



PicoTurbine Windmill Direct Current Experiments

Instructions, Teacher's Guide, and Technical Notes

An easy to build project for adults and children grade 9 and above. Explains alternating current and direct current concepts, including rectification, voltage, and frequency.

This set of plans and the associated kit are an add on to the PicoTurbine project.



WARNING:
CHOKING HAZARD - Small parts, wire. Not for children under 4 years.

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PART 1: Instructions for Building Projects

This document will show you how to build circuits that will take the output of a PicoTurbine wind turbine and convert it into a DC voltage. These instructions assume you already have built a PicoTurbine miniature windmill (see picture below).

There are four different circuits explained in this document for converting PicoTurbine's AC output to DC. Each one requires only 10 to 15 minutes to create using a solderless breadboard which is included in the kit.



PicoTurbine: normally produces alternating current, but with this add-on kit can be made to produce direct current.

A NOTE ON PICOTURBINE VERSIONS

The version 1.0 series of PicoTurbine produces about 1 to 1.5 volts at about 200 mA, while the version 1.1 series produces about 2 to 2.5 volts at about 30 mA. These experiments should work for both versions, but the text below is written such that it refers to voltages produced by the 1.1 version of PicoTurbine.

BEFORE YOU BUILD THE CIRCUITS

Step 1: Check Your Materials

The following materials are supplied with your PicoTurbine-DC kit. If you did not purchase a kit but are

- ◆ A small solderless breadboard and several pieces of 22 gauge prestripped hookup wire.
- ◆ Four germanium diodes rated at 100 milliAmps or more continuous and peak inverse voltage (PIV) of at least 6 volts.
- ◆ Two electrolytic capacitors rated 47 microFarads and at least 6 volts.
- ◆ One piezo-electric buzzer rated at 2-12 volts DC, not requiring an external driver circuit. Not all piezo buzzers will work, the one used here is Radio Shack part 273065.
- ◆ One bicolor LED with two leads.

It is also helpful to have the following tools, but not entirely necessary:

- ◆ A digital multimeter that can measure AC/DC millivolts is useful for displaying the exact voltage created.
- ◆ A small set of needle nose pliers can make inserting and removing jumper wires from the breadboard much easier.
- ◆ If you have a really well equipped lab and happen to have an oscilloscope, this is a great way to see the actual voltage waves. Oscilloscopes are quite expensive, however, so this kit was designed so you can “hear” the waves using a piezo buzzer placed in different ways. Still, nothing is quite like looking at the patterns on a ‘scope if you happen to have one or can borrow one from an electronics professional or enthusiast.

Step 2: IMPORTANT: Review Safety Rules

PicoTurbine-DC is not a dangerous project to build, but as with any construction project certain safety rules must be followed. Most of these rules are just plain common sense. Be sure to review these rules with children if you are building this project as part of an educational curriculum.

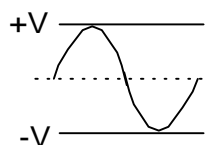
- ◆ **The electronic components used in this kit are only capable of handling the small amounts of current and voltage produced by PicoTurbine.**

UNDER NO CIRCUMSTANCES SHOULD AC CURRENT FROM A WALL OUTLET BE ATTACHED TO ANY OF THESE PARTS. HIGH VOLTAGES AND CURRENTS FOUND IN STANDARD WALL OUTLETS WILL CAUSE EXPLOSIONS, BURNS, FIRE, AND SHOCK HAZARDS, INCLUDING POSSIBLE DEATH.

- ◆ **Adult supervision is required for this project.**
- ◆ **This project is not recommended for children under 11 years old.**
- ◆ **Children must be supervised when working with scissors and other sharp parts to avoid cutting injuries.**
- ◆ **Children under 4 years old should never work with wire or small parts because they represent strangulation and choking hazards. Keep the kit parts out of the reach of small children.**
- ◆ **PicoTurbine generates low levels of electricity (under 3 volts) that are generally considered safe and are of the same order as produced by batteries used in toys or radios. But, to avoid shock hazard never work with electricity of any level when your hands or feet are wet.**
- ◆ **Persons wearing pacemakers should not handle magnets such as those found in the PicoTurbine alternator.**

Motivation

PicoTurbine produces electricity using an alternator. The word alternator is used because such a device produces alternating current, or AC for short. Alternating current constantly varies between a positive and negative voltage, usually in a sine wave pattern (see figure below).



Alternating current can be used directly by many devices, such as heating elements for an electric stove or an electric light bulb. However, many devices require direct current (DC), which does not vary but remains at a steady voltage. Luckily, it is possible to convert AC to DC. The process of converting AC to DC is called rectification, and there are several different ways to do it.

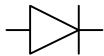
This kit allows you to build several different kinds of rectification circuit. This section will give you diagrams and figures to use the kit materials to do this easily. The Teacher's Guide and Technical Notes sections of this document go further into the theory of electrical power conditioning.

Terminology and Parts

To understand how to build these circuits, a little background on how the parts are named and what they do is in order. The table below shows some of the parts in the kits, displays the electrical symbol for each one, and explains the function of the part.

The Diode (or Rectifier)

Symbol:



Picture:



A diode (also called a rectifier) only allows current to go in one direction. Current flowing in the opposite direction is stopped. Think of a diode as a one-way valve for electricity. Diodes are rated as to how much current they can handle, and the maximum amount of reverse voltage they can withstand (this is called the Peak Inverse Voltage, or PIV).

The black band around one end of the diode (the left on the picture above) shows the positive voltage side. In a circuit diagram the convention is that electricity flows from positive to negative. So, electricity could flow from the unmarked to the marked direction, while it would be stopped from the marked to the unmarked direction. The symbol for a diode shows this as an arrow.

The Capacitor

Symbol:



Picture:

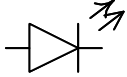


A capacitor can store electrical charge. Think of a capacitor as a kind of very small rechargeable battery that can only hold a small amount of charge. Some diodes are polarized such that one side should always be positive, others are not polarized. The symbol for a polarized capacitor shows a + sign on the positive side.

The actual capacitor typically has a stripe or a minus sign on the side of the negative lead. In the picture above, this is a lighter color stripe on the right. Sometimes this stripe has a “-“ sign imprinted within it.

The Light Emitting Diode (LED)

Symbol:

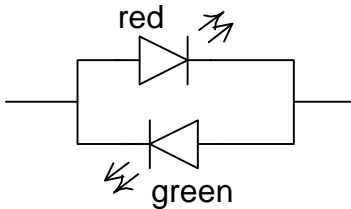


Picture:



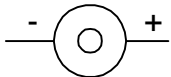
An LED is a diode, and only allows electricity to pass in one direction. The symbol for an LED is the same as for the regular diode, but two small arrows indicate that light is emitted. The actual LED has one short lead and one longer lead. The shorter lead is the negative side. When current flows in the correct direction, this has the side effect of producing light. LEDs are very efficient at converting electricity to light and can operate at very low currents compared to equivalent incandescent lamp light.

The LED included in the kit is a special bi-directional LED. It is actually two LED's connected back-to-back such that when electricity flows in one direction it lights up red and in the other direction green. In a circuit diagram this is usually shown as two diodes in parallel, perhaps with labels indicating the color of each one, such as:



The Piezo Buzzer

Symbol:



Picture:



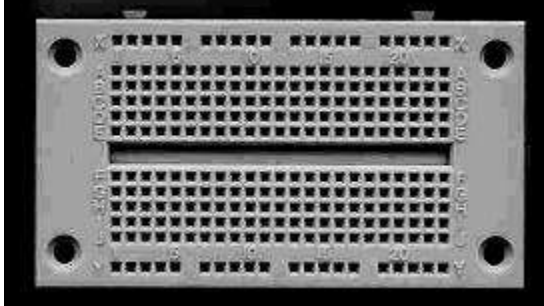
A piezo buzzer uses the piezo electric effect to convert electricity into motion of a thin slice of crystal material. With enough voltage, the piezo buzzer will make an audible sound. The experiments in this plan use a piezo buzzer because it makes it easy to “hear” that a current is alternating or not, and even how high the voltage is (by how high the frequency sounds).

There are various kinds of piezo buzzers. Some require external circuitry to drive them. The one included in your kit requires no external driver and can take a wide range of DC voltages. Even though it is rated at

12 volts, it will produce a chirping sound that is quite easy to hear even at the 2 volt level of the little PicoTurbine. The leads are marked on the bottom as to which is positive and which negative.

The Solderless Breadboard

Picture:



The solderless breadboard allows you to quickly set up circuits without having to make solder connections. This is faster and much safer in a classroom setting. The breadboard is marked so that rows have a number and columns have a letter. This kit will tell you to make connections using a combination of a letter and number. For example, “place a diode from A3 to A5”. This would mean place the unmarked side of the diode in A3 on the breadboard and the marked side in the A5 hole.

As you can see from the picture above, there is a row marked “X” at the top and another marked “Y” at the bottom. All of the “X” holes are connected to each other. All of the “Y” holes are connected to each other as well. These are called “bus bars” and they are usually used to carry the negative (or ground) and positive voltages from the battery. They run along the length of the whole breadboard to make it easy to make ground and positive voltage connections wherever necessary.

The other rows work a little differently. Each column is divided into the upper letters (A through E) and the lower letters (F through J). Each column is connected in two sections, one for the upper and one for the lower. For example, A1, B1, C1, D1, and E1 are all connected to each other. Also, F1, G1, H1, I1, and J1 are connected to each other. These groupings are also true for all the other columns, column 2, column 3, etc. The reason for this layout is to make it easy to insert a DIP Integrated Circuit (IC) chip and then allow multiple connections to each pin of the chip.

This document provides recommended layouts for each circuit, but many alternative layouts are possible. Keep in mind how the different parts of the breadboard are connected internally and try to visualize how the circuits shown in the schematic diagrams match to the breadboard layouts given.

To insert components in the breadboard, simply bend the wire leads as necessary to reach the correct pin holes, then insert the pins approximately a quarter inch. Make sure the connections are inserted completely and firmly. Use caution when removing components so you do not damage them. Simply apply a steady pulling pressure until the leads detach. Sometimes the short jumper wires you will use to make connections will break off inside the breadboard hole. If this happens, you may need to use needle nose pliers to remove such broken wires. If you cannot remove such a wire, simply use alternative holes in the breadboard for the remaining experiments.

Connecting the PicoTurbine Alternator to the Breadboard Using Jumper Wires

When connecting the PicoTurbine alternator to the breadboard, it is helpful to first connect the alternator wires to two of the short jumper wires. Twist at least a full inch of stripped alternator wire to one end of a jumper, then pinch the bare jumper wire down against the insulation. Do this for each of the two alternator wires. Now, it is a simple matter to insert and remove the other end of each short jumper. The PicoTurbine alternator wires are a little too thin to make a good connection directly to the breadboard.

Trouble Shooting

If you build one of these circuits and it fails to function as described in the text, follow these steps to solve the problem:

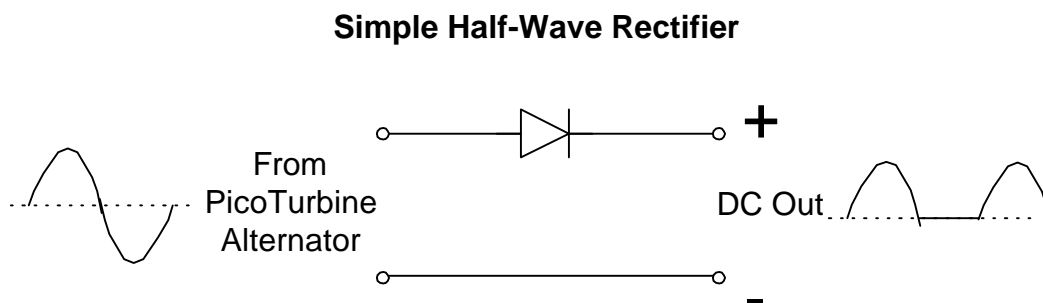
1. **Check the connections.**
Double check the list of connections to make sure all the components are in the correct positions. It is common to forget a connection or miss the correct pin hole by one slot. The piezo buzzer is especially vulnerable to this because you have to carefully look from the side while inserting it to make sure its PC mount leads are going into the correct holes.
2. **Check diode directions.**
Diodes only work in one direction, so it is critical that the black band on one side be in the proper pin hole. The instructions below always say which hole should receive the “banded” side of the diode.
3. **Check piezo buzzer direction.**
The piezo buzzer will only work if its terminals are properly positioned. They are clearly marked “+” and “-“. The directions below will indicate which hole receives the “+” terminal.
4. **Make sure all connections are tight.**
All connections must be nice and tight. At a minimum about ¼ inch of lead should be in the hole. You should feel the lead somewhat “snap” into the hole. A very slight pulling pressure should not bring the wire lead back out, it should take a bit of effort to remove in which you feel some friction.

If none of the above suggestions work, you may have a defective part. You can in some cases check this. You can check the piezo buzzer by simply connecting it to two 1.5 volt batteries in series (making sure the + lead goes to the + terminal of the battery). The buzzer should go off easily at 3 volts. You can check the LED by directly connecting it to your PicoTurbine and giving a good spin. It should flash red and green. You can check a diode in circuits that only require 2 diodes by replacing them with the other 2 diodes. If the circuit works with one diode and not another, you may have a defective or burned-out diode.

If all else fails, send email to support@picoturbine.com with a detailed description of the problem and we’ll try to help.

CIRCUIT 1: A Simple Half Wave Rectifier

We’ll start with the simplest possible rectifier, called a half-wave rectifier circuit. It is called this because it only allows one half of the sine wave (the positive side) to pass through. Although what comes out is technically direct current because it never goes negative, it is very “bumpy” as shown in the diagram below. This bumpy pattern is called “ripple”.



The circuit uses only a single diode, which you will recall, acts like a one-way valve for electricity. Sometimes two diodes, one in each direction, are used in half wave rectifiers.

Building the Circuit

To build the circuit, start with a clean breadboard and make the following connections:

- PicoTurbine alternator leads go into B1 and I1. It does not matter which lead goes in which hole.
- A diode goes from A1 to X5. Place the “banded” (positive) side in X5.
- Place a jumper wire from J1 to Y5.
- Place a jumper wire from X10 to A10.
- Place a jumper wire from Y10 to J10.
- Place the Piezo buzzer from D10 (positive) to H10 (negative)

Experiments With the Half Wave Rectifier

After following these steps, the X and Y rows will have the DC rectified current. Spin the PicoTurbine blades by hand, and you should hear the buzzer chirp. Now, reverse the buzzer so that it sits from H10 (positive) to D10 (negative). Spin PicoTurbine, and you should hear nothing from the buzzer. This is because current is only flowing in one direction, and the buzzer needs the current to be in the correct direction or it does not function.

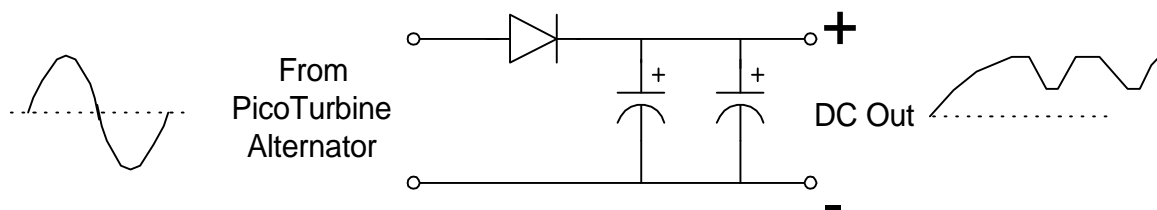
Now, move the buzzer to the position D1 to H1 and spin the PicoTurbine again. This time you should hear the buzzer chirp no matter which way it is positioned. This is because the PicoTurbine is producing AC current that shifts back and forth from one direction to the other. Whenever the direction is the same as that required by the buzzer, it chirps for a moment.

Now try using the LED. Remove the buzzer, and insert the LED from H10 to D10. It does not matter which lead goes in which hole. Spin the PicoTurbine and you will only see a single color light up, either red or green depending on which direction you hooked up the LED. However, if you place the LED in the position D1 to H1, it will alternate between red and green. This proves the current is running in both directions coming out of the PicoTurbine alternator, but in our rectification circuit only one direction of current occurs.

CIRCUIT 2: Smoothing DC Ripple Using Capacitors

The half-wave rectifier circuit is really too varied to be used effectively by most devices that require DC electricity. This circuit will smooth out this rough DC current using a capacitor. Recall that a capacitor acts like a miniature rechargeable battery that only holds a very small amount of charge. If we place a capacitor across the DC output lines, it will tend to take in some of the charge as the DC voltage rises, then as the DC voltage falls the capacitor will emit some of its charge. The result is that the output is considerably smoother. There is still some “ripple” in the current. The amount of ripple depends on the size (capacity) of the capacitor. Sometimes two or more capacitors of different sizes are used to smooth out ripple to within a tight tolerance that may be required by some devices.

Half Wave Rectifier with Smoothing Capacitors



Building the Circuit

To build the circuit, start with a clean breadboard and make the following connections:

- PicoTurbine alternator leads go into B1 and I1. It does not matter which lead goes in which hole.
- Place a diode from A1 to A5 (banded).
- Place a jumper wire from J1 to J5.
- Place a jumper wire from I5 to I15.
- Place another jumper from B5 to B15.
- Place a capacitor from E5 (positive) to F5.
- Place the buzzer from D15 to H15 (positive)

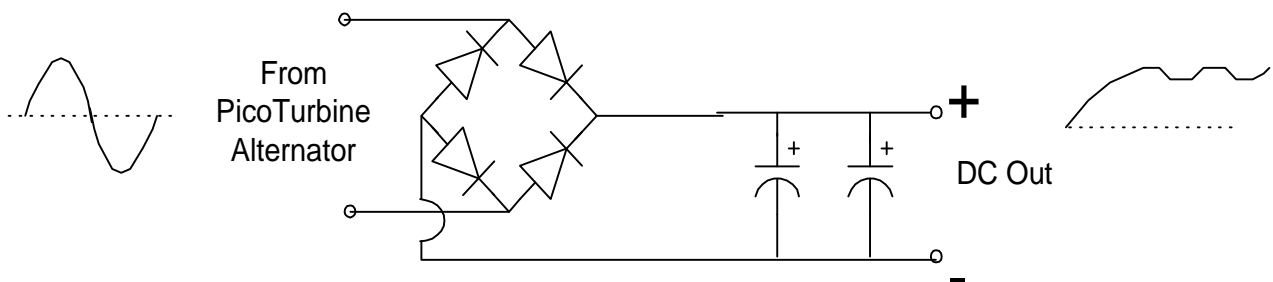
Experiments With the Smoothed Half Wave Rectifier

Spin the PicoTurbine and listen to the sound produced by the buzzer. It should sound much smoother than in the previous experiment. If you don't recall, just remove the capacitor and spin again. The circuit with no capacitor should sound a lot more varied than the one with the capacitor.

CIRCUIT 3: A Full Wave Rectifier

Half wave rectifier circuits are in effect “throwing away” half of the current by only allowing current to flow in one direction. This is undesirable because it both limits the amount of current that can be drawn from the alternator artificially, and also because it causes much more ripple in the output signal. A full wave rectifier is more complex but can overcome these problems to some degree. Although even a full wave rectifier will still have some ripple, it will be much less than the half wave rectifiers previously built. By adding smoothing capacitors as before, this ripple can be reduced even further.

Full Wave Rectifier with Smoothing Capacitors



Building the Circuit

We will first build the circuit with no smoothing capacitors. To build the circuit, start with a clean breadboard and make the following connections:

- PicoTurbine alternator leads go into A5 and J5. It does not matter which lead goes in which hole.
- Place a diode from D1 to B5 (banded).
- Place a diode from E1 to I5 (banded).
- Place a diode from C5 to F10 (banded).
- Place a diode from H5 to G10 (banded).

- Place a long jumper from A1 to A15.
- Place a jumper from J10 to J15.
- Place the buzzer from D15 to H15 (positive).

Experiments with the Full Wave Rectifier

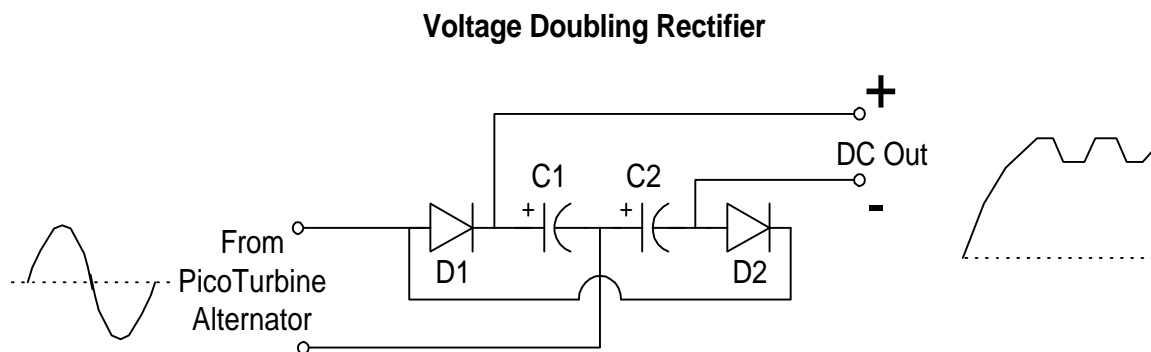
Spin the PicoTurbine blades. Without smoothing capacitors it should sound “faster” than the half wave circuit. This is because each side of the wave is contributing to the sound, while in the half wave case only one side of the wave is being used. To test this, temporarily disconnect one lead of the C5-F10 capacitor, which effectively makes this circuit a half wave. Spin PicoTurbine, then reconnect the lead and spin again. You can even disconnect the lead while PicoTurbine is spinning to hear the difference.

At this point you should know enough to connect a smoothing capacitor into this circuit. You will need to use some wire jumpers to do this. See how the sound compares with and without such a smoothing capacitor.

CIRCUIT 4: A Voltage Doubling Rectifier

The final circuit we will discuss is called a “voltage doubler”. It allows you to rectify the current and at the same time double the voltage. Note that there is no net gain of power because the current will be cut in half, and power is voltage times current. It is possible to use additional diodes and capacitors to create voltage triplers, quadruplers, etc. In fact, some circuits used many diodes and capacitors in a sort of ladder configuration to produce very high voltages (at correspondingly very low currents) for the purposes of driving camera flashes or other purposes.

In the diagram below, notice that the height of the DC output voltage wave is twice as great as the peak voltage of the input AC voltage wave. One interesting point about this rectifier is that it is a full wave rectifier and yet only uses half the number of diodes as the usual bridge style full wave rectifier circuit. However, it includes extra capacitor components.



Here’s how it works. Imagine that the alternator is generating positive voltage to the upper input lead in the diagram. The current will flow through the diode D1 and there will branch out, partially contributing to the positive voltage at the + DC output lead, and partially charging capacitor C1. Now consider what happens when positive voltage enters on the lower input lead from the alternator. This voltage charges capacitor C2. Capacitors C1 and C2 will, therefore, accumulate a voltage differential of approximately the peak voltage each. They are connected in series, and so will supply a total voltage twice as high as the peak voltage.

Building the Circuit

Follow these steps to build the doubling rectifier from an empty breadboard:

- PicoTurbine alternator leads go into A1 and A10. It does not matter which lead goes in which hole.
- Place a diode from D1 to C5 (banded).
- Place a diode from E1 (banded) to G5.

- Place a capacitor from D5 to D10 (negative).
- Place a capacitor from E10 to F5 (negative).
- Place a jumper wire from A5 to A15.
- Place a jumper wire from J5 to J15.
- Place the LED from D15 to G15.

Experiments with the Doubling Rectifier

First, try the bicolor LED directly connected to the PicoTurbine alternator by placing it perhaps in holes B1 and B10 (which are unused on this circuit). Spin the PicoTurbine and the LED will alternate between green and red flashes, and will only do this at the very fastest speeds (at least when spinning by hand). Now, remove the buzzer and place the LED from D15 to G15. Now, spin the PicoTurbine. First, you will only get a single color, red or green depending on how you connected the LED. Secondly, you should notice that the LED lights up at a much lower speed than it did when directly connected.

This is because an LED can only light when the voltage is about equal to its “forward voltage drop”. This is nearly 2 volts. Because 2 volts is near the upper range PicoTurbine is capable of, the LED only lights at the near-top speed of the turbine. On the other hand, using a voltage doubler cuts the current in half but doubles the voltage, allowing the LED to light at relatively low speeds. The LED requires very little current, and there is enough available even at half normal current.

The LED may appear brighter when connected directly to PicoTurbine. This is because it is flashing both red and green, which can be visually confusing. Also, it is able to draw twice the current. The voltage doubler lets you get some light at a lower turbine speed, which is an advantage on low wind days. It does potentially reduce the maximum light you can get at higher turbine speeds.

A more direct measurement of this effect can be made using a digital multimeter, if you have access to one. First, set the multimeter on AC volts. Measure the electricity coming directly off the PicoTurbine alternator. On a fast hand-spin, you should get around 2 volts. Now, connect the multimeter to the ends of the jumpers by removing them from A15 and J15 and instead connecting them to the multimeter. Now, place the multimeter on DC volts, and again spin the PicoTurbine as fast as you can using your hand. Now you should get close to 4 volts.

Note that it would be possible to redesign the PicoTurbine alternator to increase the voltage (and decrease current) at lower speeds, but this would require more turns of wire in the coils and using thinner wire. Because thinner wire costs more per pound than relatively thicker wire, and more labor would be required to wind twice as many turns, it can be more economical to use a doubling circuit than to redesign the alternator.

PART 2: TEACHER'S GUIDE

Concepts Required Before Building the Circuits

Before building these circuits, the teacher must be certain that some elementary electricity concepts are understood. The very minimum that needs to be understood is:

- **Voltage and Current**
Students should understand the difference between voltage and current. The simplest way is to use a water pipe analogy. Voltage is similar to the pressure in the pipe. There can be pressure even with no water flowing (perhaps a valve is turned off). Current is similar to the volume of water flowing through the pipe. It is actually the amount of electric charge flowing through the circuit per unit time, or in other words the rate of charge flow.
- **Resistance**
Resistance impedes the flow of electricity. In our water pipe analogy it might be the friction of the water along the pipe walls, or perhaps the pipe is flowing uphill. Voltage (pressure) is required to overcome resistance.
- **Ohm's Law**
The relationship between Voltage, Current, and Resistance is given by Ohm's law: $V = IR$. In other words, voltage is current times resistance. The water pipe analogy also works well here. Thinner wire has higher resistance than thicker wire. Similarly, to put a given amount of water through a larger diameter pipe requires less pressure than if the pipe is very thin. Imagine trying to pump 1 gallon of water per second through a drinking straw! That would require a great deal of pressure. However, very little pressure would be required to pump 1 gallon per second through a six-inch diameter drainage pipe. Similarly, if you want to drive a large current through a high resistance, you must have a proportionally large voltage.
- **Functions of Basic Electronic Components**
Students should understand the functions performed by diodes and capacitors. In our water pipe analogy, a diode is like a one-way valve. A capacitor is a small storage container that can store water and later release it.
- **Alternating vs. Direct Current**
Students should understand the difference between alternating and direct current. In the pipe analogy again, alternating current would be similar to water flowing in one direction, then stopping, then flowing in the other direction again. Direct current represents the more familiar situation where the "water" only flows in a single direction. It should be noted that in alternating current, both the voltage as well as the current (pressure as well as amount of water) are both varying over time.

Using the Kits in the Classroom

Kits can either be used for small group work or as a demonstration by the teacher. When demonstrating, it may be helpful to have more than one breadboard and wire up two circuits for comparison purposes. For example, wire up a simple half-wave circuit on one and a full wave with smoothing on the other. In this way it is easy to compare the sounds of the piezo buzzer.

If an oscilloscope is available, it can be used to directly display the voltage patterns. A dual-display oscilloscope is ideal because you can tap off the alternator directly for one display and tap off the place where the piezo buzzer or LED would be connected on the other display. In this way, you can show both the input AC voltage and the output DC voltage simultaneously.

It is not necessary to build the full PicoTurbine windmill to do these demonstrations. You need only build the alternator portion of the kit if the renewable energy aspect of the project is not relevant to the class. If spun by hand, the alternator will turn for a longer period of time if there is no blade attached, because there will be less air friction. If renewable energy is relevant (we hope so!) then a small fan can keep the

PicoTurbine spinning at a more consistent speed than turning by hand. This is especially desirable if using an oscilloscope so you get a nice clear wave pattern.

Even though the text gives a way to demonstrate the voltage doubling circuit without the use of a multimeter, it is a far more convincing demonstration with such a meter, since the exact voltage can be measured. The LED demonstration given in the text will, however, help drive home the reason why you might want to use a doubler circuit: with the doubler the LED will light in lower wind speeds than without.

Reasons for Alternating and Direct Current

Many students will ask, “Why bother with two kinds of electricity? Why not standardize on either alternating or direct current?”

This is a very astute question. This very debate spurred a rivalry in the early part of this century between two of the greatest inventors who have ever lived: Nichola Tesla and Thomas Edison. Edison wanted to simply run DC current through the distribution wires to everyone’s home, while Tesla argued for 60 cycle per second alternating current. Tesla won, and we still use 60 cycle alternating current today to transmit power to our homes and schools.

The reason is that alternating current has great advantages when you are transmitting current a great distance. It is a simpler matter to step up and step down alternating current. When transmitting electricity, you want to have a high voltage and a low current. This is because resistive losses are proportional to the square of the current. So, doubling voltage cuts resistive losses by a factor of 4. Long haul power lines sometimes use 50,000 volts or more. However, high voltages like this are not safe. If we actually delivered 50,000 volts through wall outlets, thousands of people would be electrocuted to death every year! So, this high voltage is transformed down to 120/240 volts before being delivered to our homes. Even at 120 volts electricity is quite dangerous, by the way, and is not to be toyed with. But at 120 volts we at least don’t have to worry about the current spontaneously jumping out of the wall outlets! This could actually occur with very high voltages, since those voltages are enough to break down the very high resistance of air itself under the right circumstances and jump over a foot to nearby objects or people.

We need DC current because many devices require it to operate properly. So, rectification circuits are commonly used by devices to translate wall outlet power (or PicoTurbine power!) to DC for use by computers, radios, TV’s and other devices.

We will caution here, once again, that the components supplied with the PicoTurbine-DC kit are only capable of handling the low voltages and currents produced by PicoTurbine, and could cause injury or death if used with wall outlet power. Only qualified adults with specific training should ever design circuits for use with wall outlet power.

PART 3: Technical Notes

Introduction

This section goes more into depth on the theory of DC and AC current and rectification. Some points were simplified in the foregoing discussions to make the project accessible to first year high school students and to simplify the explanations. These notes are for the advanced student or adults who want to know more of the details.

Even these notes are somewhat simplified. The student who wishes to go still further is directed to obtain an electronics handbook. Two excellent sources of this information that are easy to understand are:

- Electronics, A Self-Teaching Guide, by Harry Kybett
- Building Power Supplies, by David Lines (a RadioShack book).

Of these, the second is the more advanced.

Diode Losses

We glossed over in the main body of this document the concept of diode losses. Diodes experience a “forward voltage drop” when rectifying current. In effect, you lose a little of the “pressure” of the electricity in the diode. This lost pressure is dissipated as heat from the diode. Different types of diode have different levels of loss. Silicon diodes typically have losses around 0.7 volts. Germanium and Shotky diodes have losses of between 0.4 and 0.5 volts. The diodes delivered with the kit are Germanium diodes.

When you design an electric circuit, you must make sure the diode can handle the amount of current it will rectify. The power dissipated by the forward voltage drop is easily calculated: the power dissipation in watts is equal to the voltage drop times the current. Diodes are rated as to how much continuous current they can handle before they “burn up”. Yes, they can literally burn up if you exceed the rating by enough. Usually a diode can handle a surge somewhat greater than its rating for a short period of time.

Efficiency of a Rectifier

Because of diode losses and other factors, converting AC power to DC is not a 100% efficient operation (as nothing ever is). In fact, it is quite inefficient in the case of PicoTurbine because PicoTurbine only generates small voltages, around 2 volts. Thus, even using a germanium diode with a 0.4 volt drop, we will lose about $0.4/2.0 = 20\%$ of the voltage (and also power) just from the diode losses. There will be some additional losses because capacitors have a bit of resistance and other factors come into play.

Values of Capacitor Needed for Smoothing

The actual values of capacitor required to smooth ripple to a desired value can be calculated reasonably precisely. Some sensitive electronic components need a very smooth DC current and cannot tolerate more than a certain percentage of ripple. Although going through the math involved is beyond the scope of this document, the basic idea is that you must choose capacitors large enough so that only a small portion of their current discharges before being replenished by the next voltage peak. Some of the major factors that affect this are the capacitance value of the capacitor, the amount of current being drawn off by the device, and the voltage levels of both the AC and DC sides of the circuit. Formulas for these calculations and further discussions of ripple effects are contained in the reference books mentioned above. In general, the less ripple that can be tolerated, the larger the values of the capacitors. However, there are usually several capacitors in parallel in such a smoothing circuit, often with different values. Smaller capacitors may be placed in series to dampen high frequency noise, while larger capacitors do the “heavy lifting” of smoothing out the current.