical mark at the respective end of the diode. 1N4007 allows the electrical current to flow in one direction only. It can be used for the conversion alternating current to direct current [4, 5]. 1N4007 is compatible with other rectifier diodes electrically and can be replaced with any of the diodes from the 1N400X family. The real-life applications if 1N4007 diode is general purpose rectification of power supplies, inverters, converters. They are normally used in embedded systems projects.

The BC547 is an NPN transistor consisting of three terminals, generally, when power is applied to the base it will flow from the collector to the emitter. The input is generally referred to as the emitter, the output is generally referred to as the collector, and a control line generally referred to as the base. When the control line has triggered the emitter and the collector will be connected just like switching a switch. BC547 has the amplification capacity referred to as gain value in the range of 110 to 800. The maximum current that could flow through the collector terminal is 100mA. The current has to be provided to the base terminal, this current should be limited to 5mA. The application of BC547 transistor is in driver modules like relay driver, LED, and amplifier modules like audio amplifiers, signal amplifiers [6, 7].

The current across the collector and emitter terminals will be a maximum of 100mA when the transistor is fully biased. The typical voltage allowed across the Collector-Emitter (V_{CE}) can be 200mV and the typical voltage across Base-Emitter (V_{BE}) can be 900mV. The region where all these conditions hold is the Saturation Region. When base current is fully removed the transistor becomes fully off and the region is called the Cut-off Region. The Base Emitter voltage can be around 660 mV. The load resistance that drains more than 100mA because the current flowing through the collector terminal is a maximum of 100mA.

A center-tapped transformer is used for rectifier circuits. Sometimes a center-tapped transformer is also called two phases three-wire transformer. A transformer is used to step-down the high alternating-current voltage and then convert it to direct current by using a rectifier circuit. A primary voltage is induced in the primary coil is transferred to the secondary coil of a center-tapped transformer coil due to magnetic induction [7, 8]. The wire arising from the center of the secondary coil will always be zero. The center wire is combined with either wire, the voltage across terminals will be of 12V. If the center wire is ignored and the voltage across the other two wires is considered, then the voltage across terminals will be of 24V AC.

The output across the load is observed in an oscilloscope (**D37000A -70MHz to 200MHz)** where waveforms are generated and measurements of the corresponding wave are displayed.

2.2.Circuit construction

The anode of the 1N4007 diode is connected to the positive terminal of the secondary coil. The cathode is connected to the negative terminal of the coil through the load as shown in figure 1.a). In the case of the BC547 transistor, the base terminal is connected to the positive terminal of the secondary coil while the emitter is connected to the negative terminal through the resistor. The output voltage is obtained across the load connected between the collector and emitter terminal shown in figure 1.b).

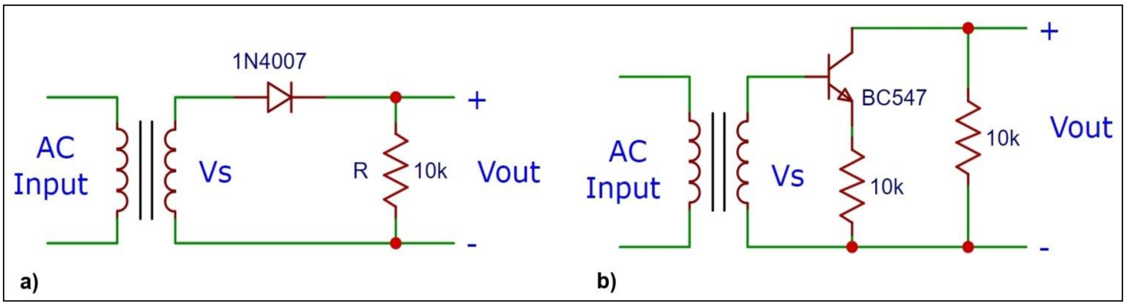

Figure 1. Half-wave rectifier using a) diode. b) transistor

The cathode of the 1N4007 diode is connected to the positive terminal of the secondary coil. The anode is connected to the negative terminal of the coil through the load as shown in figure 2.a). In the case of the BC547 transistor, the collector terminal is connected to the positive terminal of the secondary coil while the base is connected to the negative terminal through the resistor. The output voltage is obtained across the load connected between emitter and base terminal as shown in figure 2.b).

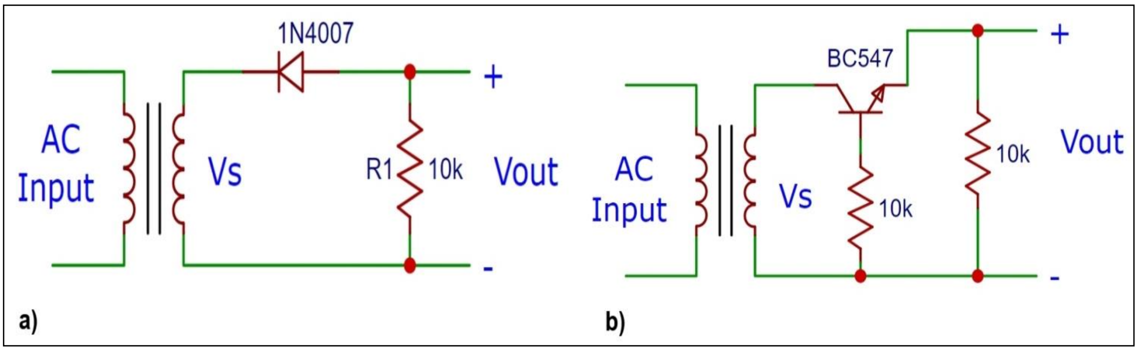

Figure 2. Reverse bias condition of a) diode. b) transistor

The base terminal in the BC547 transistor is connected to the positive terminal of the secondary coil while the emitter is connected to the negative terminal through the load. The output voltage is obtained across the load as shown in figure 3.

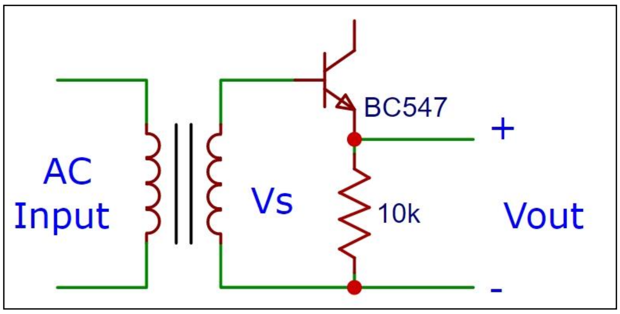

Figure 3. The output voltage across PN junction in a transistor.

The anode of 1N4007 diode1 is connected to the positive terminal of the secondary coil. The cathode is connected to the middle terminal (ground) of the coil through a load. The anode of the 1N4007 diode2 is connected to the negative terminal of the secondary coil. The cathode is connected to the middle terminal (ground) of the coil through the load as shown in figure 4.a). In the case of the BC547 transistor1, the base terminal is connected to the positive terminal of the secondary coil while the emitter is connected to the ground terminal through the resistor. In BC547 transistor2 the base terminal is connected to the negative terminal of the secondary coil while the emitter is connected to the ground terminal through the resistor. The output voltage is obtained across the load which is connected between two collector terminals and the ground terminal of the secondary coil as shown in figure 4.b).

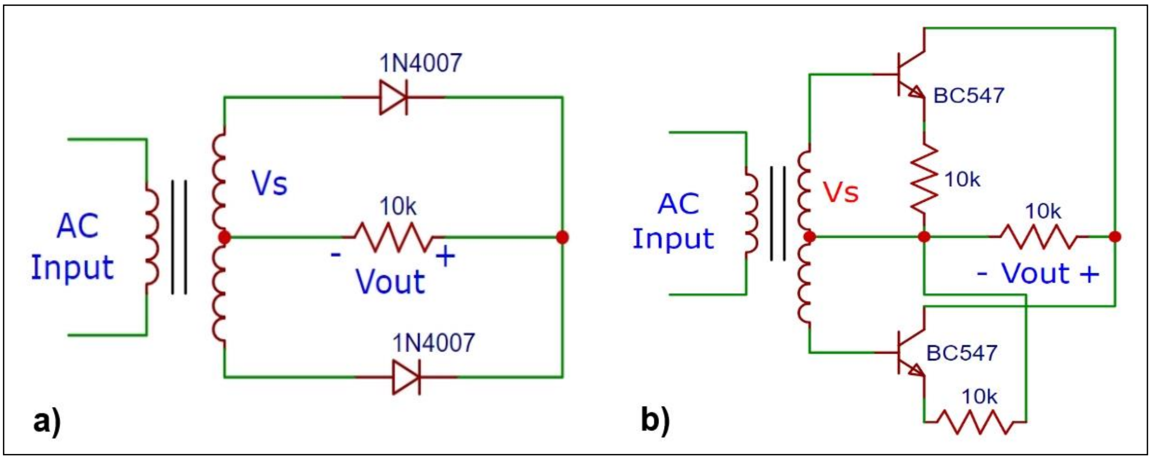

Figure 4. A full-wave rectifier using a) diodes. b) transistors.

The bridge configuration is realized using 4 diodes constructed in the form of a bridge. The terminals formed after the construction of bridge accounts to 4. The two opposite terminals from the bridge circuit are connected to the positive and negative terminal of the secondary coil. The other two terminals are connected across the load where the output is obtained as shown in figure 5.a). The 4 diodes are realized using 4 transistors and resistors to obtain a full-wave rectifier across the load as shown in figure 5.b).

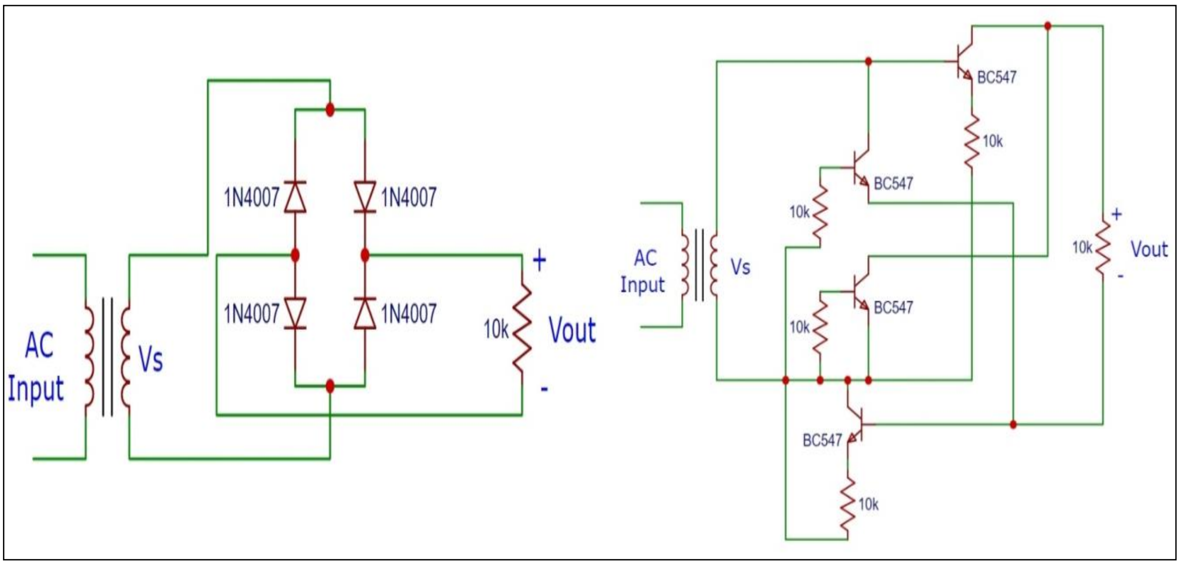

Figure 5. A full-wave bridge rectifier using a) diodes. b) transistors.

2.3. Implementation and working

The positive terminal of the secondary coil is connected to the anode of the diode, and the negative terminal is connected to the cathode. When the anode is at a positive potential than the cathode, the diode is in forwarding bias condition. The electrons are attracted to the positive terminal from the depletion region. The electrons are forced to move away from the negative terminal. The current flow in the circuit due to majority charge carriers. The direction of current due to electrons flows from negative to the positive terminal. The direction of conventional current is opposite to the electrons flow. The negative current is blocked by the diode during forwarding bias as the negative current causes anode to be at a less potential than the cathode. If the input to diode under forwarding biased condition is an alternating current signal then only the positive voltages are conducted by the diode. The negative voltages are made zero as forwarding bias condition of diode blocks the reverse current [8]. The output across the load results in a half-wave rectifier as shown in figure 6.a).

When the terminals of a diode are reversed, the cathode is connected to the positive terminal of the secondary coil and anode to the negative terminal of the coil. The circuit is fed with the alternating current signal. The diode is reverse biased and it allows only negative voltages to pass through them, thus blocking the positive voltages [9] as shown in figure 6.b). The transistor is designed to act like a half-wave rectifier blocking all the negative voltages as shown in figure 6.c). The reverse bias condition of a diode is realized using a transistor which allows only the negative values to pass through them as shown in figure 6.d).

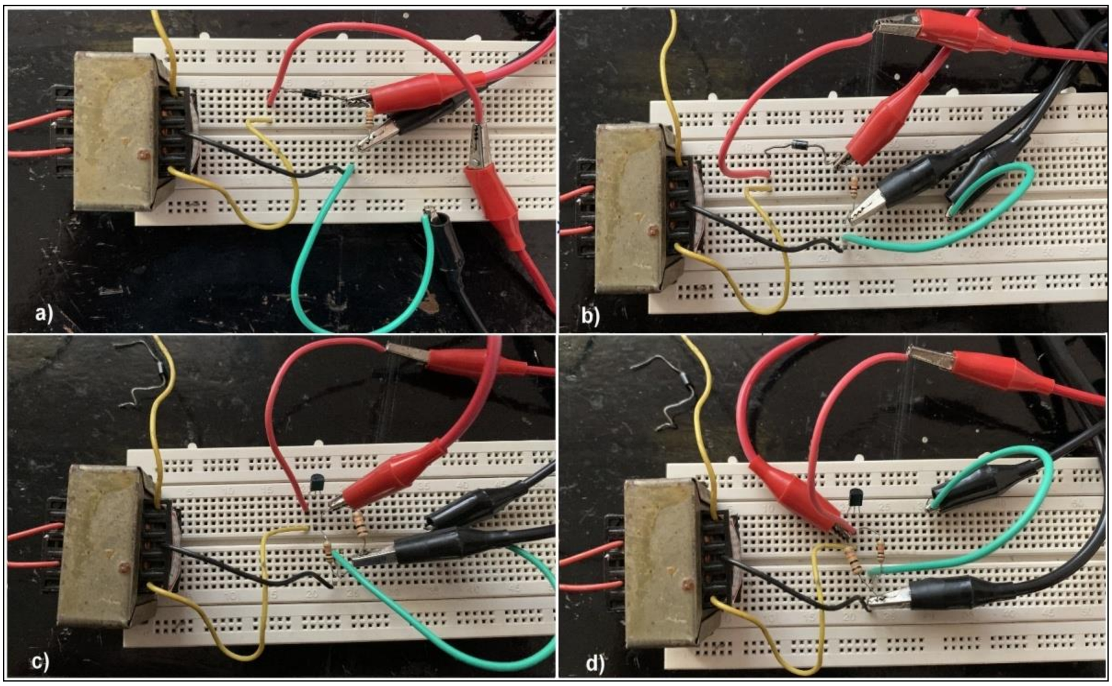

Figure 6. Implementation of rectifier using diode a) forward and b) reverse bias condition. Implementation of rectifier using transistor c) forward and d) reverse bias condition.

The transistor consists of three terminals of which two are of n-type semiconductors and the other one is a p-type semiconductor. If only two terminals are made to act like a diode connecting them across the secondary coil with other terminal having no connection, the output contains a small amount of negative current. The negative current resulting at the output is from the other terminal which is not connected to any source. If the base terminal is connected to the positive terminal of the secondary coil and emitter is connected to the negative terminal through a load. The collecter terminal is left as such with no connection. The output waveform observed from the load contained a positive peak along with a small negative peak. This negative voltage is because of the electrons from the collector as it is an n-type semiconductor.

The full-wave rectifier using a center-tapped transformer requires only two diodes as shown in figure 7.b). The diodes are connected to the opposite ends of a center-tapped secondary transformer in forwarding bias conditions. The center-tapped terminal or the middle terminal is the ground point or the zero voltage reference point. An alternating current signal is applied as input to the primary coil of the transformer. The input at the secondary coil terminals becomes positive and negative alternatively. The diode at both the ends of the transformer is forward biased and conducts for the positive half cycle. The changing polarity at the terminals of the secondary coil will make one diode to transmit when the positive polarity is across that terminal and block when there is negative polarity. The same alternately happens in other diodes. Thus, when one diode transmits other blocks and when it blocks the other diode transmits. The result at the load will be a full-wave [10].

The same circuit is realized with transistors at either terminal of the transformer and the terminals of both transistors are connected to the center-tapped terminal through the load as shown in figure 7.d). The output waveform is measured across the load.

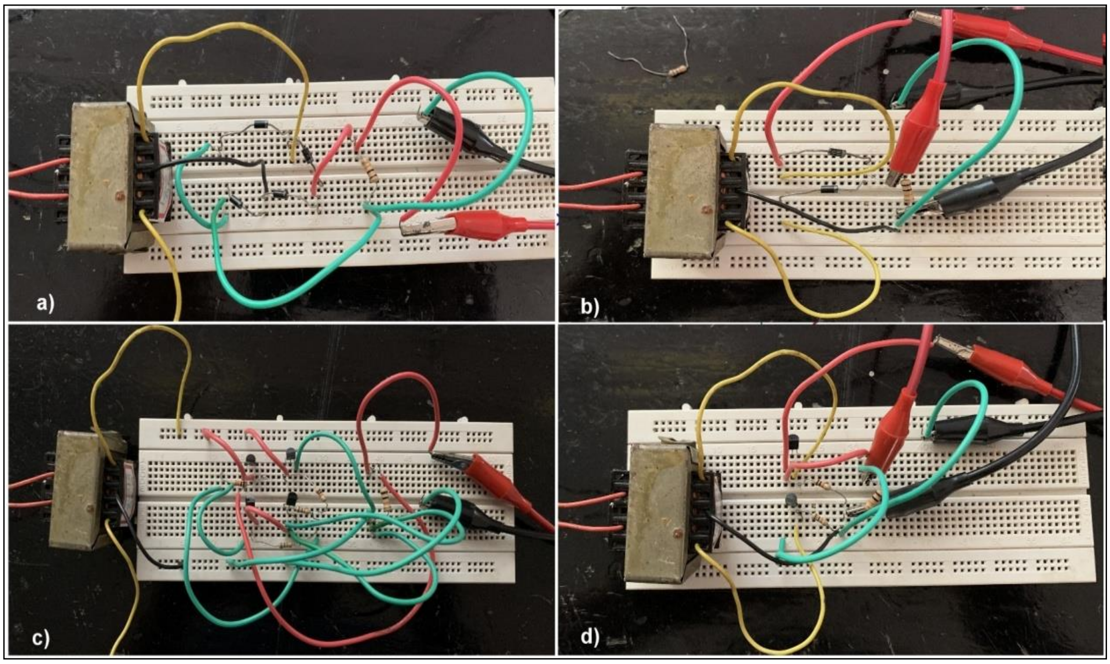

Figure 7. Implementation of full-wave rectifier using a) 4 diodes. b) 2 diodes c) 4 transistors d) 2 transistors.

The full-wave bridge rectifier using an ordinary transformer requires four diodes as shown in figure 7.a). The four diodes are constructed in the form of a bridge. The bridge configuration of the diode consists of four terminals. The two opposite terminals are connected across the secondary coil while the other two terminals are connected across the load. During the first half cycle of the alternating current voltage, the top end of the secondary coil is positive compared to the bottom end. The two diodes are forward biased and current flows through the load and return to the bottom terminal. The other two diodes are reverse biased and current is blocked. During the second half cycle of the alternating current voltage, the bottom end of the secondary coil is positive compared to the top end. The other two diodes which were reverse biased are now forward biased and current flows through the load, and returns to the top terminal. The other two diodes which were forward biased in the previous case are now reverse biased and current is blocked. The direction of flow of current through the load is the same during both half cycles of the alternating current supply voltage [11].

The full-wave bridge rectifier is constructed using 4 transistors as shown in figure 7.c). The four terminals are thus formed from the bridge configuration connection of 4 transistors. The two opposite terminals are connected across the secondary coil while the other two terminals are connected across the load. The output is measured across the load and for both positive and negative cycles of the ac input signal, the output consisted only of positive cycles [12].

3. RESULTS AND DISCUSSION

3.1. Diode Rectifier Waveforms

The diode conducts current only in one direction when the potential at the anode is greater than the potential at the cathode. The input to the diode is an alternating current signal from the secondary coil as shown in figure 8.a) and 8.c). The diode under forwarding bias condition allows positive current to flow blocking the negative current as shown in figure 8.b). The output waveform obtained across the load is the half-wave rectifier. The peak to peak voltage of the output signal is exactly half the peak to peak voltage of the input signal. The diode only allows the signals having voltages less than or equal to half the peak to peak voltage of the signal. It blocks all the voltages greater than the peak to peak voltage of the input signal. When the terminals of the diode are reversed, the diode allows negative current to flow through the load blocking the positive current as shown in figure 8.d). The waveform is observed to compare with the transistor reverse bias condition.

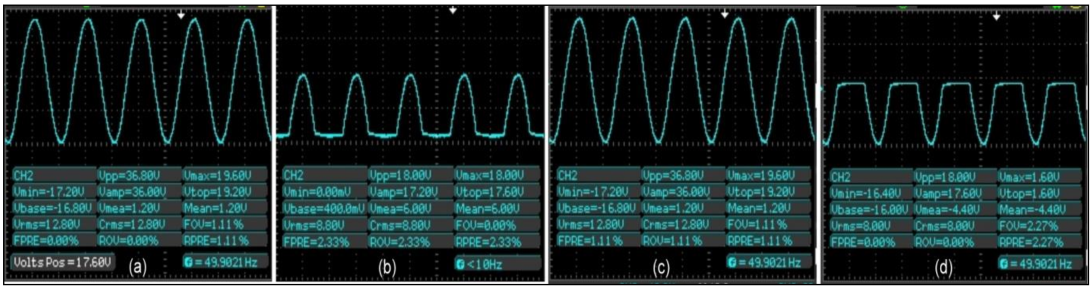

Figure 8. a) Input voltage and b) Output voltage of half-wave rectifier. c) Input voltage and d) Output voltage of the reverse-biased diode.

The center tapped full-wave rectifier accepts an input signal from the secondary coil of the transformer as shown in figure 9.a). The input signal changes the polarity and direction periodically. The positive half of the input signal is allowed and conducted by the diode at the top. The negative half is blocked by the diode, but the other diode at the bottom allows the positive current to flow across the load. Thus we can observe the full-wave rectification with the help of waveforms generated as shown in figure 9.b).

The full-wave bridge rectifier produces the same output as that of the center-tapped full-wave rectifier. The difference is in the number of diodes used and the type of transformer used. The input signal from the transformer changes the polarity and direction periodically as shown in figure 9.c). The positive half of the input signal is allowed and conducted by diodes that are forward biased to form a closed loop with the secondary coil. The negative current flows through the other two reverse-biased diodes thus generating a positive voltage across the load as shown in figure 9.d).

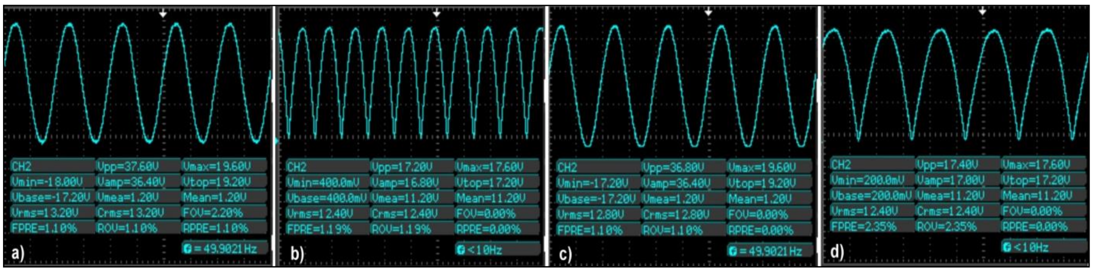

Figure 9. a) Input and b) Output voltage of center-tapped full-wave rectifier. c) Input and d) Output voltage of full-wave bridge rectifier.

3.2. Transistor rectifier waveforms

The transistors are realized based on the characteristic properties of the diode. The input to the transistor is an alternating current signal from the secondary coil which changes its direction and polarity periodically as shown in figure 10.a) and c). The forward bias condition of the diode is realized using a transistor as shown in figure 10.b) where the result obtained across the load is comparatively the same. The reverse bias condition in the diode is obtained by reversing the diode whereas in the case of transistors it is entirely different. The circuit is been rearranged and successively realized the reverse bias of diode using a transistor as shown in figure 10.d). The waveforms obtained are compared with the output waveforms of the diode and it is comparatively the same.

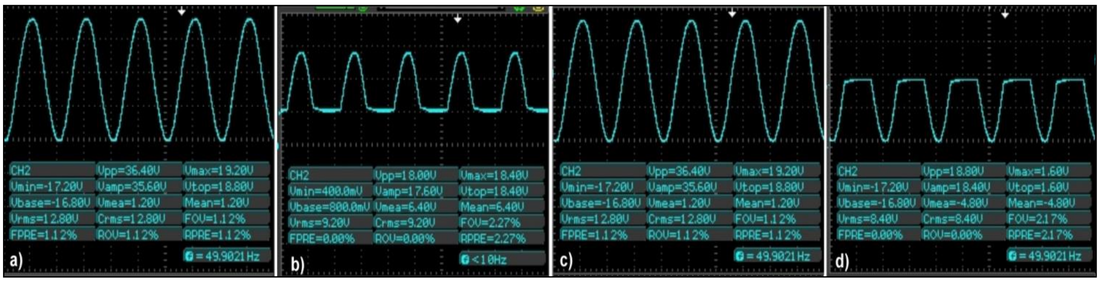

Figure 10. a) Input voltage and b) Output voltage of half-wave rectifier. c) Input voltage and d) Output voltage of the reverse-biased diode

The full-wave center-tapped rectifier has been realized using a transistor. The input signal changes the polarity and direction periodically as shown in figure 11.a). The positive half of the input signal is conducted by the diode at the top. The negative half is blocked by the diode, but the other diode at the bottom allows the positive current to flow resulting in an output of full-wave rectifier across the load as shown in figure 11.b).

The full-wave bridge rectifier has also been realized using transistors. The input is from the secondary coil which is an ac signal as shown in figure 11.c). The positive half of the input signal is allowed and conducted by transistors that are forward biased to form a closed loop with the secondary coil. The negative current flows through the other two reverse-biased transistors thus generating a positive voltage across the load as shown in figure 11.d).

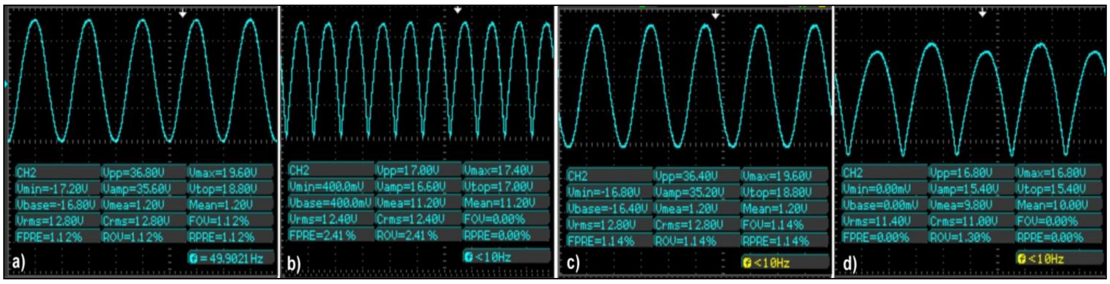

Figure 11. a) Input and b) Output voltage of center-tapped full-wave rectifier. c) Input and d) Output voltage of the full-wave bridge rectifier

The transistor is a three-terminal device consisting of a base, emitter, and collector. The base is a p-type semiconductor while the emitter is an n-type semiconductor. The base and emitter can alone be made to act like a diode, ignoring the collector terminal. The output waveform obtained when connected across the load between the emitter terminal and the negative terminal of the secondary coil as shown in figure 12. There is a small flow of electrons from the collector to the base resulting in the path of negative current across the load.

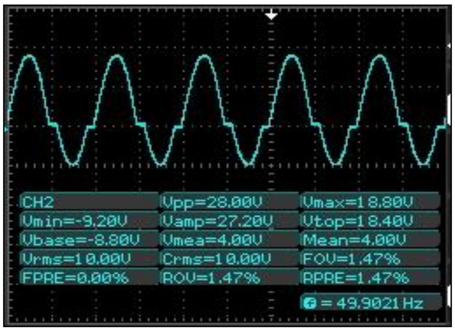

Figure 12. The output voltage across the emitter terminal of the transistor.

Under no bias condition barrier potential is developed along with the formation of the depletion region. The depletion region formation results in the accumulation of some electron onto the base. Hence, when the base-emitter is under biased condition these electrons flow across the load. Thus collector terminal cannot be ignored. The base and emitter terminals alone never act like a diode to generate a half-wave rectifier output.

3.3. Comparison of Input and output waveforms

The waveforms of the input signal and the output signal obtained are recorded and compared with the input waveforms. The output obtained is accurate as compared to its input voltage. The theory holds good and the outputs are verified successfully. The half-wave rectifier is successfully implemented and can be observed that the diode as shown in figure 13.a) and transistor rectifiers allow only the positive voltages as shown in figure13.b). The diode rectifier as well as the transistor rectifier blocks the reverse current.

The reverse bias diode condition is successfully implemented using transistors as shown in figure 14.a) and the output appears to be the same as compared with diodes as shown in figure 14.b). The full-wave rectifier circuit is designed using transistors as shown in figure 16.a) and can be observed that it produces the same output as that of output generated by diodes as shown in figure 16.b). The peak to peak voltages of both transistor rectifier and diode rectifiers are comparatively same from the obtained waveforms.

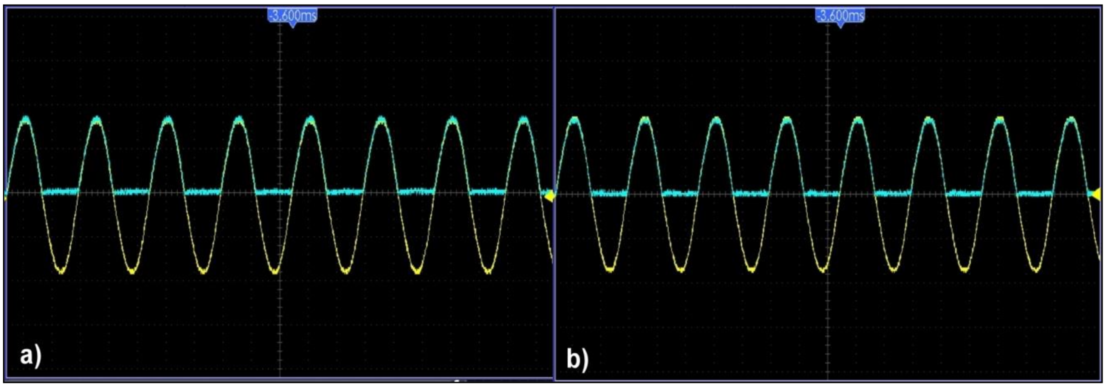

Figure 13. a) Input and the output signal of diode b) transistor half-wave rectifiers.

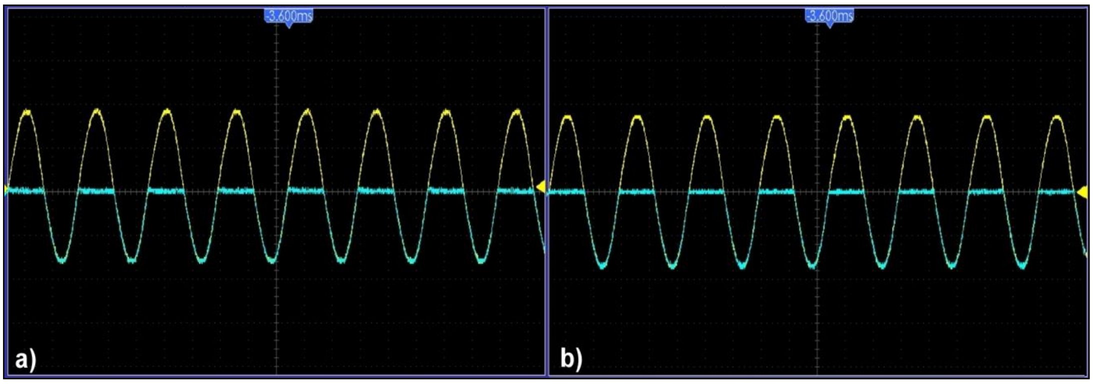

Figure 14. a) Input and the output signal of a diode and b) transistor under reverse bias condition.

If the only two terminals of a transistor are used, then there is an electron flow from the collector to the base. This is the reason why there is a slightly negative voltage peak in the waveform as shown in the figure 15.

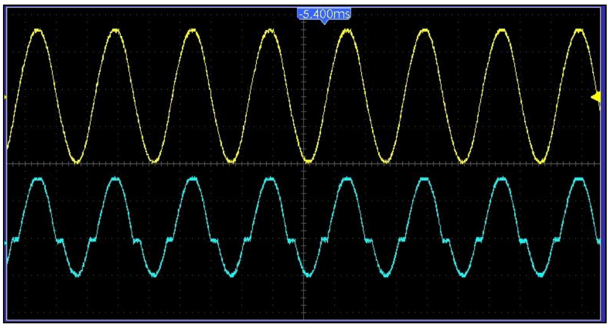

Figure 15. Input and the output signal of a transistor using two terminals.

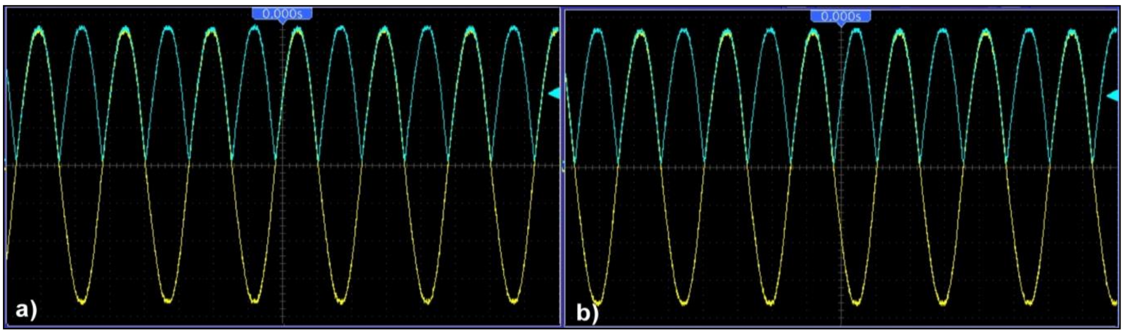

Figure 16. Input and output signal of full-wave rectifiers using a) diodes and b) transistors

3.4. Rectification efficiency

Rectification efficiency is the ratio of the dc output power across the load to the ac input power fed to the rectifier circuit. The evaluation of dc output power to the input ac power using the equation:

$$\eta_r = \frac{0.406}{1+\frac{R_f}{R_L}} \qquad (1)$$

The internal dynamic resistance is represented by R_f. When an AC source is applied across the input, the diode offers resistive nature depending on the direct current polarisation of the PN junction diode. The value of dynamic resistance is calculated by the ratio of small change in voltage in the V-I characteristic curve to the small change in current.

$$R_f = \frac{\Delta V}{\Delta I} \qquad (2)$$

For 1N4007 diode, R_L = 10kΩ, R_f = 62.47 Ω. The efficiency can thus be calculated from equation (1). The same is calculated for the transistor by referring to the values from the datasheet. The internal resistance is calculated using the formula:

$$r_0 = \frac{V_A + V_{CE}}{I_C} \qquad (3)$$

The voltage across the collector-emitter terminal is given by V_{CE} = 0.3V and the collector current obtained from the datasheet is I_C = 100mA. The early voltage denoted by V_A is equal to 100V after calculating various values from the datasheet. The calculations done above are for the half-wave rectifier. For full-wave center-tapped rectifier and full-wave bridge rectifier there is a slight modification in the formula as shown in the below equations.

$$\eta_r = \frac{0.812}{1+\frac{R_f}{R_L}} \quad \text{and} \quad \eta_r = \frac{0.812}{1+\frac{2R_f}{R_L}} \qquad (4)$$

The efficiency values obtained for center tapped full wave rectifier and full-wave bridge rectifier using diodes and transistors are shown in table 1.

Table 1. Calculated Rectification efficiency data.

Rectification type	Efficiency (%)			
	Ideal diode	Practical Diode	Ideal transistor	Practical Transistor
Half-wave	40.60	40.35	40.60	36.91
Full-wave (CT)	81.20	80.69	81.20	73.83
Full-wave (Bridge)	81.20	80.19	81.20	67.70

Rectification efficiency is the power loss from the input signal that occurred while flowing through the circuits. The transistor rectifier has a lower efficiency compared to the diode rectifier. This is because of the resistance used to limit the current across the base-emitter terminals. For a full-wave rectifier, the number of transistors used doubles, hence the efficiency decreases even more.

4. CONCLUSION

Rectification is a process of converting an alternating current into pulsating direct current. The rectification process has many applications in daily life, as the electronic gadgets, we use require a direct current voltage for the operation. The diodes have many applications such as rectification of ac voltages, isolation of signals from source supply, voltage reference, and even for controlling the size of the signal. Diodes also help in mixing signals and the detection of signals along with lighting systems. The rectifier circuit is a separate circuit connected directly to the alternating current signal thus converting it to direct current signal. Nowadays transistors play a vital role in reducing the size of the transistors in microcontrollers and various other processes. The diode plays a very important role in microcontroller-based systems. Diodes block the reverse flow of the current to the microcontroller thus preventing it from damaging. All logic gates are realized using transistors even the switch control. The diode is used for rectification purposes instead transistors can be used as rectifiers. This will help to decrease the overall size of the circuit. It can act like a diode and completely block the reverse current that can damage the sensitive components in the overall circuit. The diodes which are still used in some clamping circuits can be replaced by these transistors. However most of the circuits have been realized using transistor. The transistor is easy to build on a single surface of wafer consisting of all the circuits realized within it will help the circuits to be reduced to a smaller size.

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