Operator’s Manual

Stimulating Bone Growth Using Piezoelectric Ultrasound Transducers on the Edentulous Jaw

TEAM # 12
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Important Safety Instructions:

It is important that the user fully reads and understands the operator’s manual for this device before attempting to operate. **Failure to read and understand the operator’s manual prior to operation may lead to damage to the device and/or serious injury or death to the user, including but not limited to electric shock and severe burns.**

Circuit Safety

- When running the device in auxiliary mode, do not set the voltage of the external power supply to higher than 50 volts. This will exceed the peak source to drain voltage of the MOSFETS by 50% and is not recommended for continuous operation. The circuit is not designed to withstand these situations and will get very hot, causing it to burn out and become damaged, as well as potentially melting the enclosure or injuring the user.
- Do not run the device at a voltage greater than 30 volts for a prolonged period of time (no more than ten minutes). This can also cause the circuit to overheat in the same way that setting the voltage too high will do.
- Do not run the device in battery recharge mode with an attached external power supply set to higher than 30 volts or less than 25 volts. Also, make sure that the current stays below 200mV, as these conditions will cause a large current to be passed through the battery pack and cause it to overheat and/or explode.

Enclosure Safety

Do not run the device with the enclosure open, as the bare circuitry can cause electrocution and injury.

Transducer Safety

Before placing the transducer or mouthpiece in the mouth, make sure that the transducers are correctly insulated. If there are any wires exposed, the device can electrocute and injure the patient.
Other Safety

• The mouthpiece can become hot if is operated when the device is connected to an external power supply of greater than 30 volts. In some cases the mouthpiece will become so hot that severe burns may occur if the operator does not use proper caution.
• Do not run the device near or in water, due to the potential for electrocution.
• This ultrasound is intended to be used for research purposes only. The device has been designed to eventually be used in the human mouth. However, it has not yet been tested in humans, and therefore should not be used anywhere in the human body.
• Do not eat, drink, or smoke while using this device.
• Do not eat or chew on the mouthpiece.

Parts and Accessories:

Hand-Held Enclosure
Mouthpiece

Mouthpiece Case

Mouse Transducer
External Power Supply

Oscilloscope
**Features:**

This device provides several different features for the user:

- Produces an ultrasound signal with a transducer.
- The transducers are connected to the circuit through a 1/8” audio jack.
- Ultrasound output can be switched between 1, 2, 3, 4, and 5 MHz using the knob on the top of the enclosure.
- Depending on the desired frequency, the correct size transducer has to be connected to match.
- Runs on three 9V batteries, which can be charged by connecting an external power supply set to between 25-30 volts on the side of the enclosure and setting the switch to “Battery/Recharge” mode. It has to be connected for 1-2 hours to fully charge the batteries.
- The input can be changed from battery mode to auxiliary mode by connecting an external power supply on the side of the enclosure and flipping the switch to “AUX” mode.
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1. Introduction

1.1 General Overview

Research has shown that mechanical stimulation to bone can stimulate bone maintenance and prevent its degradation. In many cases, this stimulation can be provided in the form of an ultrasound signal applied to the bone. In edentulous patients (patients who wear dentures), the jaw bone often becomes weak and breaks down. To prevent this, this US Amplifier was designed. It provides a square-wave voltage signal (with a frequency between 1 and 5 Megahertz) to a transducer to generate an ultrasound. The transducers can be worn in the mouth, so as to provide optimum mechanical stimulation of the jaw bone. At this point, its primary application is for laboratory research in mice. However, it does have the capability to eventually be used in humans.

1.1.1 US Amplifier

This product requires little to no assembly before use. The components can be seen in the following pages. Multiple views of the device are shown below.

Figure 1. External view of top of US Amplifier.
The top side of the US Amplifier contains the power switch, which is underneath the red encasement. Also shown here is the frequency control knob, which allows a user to select a frequency between 1 and 5 Megahertz (MHz) to be supplied to a transducer.

![Figure 2. External view of right side of US Amplifier.](image)

The right side of the US Amplifier contains three components, AUX, V-, and V+. The AUX switch allows the batteries to be recharged without any disassembly of the device. V- and V+ are the connections for the ground and input voltage supply, respectively.

![Figure 3. External view of left side of US Amplifier.](image)

The left side of the device contains the connection for a transducer. This connection, labeled “Output” is one of the most important parts of the US Amplifier.
1.1.2 Mouthpieces

The mouthpiece shown here is for the human mouth. The transducers are encased in a polystyrene insulation, which protects them from the environment inside of the mouth. It also provides a more comfortable fit for the wearer. These molds can be custom fit for each individual user. The black connector is inserted into the “Output” terminal in the US Amplifier, shown in Figure 5.

Figure 4. Human Mouthpiece and Connector.

Figure 5. Mouthpiece Connection.
The mouthpiece and transducers are critical components of this device. In order to protect them and maximize the product lifetime, they should be kept in the case shown above.

Figure 7 shows a mouthpiece to be used in mice. The transducer is coated in polystyrene as well, which protects the mice from injury.

1.1.3 Internal Circuit

The internal components of the circuit are shown in the diagram below (Figure 8). Figure 9 shows a schematic of the overall circuit as well. For a detailed description of how the circuit operates, please see Section 3, Technical Description.
Figure 8. Internal Circuit Components.
1.2 How to use the US Amplifier and Mouthpiece.

This device should be used in accordance with the following instructions. Failure to comply with the directions in this manual may result in serious injury or death. This ultrasound is intended to be used for research purposes only. The device has been designed to eventually be used in the human mouth. However, it has not yet been tested in humans, and therefore should not be used anywhere in the human body.

1.2.1 Setting up the device.

Before using the device, the proper transducer must be connected to the “Output” connection. Prior to connecting the transducer, ensure that the device is off. To view the power switch, lift the red casing, as shown in Figure 10. When the switch is in the downward position (pointing toward the “OFF” label), the device is off.
Next, select the appropriate transducer for the desired frequency of operation. Insert the connector on the transducer into the “Output” terminal on the US Amplifier, as shown in Figure 11. To turn the device on, flip the switch upward towards the “ON” label, as shown in Figure 12. Select the desired frequency of operation (Figure 13 shows a selection of 3 MHz).
Once the frequency has been selected, the mouthpiece can be inserted into the mouth. Be sure that the mouthpiece is in contact with as much of the gum surface as possible. The US Amplifier is intended to be used for ten minutes at a time. Operating the device for longer than this can result in the mouthpiece overheating! This can cause injury to the user. Be sure to turn the device off when the experiment/use has been completed.

Note: The device should only be used once per day on any human or mouse patient/subject.
1.2.2 Recharging the device.

To recharge the batteries without removing them from the US Amplifier, the device must be set to the Auxiliary mode (AUX). Figure 14 demonstrates how to set the US Amplifier to Auxiliary mode. In order to charge the batteries, the device must be connected to an external power supply set at no more than 30 Volts. The V- terminal connects to the ground of the external power supply, and the V+ terminal connects to the source voltage. Allow the batteries to recharge for approximately 1-2 hours. For more detailed instructions, please refer to Section 2, Maintenance. Instructions on removing/replacing the batteries can be found there as well.

![Figure 14. AUX mode off (left) and AUX mode on (right).](image)
2. **Maintenance**

The maintenance for this product is very basic and only consists of recharging the batteries, keeping the mouthpiece clean and turning off the device when it is not in use so that the batteries are not drained.

2.1 - **Charging the Batteries**

The batteries of the US amplifier can be charged by removing the four screws on the front panel, removing the batteries, and placing them in a charger (Figure 15). Make sure to line up the positive and negative parts of the battery. Another option for charging the batteries is to use the auxiliary terminals of the US amplifier.

*Figure 15: Four Screws on the Corner of the box*
To charge the batteries of the US amplifier with the auxiliary terminals, first connect an external DC power supply to the Auxiliary Terminals of the US amplifier (Figure 16). Flip the switch on the right side of the box to battery/recharging mode (Figure 17) and be sure to connect the positive and negative terminals of the external power supply and the US amplifier respectively (Figure 18). Then turn the voltage of the external power supply to 27 volts. Switch the external power to display the current output and try to regulate the voltage so that no more than 200mA are being supplied. This may require lowering the voltage below 27 volts and slowly raising it. **WARNING: DO NOT CHARGE THE BATTERIES WITH MORE THAN 30 VOLTS OR 200mA.**
If the external power supply is supplying more than 200mA to the batteries, turn the voltage of the of the external power supply down. If the external power supply is supplying less than 50mA to the batteries, turn the voltage of the of the external power supply up. Maintain the voltage of the external power supply until a final voltage of 30 volts is reach. Leave the voltage of the external power supply at 30 volts for 1-2 hours or until the current supplied is less than 30mA.

*Figure 18: Auxiliary Power Connection (orange to positive end of DC power supply and black to negative end)*

**2.2 - Turning off and Storing**

When not in use disconnect any external power supply from the US amplifier. The US Amplifier should also be switched to AUX (Auxiliary mode) if it is not going to be used for extended periods of time (Figure 19). This will disconnect the battery pack from the ground side of the circuit and prevent any current leakage from draining the batteries.
Store in a dry place between 20-30°C when not in use. Make sure all connections to the US amplifier are disconnected. This includes auxiliary power and the mouthpiece connection.

2.3 - Cleaning the Mouthpiece

When not in use the US mouthpiece should always be kept in the US mouthpiece case, disconnected from the box (Figure 20). This will keep the US mouthpiece sterile; also this will prevent any accidental damage that may occur to the US mouthpiece.
The mouthpiece should be brushed after use and brushed using a toothbrush and non-abrasive denture cleaner. The mouthpiece should then soak in denture solution for eight hours. This will clean the mouthpiece. While in the solution it should be turned on for ten minutes at the frequency that the mouthpiece is rated for to ensure that particles are released from the mouthpiece. Then it can be disconnected from the US amplifier and allowed to soak in the solution. Do not put the connector end in the solution (Figures 21 & 22).

*Figure 21: Mouthpiece*

*Figure 22: Do not soak the audio jack when cleaning the mouthpiece.*
3. **Technical Description**

The following is a technical description of this device and its components. This will be broken down into the various components of the device and will take the operator through the use of the different components one by one. The first component will be the US Amplifier, this is the most complicated component of the device. The next component will be the US Mouthpiece and the connections to the US Amplifier.

### 3.1 US Amplifier

The job of the US Amplifier is to take the DC supplied power, which come either from the internal rechargeable batteries or the external power supply and convert it into a high power AC signal for driving the transducers of the US Mouthpiece. It is 4” wide, 6” long, and .85” high. It is controlled by a power switch which disconnects the batteries or power supply from the entire circuit. Its battery capacity is three 9 volt batteries.

A technical description of the US Amplifiers function is that the voltages are broken down into 9 volts and a high side voltage source (i.e. 27 volts in battery mode or specified volts AUX mode). This is controlled by a switch on the right side. This switch is used to either disconnect the batteries and connect the external power or vice versa. The 9 volts is used to drive the voltage regulator where the voltage is stepped down to 5 volts for use with the crystal oscillators. The 9 volts is used to drive the pin driver. The high side voltage is used to drive the main gain stage, the negative (N) and positive (P) channel MOSFETs.
The crystal oscillators are used to generate a small voltage signal of the desired frequency. The small 5 volts peak to peak voltage and small current of the crystal oscillator is boosted in two stages before being sent to the output. The first of the two gain stages is the pin drive. The pin drive is a low voltage high current device. It boosts the voltage to 9 volts peak to peak but can supply enough current to the two MOSFETs in the main gain stage to ensure that the MOSFET switches on in high load situations. Without this there might not be enough power to ensure that the MOSFET switches. The MOSFETs take the high current signal and further increase the power by switching between high voltages. There are two MOSFETs, N and P channel, so that when a high signal comes in, one MOSFET will be closed and the other will be open, and when a low signal comes in the MOSFETS will exchange positions. This will allow the voltage to switch between a positive and negative DC voltage supplied by the batteries or auxiliary power.
3.2 Crystal Oscillators

The US Amplifier has 5 different oscillators, each with different frequencies. Crystal oscillators are small piezoelectric circuits with a crystal inside that is finely tuned to a specific resonant frequency. When a 5 volt DC signal is used to power these circuits a 5 volt peak to peak output is received at a specified frequency. A five position double throw switch changes between the different frequency oscillators in the circuit and therefore switches the output frequency of the circuit. The double throw switches both the supply voltage to the oscillator and the output of the oscillator to the rest of the circuit. This is important because by switching the voltage supply it will prevent the battery by being drained by driving all 5 oscillators at once. Also, by switching the output it prevents the oscillator output from being shorted. This
would be caused by having the signal become shorted in the other oscillator’s output pins that are inactive.

Figure 25: Crystal Oscillator.

3.3 Double Throw Switch

The double throw switch is a rotary switch (Figure 26). It switches two connections at once. In this case it connects both the output and the input of the crystal oscillators. As the switch is turned, it breaks each connection and then connects to the next oscillator in the series. Figures 27 and 28 show the schematic for this design. A represents the input to the oscillator and B represents the output. The values 1-5 connect to the input of the oscillators and the values 6-10 connect to the output.
Figure 26: Rotary Switch
Figure 27: Schematic A

Figure 28: Schematic B
3.4 Pin Driver

The pin driver takes the output signal generated by the crystal oscillator and boosts it for the main gain stage. The small power signal from the oscillators might not have enough power to switch the MOSFETs. This is because of the capacitive load experienced by the MOSFETs in powering ultrasound transducers. This is the first step of the amplification on the signal. The pin drive is a low voltage high current device. It is powered by 9 volts taken from the power supply.

![Figure 29: Pin driver EL718](image)
3.5 MOSFET

A MOSFET acts as a voltage switch, when a voltage comes in at the gate it switches a larger voltage across the source and drain. The MOSFETs are controlled by the pin driver signal which dictates what frequency they will operate at. The MOSFETs in this circuit acts as fast frequency switches. While closed the voltage across the MOSFET is switched to ground making that channel inactive. There are two MOSFETs in the circuit which are used to switch between the N and P channels of the circuit. This switching is done in synchronization. While on MOSFET is open the other is closed. The open MOSFET provides the voltage to the transducer. The initial supply voltage is divided in half and makes one positive and the other negative. If the US Amplifier is being powered by 30 volts, it will have a 30 volt peak to peak going from -15 to 15 volts.

*Figure 30: MOSFET*
3.6 US Mouthpiece

The mouthpiece consists of Lead Zirconate Titanate (PZT) transducers wired together in a polystyrene mold. The wires then come out of the polystyrene mold and connect to the male end of a 1/8” audio jack.

3.7 Transducers

The transducers are made of lead zirconate titanate (PZT). PZT has piezoelectric properties meaning it changes shape when an external electric field is applied to it. The changes in voltage caused by the US Amplifier cause the PZT to rapidly change shape in an oscillation pattern. This rapid change of shape causes a mechanic signal to be outputted in the form of ultrasound.

![Image of mouthpiece showing wires and transducers.]

Figure 31: Mouthpiece showing wires and transducers

The transducers are nickel plated to improve conductance across them. There are five different transducers each encased in their own mouthpiece. Each mouthpiece has eight transducers in them. They are rated for 1, 2, 3, 4, and 5 MHz. This makes five mouthpieces in all. Each transducer is connected in parallel from the output of the US Amplifier. This was done
by soldering one side of the transducers to the output wire (red) from the US Ampflier. The other side of the transducers were soldered to the ground wire (black) going back through the output jack.

3.8 Polystyrene

Polystyrene is a thermoplastic existing at solid state at room temperature. This makes it easy to fabricate the mouthpiece, just melt the polystyrene around the transducers. A mold was used to assist with this task in order to get the shape desired. It is hard enough to keep shape and has the same acoustic impedance as gum tissue. This allows the ultrasound to transfer easily into the gums without refracting on a different impedance material. This prevents the loss of the signal.

3.9 Wires and Connections

The wires used were multi-stranded copper wire. This made them more flexible and prevented them breaking if they were bent too far. The wires were soldered to one side of the transducers and one side of the 1/8” audio jack. The audio jack was used because it had a better connection than banana plugs, this is better for high frequencies. It also works well because it has two connection in it, like a light bulb. To wires are attached, one to transmit the signal and the other to take it away. In this circuit the red wire is connected to the voltage signal and the black is connected to ground. Both wires are connected across the transducer in order to supply the signal necessary for ultrasound.
The wires that connect the auxiliary power are banana plugs. They correspond to the positive and negative ends of a DC power supply. Banana plugs only have one connection unlike the audio jack. That is fine because on most DC power supplies there is a separate connection for positive and negative. Also since they are carrying a DC signal they do not need to be able to handle high frequencies.
4. **Troubleshooting**

This troubleshooting section is intended to be a full length step by step process to ensure that the US Amplifier and all of its components are functioning properly. The steps are placed in a logical and systematic order to create the best and most efficient method for troubleshooting any problems that may occur. Please follow this section step by step as this section takes you through the most common problems first and creates check points to eliminate certain problems before proceeding to troubleshooting more difficult problems to test.

4.1 **Device does not turn on**

First check to make sure the power switch is in the on position (up). If the power switch is on and it is still not turning on refer to 4.1.1 if using batter mode and 4.1.2 if using auxiliary mode.

![Power Switch](image)

*Figure 35: Power Switch (Red part switch up and metal switch up)*

4.1.1 **Battery Mode**

If using Battery/Recharge mode first check that the switch on the right side of the US Amplifier is switched down in battery mode.
If it is and it still is not working then make sure that the batteries are fully charged. To verify that the US Amplifier has charged batteries open the box by unscrewing the four front panel screws.

Once inside make sure all the batteries are connected properly.
If they are and it still does not work place the two probes of a voltage meter on the positive and negative ends of the auxiliary power connections located on the right side of the US amplifier using the DC voltage option. They should each read about 27 Volts. If they do not and are lower than 27 Volts the batteries need to be replaced or recharged (refer to 2.1).

If the batteries are charged the next step is to check the output, which is in section 4.1.3.
4.1.2 Auxiliary Mode

If using in auxiliary mode make sure that the switch is in the AUX position. Then check to make sure the DC voltage supply device is on. If it is make sure that the positive end is connected to the positive input and that the negative end is connected to the negative input. Also make sure the DC voltage read 30 Volts. If this is the case and the device is still not working go to 4.1.3.

Figure 40: Auxiliary/Battery Switch (up for auxiliary)

4.1.3 Output Check

To verify that the US Amplifier is outputting properly attach the Oscilloscope Terminal Jack to the 1/8” output of the US amplifier located on the left side.

Figure 41: Output (attach jack here)
Next attach an oscilloscope to the two terminals of the Oscilloscope Terminal Jack. If an oscilloscope is not available than use a Digital Multimeter (DMM) set to AC voltage mode. Next turn the US Amplifier on and look for a signal on the oscilloscope monitor, or look for the peak to peak voltage measured by the DMM. If running on Battery Mode a 25~30 peak to peak voltage should be observed, if this is not observed. If running in AUX mode then the peak to peak voltage observed should be the DC voltage supplied. This should be tried on every frequency by turning the frequency knob.

![Frequency Knob](image)

If all frequencies are getting the proper peak to peak voltage the US Amplifier is working correctly. If some or all of the frequencies are not working refer to 4.2.

### 4.2 Frequencies Not Working

#### 4.2.1 Replace Oscillators

If the US Amplifier does not work at a some or all of the frequencies it is possible that one of the crystal oscillators has gone bad. Figure out which frequency(ies) is not working and replace that oscillator. Open the US Amplifier by unscrewing the four screws on the front panel. Once open, replace the crystal oscillator that was not functioning, refer to the following diagram to determine which where the crystal oscillator is. The crystal oscillators are placed in sockets, simply pull the oscillator out and replace it with a new one.
If replacing the oscillator does not fix the problem it is possible that one of the wires to the rotary switch has come loose.
4.2.2 Rotary Switch

Refer to the following diagram to locate the wires to the rotary switch.

Figure 44: Diagram showing where the rotary switch wires are located.

If the wires to the switch have become loose reconnect and resolder them. If they are not loose then there might be a problem with the voltage regulator.
4.2.3 Voltage Regulator

To check this place a voltage meter probe at Pin 3 on the voltage regulator, this should read 5 volts. If it does not read 5 volts replace the voltage regulator. If it reads 5 volts there might be a problem with the 7158 pin driver.

Figure 45: Voltage Regular
4.2.4 Pin Driver

Then place the probe to pin 3 of the 7158 Pin Driver. If a signal is not observed than there is a problem with the oscillators, refer to 4.2.2. If not then place the probe on pin seven of the 7158 pin driver. The signal voltage here should be 9 volts peak to peak, if it is not then the pin driver is broken and needs to be replaced. Before replacing try measuring the voltage supply to the pin driver. Place the probe on pin 1, the voltage on pin 1 should be 9 volts DC, if this is not the case then the batteries or power supply are not charged and refer to 4.1. If it still does not work the problem is in the MOSFETs.

Figure 46: Pin Driver
4.2.5 MOSEFTs

Replace both MOSFET's. This is easiest since these are cheap then it saves the trouble of trying to find which one is broken. If none of these solutions work contact University of Connecticut Biomedical Engineering Senior Design Team 12.

Figure 47: MOSFETs