1 Low Cost Arbitrary Function Generator

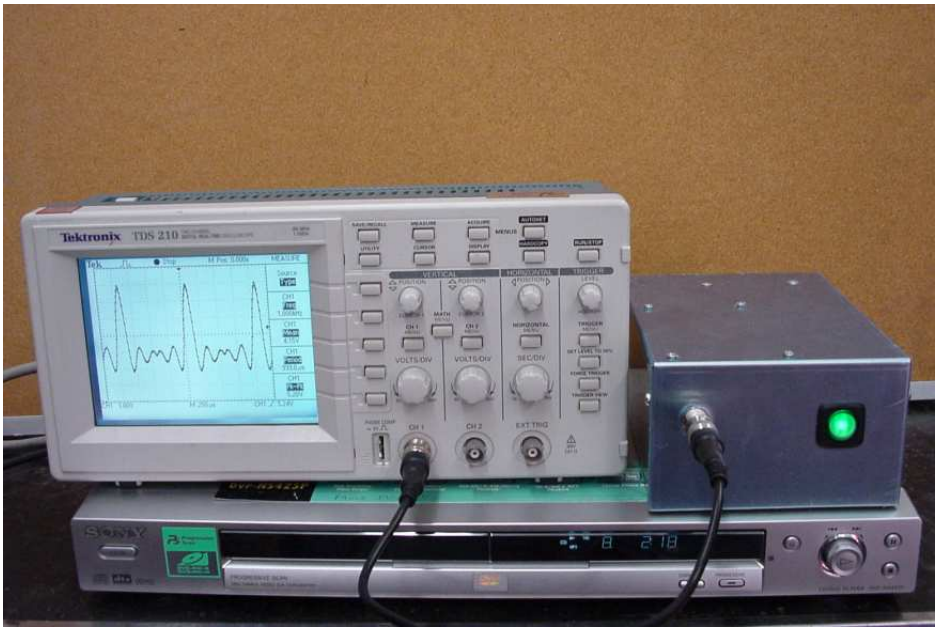


Figure 1: A low cost arbitrary function generator. The accessory device uses the audio output from a DVD player to generate various signals. The oscilloscope is displaying an output signal.

The undergraduate electricity and magnetism classes at CSULB have a lab experiment in which students learn how to use an oscilloscope. This article is about a low cost arbitrary function generator which produces various waveforms for students to measure with an oscilloscope. This low cost function generator consists of a DVD player and an accessory device. The left and right audio outputs from a DVD player are used as the input signals to the accessory device. These signals from the DVD player are altered inside the accessory device to produce a desired output signal that can be measured with an oscilloscope. The DVD player, the accessory device, and an oscilloscope that is displaying a typical waveform are shown in Figure 1.

Students can practice finding the peak to peak voltages, frequencies, and DC offsets of several "unknown" signals that don't necessarily look like square, triangle, and sine waves that come from most signal generators. Since the information about the characteristics of a signal originate from a DVD player, it easy to create different signals by making WAV files that describe the signal you want, and then burning these WAV files onto a CD or DVD. The main disadvantage to this strategy is that the signal frequency cannot get above around 15 kHz, since the sampling frequency is only 44100 samples/second. But this is not a big disadvantage for our purposes. This low cost arbitrary function generator has the following features:

	Min	Max
Voltage_{pp}	200 mV	18 V
Frequency	no limit	15 kHz
DC offset	-6.5 V	+9 V

DVD players (and music players in general) remove any DC offset at the audio output. To get around this obstacle, recall that a stereo audio signal has 2 channels. Therefore, the accessory device uses the LEFT channel from the audio output of a DVD player for information about the characteristics of the AC signal. And the accessory device uses the RIGHT channel from the audio output of a DVD player for information about the DC offset. The signal from the right channel goes to a frequency to voltage converter inside the accessory device. The output voltage from the frequency to voltage converter is added to the AC signal from the left channel. Figure 2 shows how the left and right channels from the audio output of the DVD player connect to the accessory device.

Figure 2: The left and right channels from the audio output of the DVD player are used as the input signals to the accessory device.

There is one more small complication about the accessory device. We wanted to have a large range of signal amplitudes, from around 200 mVpp to 18 Vpp. To have such a wide range, the accessory device has two ranges for the gain of the signal that

comes from the left channel of the DVD player. Normally, the gain is 20. However, there is also an "attenuation" feature that makes the gain only $\frac{1}{2}$. The right channel not only contains information about the DC offset, but also information on whether to attenuate the AC signal on the left channel. If the amplitude of the signal on the right channel is small, then the AC signal on the left channel will be attenuated.

2 Low Frequency signals - a nice feature

For instructional purposes, it's helpful to have some very low frequency signals, say 0.2 Hz, or one cycle every 5 seconds. This is nice because a handheld multimeter and an oscilloscope can be connected to the unknown signal generator at the same time. And at a low frequency like 0.2 Hz, a student can SEE the meter change AND the trace on the ocsilloscope change when the voltages from the accessory device change. This is shown in Figures 3 and 4. Other signals can be made that demonstrate that as the signal frequency increases, a handheld meter becomes less useful, and an oscilloscope is needed to measure the features of a signal. A very low frequency signal can be produced by setting the left channel to zero, and using the information on the right channel to shift the DC offset voltages up and down.

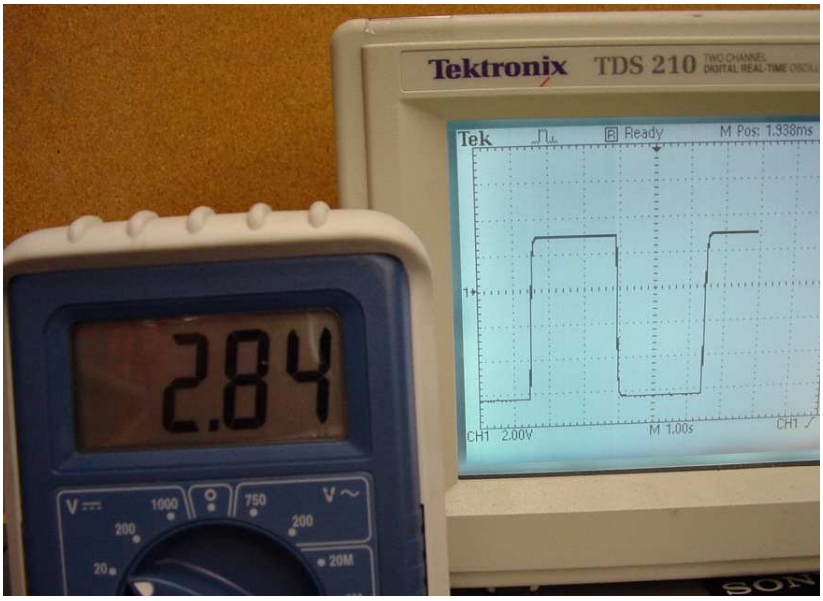


Figure 3: A very low frequency that is near 2.8 Volts. This signal that can be measured with a handheld DMM and with an oscilloscope.

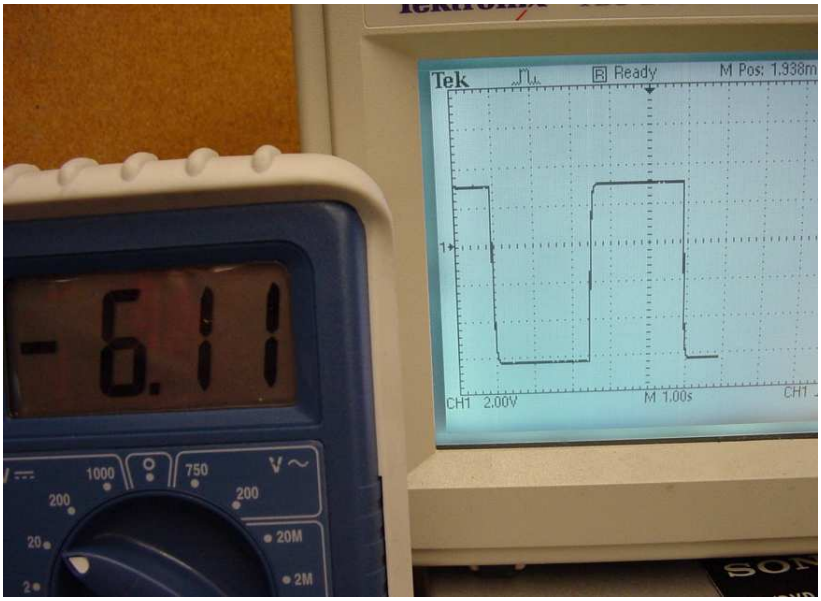
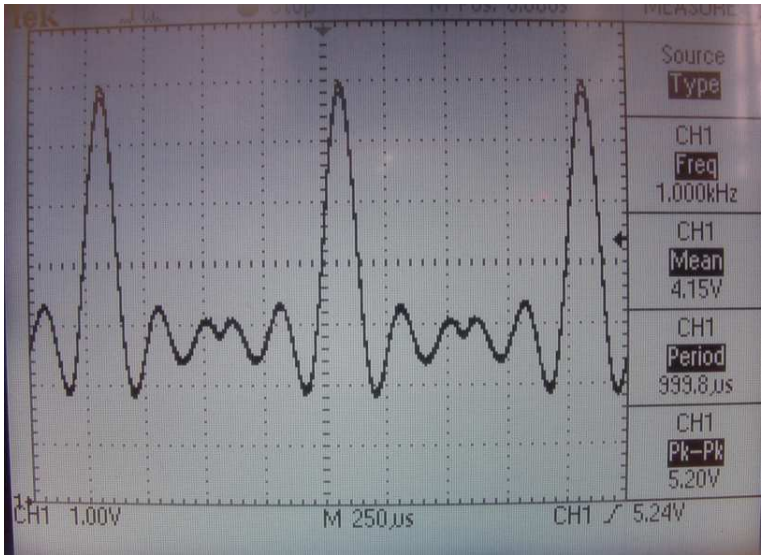
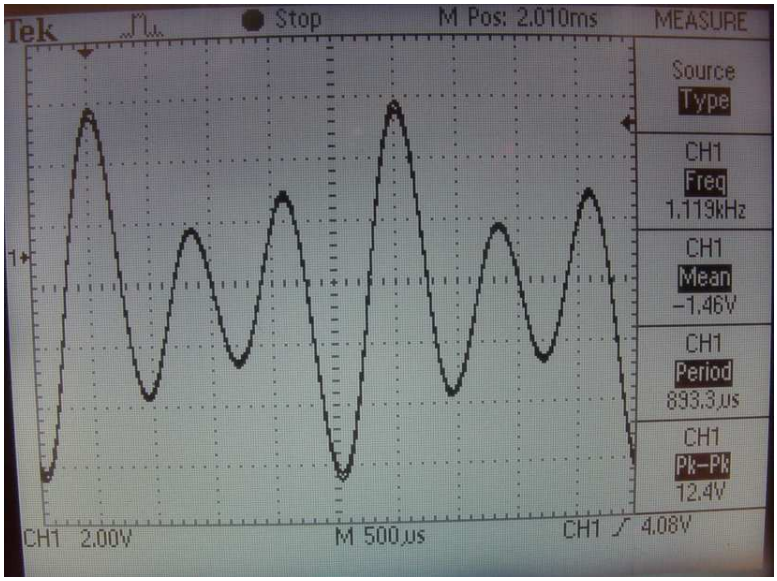


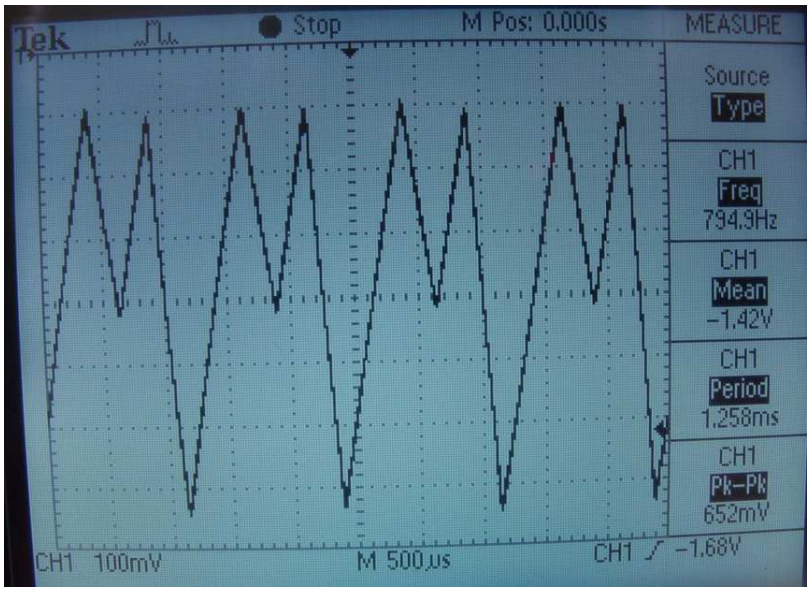
Figure 4: A very low frequency that is near -6 Volts. This signal that can be measured with a handheld DMM and with an oscilloscope.

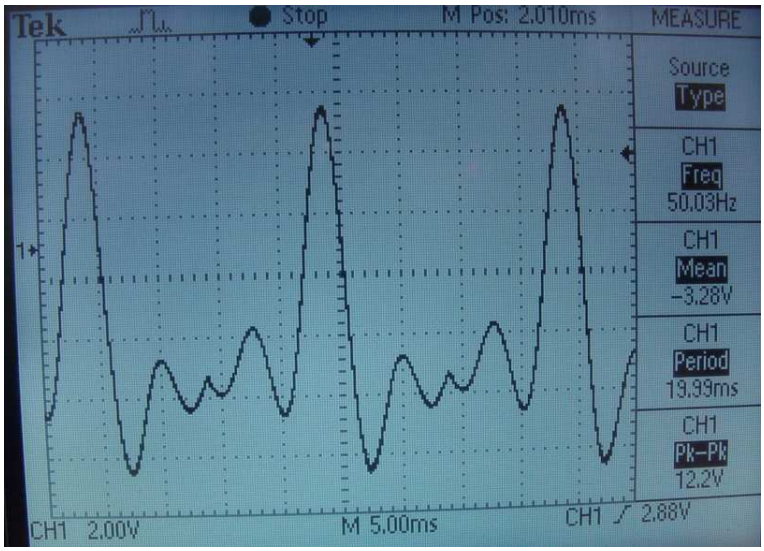
3 Pictures of some signals that can be produced

Here are some pictures of other signals that were produced with the arbitrary function generator.






Tek
Stop
M Pos: 0.000s
MEASURE
Source
Type
CH1
Freq
794.9Hz
CH1
Mean
-1.42V
CH1
Period
1.258ms
CH1
Pk-Pk
652mV
CH1 100mV
M 500µs
CH1 -1.68V


Tek
Stop
M Pos: 2.010ms
MEASURE
Source
Type
CH1
Freq
50.03Hz
CH1
Mean
-3.28V
CH1
Period
19.99ms
CH1
Pk-Pk
12.2V
CH1 2.00V
M 5.00ms
CH1 2.88V

4 How the Accessory Device Works

The circuit diagram for the accessory device is shown in Figure 5. There are 4 main circuit features in the accessory device. They are a regulated power supply, an amplifier, a frequency to voltage converter, and a window comparator.

The regulated power supply uses an LM317 to produce a regulated positive supply of +15 Volts, and an LM337 to produce a regulated negative supply of -15 Volts.

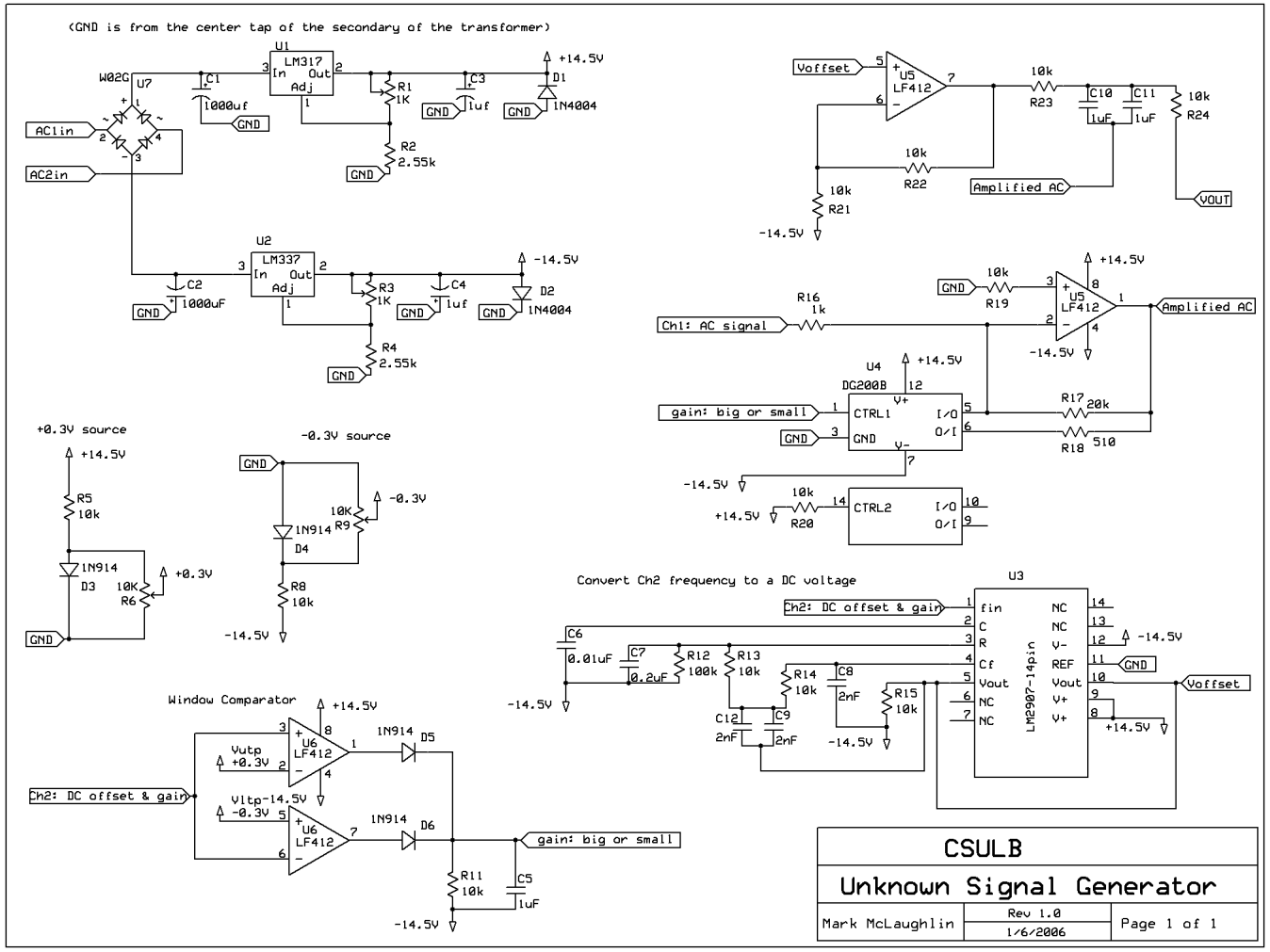
The right channel from the DVD player is called *Ch2:DC offset & gain* on the circuit diagram in Figure 5. This signal goes to U3, a frequency to voltage converter, and to U6, a window comparator.

The external resistors and capacitors that are connected to U3 provide a DC offset of -6 volts when the input frequency of *Ch2:DC offset & gain* is near 80 Hz, and a DC offset of +9.5 Volts when the input frequency is near 550 Hz. The output voltage from U3 is called *Voffset* . Note that we didn't want the lowest DC offset to occur when the input frequency was near 0 Hz, because the information about the peak to peak voltage of *Ch2:DC offset & gain* is also needed by U6, the window comparator.

Ch2:DC offset & gain also goes to U6, a window comparator. When the amplitude of this input signal to U6 is small, i.e. its peak to peak voltages are in between +0.3 to -0.3 Volts, the output of the window comparator, called *gain:big or small* is -15 Volts. On the other hand, if the amplitude of *Ch2:DC offset & gain* is large, i.e. its peak to peak voltages are outside of the range of +0.3 to -0.3 Volts, then *gain:big or small* is +15 Volts. R11 and C5 are needed to keep *gain:big or small* high during the zero crossings of *Ch2:DC offset & gain* when this signal is large.

The left channel from the DVD player is called *Ch1:AC signal* . This signal is amplified by half of U5. The gain is controlled by U4, an analog switch. If *gain:big or small* is -15 Volts, then pin 5 on U4 is connected to pin 6 on U4. This results in a gain of approximately $\frac{1}{2}$. If *gain:big or small* is +15 Volts, then pin 5 on U4 is not connected to pin 6 on U4. This results in a gain of approximately 20. The output of U5 is called *Amplified AC* .

Amplified AC is coupled to *Voffset* by C10 and C11. *VOUT* is the final output signal, which is the signal students measure with an oscilloscope.



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Unknown Signal Generator		
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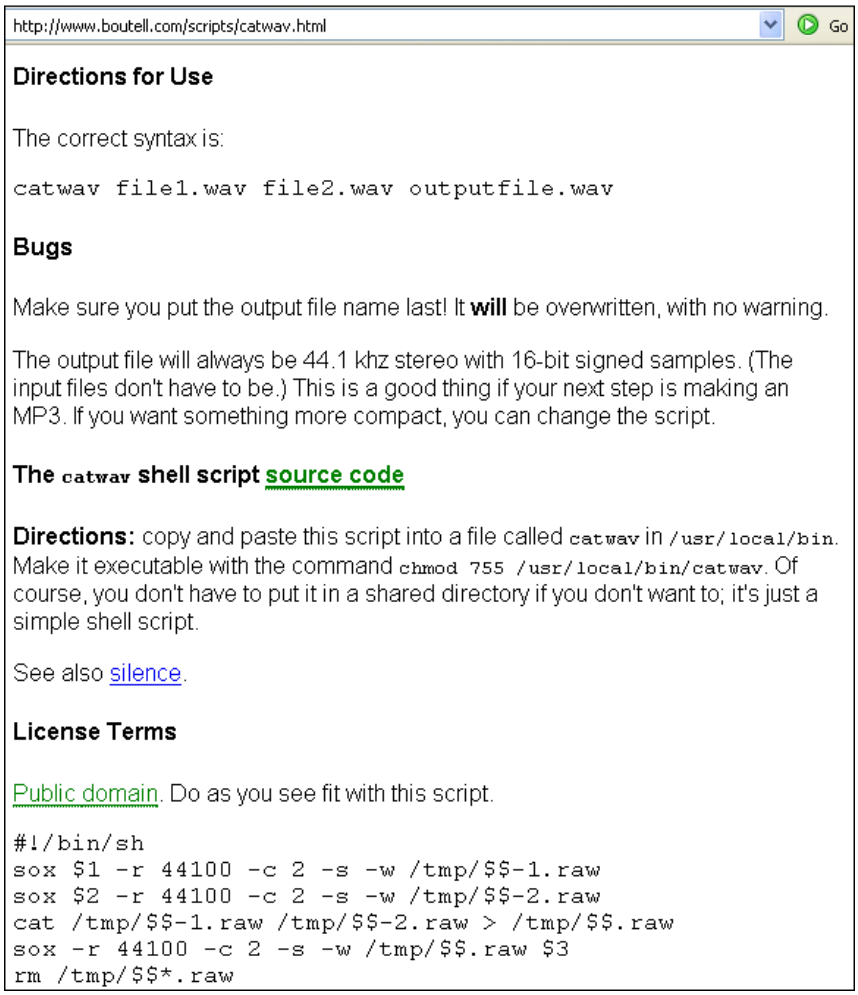
5 The Matlab code to produce a signal

An example of a program to produce a signal is shown below.

```
%Program explanation:
%The left channel contains information for the AC part
%of the waveform. This includes features like the shape of the waveform
%and the frequency and amplitude of the waveform.
%
%The right channel contains information for the DC offset of the signal from
%the left channel. The output of the right channel goes to a frequency to
%voltage converter. This frequency is converted to a DC voltage.
%This DC voltage is added to the signal from the left channel.
%80 Hz corresponds to a DC offset of about -6.5 Volts
%550 Hz corresponds to a DC offset of about 9.5 Volts
%
%The right channel also contains information about whether the signal from the left channel
%should be attenuated. If the signal on the right channel is anywhere from about 0.05 to 0.35
%of its maximum, then the signal on the left channel will be attenuated.
%Amplitude range of attenuated signal is about 400 mV to 1.5 Volts (although I need to test more)
%Amplitude range for signals that are not attenuated is about 3 Volts to 17 Volts (although
%I need to test more.)
%sampling settings
fs=96000;
Ts=1/fs;
nbits=16;

%left channel is for AC signal
%1000 Hz signal
t=-0.0005:Ts:(0.0005-Ts);
[row,col]=size(t);
left=(sin(10000*pi*t)./(10000*pi*t));
for i=1:col
 if t(1,i)==0
    left(1,i)=1;
 end;
end;
left=0.99*left;
[A,B]=size(left); %one cycle of left contains B columns

%right channel is for DC offset and gain
approxSignalFreq=100;
approxOneCycle=1/(approxSignalFreq);
t=0:Ts:(approxOneCycle - Ts);
[C,D]=size(t);

if (B > D)
%In this case, the AC signal from the left channel is at
%a lower frequency than the DC offset signal.
%Therefore, left has more columns than right.
%
%Let's find the closest frequency to our "approxSignalFreq" that is
%also a multiple of the frequency on the left channel.
%That way the right channel frequency will also be smooth.
   n=round(B/D);
   signalFreq=(n/(B*Ts));
   signalPeriod=(B*Ts)/n;
   t=0:Ts:(signalPeriod-Ts);
   right=0.99*sin(2*pi*signalFreq.*t);

   %make right have the same number of columns as left
   tempRight=right;
   j=1;
   for j=1:(n-1)
      right=[right,tempRight];
   end;
else
%In this case right has more columns than left
%Let's find the closest frequency to our "approxSignalFreq" that is
%also a multiple of the frequency on the left channel.
%That way the right channel frequency will also be smooth.

   n=round(D/B);
   signalFreq=1/(n*B*Ts);
   signalPeriod=n*B*Ts;
   t=0:Ts:(signalPeriod-Ts);
   right=0.35*0.99*sin(2*pi*signalFreq.*t);   %multiply by 0.35 for smaller gain

   %make left have the same number of columns as right
   tempLeft=left;
   j=1;
   for j=1:(n-1)
      left=[left,tempLeft];
   end;
end;

i=1;
for i=1:13 %append so song is approx 5 min for i=1:13
right=[right,right];
left=[left,left];
i=i+1;
end;

total=[left' right'];
wavwrite(total, fs, nbits, 'track027.wav');
```

6 Catwav -A Unix program to make WAV files longer

My computer ran out of memory when I tried to make a WAV file in Matlab longer than a few minutes. To make the track longer, another program called catwav is needed. Catwav is a script that concatenates WAV files. This will allow you to make a WAV file as long as you want. Just concatenate a WAV file that was created in Matlab to itself until the WAV file is the desired length. A more detailed explanation of catwav is shown below. This information came from the website, http://www.boutell.com/scripts/catwav.html



http://www.boutell.com/scripts/catwav.html Go

Directions for Use

The correct syntax is:

```
catwav file1.wav file2.wav outputfile.wav
```

Bugs

Make sure you put the output file name last! It **will** be overwritten, with no warning.

The output file will always be 44.1 khz stereo with 16-bit signed samples. (The input files don't have to be.) This is a good thing if your next step is making an MP3. If you want something more compact, you can change the script.

The `catwav` shell script source code

Directions: copy and paste this script into a file called `catwav` in `/usr/local/bin`. Make it executable with the command `chmod 755 /usr/local/bin/catwav`. Of course, you don't have to put it in a shared directory if you don't want to; it's just a simple shell script.

See also silence.

License Terms

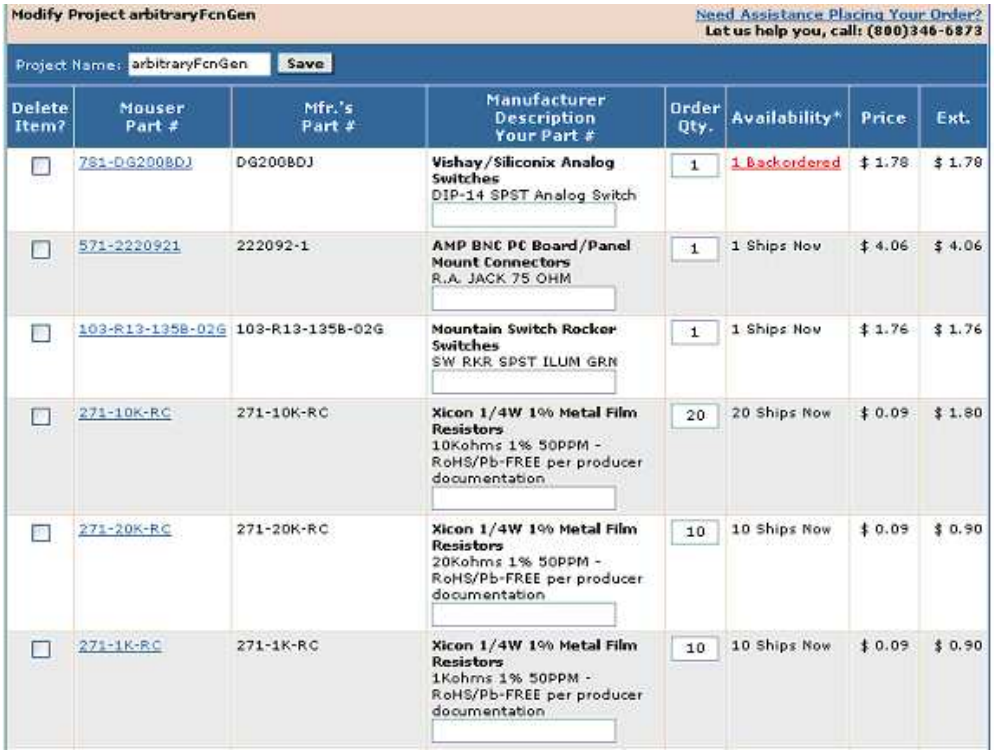
Public domain. Do as you see fit with this script.

```
#!/bin/sh
sox $1 -r 44100 -c 2 -s -w /tmp/$$-1.raw
sox $2 -r 44100 -c 2 -s -w /tmp/$$-2.raw
cat /tmp/$$-1.raw /tmp/$$-2.raw > /tmp/$$.raw
sox -r 44100 -c 2 -s -w /tmp/$$.raw $3
rm /tmp/$$*.raw
```

7 Bill of Materials

The parts to make the accessory device came from Mouser Electronics and Digikey. The prices are as of January 2006.

The following items were ordered from Mouser Electronics:



Modify Project arbitraryFcnGen

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Project Name: arbitraryFcnGen Save

Delete Item?	Mouser Part #	Mfr.'s Part #	Manufacturer Description Your Part #	Order Qty.	Availability*	Price	Ext.
☐	781-DG200BDJ	DG200BDJ	**Vishay/Siliconix Analog Switches** DIP-14 SPST Analog Switch	1	1 Backordered	$ 1.78	$ 1.78
☐	571-2220921	222092-1	**AMP BNC PC Board/Panel Mount Connectors** R.A. JACK 75 OHM	1	1 Ships Nov	$ 4.06	$ 4.06
☐	103-R13-135B-02G	103-R13-135B-02G	**Mountain Switch Rocker Switches** SW RKR SPST ILUM GRN	1	1 Ships Nov	$ 1.76	$ 1.76
☐	271-10K-RC	271-10K-RC	**Xicon 1/4W 1% Metal Film Resistors** 10Kohms 1% 50PPM - RoHS/Pb-FREE per producer documentation	20	20 Ships Now	$ 0.09	$ 1.80
☐	271-20K-RC	271-20K-RC	**Xicon 1/4W 1% Metal Film Resistors** 20Kohms 1% 50PPM - RoHS/Pb-FREE per producer documentation	10	10 Ships Now	$ 0.09	$ 0.90
☐	271-1K-RC	271-1K-RC	**Xicon 1/4W 1% Metal Film Resistors** 1Kohms 1% 50PPM - RoHS/Pb-FREE per producer documentation	10	10 Ships Now	$ 0.09	$ 0.90

☐	271-100K-RC	271-100K-RC	**Xicon 1/4W 1% Metal Film Resistors** 100Kohms 1% 50PPM - RoHS/Pb-FREE per producer documentation	10	10 Ships Nov	$ 0.09	$ 0.90
☐	271-240-RC	271-240-RC	**Xicon 1/4W 1% Metal Film Resistors** 240ohms 1% 50PPM - RoHS/Pb-FREE per producer documentation	10	10 Ships Nov	$ 0.09	$ 0.90
☐	271-2.55K-RC	271-2.55K-RC	**Xicon 1/4W 1% Metal Film Resistors** 2.55Kohms 1% 50PPM - RoHS/Pb-FREE per producer documentation	10	10 Ships Nov	$ 0.09	$ 0.90
☐	78-1N914	1N914	**Vishay Semiconductor Small Signal Diodes** DO-35 100 Volt 300mA T/R - ROHS EXEMPT per producer documentation	12	12 Ships Nov	$ 0.03	$ 0.36
☐	512-1N4004	1N4004	**Fairchild Rectifiers** DO-41 Vr/400V Io/1A T/R	2	2 Ships Now	$ 0.05	$ 0.10
☐	41FK200	41FK200	**Xicon Heavy Duty Power Transformers** TRANS FIL 24V 200MA	1	1 Backordered	$ 4.29	$ 4.29
☐	546-1411QU	1411QU	**Hammond Aluminum Utility Cases** 7.0 X 5.0 X 3.0 Unpainted - RoHS COMPLIANT per producer documentation	1	1 Ships Now	$ 9.28	$ 9.28
☐	23PW220	23PW220	**Xicon Polystyrene Film Capacitors** STYRENE 50V .002uF - RoHS non-compliant/CONTAINS Pb	3	3 Ships Nov	$ 0.24	$ 0.72
☐	271-510-RC	271-510-RC	**Xicon 1/4W 1% Metal Film Resistors** 510ohms 1% 50PPM - RoHS/Pb-FREE per producer documentation	10	10 Ships Nov	$ 0.09	$ 0.90
☐	575-199308	110-99-308-41-001000	**Mill-Max DIP Low Profile Sockets** 8P TIN PIN TIN CONT	2	2 Ships Nov	$ 0.20	$ 0.40
☐	575-199314	110-99-314-41-001000	**Mill-Max DIP Low Profile Sockets** 14P TIN PIN TIN CONT	2	2 Ships Nov	$ 0.34	$ 0.68
						Sub Total:	$ 30.63

Update Project

Order Project ×

1

The following items were ordered from Digikey:

Click on the **Index** number to **MODIFY** or **DELETE** an item from your order.

Index	Quantity	Part Number	Description	Customer Reference	Backorder Quantity	Unit Price USD	Extended Price USD
1	1	WO2GDI-ND	RECT BRIDGE 200V 1.5A GPP WOG		0	0.60000	$0.60
2	1	LM2907N-ND	IC CONVERTER FREQ TO VOLT 14-DIP		1 Lead Time	1.86000	$1.86
3	1	LM317LZOS-ND	IC REG VOLT ADJ 100MA TO92		0	0.44000	$0.44
4	1	LM337LZ-ND	IC REGULATOR NEG ADJ TO-92		0	1.04000	$1.04
5	1	AE1265-ND	CABLE 2RCA MALE-MALE 2M		0	2.21000	$2.21
6	2	P5197-ND	CAP 1000UF 63V ALUM LYTIC RADIAL		2 Lead Time	1.40000	$2.80
7	1	478-2462-ND	CAP CER 10000PF 100V 10% RADIAL		0	0.24000	$0.24
8	1	F1470-ND	FUSEHOLDER 2AG SOLDER 1 POS		0	1.07000	$1.07
9	2	3386H-102-ND	POT 1.0K OHM 3/8" SQ CERM SL ST		0	1.29000	$2.58
10	2	3386H-103-ND	POT 10K OHM 3/8" SQ CERM SL ST		0	1.29000	$2.58
11	2	LF412CN-ND	IC OP AMP DUAL LOW JFET IN 8-DIP		0	1.66000	$3.32
12	10	495-1490-1-ND	CAP 1.0UF 50V CERAMIC MONO 20%		0	0.84900	$8.49
13	10	879K-ND	SPACER ROUND #4 SCREW NYLON CLR		0	0.15500	$1.55
						Subtotal	$28.78
						Handling	$0.00
						Shipping	unknown
						Sales Tax	unknown
						Total	unknown

8 Printed Circuit Board

The printed circuit board was ordered from ExpressPCB.com, http://www.expresspcb.com. It costs $63 for 3 boards. The printed circuit board layout is shown below in Figure 5.

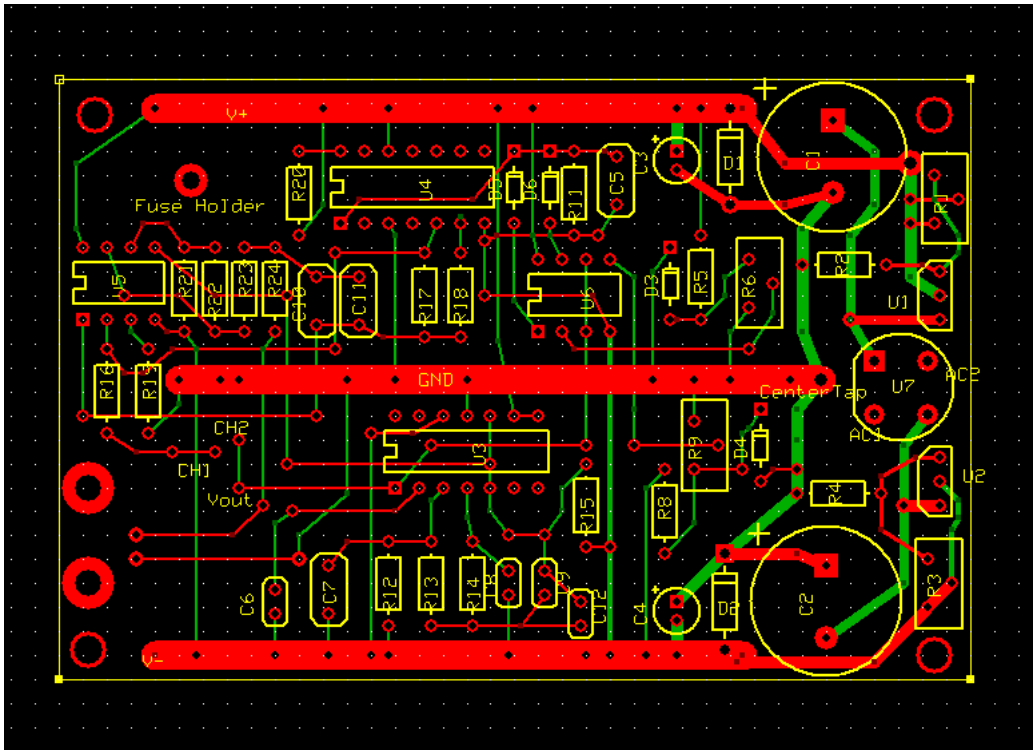

Figure 5: The printed circuit board layout.

If you have any questions about this device, please feel free to contact me at mmclaugh@csulb.edu